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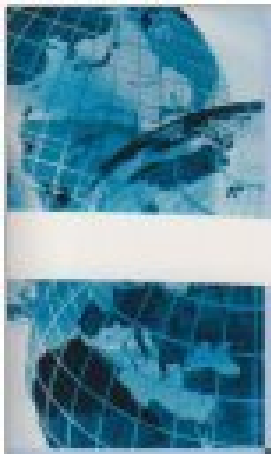

Supply Chain Management

Strategy, Planning & Operations

Third Edition

Sunil Chopra

Peter Meindl

THIRD EDITION

SUPPLY CHAIN MANAGEMENT

Strategy, Planning, and Operation



Sunil Chopra

Kellogg School of Management
Northwestern University

Peter Meindl

Stanford University



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DEDICATION



I would like to thank my colleagues at Kellogg for all that I have learned from them about logistics and supply chain management. I am grateful for the love and encouragement my parents, Krishan and Pushpa, and sisters, Sudha and Swati, have always provided during every endeavor in my life. I thank my children, Ravi and Rajiv, for the joy they have brought me. Finally, none of this would have been possible without the constant love, caring, and support of my wife, Maria Cristina.

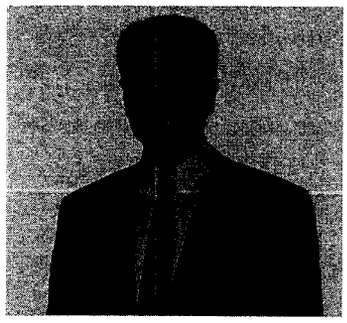
Sunil Chopra

I would like to thank three mentors—Sunil Chopra, Hau Lee, and Gerry Lieberman—who have taught me a great deal. Thank you also to my parents and sister for their love, and to my sons, Jamie and Eric, for making me smile and teaching me what life is truly all about. Most important, I thank my wife, Sarah, who makes life wonderful and whom I love with all of my heart.

Pete Meindl

ABOUT THE AUTHORS

SUNIL CHOPRA



Sunil Chopra is the IBM Distinguished Professor of Operations Management and Information Systems at the Kellogg School of Management. He is also the Codirector of the Masters of Management and Manufacturing program, a joint dual-degree program between the Kellogg School of Management and the McCormick School of Engineering at Northwestern University. He has a PhD in Operations Research from SUNY at Stony Brook. Prior to joining Kellogg, he taught at New York University and spent a year at IBM Research.

Professor Chopra's research and teaching interests are in supply chain and logistics management, operations management, and the design of telecommunication networks. He has won several teaching awards at the MBA and Executive programs of Kellogg. He has authored more than 35 papers and two books.

He has been a Department Editor for *Management Science* and an Associate Editor for *Manufacturing & Service Operations Management*, *Operations Research,* and *Decision Sciences Journal.* His recent research has focused on supply chain risk to understand sources of risk and devise mitigation strategies that buffer risk effectively at low cost. He has also consulted for several firms in the area of supply chain and operations management.

PETER MEINDL



Peter Meindl is a Finance and Economics PhD candidate in Stanford University's Management Science & Engineering Department. His research focuses on portfolio optimization and dynamic hedging using stochastic programming, receding horizon control, and Monte Carlo simulation. He was previously a strategy consultant with the Boston Consulting Group and the Director of Corporate Strategy for i2 Technologies, a software firm. He holds an MBA from Northwestern University's Kellogg School and three degrees from Stanford University.

The first edition of this book won the prestigious Book of the Year award in 2001 from the Institute of Industrial Engineers.

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PREFACE



This book is targeted toward an academic as well as a practitioner audience. On the academic side, it should be appropriate for MBA students, engineering master's students, and senior undergraduate students interested in supply chain management and logistics. It should also serve as a suitable reference for both concepts as well as methodology for practitioners in consulting and industry.

The book has grown from a course on supply chain management taught to second-year MBA students at the Kellogg School of Management at Northwestern University. The goal of this class was to cover not only high-level supply chain strategy and concepts, but also to give students a solid understanding of the analytical tools necessary to solve supply chain problems. With this class goal in mind, our objective was to create a book that would develop an understanding of the following key areas and their interrelationships:

- The strategic role of a supply chain
- The key strategic drivers of supply chain performance
- Analytic methodologies for supply chain analysis

Our first objective in this book is for the reader to learn the strategic importance of good supply chain design, planning, and operation for every firm. The reader will be able to understand how good supply chain management can be a competitive advantage, whereas weaknesses in the supply chain can hurt the performance of a firm. We use many examples to illustrate this idea and develop a framework for supply chain strategy.

Within the strategic framework, we identify facilities, inventory, transportation, information, sourcing, and pricing as the key drivers of supply chain performance. Our second goal in the book is to convey how these drivers may be used on a conceptual and practical level during supply chain design, planning, and operation to improve performance. We have included a case on Seven-Eleven Japan that can be used to illustrate how the company uses various drivers to improve supply chain performance. For each driver of supply chain performance, our goal is to provide readers with practical managerial levers and concepts that may be used to improve supply chain performance.

Utilizing these managerial levers requires knowledge of analytic methodologies for supply chain analysis. Our third goal is to give the reader an understanding of these methodologies. Every methodological discussion is illustrated with its application in Excel. In this discussion, we also stress the managerial context in which they are used and the managerial levers for improvement that they support.

The strategic frameworks and concepts discussed in the book are tied together through a variety of examples that show how a combination of concepts is needed to achieve significant increases in performance.

CHANGES TO THE THIRD EDITION

The third edition has several changes that we believe significantly improve the book.

- After much thought on how supply chain management has changed and expanded over the past several years, we have expanded the collection of supply chain drivers from four to six, with the new additions being the cross-functional drivers of sourcing and pricing. Both sourcing and pricing were covered in the earlier editions, but we felt that the framework was more complete with each being considered as a driver. The supply chain drivers are a structure that appears throughout the book, so making this change—and thus changing much of the structure of the book—is, we believe, a major improvement. As supply chain management has become more and more about relationships among different enterprises in the supply chain, we feel it is only natural to include these two new drivers that encompass significant processes with both upstream and downstream supply chain partners.
- Along with the expansion of the supply chain drivers comes a fuller treatment of the two new drivers, sourcing and pricing. The chapters on sourcing and pricing have increased depth, with particular emphasis on improvement and expansion of the sourcing chapter. Included in this expansion are new discussions on such important issues as how to determine whether to perform functions in-house or to outsource them as well as discussion of the services offered by various types of logistics providers. This adds a great deal of richness to the discussion of our new drivers, which we believe is necessary given their importance in the supply chain.

Supply chain metrics are crucial in monitoring a supply chain's performance and in helping to improve that performance.

- To this end, we have added a significant section to Chapter 3 on supply chain metrics. Without supply chain metrics, it is very difficult to implement supply chain changes effectively. With this new material, we hope readers will come away with an understanding of what ought to be measured and why it is important to do so. These metrics show up in the following chapters as we discuss each driver, so the reader can understand the importance of using the metric and how the metric can be improved.

In the previous editions, we combined virtually all of our discussion of the use of information technology into a chapter with that specific focus.

- We still have an IT chapter in this edition, but we have made a significant change by adding IT-focused sections within individual chapters that address IT issues specific to the realm on which the particular chapter focuses. We believe this more integrated view of IT better portrays the importance of IT and its permeation through virtually all supply chain functions.
- Similar to the IT sections within many of the chapters, we have also added sections in many chapters focused on supply chain risk. In the past, we mentioned supply chain risk in various discussions, but we believe it is such an important topic that it deserves more attention than it received. As with the IT sections, each risk section is focused on risk factors pertaining to the topic on which the chapter focuses, thus giving readers a more integrated view of all factors affecting decisions within the area of the chapter topic.
- We have also moved the content from the e-business chapter into other chapters, most notably into Chapter 4 on distribution networks. As before, we believe this presents a more integrated view of the supply chain issues one must grapple with and thus is a worthwhile change.

- Finally, we have added two cases that can be used to discuss the strategic framework as well as supply chain network design.

FOR INSTRUCTORS

For adopters of this edition we have provided the following:

- An instructor Solutions Manual in Word, with solutions spreadsheets provided in Excel. Each of the end-of-chapter problems has been carefully solved by Srinivas Talluri of Michigan State University. Where applicable, the Excel and Word solutions are both provided. These files may be downloaded from http://prenhall.com/irc.
- An Instructor Manual, containing sample syllabi and chapter lecture notes, is available in Word and may be downloaded from http://www.prenhall.com/irc.
- PowerPoint Presentation Files for each chapter of the text are available and may be downloaded from http://www.prenhall.com/irc.

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There are many people we would like to thank who helped us throughout this process. We thank the reviewers whose suggestions significantly improved the book, including Daniel Marrone, SUNY Farmingdale; Jatinder (Jeet) Gupta, University of Alabama, Huntsville; Srinagesh Gavirneni, Cornell University; Iqbal Ali, University of Massachusetts, Amherst; Ming Ling Chuang, Western Connecticut State University; Subroto Roy, University of New Haven; Mehdi Kaighobadi, Florida Atlantic University; Sime Curkovic, Western Michigan University; Alireza Lari, Fayetteville State University; Bryan Lee, Missouri Western State College; Richard Germain, University of Louisville; Frenck Waage, University of Massachusetts, Boston; James Noble, University of Missouri—Columbia; Effie Stavrulaki, Pennsylvania State University; and James K. Higginson, University of Waterloo (Ontario).

We are grateful to the students at the Kellogg School of Management who suffered through typo-ridden drafts of earlier versions of the book. Specifically, we thank Christoph Roettelle and Vikas Vats for carefully reviewing several chapters and solving problems at the end of the chapters in early editions. We thank Srinivas Talluri of Michigan State University for his tremendous help in preparing the instructor's manual, instructor's solutions manual, and PowerPoint files for the current edition. We would also like to thank our editors, Mark Pfaltzgraff and Alana Bradley, and the staff at Prentice Hall, including Melissa Feimer, Production Editor, Debbie Clare, Executive Marketing Manager, and Barbara Witmer, Editorial Assistant, for their efforts with the book. Finally, we would like to thank you, our readers, for reading and using this book. We hope it contributes to all of your efforts to improve the performance of companies and supply chains throughout the world.

We would be pleased to hear your comments and suggestions for future editions of this text.

Sunil Chopra
Kellogg School of Management
Northwestern University

Peter Meindl
Stanford University

PART I

BUILDING A STRATEGIC FRAMEWORK TO ANALYZE SUPPLY CHAINS

CHAPTER 1
UNDERSTANDING THE SUPPLY CHAIN

CHAPTER 2
SUPPLY CHAIN PERFORMANCE: ACHIEVING STRATEGIC FIT AND SCOPE

CHAPTER 3
SUPPLY CHAIN DRIVERS AND METRICS

The goal of the three chapters in Part I is to provide a strategic framework to analyze the design, planning, and operational decisions within supply chains. Such a framework helps clarify supply chain goals and identify managerial actions that improve supply chain performance in terms of the desired goals.

Chapter 1 defines a supply chain and establishes the impact that supply chain decisions have on a firm's performance. A variety of examples are used to illustrate supply chain decisions, their influence on performance, and their role in a firm's competitive strategy. Chapter 2 describes the relationship between supply chain strategy and the competitive strategy of a firm and emphasizes the importance of ensuring that strategic fit exists between the two strategies. The chapter also discusses how expanding the scope of strategic fit across all functions and stages within the supply chain improves performance. Chapter 3 describes the major drivers of supply chain performance: facilities, inventory, transportation, information, sourcing, and pricing. Key decisions and metrics related to each driver are identified and linked to a company's ability to support its competitive strategy.

CHAPTER 1
UNDERSTANDING THE SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Discuss the goal of a supply chain and explain the impact of supply chain decisions on the success of a firm.
2. Identify the three key supply chain decision phases and explain the significance of each one.
3. Describe the cycle and push/pull views of a supply chain.
4. Classify the supply chain macro processes in a firm.

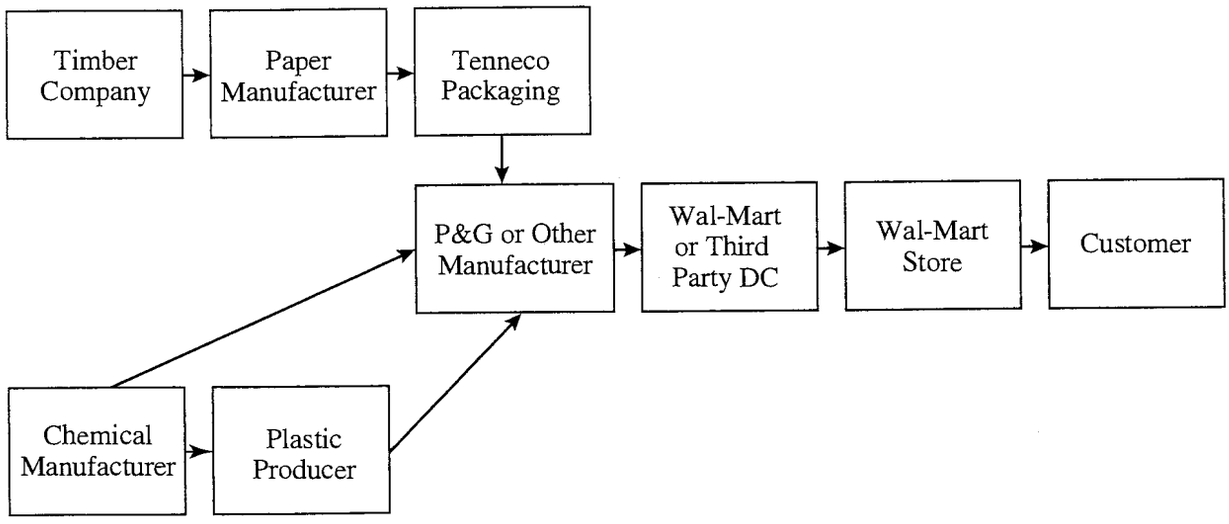
In this chapter, we provide a conceptual understanding of what a supply chain is and the various issues that need to be considered when designing, planning, or operating a supply chain. We discuss the significance of supply chain decisions and supply chain performance for the success of a firm. We also provide several examples from different industries to emphasize the variety of supply chain issues that companies need to consider at the strategic, planning, and operational levels.

1.1 WHAT IS A SUPPLY CHAIN?

A *supply chain* consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves. Within each organization, such as a manufacturer, the supply chain includes all functions involved in receiving and filling a customer request. These functions include, but are not limited to, new product development, marketing, operations, distribution, finance, and customer service.

Consider a customer walking into a Wal-Mart store to purchase detergent. The supply chain begins with the customer and his or her need for detergent. The next stage of this supply chain is the Wal-Mart retail store that the customer visits. Wal-Mart stocks its shelves using inventory that may have been supplied from a finished-goods warehouse or a distributor using trucks supplied by a third party. The distributor in turn is stocked by the manufacturer (say, Proctor & Gamble [P&G] in this case). The P&G manufacturing plant receives raw material from a variety of suppliers, who may themselves have been supplied by lower-tier suppliers. For example, packaging material may come from Tenneco packaging, while Tenneco receives raw materials to manufacture the packaging from other suppliers. This supply chain is illustrated in Figure 1-1, with the arrows corresponding to the direction of physical product flow.

FIGURE 1-1 Stages of a Detergent Supply Chain



A supply chain is dynamic and involves the constant flow of information, product, and funds between different stages. In our example, Wal-Mart provides the product, as well as pricing and availability information, to the customer. The customer transfers funds to Wal-Mart. Wal-Mart conveys point-of-sales data as well as replenishment orders to the warehouse or distributor, who transfers the replenishment order via trucks back to the store. Wal-Mart transfers funds to the distributor after the replenishment. The distributor also provides pricing information and sends delivery schedules to Wal-Mart. Wal-Mart may send back packaging material to be recycled. Similar information, material, and fund flows take place across the entire supply chain.

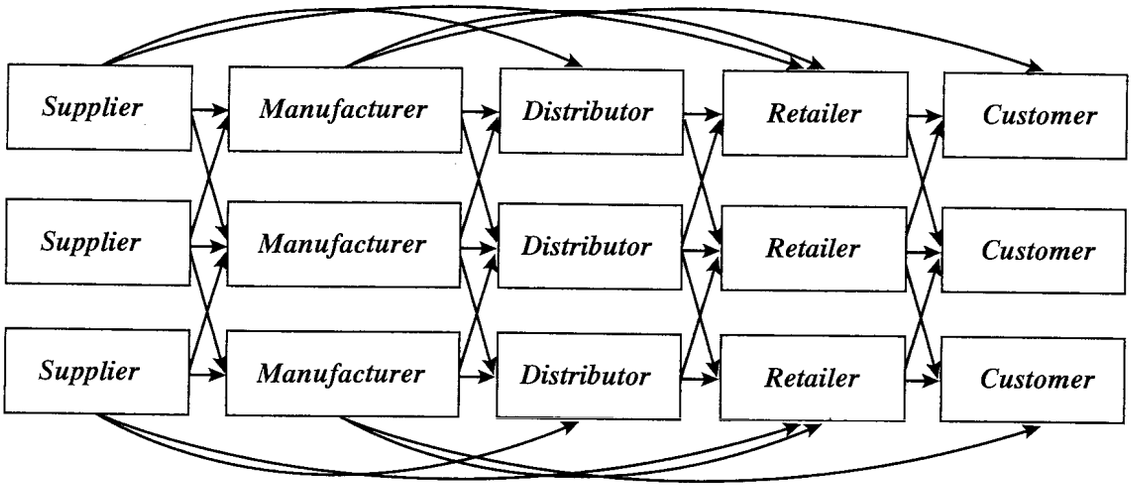
In another example, when a customer makes a purchase online from Dell Computer, the supply chain includes, among others, the customer, Dell's Web site, the Dell assembly plant, and all of Dell's suppliers and their suppliers. The Web site provides the customer with information regarding pricing, product variety, and product availability. Having made a product choice, the customer enters the order information and pays for the product. The customer may later return to the Web site to check the status of the order. Stages farther up the supply chain use customer order information to fill the request. That process involves an additional flow of information, product, and funds between various stages of the supply chain.

These examples illustrate that the customer is an integral part of the supply chain. In fact, the primary purpose of any supply chain is to satisfy customer needs and, in the process, generate profit for itself. The term *supply chain* conjures up images of product or supply moving from suppliers to manufacturers to distributors to retailers to customers along a chain. This is certainly part of the supply chain, but it is also important to visualize information, funds, and product flows along both directions of this chain. The term *supply chain* may also imply that only one player is involved at each stage. In reality, a manufacturer may receive material from several suppliers and then supply several distributors. Thus, most supply chains are actually networks. It may be more accurate to use the term *supply network* or *supply web* to describe the structure of most supply chains, as shown in Figure 1-2.

A typical supply chain may involve a variety of stages. These supply chain stages include:

- Customers
- Retailers

FIGURE 1-2 Supply Chain Stages



- Wholesalers/distributors
- Manufacturers
- Component/raw material suppliers

Each stage in a supply chain is connected through the flow of products, information, and funds. These flows often occur in both directions and may be managed by one of the stages or an intermediary. Each stage in Figure 1-2 need not be present in a supply chain. The appropriate design of the supply chain depends on both the customer's needs and the roles played by the stages involved. In some cases, such as Dell, a manufacturer may fill customer orders directly. Dell builds-to-order; that is, a customer order initiates manufacturing at Dell. Dell does not have a retailer, wholesaler, or distributor in its supply chain. In other cases, such as the mail-order company L.L.Bean, manufacturers do not respond to customer orders directly. In this case, L.L.Bean maintains an inventory of product from which it fills customer orders. Compared to the Dell supply chain, the L.L.Bean supply chain contains an extra stage (the retailer, L.L.Bean itself) between the customer and the manufacturer. In the case of other retail stores, the supply chain may also contain a wholesaler or distributor between the store and the manufacturer.

1.2 THE OBJECTIVE OF A SUPPLY CHAIN

The objective of every supply chain should be to maximize the overall value generated. The *value* a supply chain generates is the difference between what the final product is worth to the customer and the costs the supply chain incurs in filling the customer's request. For most commercial supply chains, value will be strongly correlated with *supply chain profitability* (also known as *supply chain surplus*), the difference between the revenue generated from the customer and the overall cost across the supply chain. For example, a customer purchasing a wireless router from Best Buy pays $60, which represents the revenue the supply chain receives. Best Buy and other stages of the supply chain incur costs to convey information, produce components, store them, transport them, transfer funds, and so on. The difference between the $60 that the customer paid and the sum of all costs incurred by the supply chain to produce and distribute the router represents the supply chain profitability or surplus. Supply chain profitability or

surplus is the total profit to be shared across all supply chain stages and intermediaries. The higher the supply chain profitability, the more successful is the supply chain. Supply chain success should be measured in terms of supply chain profitability and not in terms of the profits at an individual stage. (In subsequent chapters we see that a focus on profitability at individual stages may lead to a reduction in overall supply chain profits.)

Having defined the success of a supply chain in terms of supply chain profitability, the next logical step is to look for sources of revenue and cost. For any supply chain, there is only one source of revenue: the customer. At Wal-Mart, a customer purchasing detergent is the only one providing positive cash flow for the supply chain. All other cash flows are simply fund exchanges that occur within the supply chain, given that different stages have different owners. When Wal-Mart pays its supplier, it is taking a portion of the funds the customer provides and passing that money on to the supplier. All flows of information, product, or funds generate costs within the supply chain. Thus, the appropriate management of these flows is a key to supply chain success. Effective *supply chain management* involves the management of supply chain assets and product, information, and fund flows to maximize total supply chain profitability.

In this book we will have a strong focus on analyzing all supply chain decisions in terms of their impact on the supply chain surplus. These decisions and their impact can vary for a wide variety of reasons. For instance, consider the difference in the supply chain structure for fast-moving consumer goods observed in the United States and India. U.S. distributors play a much smaller role in this supply chain compared to their Indian counterparts. We argue that the difference in supply chain structure can be explained by the impact a distributor has on the supply chain surplus in the two countries.

Retailing in the United States is largely consolidated, with large chains buying consumer goods from most manufacturers. This consolidation gives retailers sufficient scale that the introduction of an intermediary such as a distributor does little to reduce costs and may actually increase costs because of an additional transaction. In contrast, India has millions of small retail outlets. The small size of Indian retail outlets limits the amount of inventory they can hold, thus requiring frequent replenishment—an order can be compared with the weekly grocery shopping for a family in the United States. The only way for a manufacturer to keep transportation costs low is to bring full truckloads of product close to the market and then distribute locally using "milk runs" with smaller vehicles. The presence of an intermediary who can receive a full truckload shipment, break bulk, and then make smaller deliveries to the retailers is crucial if transportation costs are to be kept low. Most Indian distributors are one-stop shops, stocking everything from cooking oil to soaps and detergents made by a variety of manufacturers. Besides the convenience provided by one-stop shopping, distributors in India are also able to reduce transportation costs for outbound delivery to the retailer by aggregating products across multiple manufacturers during the delivery runs. Distributors in India also handle collections, because their cost of collection is significantly lower than each manufacturer collecting from retailers on its own. Thus, the important role of distributors in India can be explained by the growth in supply chain surplus that results from their presence. The supply chain surplus argument implies that as retailing in India begins to consolidate, the role of distributors will diminish.

1.3 THE IMPORTANCE OF SUPPLY CHAIN DECISIONS

There is a close connection between the design and management of supply chain flows (product, information, and funds) and the success of a supply chain. Wal-Mart, Dell Computer, and Seven-Eleven Japan are examples of companies that have built

their success on superior design, planning, and operation of their supply chain. In contrast, the failure of many e-businesses such as Webvan can be attributed to weaknesses in their supply chain design and planning. Similarly, Quaker Oats's acquisition of Snapple in 1994 is an example of how the inability to design and manage supply chain flows effectively led to failure. We discuss these examples later in this section.

Wal-Mart has been a leader at using supply chain design, planning, and operation to achieve success. From its beginning, the company invested heavily in transportation and information infrastructure to facilitate the effective flow of goods and information. Wal-Mart designed its supply chain with clusters of stores around distribution centers to facilitate frequent replenishment at its retail stores in a cost-effective manner. Frequent replenishment allows stores to match supply and demand more effectively than the competition. Wal-Mart has been a leader in sharing information and collaborating with suppliers to bring down costs and improve product availability. The results are impressive. In their 2004 annual report, the company reported a net income of more than $9 billion on revenues of about $250 billion. These are dramatic results for a company that reached annual sales of only $1 billion in 1980. The growth in sales represents an annual compounded growth rate of 26 percent.

Dell has, over a relatively short period of time, become the world's largest personal computer (PC) manufacturer. In 2004 Dell had a net income of over $2.6 billion on revenues of just over $41 billion. The company has attributed a significant part of its success to the way it manages flows—product, information, and funds—within its supply chain.

Dell bypasses distributors and retailers and sells directly to customers. Close contact with its customers and an understanding of customers' needs allow Dell to develop better forecasts. To further improve the match between supply and demand, Dell makes an active effort to steer customers in real time, on the phone or via the Internet, toward PC configurations that can be built given the components available.

On the operational side, Dell centralizes manufacturing and inventories in a few locations and postpones final assembly until orders arrive. As a result, Dell is able to provide a large variety of PC configurations while keeping very low levels of inventory. In 2004, Dell carried less than five days' worth of inventory; in contrast, the competition, selling through retailers, carries several weeks' worth of inventory. If Intel introduces a new chip, the low level of inventory allows Dell to go to market with a PC containing the chip faster than the competition. If prices drop suddenly, as they often do, Dell has less inventory that loses value relative to its competitors. For some products, such as monitors manufactured by Sony, Dell maintains no inventory. The transportation company simply picks up the appropriate number of computers from Dell's Austin, Texas, plant and monitors from Sony's factory in Mexico, matches them by customer order, and delivers them to the customers. This procedure allows Dell to save time and money associated with the extra handling of monitors.

The success of the Dell supply chain is facilitated by sophisticated information exchange. Dell provides real-time data to suppliers on the current state of demand. Suppliers are able to access their components' inventory levels at the factories along with daily production requirements. Dell has created customized Web pages for its major suppliers to view demand forecasts and other customer-sensitive information, thus helping suppliers to get a better idea of customer demand and better match their production schedules to that of Dell.

Dell's low levels of inventory also help ensure that defects are not introduced into a large quantity of products. When a new product is launched, supplier engineers are stationed right in the plant. If a customer calls in with a problem, production can be

stopped and flaws fixed in real time. As there is no finished product in inventory, the amount of defective merchandise produced is minimized.

Dell also manages its cash flows very effectively. By managing inventories, receivables, and payables very closely, it managed a cash conversion cycle of negative 36 days in 2004. In other words, Dell ran its business on other people's money!

Clearly, Dell's supply chain design and its management of product, information, and cash flows play a key role in the company's success. In the changing marketplace, however, the company's supply chain design presents some new challenges for Dell. Whereas it has a supply chain that is very well suited to provide a high degree of customization at a low cost, it is not clear that hardware customization will stay significant for PCs and other products that Dell sells. In the future, Dell may have to rethink its supply chain design to maintain success.

The failure of many e-businesses such as Webvan and Kozmo can be attributed to their inability to design appropriate supply chains or manage supply chain flows effectively. Webvan designed a supply chain with large warehouses in several major cities in the United States, from which groceries were delivered to customer homes. This supply chain design could not compete with traditional supermarket supply chains in terms of cost. Traditional supermarket chains bring product to a supermarket close to the consumer using full truckloads, resulting in very low transportation costs. They turn their inventory relatively fast and let the customer perform most of the picking activity in the store. In contrast, Webvan turned its inventory marginally faster than supermarkets but incurred much higher transportation costs for home delivery and high labor costs to pick customer orders. The result was a company that folded in 2001 within two years of a very successful initial public offering.

Quaker Oats, with its acquisition of Snapple, provides another example in which failure to design and manage supply chain flows led to financial failure. In December 1994, Quaker Oats purchased Snapple, a producer of bottled natural drinks such as teas, at a cost of $1.7 billion. Gatorade, the top-selling brand in the sports drink segment, was Quaker Oats's most successful beverage. Gatorade was very strong in the South and Southwest of the United States, whereas Snapple was strong in the Northeast and on the West Coast.

Quaker Oats announced that a major motivation of the merger was the potential synergies between the two distribution systems of Snapple and Gatorade. The company, however, was unable to take advantage of these synergies. Problems stemmed from causes such as disparate manufacturing facilities and different customer types. Gatorade was manufactured in plants owned by Quaker Oats, whereas Snapple was produced under contract by outside plants. Gatorade sold significant amounts through supermarkets and grocery stores, whereas Snapple sold primarily through restaurants and independent retailers. Over the two years following its acquisition of Snapple, Quaker Oats was unable to gain much synergy between the two distribution systems in its attempts to merge them. Just 28 months later, Quaker Oats sold Snapple to Triarc Companies for about $300 million, about 20 percent of the purchase price. The inability to achieve synergies between the two supply chains was a significant reason for the failure of Snapple for Quaker Oats.

KEY POINT Supply chain design, planning, and operation decisions play a significant role in the success or failure of a firm.

In the next section, we categorize supply chain decision phases based on the frequency with which they are made and the time frame they take into account.

1.4 DECISION PHASES IN A SUPPLY CHAIN

Successful supply chain management requires many decisions relating to the flow of information, product, and funds. Each decision should be made to raise the supply chain surplus. These decisions fall into three categories or phases, depending on the frequency of each decision and the time frame during which a decision phase has an impact. As a result, each category of decisions must consider uncertainty over the decision horizon.

1. ***Supply Chain Strategy or Design:*** During this phase, given the marketing and pricing plans for a product, a company decides how to structure the supply chain over the next several years. It decides what the chain's configuration will be, how resources will be allocated, and what processes each stage will perform. Strategic decisions made by companies include whether to outsource or perform a supply chain function in-house, the location and capacities of production and warehousing facilities, the products to be manufactured or stored at various locations, the modes of transportation to be made available along different shipping legs, and the type of information system to be utilized. A firm must ensure that the supply chain configuration supports its strategic objectives and increases the supply chain surplus during this phase. Cisco's decisions regarding its choice of supply sources for components, contract manufacturers for manufacturing, and the location and capacity of its warehouses, are all supply chain design or strategic decisions. Supply chain design decisions are typically made for the long term (a matter of years) and are very expensive to alter on short notice. Consequently, when companies make these decisions, they must take into account uncertainty in anticipated market conditions over the next few years.

2. ***Supply Chain Planning:*** For decisions made during this phase, the time frame considered is a quarter to a year. Therefore, the supply chain's configuration determined in the strategic phase is fixed. This configuration establishes constraints within which planning must be done. The goal of planning is to maximize the supply chain surplus that can be generated over the planning horizon given the constraints established during the strategic or design phase. Companies start the planning phase with a forecast for the coming year (or a comparable time frame) of demand in different markets. Planning includes making decisions regarding which markets will be supplied from which locations, the subcontracting of manufacturing, the inventory policies to be followed, and the timing and size of marketing and price promotions. Dell's decisions regarding markets supplied by a production facility and target production quantities at each location are classified as planning decisions. Planning establishes parameters within which a supply chain will function over a specified period of time. In the planning phase, companies must include uncertainty in demand, exchange rates, and competition over this time horizon in their decisions. Given a shorter time frame and better forecasts than the design phase, companies in the planning phase try to incorporate any flexibility built into the supply chain in the design phase and exploit it to optimize performance. As a result of the planning phase, companies define a set of operating policies that govern short-term operations.

3. ***Supply Chain Operation:*** The time horizon here is weekly or daily, and during this phase companies make decisions regarding individual customer orders. At the operational level, supply chain configuration is considered fixed, and planning policies are already defined. The goal of supply chain operations is to handle incoming customer orders in the best possible manner. During this phase, firms allocate inventory or production to individual orders, set a date that an order is to be filled, generate pick lists at a warehouse, allocate an order to a particular shipping mode and shipment, set delivery

schedules of trucks, and place replenishment orders. Because operational decisions are being made in the short term (minutes, hours, or days), there is less uncertainty about demand information. Given the constraints established by the configuration and planning policies, the goal during the operation phase is to exploit the reduction of uncertainty and optimize performance.

The design, planning, and operation of a supply chain have a strong impact on overall profitability and success. It is fair to state that a large part of the success of firms like Wal-Mart and Dell can be attributed to their effective supply chain design, planning, and operation.

In later chapters, we develop concepts and present methodologies that can be used at each of the three decision phases described earlier. Most of our discussion addresses the supply chain design and planning phases.

KEY POINT Supply chain decision phases may be categorized as design, planning, or operational, depending on the time frame during which the decisions made apply.

1.5 PROCESS VIEWS OF A SUPPLY CHAIN

A supply chain is a sequence of processes and flows that take place within and between different stages and combine to fill a customer need for a product. There are two different ways to view the processes performed in a supply chain.

1. ***Cycle View:*** The processes in a supply chain are divided into a series of cycles, each performed at the interface between two successive stages of a supply chain.
2. ***Push/Pull View:*** The processes in a supply chain are divided into two categories depending on whether they are executed in response to a customer order or in anticipation of customer orders. *Pull* processes are initiated by a customer order, whereas *push* processes are initiated and performed in anticipation of customer orders.

CYCLE VIEW OF SUPPLY CHAIN PROCESSES

Given the five stages of a supply chain shown in Figure 1-2, all supply chain processes can be broken down into the following four process cycles, as shown in Figure 1-3:

- Customer order cycle
- Replenishment cycle
- Manufacturing cycle
- Procurement cycle

Each cycle occurs at the interface between two successive stages of the supply chain. The five stages thus result in four supply chain process cycles. Not every supply chain will have all four cycles clearly separated. For example, a grocery supply chain in which a retailer stocks finished-goods inventories and places replenishment orders with a distributor is likely to have all four cycles separated. Dell, in contrast, sells directly to customers, thus bypassing the retailer and distributor.

Each cycle consists of six subprocesses as shown in Figure 1-4. Each cycle starts with the supplier marketing the product to customers. A buyer then places an order that is received by the supplier. The supplier supplies the order, which is received by the buyer. The buyer may return some of the product or other recycled material to the supplier or a third party. The cycle of activities then begins all over again.

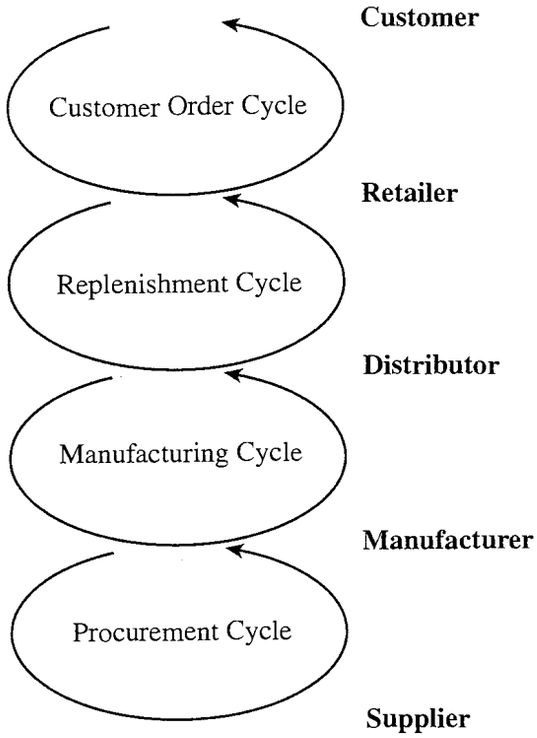


FIGURE 1-3 Supply Chain Process Cycles

Depending on the transaction in question, the subprocesses in Figure 1-4 can be applied to the appropriate cycle. When customers shop online at Amazon, they are part of the customer order cycle—with the customer as the buyer and Amazon as the supplier. In contrast, when Amazon orders books from a distributor to replenish its inventory, it is part of the replenishment cycle—with Amazon as the buyer and the distributor as the supplier.

Within each cycle, the goal of the buyer is to ensure product availability and to achieve economies of scale in ordering. The supplier attempts to forecast customer orders and reduce the cost of receiving the order. The supplier then works to fill the order on time and improve efficiency and accuracy of the order fulfillment process. The buyer then works to reduce the cost of the receiving process. Reverse flows are managed to reduce cost and meet environmental objectives.

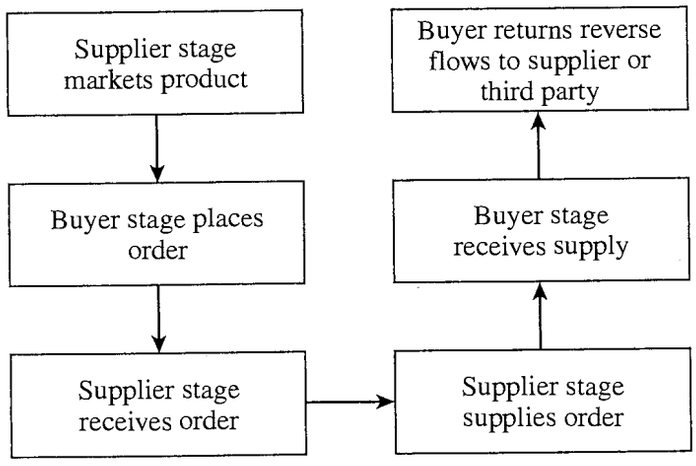


FIGURE 1-4 Subprocesses in Each Supply Chain Process Cycle

Even though each cycle has the same basic subprocesses, there are a few important differences between cycles. In the customer order cycle, demand is external to the supply chain and thus uncertain. In all other cycles, order placement is uncertain but can be projected based on policies followed by the particular supply chain stage. For example, in the procurement cycle, a tire supplier to an automotive manufacturer can predict tire demand precisely once the production schedule at the manufacturer is known. The second difference across cycles relates to the scale of an order. Whereas a customer buys a single car, the dealer orders multiple cars at a time from the manufacturer, and the manufacturer, in turn, orders an even larger quantity of tires from the supplier. As we move from the customer to the supplier, the number of individual orders declines and the size of each order increases. Thus, sharing of information and operating policies across supply chain stages becomes more important as we move farther from the end customer.

A cycle view of the supply chain is very useful when considering operational decisions because it clearly specifies the roles of each member of the supply chain. The detailed process description of a supply chain in the cycle view forces a supply chain designer to consider the infrastructure required to support these processes. The cycle view is useful, for example, when setting up information systems to support supply chain operations.

KEY POINT A cycle view of the supply chain clearly defines the processes involved and the owners of each process. This view is very useful when considering operational decisions because it specifies the roles and responsibilities of each member of the supply chain and the desired outcome for each process.

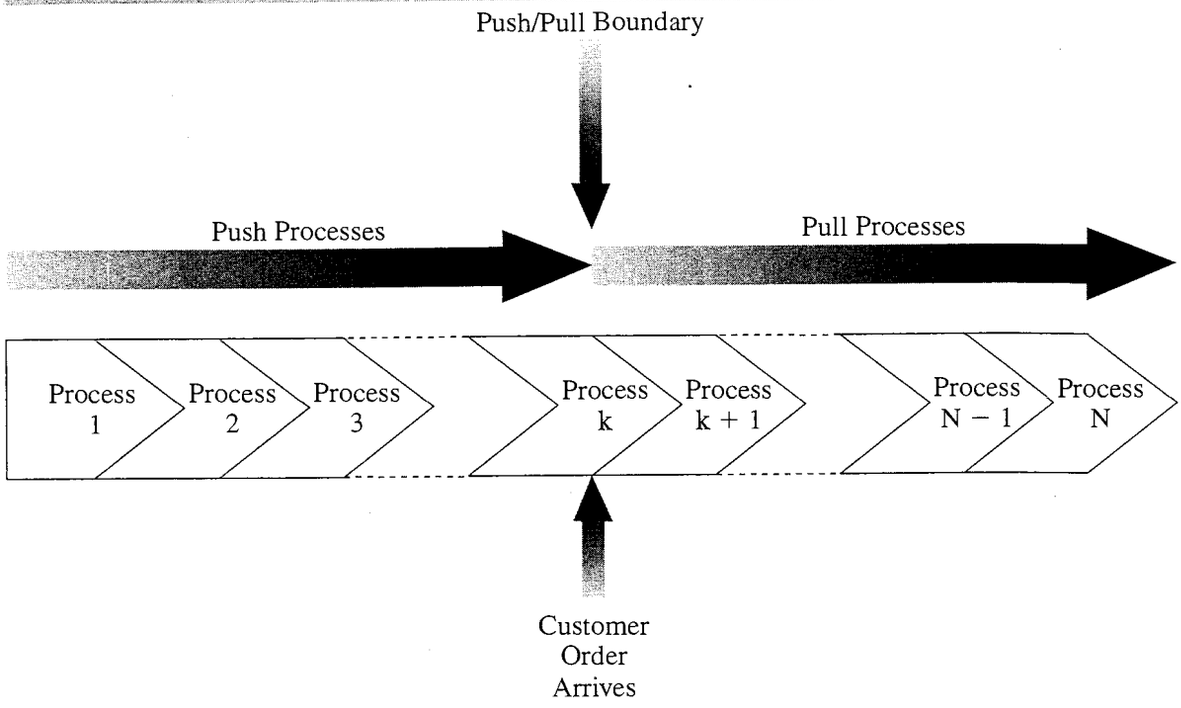
PUSH/PULL VIEW OF SUPPLY CHAIN PROCESSES

All processes in a supply chain fall into one of two categories depending on the timing of their execution relative to end customer demand. With pull processes, execution is initiated in response to a customer order. With push processes, execution is initiated in anticipation of customer orders. Therefore, at the time of execution of a pull process, customer demand is known with certainty, whereas at the time of execution of a push process, demand is not known and must be forecast. Pull processes may also be referred to as *reactive processes* because they react to customer demand. Push processes may also be referred to as *speculative processes* because they respond to speculated (or forecasted) rather than actual demand. The *push/pull boundary* in a supply chain separates push processes from pull processes as shown in Figure 1-5. Push processes operate in an uncertain environment because customer demand is not yet known. Pull processes operate in an environment in which customer demand is known. They are, however, often constrained by inventory and capacity decisions that were made in the push phase.

Let us compare a make-to-stock environment like that of L.L.Bean and a build-to-order environment like that of Dell to compare the push/pull view and the cycle view.

L.L.Bean executes all processes in the customer order cycle *after* the customer arrives. All processes that are part of the customer order cycle are thus pull processes. Order fulfillment takes place from product in inventory that is built up in anticipation of customer orders. The goal of the replenishment cycle is to ensure product availability when a customer order arrives. All processes in the replenishment cycle are performed in anticipation of demand and are thus push processes. The same holds true for processes in the manufacturing and procurement cycle. In fact, raw material such as

FIGURE 1-5 Push/Pull View of the Supply Chain



fabric is often purchased six to nine months before customer demand is expected. Manufacturing itself begins three to six months before the point of sale. The processes in the L.L.Bean supply chain break up into pull and push processes, as shown in Figure 1-6.

The situation is different for a build-to-order computer manufacturer like Dell. Dell does not sell through a reseller or distributor but directly to the consumer. Demand is not filled from finished-product inventory, but from production. The arrival of a customer order triggers production of the product. The manufacturing cycle is thus

FIGURE 1-6 Push/Pull Processes for the L.L.Bean Supply Chain

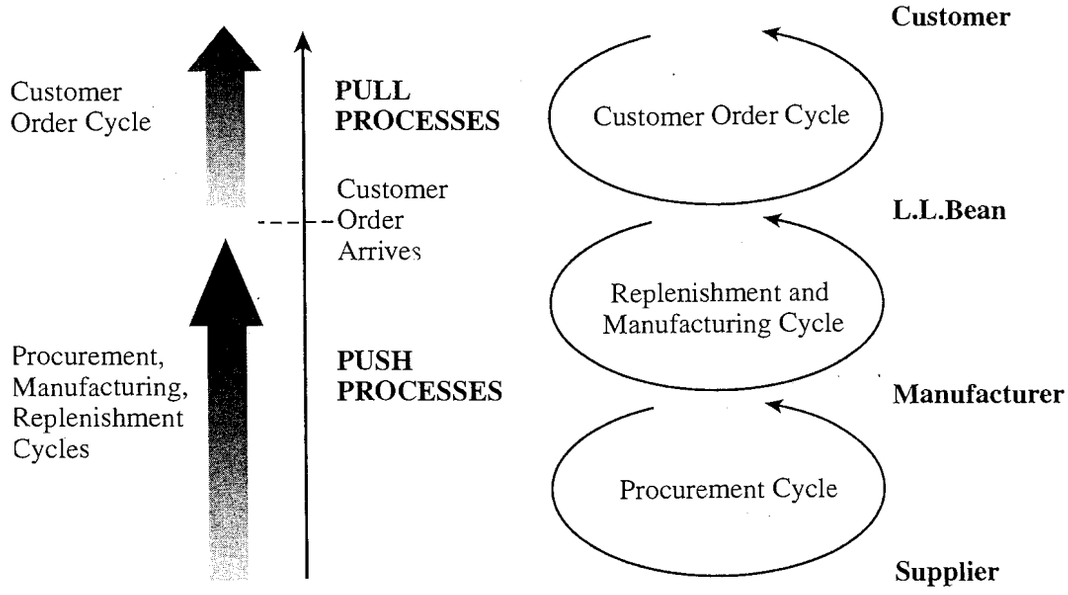
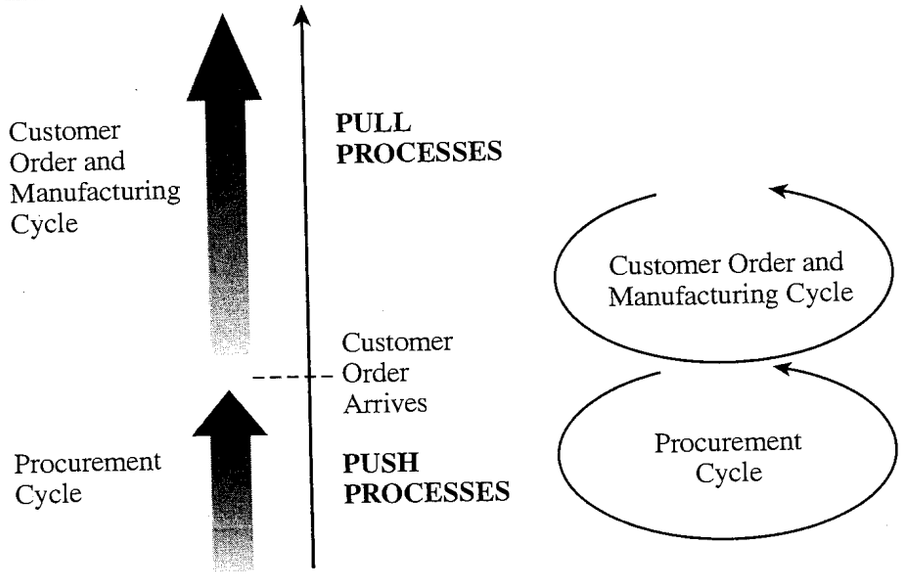


FIGURE 1-7 Push/Pull Processes for Dell Supply Chain



part of the customer order fulfillment process in the customer order cycle. There are effectively only two cycles in the Dell supply chain: (1) a customer order and manufacturing cycle and (2) a procurement cycle, as shown in Figure 1-7.

All processes in the customer order and manufacturing cycle at Dell are thus classified as pull processes because they are initiated by customer arrival. Dell, however, does not place component orders in response to a customer order. Inventory is replenished in anticipation of customer demand. All processes in the procurement cycle for Dell are thus classified as push processes, because they are in response to a forecast. The processes in the Dell supply chain break up into pull and push processes as shown in Figure 1-7.

A push/pull view of the supply chain is very useful when considering strategic decisions relating to supply chain design. The goal is to identify an appropriate push/pull boundary such that the supply chain can match supply and demand effectively.

The paint industry provides another excellent example of the gains from suitably adjusting the push/pull boundary. The manufacture of paint requires production of the base, mixing of suitable colors, and packing. Until the 1980s, all these processes were performed in large factories and paint cans were shipped to stores. These qualified as push processes, as they were performed to a forecast in anticipation of customer demand. Given the uncertainty of demand, the paint supply chain had great difficulty matching supply and demand. In the 1990s, paint supply chains were restructured such that mixing of colors was done at retail stores after customers placed their orders. In other words, color mixing was shifted from the push to the pull phase of the supply chain even though base preparation and packing of cans was still performed in the push phase. The result is that customers are always able to get the color of their choice, while total paint inventories across the supply chain have declined.

KEY POINT A push/pull view of the supply chain categorizes processes based on whether they are initiated in response to a customer order (pull) or in anticipation of a customer order (push). This view is very useful when considering strategic decisions relating to supply chain design.

SUPPLY CHAIN MACRO PROCESSES IN A FIRM

All supply chain processes discussed in the two process views and throughout this book can be classified into the following three macro processes as shown in Figure 1-8.

1. ***Customer Relationship Management (CRM):*** All processes that focus on the interface between the firm and its customers
2. ***Internal supply chain management (ISCM):*** All processes that are internal to the firm
3. ***Supplier Relationship Management (SRM):*** All processes that focus on the interface between the firm and its suppliers

The three macro processes manage the flow of information, product, and funds required to generate, receive, and fulfill a customer request. The CRM macro process aims to generate customer demand and facilitate the placement and tracking of orders. It includes processes such as marketing, pricing, sales, order management, and call center management. At an industrial distributor such as W.W. Grainger, CRM processes include the preparation of catalogs and other marketing materials, management of the Web site, and management of the call center that takes orders and provides service. The ISCM macro process aims to fulfill demand generated by the CRM process in a timely manner and at the lowest possible cost. ISCM processes include the planning of internal production and storage capacity, preparation of demand and supply plans, and fulfillment of actual orders. At W.W. Grainger, ISCM processes include planning for the location and size of warehouses; deciding which products to carry at each warehouse; preparing inventory management policies; and picking, packing, and shipping actual orders. The SRM macro process aims to arrange for and manage supply sources for various goods and services. SRM processes include the evaluation and selection of suppliers, negotiation of supply terms, and communication regarding new products and orders with suppliers. At W.W. Grainger, SRM processes include the selection of suppliers for various products, negotiation of pricing and delivery terms with suppliers, sharing of demand and supply plans with suppliers, and the placement of replenishment orders.

All three supply chain macro processes and their component processes are shown in Figure 1-8.

Observe that all three macro processes are aimed at serving the same customer. For a supply chain to be successful, it is crucial that the three macro processes are well integrated. The importance of this integration is discussed in Chapters 16 and 17. The organizational structure of the firm has a strong influence on the success or failure of the integration effort. In many firms, marketing is in charge of the CRM macro process, manufacturing handles the ISCM macro process, and purchasing oversees the SRM macro process—with very little communication among them. It is not unusual for

FIGURE 1-8 Supply Chain Macro Processes



marketing and manufacturing to have two different forecasts when making their plans. This lack of integration hurts the supply chain's ability to match supply and demand effectively, leading to dissatisfied customers and high costs. Thus, firms should structure a supply chain organization that mirrors the macro processes and ensures good communication and coordination among the owners of processes that interact with each other.

KEY POINT Within a firm, all supply chain activities belong to one of three macro processes: CRM, ISCM, and SRM. Integration among the three macro processes is crucial for successful supply chain management.

1.6 EXAMPLES OF SUPPLY CHAINS

In this section, we consider several supply chains and raise questions that must be answered during the design, planning, and operation phases of these supply chains. In later chapters, we discuss concepts and present methodologies that can be used to answer these questions.

GATEWAY: A DIRECT SALES MANUFACTURER

Gateway is a manufacturer of PCs that was founded in 1985 and started as a direct sales manufacturer with no retail footprint. In 1996, Gateway was one of the first PC manufacturers to start selling PCs online. Over the years Gateway expanded its operations worldwide, with sales and manufacturing presence in Europe and Asia Pacific. In 1999, the company had three plants in the United States, a plant in Ireland, and one in Malaysia.

In the late 1990s, Gateway introduced an aggressive strategy of opening Gateway retail stores throughout the United States. By January 2002, Gateway had approximately 280 retail stores in the United States. Gateway's strategy was to avoid carrying any finished-goods inventory at the retail stores and simply use these stores for customers to try the PCs and obtain help in deciding on the right configuration to purchase. When customers placed their order, PCs were manufactured to order and shipped from one of the assembly plants.

Initially, investors rewarded Gateway for this strategy and raised the stock price to more than $80 per share in late 1999. However, this success did not last. By November 2002, Gateway shares had dropped to less than $4 and Gateway was losing a significant amount of money. Plants in Salt Lake City, Ireland, and Malaysia were shut. By April 2004, Gateway had closed all its retail outlets and reduced the number of configurations offered to customers. The company was looking to sell its PCs through electronics retailers such as Best Buy and Circuit City. As you can imagine, this was quite a transition for the company to experience.

The following questions highlight supply chain decisions that have a bearing on Gateway's performance:

1. Why did Gateway have multiple production facilities in the United States? In the last few years Dell has also increased the number of facilities in the United States to four. What advantages or disadvantages does increasing the number of production facilities offer? How does Gateway decide which production facility will produce and ship a customer order?
2. What factors did Gateway consider when deciding which plants to close?

3. Why did Gateway choose not to carry any finished-product inventory at its retail stores?
4. Should a firm with an investment in retail stores carry any finished-goods inventory? What are the characteristics of products that are most suitable to be carried in finished-goods inventory? What characterizes products that are best manufactured to order?
5. Is the Dell model of selling directly without retail stores always less expensive than a supply chain with retail stores?
6. What are the supply chain implications of Gateway's decision to offer fewer configurations?

ZARA: APPAREL MANUFACTURING AND RETAIL

Zara is a chain of fashion stores owned by Inditex, Spain's largest apparel manufacturer and retailer. In 2004, Inditex reported sales of 13 billion euros from more than 2,200 retail outlets in 56 countries. The company opened a new store for each day in 2004. In an industry in which customer demand is fickle, Zara has grown rapidly with a strategy to be highly responsive to changing trends with affordable prices. Whereas design-to-sales cycle times in the apparel industry have traditionally averaged more than six months, Zara has achieved cycle times of five to six weeks. This speed allows Zara to introduce new designs every week and to change 75 percent of its merchandise display every three to four weeks. Thus, Zara's products on display match customer preferences much more closely than the competition. The result is that Zara sells most of its products at full price and has about half the markdowns in its stores compared to the competition.

Zara manufactures its apparel using a combination of flexible and quick sources in Europe (mostly Portugal and Spain) and low-cost sources in Asia. This contrasts with most apparel manufacturers, who have moved most of their manufacturing to Asia. About 40 percent of the manufacturing capacity is owned by Inditex, with the rest outsourced. Products with highly uncertain demand are sourced out of Europe, whereas products that are more predictable are sourced from its Asian locations. More than 40 percent of its finished-goods purchases and most of its in-house production occur after the sales season starts. This compares with less than 20 percent production after the start of a sales season for a typical retailer. This responsiveness and the postponement of decisions until after trends are known allow Zara to reduce inventories and forecast error. Zara has also invested heavily in information technology to ensure that the latest sales data are available to drive replenishment and production decisions.

Until 2002, Zara centralized all its European distribution and some of its global distribution through a single distribution center (DC) in Spain. It also had some smaller satellite DCs in Latin American countries. Shipments from the DCs to stores were made twice a week. This allowed store inventory to closely match customer demand. As Zara has grown, it has built another distribution center in Spain.

The following questions raise supply chain issues that are central to Zara's strategy and success:

1. What advantage does Zara gain against the competition by having a very responsive supply chain?
2. Why has Inditex chosen to have both in-house manufacturing and outsourced manufacturing? Why has Inditex maintained manufacturing capacity in Europe even though manufacturing in Asia is much cheaper?
3. Why does Zara source products with uncertain demand from local manufacturers and products with predictable demand from Asian manufacturers?

4. Why is Zara building a new distribution center as its sales grow? Is it better to have the new distribution center near the existing one, or at a completely different location?
5. What advantage does Zara gain from replenishing its stores twice a week compared to a less frequent schedule? How does the frequency of replenishment affect the design of its distribution system?
6. What information infrastructure does Zara need in order to operate its production, distribution, and retail network effectively?

W.W. GRAINGER AND McMASTER-CARR: MRO SUPPLIERS

W.W. Grainger and McMaster-Carr sell maintenance, repair, and operations (MRO) products. Both companies have catalogs, as well as Web pages through which orders can be placed. W.W. Grainger also has several hundred stores throughout the United States. Customers can walk into a store, call in an order, or place it via the Web. W.W. Grainger orders are either shipped to the customer or picked up by the customer at one of its stores. McMaster-Carr, on the other hand, ships almost all its orders (though a few customers near its DCs do pick up their own orders). W.W. Grainger has nine DCs that both replenish stores and fill customer orders. McMaster has DCs from which all orders are filled. Neither McMaster nor W.W. Grainger manufactures any product. They primarily serve the role of a distributor or retailer. Their success is largely linked to their supply chain management ability.

Both firms offer several hundred thousand products to their customers. Each firm stocks more than 100,000 products, with the rest being obtained from the supplier as needed. Both firms face the following strategic and operational issues:

1. How many DCs should be built and where should they be located?
2. How should product stocking be managed at the DCs? Should all DCs carry all products?
3. What products should be carried in inventory and what products should be left with the supplier?
4. What products should W.W. Grainger carry at a store?
5. How should markets be allocated to DCs in terms of order fulfillment? What should be done if an order cannot be completely filled from a DC? Should there be specified backup locations? How should they be selected?
6. How should replenishment of inventory be managed at the various stocking locations?
7. How should Web orders be handled relative to the existing business? Is it better to integrate the Web business with the existing business or to set up separate distribution?
8. What transportation modes should be used for order fulfillment and stock replenishment?

TOYOTA: A GLOBAL AUTO MANUFACTURER

Toyota Motor Corporation is Japan's top auto manufacturer and has experienced significant growth in global sales over the last two decades. A key issue facing Toyota is the design of its global production and distribution network. Part of Toyota's global strategy is to open factories in every market it serves. Toyota must decide what the production capability of each of the factories will be, as this has a significant impact on the desired distribution system. At one extreme, each plant can be equipped only for local production. At the other extreme, each plant is capable of supplying every market.

Prior to 1996, Toyota used specialized local factories for each market. After the Asian financial crisis in 1996/1997, Toyota redesigned its plants so that it can also export to markets that remain strong when the local market weakens. Toyota calls this strategy "global complementation."

Whether to be global or local is also an issue for Toyota's parts plants. Should they be designed for local consumption or should there be few parts plants globally that supply multiple assembly plants? For any global manufacturer like Toyota, one must address the following questions regarding the configuration and capability of the supply chain:

1. Where should the plants be located and what degree of flexibility should be built into each? What capacity should each plant have?
2. Should plants be able to produce for all markets or only specific contingency markets?
3. How should markets be allocated to plants and how frequently should this allocation be revised?
4. What kind of flexibility should be built into the distribution system?
5. How should this flexible investment be valued?
6. What actions may be taken during product design to facilitate this flexibility?

AMAZON.COM: AN E-BUSINESS

Amazon.com sells books, music, and other items over the Internet and is one of the pioneers of consumer e-business. Amazon, based in Seattle, started by filling all orders using books purchased from a distributor in response to customer orders. This practice differs from that of a traditional bookstore, which usually purchases directly from publishers and stocks books in anticipation of customer orders. Today, Amazon has six warehouses where it holds inventory. Amazon stocks best-selling books, though it still gets other titles from distributors or publishers. It uses the U.S. Postal Service and other package carriers such as UPS and FedEx to send books to customers.

Amazon has continued to expand the set of products that it sells online. Besides books and music, Amazon has added many product categories such as toys, apparel, electronics, jewelry, and shoes. After several years of losses, Amazon has been profitable since 2003.

Several brick-and-mortar players including traditional booksellers such as Borders and Barnes & Noble have also started selling using the Internet channel. Barnes & Noble has set up Barnes&Noble.com as a separate company, whereas Borders uses Amazon to fulfill its online orders after initially trying to operate an online business. In the case of Barnes & Noble, the retail store and the online supply chains share warehousing and transportation to some extent. This is a departure from the company's original strategy, when Barnes&Noble.com was not visible in any Barnes & Noble bookstore.

Several questions arise concerning how Amazon is structured and how traditional booksellers have responded:

1. Why is Amazon building more warehouses as it grows? How many warehouses should it have and where should they be located?
2. What advantages does selling books via the Internet provide over a traditional bookstore? Are there any disadvantages to selling via the Internet?
3. Should Amazon stock every book it sells?
4. What advantage can brick-and-mortar players derive from setting up an online channel? How should they use the two channels to gain maximum advantage?

5. Should traditional booksellers like Barnes and Noble integrate e-commerce into their current supply chain or manage it as a separate supply chain?
6. For what products does the e-commerce channel offer the greatest advantage? What characterizes these products?

1.7 SUMMARY OF LEARNING OBJECTIVES

1. Discuss the goal of a supply chain and explain the impact of supply chain decisions on the success of a firm.

   The goal of a supply chain should be to maximize overall supply chain profitability. Supply chain profitability is the difference between the revenue generated from the customer and the total cost incurred across all stages of the supply chain. Supply chain decisions have a large impact on the success or failure of each firm because they significantly influence both the revenue generated and the cost incurred. Successful supply chains manage flows of product, information, and funds to provide a high level of product availability to the customer while keeping costs low.
2. Identify the three key supply chain decision phases and explain the significance of each one.

   Supply chain decisions may be characterized as strategic (design), planning, or operational, depending on the time period during which they apply. Strategic decisions relate to supply chain configuration. These decisions have a long-term impact lasting several years. Planning decisions cover a period of a few months to a year and include decisions such as production plans, subcontracting, and promotions over that period. Operational decisions span from minutes to days and include sequencing production and filling specific orders. Strategic decisions define the constraints for planning decisions, and planning decisions define the constraints for operational decisions.
3. Describe the cycle and push/pull views of a supply chain.

   A cycle view of a supply chain divides processes into cycles, each performed at the interface between two successive stages of a supply chain. Each cycle starts with an order placed by one stage of the supply chain and ends when the order is received from the supplier stage. A push/pull view of a supply chain characterizes processes based on their timing relative to that of a customer order. Pull processes are performed in response to a customer order, whereas push processes are performed in anticipation of customer orders.
4. Classify the supply chain macro processes in a firm.

   All supply chain processes can be classified into three macro processes based on whether they are at the customer or supplier interface or are internal to the firm. The CRM macro process consists of all processes at the interface between the firm and the customer that work to generate, receive, and track customer orders. The ISCM macro process consists of all supply chain processes that are internal to the firm and work to plan for and fulfill customer orders. The SRM macro process consists of all supply chain processes at the interface between the firm and its suppliers that work to evaluate and select suppliers and then source goods and services from them.

Discussion Questions

1. Consider the purchase of a can of soda at a convenience store. Describe the various stages in the supply chain and the different flows involved.
2. Why should a firm like Dell take into account total supply chain profitability when making decisions?
3. What are some strategic, planning, and operational decisions that must be made by an apparel retailer like The Gap?

4. Consider the supply chain involved when a customer purchases a book at a bookstore. Identify the cycles in this supply chain and the location of the push/pull boundary.
5. Consider the supply chain involved when a customer orders a book from Amazon. Identify the push/pull boundary and two processes each in the push and pull phases.
6. In what way do supply chain flows affect the success or failure of a firm like Amazon? List two supply chain decisions that have a significant impact on supply chain profitability.

Bibliography

Cavinato, Joseph L. "What's Your Supply Chain Type?" *Supply Chain Management Review* (May–June 2002): 60–66.

Fisher, Marshall L. "What Is the Right Supply Chain for Your Product?" *Harvard Business Review* (March–April 1997): 83–93.

Fuller, Joseph B., James O'Conner, and Richard Rawlinson. "Tailored Logistics: The Next Advantage." *Harvard Business Review* (May–June 1993): 87–98.

Kopczak, Laura R., and M. Eric Johnson. "The Supply Chain Management Effect." *Sloan Management Review* (Spring 2003): 27–34.

Lambert, Douglas M. "The Eight Essential Supply Chain Management Processes." *Supply Chain Management Review* (September 2004): 18–26.

Lee, Hau L. "Aligning Supply Chain Strategies with Product Uncertainties." *California Management Review* (Spring 2002): 105–19.

Magretta, Joan. "Fast, Global, and Entrepreneurial: Supply Chain Management, Hong Kong Style." *Harvard Business Review* (September–October 1998): 102–14.

Magretta, Joan. "The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell." *Harvard Business Review* (March–April 1998): 72–84.

Quinn, Francis J. 1999. "Reengineering the Supply Chain: An Interview with Michael Hammer." *Supply Chain Management Review* (Spring 1999): 20–26.

Robeson, James F., and William C. Copacino, eds. *The Logistics Handbook.* New York: Free Press, 1994.

Shapiro, Roy D. "Get Leverage from Logistics." *Harvard Business Review* (May–June 1984): 119–27.

Slone, Reuben E. Leading a Supply Chain Turnaround." *Harvard Business Review* (October 2004) 114–21.

CHAPTER 2

SUPPLY CHAIN PERFORMANCE: ACHIEVING STRATEGIC FIT AND SCOPE

Learning Objectives

After reading this chapter, you will be able to:

1. Explain why achieving strategic fit is critical to a company's overall success.
2. Describe how a company achieves strategic fit between its supply chain strategy and its competitive strategy.
3. Discuss the importance of expanding the scope of strategic fit across the supply chain.

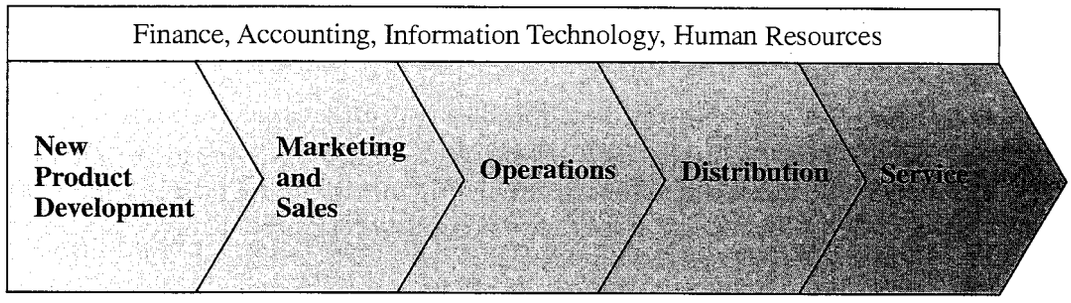
In Chapter 1, we discuss what a supply chain is and the importance of supply chain design, planning, and operation to a firm's success. In this chapter, we define supply chain strategy and explain how creating a strategic fit between a company's competitive strategy and its supply chain strategy affects performance. We also discuss the importance of expanding the scope of strategic fit from one operation within a company to all stages of the supply chain.

2.1 COMPETITIVE AND SUPPLY CHAIN STRATEGIES

A company's *competitive strategy* defines, relative to its competitors, the set of customer needs that it seeks to satisfy through its products and services. For example, Wal-Mart aims to provide high availability of a variety of products of reasonable quality at low prices. Most products sold at Wal-Mart are commonplace (everything from home appliances to clothing) and can be purchased elsewhere. What Wal-Mart provides is a low price and product availability. McMaster-Carr sells maintenance, repair, and operations (MRO) products. It offers more than 400,000 different products through both a catalog and a Web site. Its competitive strategy is built around providing the customer with convenience, availability, and responsiveness. With this focus on responsiveness, McMaster does not compete based on low price. Clearly, the competitive strategy at Wal-Mart is different from that at McMaster.

We can also contrast Dell, with its build-to-order model, with a firm like Gateway selling eMachines PCs through retailers. Dell has stressed customization and variety at a reasonable cost, with customers having to wait approximately one week to get their product. In contrast, a customer can walk into a computer retailer, be helped by a salesperson, and leave the same day with an eMachines computer. The amount of variety and customization available at the retailer, however, is limited. In each case, the competitive strategy is defined based on how the customer prioritizes product cost, delivery time, variety, and quality. A McMaster-Carr customer places greater emphasis on product variety and response time than on cost. A Wal-Mart customer, in contrast,

FIGURE 2-1 The Value Chain in a Company



places greater emphasis on cost. A Dell customer, purchasing online, places great emphasis on product variety and customization. A customer purchasing an eMachines PC at a retailer is most concerned with price, fast response time, and help in product selection. Thus, a firm's competitive strategy will be defined based on its customers' priorities. Competitive strategy targets one or more customer segments and aims to provide products and services that satisfy these customers' needs.

To see the relationship between competitive and supply chain strategies, we start with the value chain for a typical organization, as shown in Figure 2-1.

The value chain begins with new product development, which creates specifications for the product. Marketing and sales generate demand by publicizing the customer priorities that the products and services will satisfy. Marketing also brings customer input back to new product development. Using new product specifications, operations transforms inputs to outputs to create the product. Distribution either takes the product to the customer or brings the customer to the product. Service responds to customer requests during or after the sale. These are core processes or functions that must be performed for a successful sale. Finance, accounting, information technology, and human resources support and facilitate the functioning of the value chain.

To execute a company's competitive strategy, all these functions play a role, and each must develop its own strategy. Here, strategy refers to what each process or function will try to do particularly well.

A *product development* strategy specifies the portfolio of new products that a company will try to develop. It also dictates whether the development effort will be made internally or outsourced. A *marketing and sales* strategy specifies how the market will be segmented and how the product will be positioned, priced, and promoted. A *supply chain strategy* determines the nature of procurement of raw materials, transportation of materials to and from the company, manufacture of the product or operation to provide the service, and distribution of the product to the customer, along with any follow-up service and a specification of whether these processes will be performed in-house or outsourced. Given that firms are rarely completely vertically integrated, it is important to recognize that the supply chain strategy defines not only what processes within the firm should do well but also what the role played by each supply chain entity is. For example, Cisco's supply chain strategy calls for most component manufacturing and assembly to be outsourced. In this case, Cisco's supply chain strategy identifies not just what Cisco should do well but also the role of each third party to which supply chain tasks are outsourced. Supply chain strategy specifies what the operations, distribution, and service functions, whether performed in-house or outsourced, should do particularly well. Because our focus here is on supply chain strategy, we define it in more detail. Supply chain strategy includes a specification of the broad structure of the

supply chain and what many traditionally call "supplier strategy," "operations strategy," and "logistics strategy." For example, Dell's decision to sell direct, Gateway's decision to start selling PCs through resellers, and Cisco's decision to use contract manufacturers define the broad structure of their supply chains and are all part of their supply chain strategies. Supply chain strategy also includes design decisions regarding inventory, transportation, operating facilities, and information flows. For example, Amazon's decisions to build warehouses to stock some products and to continue using distributors as a source of other products are part of its supply chain strategy. Similarly, Toyota's decision to have production facilities in each of its major markets is part of its supply chain strategy.

The value chain emphasizes the close relationship between the functional strategies within a company. Each function is crucial if a company is to satisfy customer needs profitably. Thus, the various functional strategies cannot be formulated in isolation. They are closely intertwined and must fit and support each other if a company is to succeed.

For example, Seven-Eleven Japan's success can be related to the excellent fit among its functional strategies. Marketing at Seven-Eleven has emphasized convenience in the form of easy access to stores and availability of a wide range of products and services. New product development at Seven-Eleven is constantly adding products and services, such as bill payment services that draw customers in and exploit the excellent information infrastructure and the fact that customers frequently visit Seven-Eleven. Operations and distribution at Seven-Eleven have focused on having a high density of stores, being very responsive, and providing an excellent information infrastructure. The result is a virtuous cycle in which supply chain infrastructure is exploited to offer new products and service that increase demand, and the increased demand in turn makes it easier for operations to improve the density of stores, responsiveness in replenishment, and the information infrastructure.

In the next section we elaborate on this notion of fit and seek to answer this question: Given its competitive strategy, what should a company's supply chain try to do particularly well?

2.2 ACHIEVING STRATEGIC FIT

This chapter is built on the idea that for any company to be successful, its supply chain strategy and competitive strategy must fit together. *Strategic fit* means that both the competitive and supply chain strategies have aligned goals. It refers to consistency between the customer priorities that the competitive strategy hopes to satisfy and the supply chain capabilities that the supply chain strategy aims to build. The issue of achieving strategic fit is a key consideration during the supply chain strategy or design phase discussed in Chapter 1.

All processes and functions that are part of a company's value chain contribute to its success or failure. These processes and functions do not operate in isolation; no one process or function can ensure the chain's success. Failure at any one process or function, however, may lead to failure of the overall chain. A company's success or failure is thus closely linked to the following keys:

1. The competitive strategy and all functional strategies must fit together to form a coordinated overall strategy. Each functional strategy must support other functional strategies and help a firm reach its competitive strategy goal.

2. The different functions in a company must appropriately structure their processes and resources to be able to execute these strategies successfully.
3. The design of the overall supply chain and the role of each stage must be aligned to support the supply chain strategy.

A company may fail either because of a lack of strategic fit or because its overall supply chain design, processes, and resources do not provide the capabilities to support the desired strategic fit. In thinking of the major tasks of a chief executive officer (CEO), there are few greater than the job of aligning the supply chain design and all of the core functional strategies with the overall competitive strategy to achieve strategic fit. If this alignment is not achieved, conflicts arise between different functional goals within the firm, or between the goals of different supply chain stages. Such conflicts result in different functions within the firm and stages across the supply chain targeting different customer priorities. This conflict within the firm or across the supply chain leads to conflicts during supply chain operation.

Consider, for example, a situation in which marketing is publicizing a company's ability to provide a large variety of products very quickly; simultaneously, distribution is targeting the lowest cost means of transportation. In this situation, it is very likely that distribution will delay orders so it can get better transportation economies by grouping orders together or using inexpensive but slow modes of transportation. This action conflicts with marketing's stated goal of providing variety quickly. Similarly, consider a scenario where a retailer has decided to provide a high level of variety while carrying low levels of inventory but has selected suppliers and carriers based on their low price and not their responsiveness. In this case, the retailer is likely to end up with unhappy customers because of poor product availability.

To elaborate on strategic fit, let us return to the example of Dell Computer from Chapter 1. Dell's competitive strategy is to provide a large variety of customizable products at a reasonable price. Its customers can select from among thousands of possible PC configurations. In terms of supply chain strategy, a PC manufacturer has a range of options. At one extreme, a company can have an efficient supply chain with a focus on the ability to produce low-cost PCs by limiting variety and exploiting economies of scale. At the other extreme, a company can have a highly flexible and responsive supply chain that is very good at producing a large variety of products. In this second case, costs will be higher than in an efficient supply chain. Both supply chain strategies are viable by themselves, but do not necessarily fit with Dell's competitive strategy. A supply chain strategy that emphasizes flexibility and responsiveness has a better strategic fit with Dell's competitive strategy of providing a large variety of customizable products.

This notion of fit also extends to Dell's other functional strategies. For instance, its new product development strategy should emphasize designing products that are easily customizable, which may include designing common platforms across several products and the use of common components. Dell products use common components and are designed to be assembled quickly. This feature allows Dell to assemble customized PCs quickly in response to a customer order. The design of new products at Dell supports the supply chain's ability to assemble customized PCs in response to customer orders. This capability, in turn, supports Dell's strategic goal of offering customization to its customers. Dell has clearly achieved strong strategic fit among its different functional strategies and its competitive strategy. The notion of fit also extends to other stages in the Dell supply chain. Given that Dell provides a high degree of customization while operating with low levels of inventory, it is crucial that its suppliers and carriers be responsive. For example, the ability of carriers to merge a PC from Dell with a

monitor from Sony allows Dell not to carry any Sony monitors in inventory. Dell has tried to achieve this alignment of capabilities across the supply chain.

HOW IS STRATEGIC FIT ACHIEVED?

What does a company need to do to achieve that all-important strategic fit between the supply chain and competitive strategies? A competitive strategy will specify, either explicitly or implicitly, one or more customer segments that a company hopes to satisfy. To achieve strategic fit, a company must ensure that its supply chain capabilities support its ability to satisfy the targeted customer segments.

There are three basic steps to achieving this strategic fit, which we outline here and then discuss in more detail:

1. ***Understanding the Customer and Supply Chain Uncertainty:*** First, a company must understand the customer needs for each targeted segment and the uncertainty the supply chain faces in satisfying these needs. These needs help the company define the desired cost and service requirements. The supply chain uncertainty helps the company identify the extent of the unpredictability of demand, disruption, and delay that the supply chain must be prepared for.
2. ***Understanding the Supply Chain Capabilities:*** There are many types of supply chains, each of which is designed to perform different tasks well. A company must understand what its supply chain is designed to do well.
3. ***Achieving Strategic Fit:*** If a mismatch exists between what the supply chain does particularly well and the desired customer needs, the company will either need to restructure the supply chain to support the competitive strategy or alter its competitive strategy.

Step 1: Understanding the Customer and Supply Chain Uncertainty

To understand the customer, a company must identify the needs of the customer segment being served. Let us compare Seven-Eleven Japan and a discounter such as Sam's Club (a part of Wal-Mart). When customers go to Seven-Eleven to purchase detergent, they go there for the convenience of a nearby store and are not necessarily looking for the lowest price. In contrast, low price is very important to a Sam's Club customer. This customer may be willing to tolerate less variety and even purchase very large package sizes as long as the price is low. Even though customers purchase detergent at both places, the demand varies along certain attributes. In the case of Seven-Eleven, customers are in a hurry and want convenience. In the case of Sam's Club, they want a low price and are willing to spend time getting it. In general, customer demand from different segments varies along several attributes as follows.

- ***The Quantity of the Product Needed in Each Lot:*** An emergency order for material needed to repair a production line is likely to be small. An order for material to construct a new production line is likely to be large.
- ***The Response Time that Customers are Willing to Tolerate:*** The tolerable response time for the emergency order is likely to be short, whereas the allowable response time for the construction order is apt to be long.
- ***The Variety of Products Needed:*** A customer may place a high premium on the availability of all parts of an emergency repair order from a single supplier. This may not be the case for the construction order.
- ***The Service Level Required:*** A customer placing an emergency order expects a high level of product availability. This customer may go elsewhere if all parts of the order are not immediately available. This is not apt to happen in the case of the construction order, for which a long lead time is likely.

- ***The Price of the Product:*** The customer placing the emergency order is apt to be much less sensitive to price than the customer placing the construction order.
- ***The Desired Rate of Innovation in the Product:*** Customers at a high-end department store expect a lot of innovation and new designs in the store's apparel. Customers at Wal-Mart may be less sensitive to new product innovation.

Each customer in a particular segment will tend to have similar needs, whereas customers in a different segment can have very different needs.

Although we have described the many attributes along which customer demand varies, our goal is to identify one key measure for combining all of these attributes. This single measure then helps define what the supply chain should do particularly well.

Implied Demand Uncertainty. At first glance, it may appear that each of the customer need categories should be viewed differently, but in a very fundamental sense, each customer need can be translated into the metric of implied demand uncertainty. *Implied demand uncertainty* is demand uncertainty due to the portion of demand that the supply chain is targeting, not the entire demand.

We make a distinction between demand uncertainty and implied demand uncertainty. *Demand uncertainty* reflects the uncertainty of customer demand for a product. Implied demand uncertainty, in contrast, is the resulting uncertainty for only the portion of the demand that the supply chain plans to satisfy and the attributes the customer desires. For example, a firm supplying only emergency orders for a product will face a higher implied demand uncertainty than a firm that supplies the same product with a long lead time, as the second firm has an opportunity to fulfill the orders evenly over the long lead time.

Another illustration of the need for this distinction is the impact of service level. As a supply chain raises its level of service, it must be able to meet a higher and higher percentage of actual demand, forcing it to prepare for rare surges in demand. Thus, raising the service level increases the implied demand uncertainty even though the product's underlying demand uncertainty does not change.

Both the product demand uncertainty and various customer needs that the supply chain tries to fill affect implied demand uncertainty. Table 2-1 illustrates how various customer needs affect implied demand uncertainty.

As each individual customer need contributes to the implied demand uncertainty, we can use implied demand uncertainty as a common metric with which to distinguish different types of demand.

TABLE 2-1 Impact of Customer Needs on Implied Demand Uncertainty

Customer Need	*Causes Implied Demand Uncertainty to ...*
Range of quantity required increases	Increase because a wider range of the quantity required implies greater variance in demand
Lead time decreases	Increase because there is less time in which to react to orders
Variety of products required increases	Increase because demand per product becomes more disaggregate
Number of channels through which product may be acquired increases	Increase because the total customer demand is now disaggregated over more channels
Rate of innovation increases	Increase because new products tend to have more uncertain demand
Required service level increases	Increase because the firm now has to handle unusual surges in demand

TABLE 2-2 Correlation Between Implied Demand Uncertainty and Other Attributes

	Low Implied Uncertainty	*High Implied Uncertainty*
Product margin	Low	High
Average forecast error	10%	40% to 100%
Average stockout rate	1% to 2%	10% to 40%
Average forced season-end markdown	0%	10% to 25%

Source: Adapted from "What Is the Right Supply Chain for Your Product?" Marshall L. Fisher, *Harvard Business Review* (March–April 1997), 83–93.

Fisher (1997) pointed out that implied demand uncertainty is often correlated with other characteristics of demand, as shown in Table 2-2. An explanation follows.

1. Products with uncertain demand are often less mature and have less direct competition. As a result, margins tend to be high.
2. Forecasting is more accurate when demand has less uncertainty.
3. Increased implied demand uncertainty leads to increased difficulty in matching supply with demand. For a given product, this dynamic can lead to either a stockout or an oversupply situation. Increased implied demand uncertainty thus leads to both higher oversupply and a higher stockout rate.
4. Markdowns are high for products with high implied demand uncertainty because oversupply often results.

First let us take an example of a product with low implied demand uncertainty—such as table salt. Salt has a very low margin, accurate demand forecasts, low stockout rates, and virtually no markdowns. These characteristics match well with Fisher's chart of characteristics for products with highly certain demand.

On the other end of the spectrum, a new palmtop computer has high implied demand uncertainty. It will likely have a high margin, very inaccurate demand forecasts, high stockout rates (if it is successful), and large markdowns (if it is a failure). This too matches well with Table 2-2.

Another example is a circuit board supplier whose customers include two different types of PC manufacturers. One of its customers is a build-to-order PC manufacturer such as Dell that requires same-day lead times. In this case, the supplier might need to build up inventory or have very flexible manufacturing to be prepared for whatever demand Dell has that day. Forecast error and supplier inventories would be high; because of these factors, margins would likely be higher. The supplier's other customer builds a small variety of PCs and specifies in advance the number and type of PCs to be built. This information gives the supplier a longer lead time and reduces the forecasting errors and inventories. Thus, the supplier would likely get smaller margins from the latter PC manufacturer. These examples demonstrate that even with the same product, different customer segments can have different implied demand uncertainty given disparate service requirements.

Lee (2002) pointed out that, along with demand uncertainty, it is important to consider uncertainty resulting from the capability of the supply chain. For example, when a new component is introduced in the PC industry, the quality yields of the production process tend to be low and breakdowns are frequent. As a result, companies have difficulty delivering according to a well-defined schedule, resulting in high supply uncertainty for PC manufacturers. As the production technology matures and yields improve, companies are able to follow a fixed delivery schedule, resulting in low

TABLE 2-3 Impact of Supply Source Capability on Supply Uncertainty

Supply Source Capability	*Causes Supply Uncertainty to ...*
Frequent breakdowns	Increase
Unpredictable and low yields	Increase
Poor quality	Increase
Limited supply capacity	Increase
Inflexible supply capacity	Increase
Evolving production process	Increase

Source: Adapted from "Aligning Supply Chain Strategies with Product Uncertainties." Hau L. Lee, *California Management Review* (Spring 2002), 105–19.

supply uncertainty. Table 2-3 illustrates how various characteristics of supply sources affect the supply uncertainty.

Supply uncertainty is also strongly affected by the life-cycle position of the product. New products being introduced have higher supply uncertainty because designs and production processes are still evolving. In contrast, mature products have less supply uncertainty.

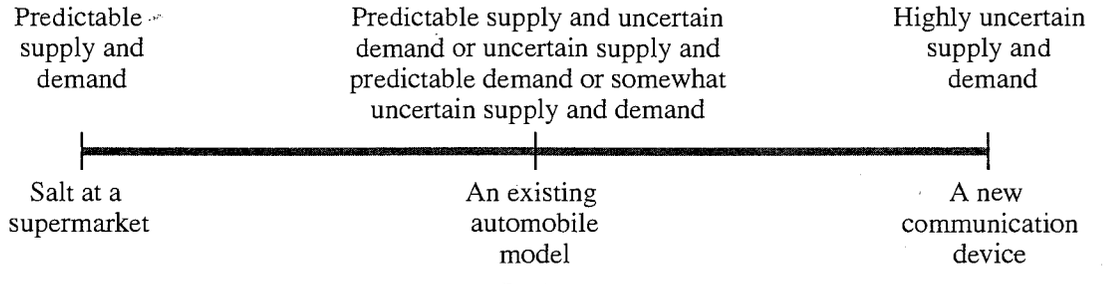
We can create a spectrum of uncertainty by combining the demand and supply uncertainty. This implied uncertainty spectrum is shown in Figure 2-2.

A company introducing a brand-new cell phone based on entirely new components and technology faces high implied demand uncertainty and high supply uncertainty. As a result, the implied uncertainty faced by the supply chain is very high. In contrast, a supermarket selling salt faces low implied demand uncertainty and low levels of supply uncertainty, resulting in a low implied uncertainty. Many agricultural products such as coffee are examples where supply chains face low levels of implied demand uncertainty but significant supply uncertainty based on weather. The supply chain thus has to face an intermediate level of implied uncertainty.

Several factors contribute risk to various portions of the supply chain and thus increase uncertainty. Throughout the book we will note the particular risks and discuss some ways that these risks can be mitigated.

KEY POINT The first step in achieving strategic fit between competitive and supply chain strategies is to understand customers and supply chain uncertainty. Uncertainty from the customer and the supply chain can be combined and mapped on the implied uncertainty spectrum.

FIGURE 2-2 The Implied Uncertainty (Demand and Supply) Spectrum



Step 2: Understanding the Supply Chain Capabilities

After understanding the uncertainty that the company faces, the next question is: How does the firm best meet demand in that uncertain environment? Creating strategic fit is all about creating a supply chain strategy that best meets the demand a company has targeted given the uncertainty it faces.

We now consider the characteristics of supply chains and categorize them. Similar to the way we placed demand on a one-dimensional spectrum (the implied uncertainty spectrum), we will also place each supply chain on a spectrum. Like customer needs, supply chains have many different characteristics that influence their responsiveness and efficiency.

First we provide some definitions. *Supply chain responsiveness* includes a supply chain's ability to do the following:

- Respond to wide ranges of quantities demanded
- Meet short lead times
- Handle a large variety of products
- Build highly innovative products
- Meet a high service level
- Handle supply uncertainty

These abilities are similar to many of the characteristics of demand and supply that led to high implied uncertainty. The more of these abilities a supply chain has, the more responsive it is.

Responsiveness, however, comes at a cost. For instance, to respond to a wider range of quantities demanded, capacity must be increased, which increases costs. This increase in cost leads to the second definition: *Supply chain efficiency* is the inverse of the cost of making and delivering a product to the customer. Increases in cost lower efficiency. For every strategic choice to increase responsiveness, there are additional costs that lower efficiency.

The *cost-responsiveness efficient frontier* is the curve in Figure 2-3 showing the lowest possible cost for a given level of responsiveness. Lowest cost is defined based on existing technology; not every firm is able to operate on the efficient frontier. The efficient frontier represents the cost-responsiveness performance of the best supply chains. A

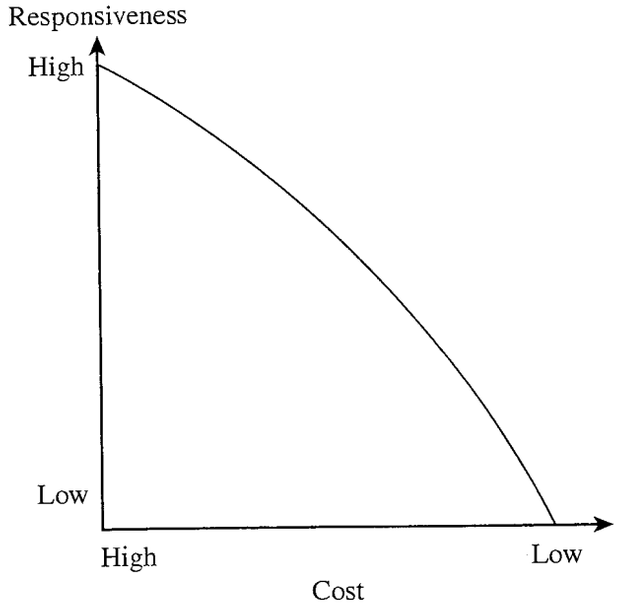
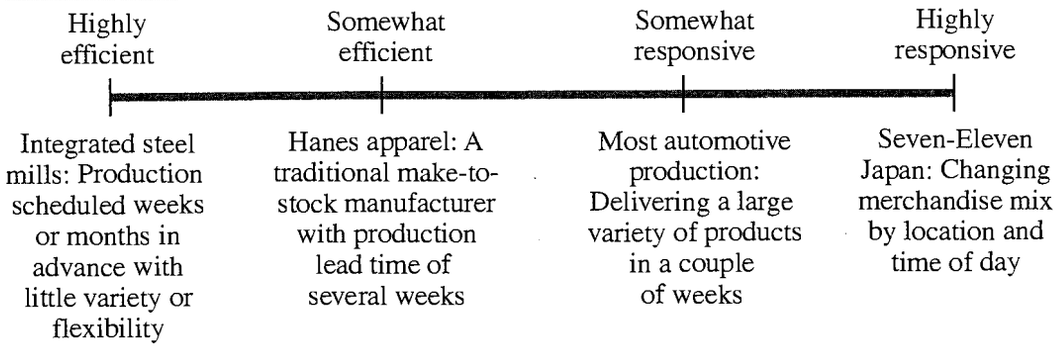


FIGURE 2-3
Cost-Responsiveness Efficient Frontier

FIGURE 2-4 The Responsiveness Spectrum



firm that is not on the efficient frontier can improve both its responsiveness and its cost performance by moving toward the efficient frontier. In contrast, a firm on the efficient frontier can improve its responsiveness only by increasing cost and becoming less efficient. Such a firm must then make a trade-off between efficiency and responsiveness. Of course, firms on the efficient frontier are also continuously improving their processes and changing technology to shift the efficient frontier itself. Given the trade-off between cost and responsiveness, a key strategic choice for any supply chain is the level of responsiveness it seeks to provide.

Supply chains range from those that focus solely on being responsive to those that focus on a goal of producing and supplying at the lowest possible cost. Figure 2-4 shows the responsiveness spectrum and where some supply chains fall on this spectrum.

The more capabilities constituting responsiveness a supply chain has, the more responsive it is. Seven-Eleven Japan replenishes its stores with breakfast items in the morning, lunch items in the afternoon, and dinner items at night. As a result, the available product variety changes by time of day. Seven-Eleven responds very quickly to orders, with store managers placing replenishment orders less than 12 hours before they are supplied. This practice makes the Seven-Eleven supply chain very responsive. The Dell supply chain allows a customer to customize any of several thousand PC configurations. Dell then delivers the appropriate PC to the customer within days. The Dell supply chain is also considered very responsive. Another example of a responsive supply chain is W.W. Grainger. The company faces both demand and supply uncertainty; therefore, the supply chain has been designed to deal effectively with both. An efficient supply chain, in contrast, lowers cost by eliminating some of its responsive capabilities. For example, Sam's Club sells a limited variety of products in large package sizes. The supply chain is capable of low costs, and the focus of this supply chain is clearly on efficiency.

KEY POINT The second step in achieving strategic fit between competitive and supply chain strategies is to understand the supply chain and map it on the responsiveness spectrum.

Step 3: Achieving Strategic Fit

After mapping the level of implied uncertainty and understanding the supply chain position on the responsiveness spectrum, the third and final step is to ensure that the degree of supply chain responsiveness is consistent with the implied uncertainty. The goal is to target high responsiveness for a supply chain facing high implied uncertainty, and efficiency for a supply chain facing low implied uncertainty.

For example, the competitive strategy of Dell targets customers who value having customized PCs delivered within days. Given the vast variety of PCs, the high level of innovation, and rapid delivery, demand from Dell customers can be characterized as having high demand uncertainty. Some supply uncertainty also exists, especially for newly introduced components. Dell has the option of designing an efficient or responsive supply chain. An efficient supply chain may use slow, inexpensive modes of transportation and economies of scale in production. If Dell made these choices, it would have difficulty supporting the customer's desire for rapid delivery and a wide variety of customizable products. Building a responsive supply chain, however, will allow Dell to meet its customers' needs. Therefore, a responsive supply chain strategy is best suited to meet the needs of Dell's targeted customers.

Now, consider a pasta manufacturer such as Barilla. Pasta is a product with relatively stable customer demand, giving it a low implied demand uncertainty. Supply is also quite predictable. Barilla could design a highly responsive supply chain in which pasta is custom-made in very small batches in response to customer orders and shipped via a rapid transportation mode such as FedEx. This choice would obviously make the pasta prohibitively expensive, resulting in a loss of customers. Barilla, therefore, is in a much better position if it designs a more efficient supply chain with a focus on cost reduction.

From the preceding discussion, it follows that increasing implied uncertainty from customers and supply sources is best served by increasing responsiveness from the supply chain. This relationship is represented by the "zone of strategic fit" illustrated in Figure 2-5. For a high level of performance, companies should move their competitive strategy (and resulting implied uncertainty) and supply chain strategy (and resulting responsiveness) toward the zone of strategic fit.

The first step in achieving strategic fit is to assign roles to different stages of the supply chain that ensure the appropriate level of responsiveness. It is important to understand that the desired level of responsiveness required across the supply chain may be attained by assigning different levels of responsiveness and efficiency to each stage of the supply chain as illustrated by the following examples.

IKEA is a Swedish furniture retailer with large stores in more than 20 countries. IKEA has targeted customers who want stylish furniture at a reasonable cost. The company limits the variety of styles that it sells. The large scale of each store and the limited variety of furniture decrease the implied uncertainty faced by the supply chain. IKEA stocks all styles in inventory and serves customers from stock. Thus, it uses inventory to absorb all the uncertainty faced by the supply chain. The presence of inventory at IKEA

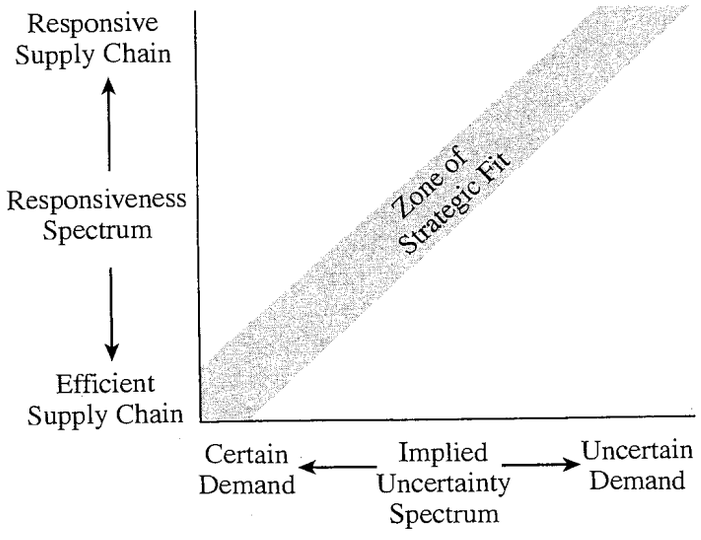


FIGURE 2-5
Finding the Zone of Strategic Fit

stores allows replenishment orders to its manufacturers to be more stable and predictable. As a result, IKEA passes along very little uncertainty to its manufacturers, who tend to be located in low-cost countries and focus on efficiency. IKEA provides responsiveness in the supply chain, with the stores absorbing most of the uncertainty and being responsive, and the suppliers absorbing very little uncertainty and being efficient.

In contrast, another approach for responsiveness may involve the retailer holding very little inventory. In this case, the retailer does not contribute significantly to supply chain responsiveness and most of the implied demand uncertainty is passed on to the manufacturer. For the supply chain to be responsive, the manufacturer now needs to be flexible and have low response times. An example of this approach is England, Inc., a furniture manufacturer located in Tennessee. Every week, the company makes several thousand sofas and chairs to order, delivering them to furniture stores across the country within three weeks. England's retailers allow customers to select from a very wide variety of styles and promise relatively quick delivery. This imposes a high level of implied uncertainty on the supply chain. The retailers, however, do not carry much inventory and pass most of the implied uncertainty on to England, Inc. The retailers can thus be efficient because most of the implied uncertainty for the supply chain is absorbed by England, Inc. with its flexible manufacturing process. England, Inc. itself has a choice of how much uncertainty it passes along to its suppliers. By holding more raw material inventories, the company allows its suppliers to focus on efficiency. If it decreases its raw material inventories, its suppliers must become more responsive.

The preceding discussion illustrates that the supply chain can achieve a given level of responsiveness by adjusting the roles of each stage of the supply chain. Making one stage more responsive allows other stages to focus on becoming more efficient. The best combination of roles depends on the efficiency and flexibility available at each stage. The notion of achieving a given level of responsiveness by assigning different roles and level of uncertainty to different stages of the supply chain is illustrated in Figure 2-6. The figure shows two supply chains that face the same implied uncertainty

FIGURE 2-6 Different Roles and Allocations of Implied Uncertainty for a Given Level of Supply Chain Responsiveness

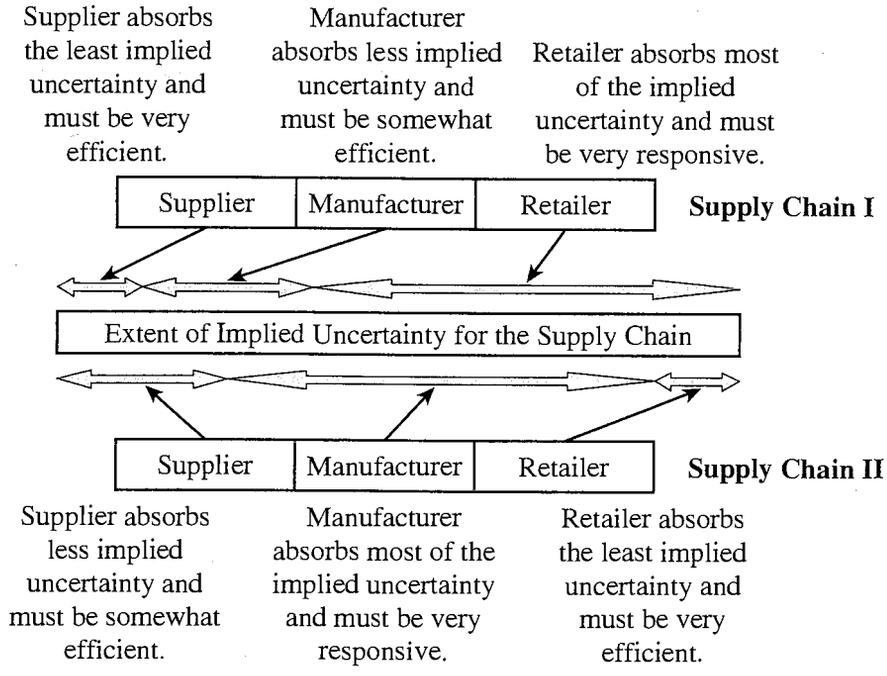
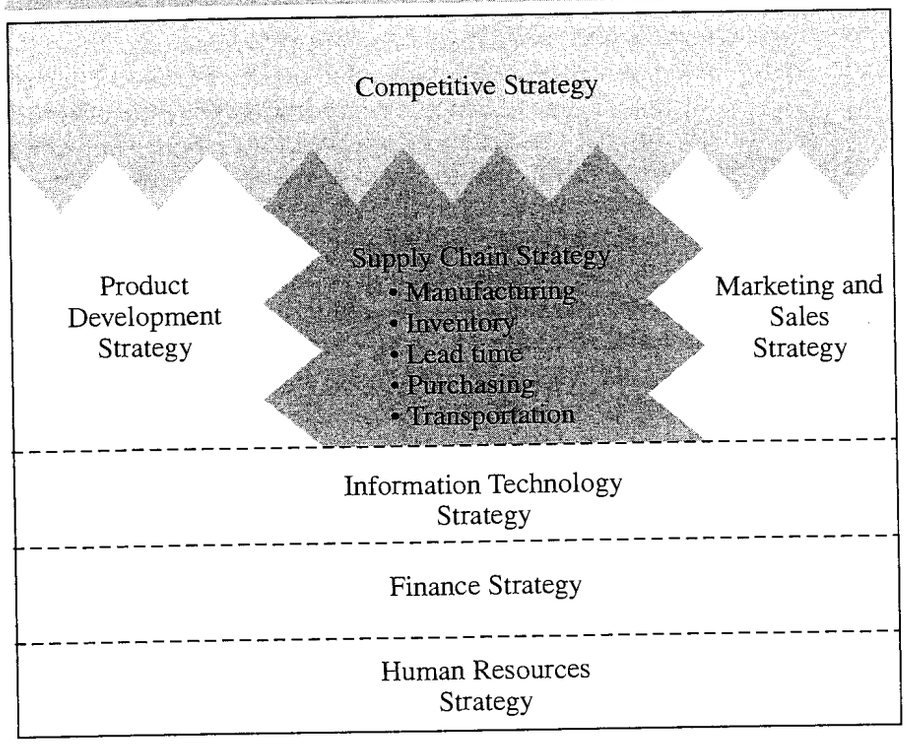


FIGURE 2-7 Fit Between Competitive and Functional Strategies



but achieve the desired level of responsiveness with different allocations of uncertainty and responsiveness across the supply chain. Supply Chain I has a very responsive retailer who absorbs most of the uncertainty, allowing (actually requiring) the manufacturer and supplier to be efficient. Supply Chain II, in contrast, has a very responsive manufacturer who absorbs most of the uncertainty, thus allowing the other stages to focus on efficiency.

To achieve complete strategic fit, a firm must also ensure that all its functions maintain consistent strategies that support the competitive strategy, as shown in Figure 2-7. All functional strategies must support the goals of the competitive strategy. All substrategies within the supply chain—such as manufacturing, inventory, and purchasing—must also be consistent with the supply chain's level of responsiveness.

Thus, firms with different locations along the responsiveness spectrum must have different supply chain designs and different functional strategies that support their responsiveness. We discuss the impact of supply chain design on the level of responsiveness in Chapter 4. Table 2-4 lists some of the major differences in functional strategy between supply chains that are efficient and those that are responsive.

KEY POINT The final step in achieving strategic fit is to match supply chain responsiveness with the implied uncertainty from demand and supply. The supply chain design and all functional strategies within the firm must also support the supply chain's level of responsiveness.

Changing the strategies to achieve strategic fit may sound easy enough to do, but in reality it can be quite difficult. In later chapters, we will discuss many of the obstacles

TABLE 2-4 Comparison of Efficient and Responsive Supply Chains

	Efficient Supply Chains	*Responsive Supply Chains*
Primary goal	Supply demand at the lowest cost	Respond quickly to demand
Product design strategy	Maximize performance at a minimum product cost	Create *modularity* to allow postponement of product differentiation
Pricing strategy	Lower margins because price is a prime customer driver	Higher margins because price is not a prime customer driver
Manufacturing strategy	Lower costs through high utilization	Maintain capacity flexibility to buffer against demand/supply uncertainty
Inventory strategy	Minimize inventory to lower cost	Maintain *buffer inventory* to deal with demand/supply uncertainty
Lead time strategy	Reduce, but not at the expense of costs	Reduce aggressively, even if the costs are significant
Supplier strategy	Select based on cost and quality	Select based on speed, flexibility, reliability, and quality

Source: Adapted from "What Is the Right Supply Chain for Your Product?" Marshall L. Fisher, *Harvard Business Review* (March–April 1997), 83–93.

to achieving this fit. Right now, the important points to remember from this discussion are the following.

1. There *is no* supply chain strategy that is always right.
2. There *is* a right supply chain strategy for a given competitive strategy.

The drive for strategic fit should come from the highest levels of the organization. In many companies, different groups devise competitive and functional strategies. Without proper communication between the groups and coordination by high-level management such as the CEO, these strategies are not likely to achieve strategic fit. For many firms, the failure to achieve strategic fit is a key reason for their inability to succeed.

OTHER ISSUES AFFECTING STRATEGIC FIT

Our previous discussion focused on achieving strategic fit when a firm serves a single market segment and the result is a well-defined strategic position. We now consider how multiple products, multiple customer segments, and product life cycle affect strategic fit.

Multiple Products and Customer Segments

Most companies produce and sell multiple products to multiple customer segments, each with different characteristics. A department store may sell seasonal products with high implied demand uncertainty, such as ski jackets, along with products with low implied demand uncertainty, such as black socks. The demand in each case maps to a different part of the uncertainty spectrum. W.W. Grainger sells MRO products to both large firms, such as Ford and Boeing, and small manufacturers and contractors. The customer needs in the two cases are very different. A large firm is much more likely to be concerned with price, given the large volumes they generate from W.W. Grainger, whereas a smaller company is apt to go to W.W. Grainger because it is responsive. The two segments that are served map to different positions along the implied uncertainty spectrum. Another example is Levi Strauss, which sells both customized and

standard-sized jeans. Demand for standard-sized jeans has a much lower demand uncertainty than demand for customized jeans.

In each of the aforementioned examples, the products sold and the customer segments served have different implied demand uncertainty. When devising supply chain strategy in these cases, the key issue for a company is to design a supply chain that balances efficiency and responsiveness given its portfolio of products, customer segments, and supply sources.

There are several possible routes a company can take to achieve this balance. One is to set up independent supply chains for each different product or customer segment. This strategy is feasible if each segment is large enough to support a dedicated supply chain. It fails, however, to take advantage of any economies of scope that often exist among a company's different products. Therefore, a preferable strategy is to tailor the supply chain to best meet the needs of each product's demand.

Tailoring the supply chain requires sharing some links in the supply chain with some products, while having separate operations for other links. The links are shared to achieve maximum possible efficiency while providing the appropriate level of responsiveness to each segment. For instance, all products may be made on the same line in a plant, but products requiring a high level of responsiveness may be shipped using a fast mode of transportation such as FedEx. Those products that do not have high responsiveness needs may be shipped by slower and less expensive means such as truck, rail, or even ship. In other instances, products requiring high responsiveness may be manufactured using a very flexible process, whereas products requiring less responsiveness may be manufactured using a less responsive but more efficient process. The mode of transportation used in both cases, however, may be the same. In other cases, some products may be held at regional warehouses close to the customer whereas others may be held in a centralized warehouse far from the customer. W.W. Grainger holds fast-moving items in its decentralized locations close to the customer. It holds slow-moving items with higher implied demand uncertainty in a centralized warehouse. Appropriate tailoring of the supply chain helps a firm achieve varying levels of responsiveness for a low overall cost. The level of responsiveness is tailored to each product or customer segment. Tailoring of the supply chain is an important concept that we develop further in subsequent chapters.

Product Life Cycle

As products go through their life cycle, the demand characteristics and the needs of the customer segments being served change. Supply characteristics also change as the product and production technologies mature. High-tech products are particularly prone to these life-cycle swings over a very short time span. A product goes through its life cycle from the introductory phase, when only the leading edge of customers is interested and supply is uncertain, all the way to the point at which the product becomes a commodity, the market is saturated, and supply is predictable. Thus, if a company is to maintain strategic fit, its supply chain strategy must evolve as its products enter different phases.

Let us consider changes in demand and supply characteristics over the life cycle of a product. Toward the beginning stages of a product's life cycle:

1. Demand is very uncertain and supply may be unpredictable.
2. Margins are often high, and time is crucial to gaining sales.
3. Product availability is crucial to capturing the market.
4. Cost is often a secondary consideration.

Consider a pharmaceutical firm introducing a new drug. Initial demand for the drug is highly uncertain, margins are typically very high, and product availability is the

key to capturing market share. The introductory phase of a product's life cycle corresponds to high implied uncertainty given the high demand uncertainty and the need for a high level of product availability. In such a situation, responsiveness is the most important characteristic of the supply chain.

As the product becomes a commodity product later in its life cycle, the demand and supply characteristics change. At this stage it is typically the case that:

1. Demand has become more certain and supply is predictable.
2. Margins are lower due to an increase in competitive pressure.
3. Price becomes a significant factor in customer choice.

In the case of a pharmaceutical company, these changes occur when a drug's patent expires and generic drugs are introduced. At this stage, demand for the drug stabilizes and margins shrink. Customers make their selections from the various choices based on price. Production technologies are well developed and supply is predictable. This stage corresponds to a low level of implied uncertainty. As a result, the supply chain needs to change. In such a situation, efficiency is the most important characteristic of the supply chain.

This discussion illustrates that as products mature, the corresponding supply chain strategy should, in general, move from being responsive to being efficient, as illustrated in Figure 2-8.

To illustrate these ideas, consider the example of Intel Corporation. Each time Intel introduces a new computer processor, there is great uncertainty with respect to demand for this new product, as it depends on the sales of new high-end PCs. Typically there is high uncertainty regarding how the market will receive these PCs and what the demand will be. Supply is unpredictable because yield is low and variable. At this stage, the Intel supply chain must be very responsive so it can react if demand is very high.

As the Intel processor becomes more mainstream, demand begins to stabilize, and yield from the production process is higher and more predictable. At this point demand and supply normally display lower implied uncertainty and price becomes a greater determinant of sales. Now it is important for Intel to have an efficient supply chain in place for producing processors.

All PC manufacturers are subject to the cycle described earlier. When a new model is introduced, margins are high, but demand is highly uncertain. In such a situation, a

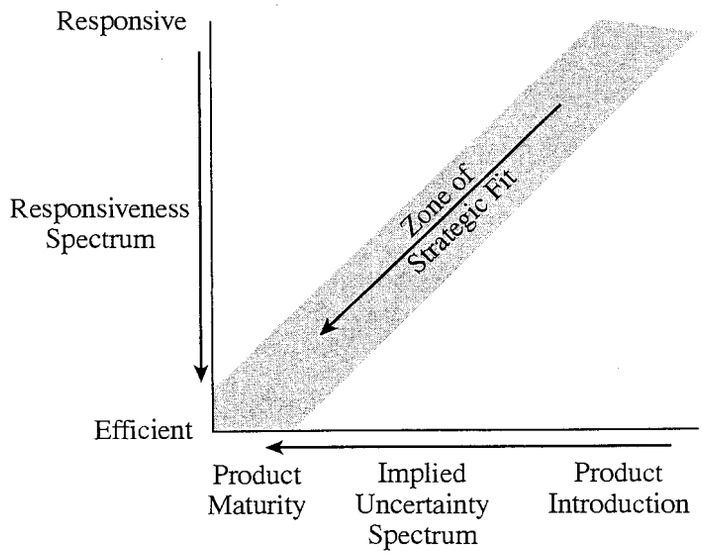


FIGURE 2-8 Changes in Supply Chain Strategy over a Product Life Cycle

responsive supply chain best serves the PC manufacturer. As the model matures, demand stabilizes and margins shrink. At this stage it is important that the manufacturer have an efficient supply chain. Apple Computer is an example of a firm that has had difficulty during product introduction. When it introduced the G4 in 1999, demand for the machine far exceeded the available supply of processors, resulting in significant lost sales. The supply chain in this case did not display sufficient responsiveness during the product's introductory phase.

The key point here is that demand and supply characteristics change over a product's life cycle. Because demand and supply characteristics change, the supply chain strategy must also change over the product life cycle if a company is to continue achieving strategic fit.

Globalization and Competitive Changes over Time

A final dimension to consider when matching supply chain and competitive strategy is the change in competitor behavior resulting from changes in the marketplace or increased globalization. Like product life cycles, competitors can change the landscape, thereby requiring a change in the firm's competitive strategy. An example is the growth of mass customization in various industries since the last decade of the twentieth century. As competitors flood the marketplace with product variety, customers are becoming accustomed to having their individual needs satisfied. Thus, the competitive focus today is on producing sufficient variety at a reasonable price. As more firms increase the level of variety offered, supply chains have been forced to develop the ability to support a wider range of products. Another big change is the increase in global sourcing of products. The availability of a Chinese-made leather recliner at Wal-Mart for $199 has put pressure on U.S. manufacturers to become much more responsive than they were in the past. Successful furniture manufacturers in the United States have responded by offering enough variety to make choice an advantage, while bringing down response time and keeping prices in check. Similar pressures of globalization are being felt in the apparel sector with the end of quotas, and local firms in developed countries are forced to respond. As the competitive landscape changes, a firm is forced to alter its competitive strategy. With the change in competitive strategy, a firm must also change its supply chain strategy to maintain strategic fit.

KEY POINT To achieve strategic fit, a firm must tailor its supply chain to best meet the needs of different customer segments. To retain strategic fit, supply chain strategy must be adjusted over the life cycle of a product and as the competitive landscape changes.

In the next section, we describe how the scope of the supply chain has expanded when achieving strategic fit. We also discuss why expanding the scope of strategic fit is critical to supply chain success.

2.3 EXPANDING STRATEGIC SCOPE

A key issue relating to strategic fit is the scope, in terms of supply chain stages, across which the strategic fit applies. *Scope of strategic fit* refers to the functions within the firm and stages across the supply chain that devise an integrated strategy with a shared objective. At one extreme, every operation within each functional area devises its own independent strategy with the objective of optimizing its individual performance. In

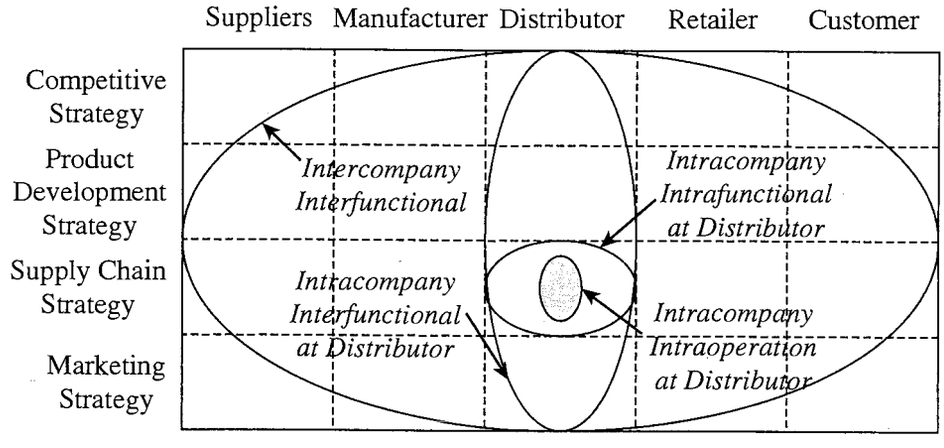
this case the scope of strategic fit is restricted to an operation in a functional area within a stage of the supply chain. At the opposite extreme, all functional areas across all stages of the supply chain devise strategy jointly with a common objective of maximizing supply chain profit. In this case the scope of strategic fit extends to the entire supply chain.

In this section we discuss how expanding the scope of strategic fit improves supply chain performance. We represent the scope of strategic fit on a two-dimensional grid. Horizontally, the scope of strategic fit is considered across different supply chain stages, starting from suppliers and moving all the way along the chain to the customer. Vertically, the scope is applied to the fit achieved across different functional strategies—competitive, product development, supply chain, and marketing.

INTRACOMPANY INTRAOPERATION SCOPE: THE MINIMIZE LOCAL COST VIEW

The most limited scope over which strategic fit is considered is one operation within a functional area within a company. This is referred to as *intracompany intraoperation scope.* Here, each operation within each stage of the supply chain devises strategy independently. In such a setting, the resulting collection of strategies will most likely not come close to maximizing supply chain profit, because different functions and operations have conflicting local objectives. This limited scope was the dominant practice during the 1950s and 1960s, when each operation within each stage of the supply chain attempted to minimize its own costs. Consider an example of a distribution company in which a transportation operation is evaluated based on average shipping cost per unit. Shipping the product individually costs $5/item, whereas shipping by truckload costs only $1/item. To minimize cost, the transportation group ships the product in full truckloads because this practice results in the lowest shipping cost per unit. This decision, while minimizing transportation cost per unit, increases response time and may undermine a competitive strategy based on responsiveness. The key point here is that the transportation decision was made independent of other functions within the firm and the rest of the supply chain. In this case, the scope of strategic fit is restricted to a portion (transportation) of the distributor stage within the supply chain. The smallest ellipse in Figure 2-9 represents the scope of strategic fit at the distributor in this instance.

FIGURE 2-9 The Different Scopes of Strategic Fit Across a Supply Chain



INTRACOMPANY INTRAFUNCTIONAL SCOPE: THE MINIMIZE FUNCTIONAL COST VIEW

Given that many operations together form each function within a firm, managers recognized the weakness of the intracompany intraoperation scope. Supply chain operations include manufacturing, warehousing, and transportation, among others. With the intracompany intrafunctional scope, the strategic fit is expanded to include all operations within a function. In this case, the warehousing manager no longer minimizes warehousing costs while the transportation manager independently minimizes transportation costs. By working together and developing a joint strategy, the two minimize the total functional cost.

Applying the intracompany intrafunctional scope and continuing with the distribution example, managers now look not only at transportation costs, but also at warehousing and other supply chain–related costs. Although truckload transportation saves the company $4/item, it costs an additional $8/item because of increased inventory and warehousing costs. Therefore, it costs less for the company to ship each item individually because the extra $4 transportation charge saves the company $8 in inventory-related costs.

In this case the scope of strategic fit expands to an entire function within a stage of the supply chain. Figure 2-9 shows the intracompany intrafunctional scope as it applies to the supply chain strategy at the distributor.

INTRACOMPANY INTERFUNCTIONAL SCOPE: THE MAXIMIZE COMPANY PROFIT VIEW

The key weakness of the intracompany intrafunctional view is that different functions may have conflicting objectives. Over time, companies became aware of this weakness as they saw, for example, marketing and sales focusing on revenue generation, and manufacturing and distribution focusing on cost reduction. Actions the two functions took were often in conflict, hurting the firm's overall performance. Companies realized the importance of expanding the scope of strategic fit across all functions within the firm. With the intracompany interfunctional scope, the goal is to maximize company profit. To achieve this goal, all functional strategies are developed to support both each other and the competitive strategy.

How does this change manifest itself? To return to our example, instead of looking only at the supply chain costs, the company will now look at revenue as well. Although the company had already decided to ship individual units to bring down inventory costs, marketing wanted to increase inventory so the company could take advantage of increased sales as a result of higher service levels. If the revenues and margins gained from holding more inventory outweigh the additional costs, the company should go ahead and increase inventory. The basic point is that both operational and marketing decisions have revenue and cost impact. They must thus be coordinated. The intracompany interfunctional scope of strategic fit as it applies to the distributor is shown in Figure 2-9.

INTERCOMPANY INTERFUNCTIONAL SCOPE: THE MAXIMIZE SUPPLY CHAIN SURPLUS VIEW

The intracompany interfunctional scope of strategic fit has two major weaknesses. First, it leads to each stage of the supply chain trying to maximize its own profits, which does not necessarily result in the maximization of supply chain surplus. Supply chain surplus is maximized only when all supply chain stages coordinate strategy together. This occurs with the intercompany interfunctional scope, in which all stages of the

supply chain coordinate strategy across all functions, ensuring that together they best meet the customer's needs and maximize supply chain surplus.

The second major weakness of the intracompany scope was noted in the 1990s when speed became a key driver of supply chain success. Today, more and more companies are succeeding not because they have the lowest priced product and not because they have the highest-quality or best-performing product, but because they are able to respond quickly to market needs and get the right product to the right customer at the right time. Companies like Zara, the Spanish apparel retailer, have used speed as their primary competitive advantage to succeed in the marketplace.

This shift toward speed has forced companies to ask what creates the level of speed that customers are demanding. When this question is examined, the answer for most companies lies to a large extent outside their own boundaries. The most significant delays are created at the interface between the boundaries of different stages of a supply chain. Thus, managing these interfaces becomes key to providing quick response to customers. The intracompany scope restricts strategic attention within each stage of the supply chain, leading to the interfaces being neglected. The intercompany scope forces every stage of the supply chain to look across the supply chain and evaluate the impact of its actions on other stages as well as on the interfaces. The intercompany scope allows the supply chain to raise the supply chain surplus and increase the size of the pie that all stages have to share among themselves.

The intercompany interfunctional scope of strategic fit is shown in Figure 2-9.

KEY POINT The intercompany scope of strategic fit is essential today because the competitive playing field has shifted from company versus company to supply chain versus supply chain. A company's partners in the supply chain may well determine the company's success, as the company is intimately tied to its supply chain.

Taking this view requires each company to evaluate its actions in the context of the entire supply chain. This means treating stages in the supply chain that a company does not own as belonging to the company. For example, a supply chain theme that has received a great deal of press in recent years is the reduction of inventory. Many companies strive to reduce their own inventories because they assume that the less inventory they have, the better. This assumption has led to a rash of changes in ownership of inventory from stage to stage in the supply chain without necessarily achieving any real reduction in overall inventory. Manufacturers feel that if they force their suppliers to own the parts inventory, they will not have to finance this inventory and therefore their costs will go down. In many cases, however, the suppliers simply take ownership of the parts inventory without making any changes in the way this inventory is managed. Because holding this inventory increases the suppliers' costs, they are forced to raise their prices to the manufacturer or lower their margins. In the end, there is no real increase in supply chain surplus because the supply chain merely shifts costs back and forth between its links.

The intercompany interfunctional scope proposes a different approach. Instead of just forcing the inventory on the supplier, who then increases price, the manufacturer and the supplier need to work together to actually reduce the amount of inventory that is required. For example, by sharing demand information with the supplier, the manufacturer can lower the amount of inventory needed in the chain, thus reducing overall cost, increasing the supply chain surplus, and making firms in that supply chain more competitive.

This result will allow the supply chain to either increase profits by sharing the extra surplus or reduce price by passing along some of the surplus to the customer. Overall,

the supply chain will be more competitive if it can achieve the intercompany scope of strategic fit.

KEY POINT The intercompany scope of strategic fit requires firms to evaluate every action in the context of the entire supply chain. This broad scope increases the size of the surplus to be shared among all stages of the supply chain.

AGILE INTERCOMPANY INTERFUNCTIONAL SCOPE

Up to this point, we have discussed strategic fit in a static context; that is, the players in a supply chain and the customer needs do not change over time. In reality, the situation is much more dynamic. Product life cycles are getting shorter and companies must satisfy the changing needs of individual customers. A company may have to partner with many different firms, depending on the product being produced and the customer being served. The strategy and operations at firms must be agile enough to maintain strategic fit in a changing environment.

Agile intercompany scope refers to a firm's ability to achieve strategic fit when partnering with supply chain stages that change over time. Firms must think in terms of supply chains consisting of many players at each stage. For example, a manufacturer may interface with a different set of suppliers and distributors depending on the product being produced and the customer being served. Furthermore, as customer needs vary over time, firms must have the ability to become part of new supply chains while ensuring strategic fit. This level of agility becomes more important as the competitive environment becomes more dynamic.

2.4 SUMMARY OF LEARNING OBJECTIVES

1. Explain why achieving strategic fit is critical to a company's overall success.

   A lack of strategic fit between the competitive and supply chain strategy can result in the supply chain taking actions that are not consistent with customer needs, leading to a reduction in supply chain surplus and decreasing supply chain profitability. Strategic fit requires that all functions within a firm and stages in the supply chain target the same goal, one that is consistent with customer needs.
2. Describe how a company achieves strategic fit between its supply chain strategy and its competitive strategy.

   To achieve strategic fit, a company must first understand the needs of the customers being served, understand the uncertainty of the supply chain, and identify the implied uncertainty. The second step is to understand the supply chain's capabilities in terms of efficiency and responsiveness. The key to strategic fit is ensuring that supply chain responsiveness is consistent with customer needs, supply capabilities, and the resulting implied uncertainty.
3. Discuss the importance of expanding the scope of strategic fit across the supply chain.

   The scope of strategic fit refers to the functions and stages within a supply chain that coordinate strategy and target a common goal. When the scope is narrow, individual functions try to optimize their performance based on their own goals. This practice often results in conflicting actions that reduce the supply chain surplus. As the scope of strategic fit is enlarged to include the entire supply chain, actions are evaluated based on their impact on overall supply chain performance, which helps increase supply chain surplus.

Discussion Questions

1. How would you characterize the competitive strategy of a high-end department store chain such as Nordstrom? What are the key customer needs that Nordstrom aims to fill?
2. Where would you place the demand faced by Nordstrom on the implied demand uncertainty spectrum? Why?
3. What level of responsiveness would be most appropriate for Nordstrom's supply chain? What should the supply chain be able to do particularly well?
4. How can Nordstrom expand the scope of strategic fit across its supply chain?
5. Reconsider the previous four questions for other companies such as Amazon, a supermarket chain, an auto manufacturer, and a discount retailer such as Wal-Mart.
6. Give arguments to support the statement that Wal-Mart has achieved very good strategic fit between its competitive and supply chain strategies.

Bibliography

Blackwell, Roger D., and Kristina Blackwell. "The Century of the Consumer: Converting Supply Chains into Demand Chains." *Supply Chain Management Review* (Fall 1999): 22–32.

Bovet, David M., and David G. Frentzel. "The Value Net: Connecting for Profitable Growth." *Supply Chain Management Review* (Fall 1999): 96–104.

Fine, Charles H. *Clock Speed, Winning Industry Control in the Age of Temporary Advantage.* Reading, MA: Perseus Books, 1999.

Fisher, Marshall L. "What Is the Right Supply Chain for Your Product?" *Harvard Business Review* (March–April 1997): 83–93.

Fuller, Joseph B., James O'Conner, and Richard Rawlinson. "Tailored Logistics: The Next Advantage." *Harvard Business Review* (May–June 1993): 87–98.

Gilmore, James H., and B. Joseph Pine II. *Markets of One: Creating Customer Unique Value Through Mass Customization.* Boston: Harvard Business School Press, 2000.

Lee, Hau L. "Aligning Supply Chain Strategies with Product Uncertainties." *California Management Review* (Spring 2002): 105–19.

Lee, Hau L. "The Triple-A Supply Chain." *Harvard Business Review* (October 2004): 102–12.

Magretta, Joan. "Fast, Global, and Entrepreneurial: Supply Chain Management, Hong Kong Style." *Harvard Business Review* (September–October 1998): 102–14.

Magretta, Joan. "The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell." *Harvard Business Review* (March–April 1998): 72–84.

Pine, B. Joseph II. *Mass Customization.* Boston: Harvard Business School Press, 1999.

Shapiro, Roy D. "Get Leverage from Logistics." *Harvard Business Review* (May–June 1984): 119–27.

Shapiro, Roy D., and James L. Heskett. 1985. *Logistics Strategy: Cases and Concepts.* St. Paul, MN: West Publishing Company, 1985.

Stalk, George, Jr., and Thomas M. Hout. *Competing Against Time.* New York: Free Press, 1990.

CHAPTER 3
SUPPLY CHAIN DRIVERS AND METRICS



Learning Objectives

After reading this chapter, you will be able to:

1. Identify the major drivers of supply chain performance.
2. Discuss the role each driver plays in creating strategic fit between the supply chain strategy and the competitive strategy.
3. Define the key metrics that track the performance of the supply chain in terms of each driver.
4. Describe the major obstacles that must be overcome to manage a supply chain successfully.

In this chapter, we introduce the three logistical drivers—facilities, inventory, and transportation—and the three cross-functional drivers—information, sourcing, and pricing—that determine the performance of any supply chain. We discuss how these drivers are used in the design, planning, and operation of the supply chain. We define several metrics that can be used to gauge the performance of each driver. We also introduce many of the obstacles faced by supply chain managers.

3.1 DRIVERS OF SUPPLY CHAIN PERFORMANCE

The strategic fit discussed in Chapter 2 requires that a company's supply chain achieve the balance between responsiveness and efficiency that best meets the needs of the company's competitive strategy. To understand how a company can improve supply chain performance in terms of responsiveness and efficiency, we must examine the logistical and cross-functional drivers of supply chain performance: facilities, inventory, transportation, information, sourcing, and pricing. These drivers interact with each other to determine the supply chain's performance in terms of responsiveness and efficiency. As a result, the structure of these drivers determines if and how strategic fit is achieved across the supply chain.

First we define each driver and discuss its impact on the performance of the supply chain.

1. ***Facilities*** are the actual physical locations in the supply chain network where product is stored, assembled, or fabricated. The two major types of facilities are production sites and storage sites. Decisions regarding the role, location, capacity, and flexibility of facilities have a significant impact on the supply chain's performance. For instance, an auto-parts distributor striving for responsiveness could have many warehousing facilities located close to customers even though this practice reduces efficiency. Alternatively, a high-efficiency distributor would have fewer warehouses to increase efficiency despite the fact that this practice will reduce responsiveness.

2. ***Inventory*** encompasses all raw materials, work in process, and finished goods within a supply chain. Changing inventory policies can dramatically alter the supply chain's efficiency and responsiveness. For example, a clothing retailer can make itself more responsive by stocking large amounts of inventory and satisfying customer demand from stock. A large inventory, however, increases the retailer's cost, thereby making it less efficient. Reducing inventory makes the retailer more efficient but hurts its responsiveness.

3. ***Transportation*** entails moving inventory from point to point in the supply chain. Transportation can take the form of many combinations of modes and routes, each with its own performance characteristics. Transportation choices have a large impact on supply chain responsiveness and efficiency. For example, a mail-order catalog company can use a faster mode of transportation such as FedEx to ship products, thus making its supply chain more responsive, but also less efficient given the high costs associated with using FedEx. Or the company can use slower but cheaper ground transportation to ship the product, making the supply chain efficient but limiting its responsiveness.

4. ***Information*** consists of data and analysis concerning facilities, inventory, transportation, costs, prices, and customers throughout the supply chain. Information is potentially the biggest driver of performance in the supply chain because it directly affects each of the other drivers. Information presents management with the opportunity to make supply chains more responsive *and* more efficient. For example, with information on customer demand patterns, a pharmaceutical company can produce and stock drugs in anticipation of customer demand, which makes the supply chain very responsive because customers will find the drugs they need when they need them. This demand information can also make the supply chain more efficient because the pharmaceutical firm is better able to forecast demand and produce only the required amount. Information can also make this supply chain more efficient by providing managers with shipping options, for instance, that allow them to choose the lowest-cost alternative while still meeting the necessary service requirements.

5. ***Sourcing*** is the choice of who will perform a particular supply chain activity such as production, storage, transportation, or the management of information. At the strategic level, these decisions determine what functions a firm performs and what functions the firm outsources. Sourcing decisions affect both the responsiveness and efficiency of a supply chain. After Motorola outsourced much of its production to contract manufacturers in China, it saw its efficiency improve but its responsiveness suffer because of the long distances. To make up for the drop in responsiveness, Motorola started flying in some of its cell phones from China even though this choice increased transportation cost. Flextronics, an electronics contract manufacturer, is hoping to offer both responsive and efficient sourcing options to its customers. It is trying to make its production facilities in the United States very responsive while keeping its facilities in low-cost countries efficient. Flextronics hopes to become an effective source for all customers using this combination of facilities.

6. ***Pricing*** determines how much a firm will charge for goods and services that it makes available in the supply chain. Pricing affects the behavior of the buyer of the good or service, thus affecting supply chain performance. For example, if a transportation company varies its charges based on the lead time provided by the customers, it is very likely that customers who value efficiency will order early and customers who value responsiveness will be willing to wait and order just before they need a product transported. Early orders are less likely if prices do not vary with lead time.

Our definition of these drivers attempts to delineate logistics and supply chain management. Supply chain management includes the use of logistical and cross-functional drivers to increase the supply chain surplus. Cross-functional drivers have become

increasingly important in raising the supply chain surplus in recent years. While logistics remains a major part, supply chain management is increasingly becoming focused on the three cross-functional drivers.

It is important to realize that these drivers do not act independently but interact with each other to determine the overall supply chain performance. Good supply chain design and operation recognizes this interaction and makes the appropriate trade-offs to deliver the desired level of responsiveness. Consider, for example, the furniture industry in the United States. Low-cost furniture sourced from Asia is available at many discount retailers. The primary goal of this supply chain is to deliver a low price and acceptable quality. Variety is typically low and retailers such as Wal-Mart stock inventory of finished goods. The low variety and stable replenishment orders allow furniture manufacturers in Asia to focus on efficiency. Given the available inventory, low-cost modes of transportation from Asia are used. In this instance, relatively low-cost inventory at the retailer allows the supply chain to become efficient by lowering transportation and production costs. In contrast, some U.S. furniture makers have chosen to focus on providing variety. Given the high variety and high prices, keeping inventory of all variants at a retailer would be very expensive. In this case the supply chain has been designed so the retailer carries very little inventory. Customers place their orders with the retailer by seeing one variant of the furniture and selecting among the various options. The supply chain is made responsive by using information technology to convey order information effectively, structuring very flexible manufacturing facilities to be able to produce in small lots, and using responsive transportation to deliver the furniture to the customer. In this instance, responsive facilities, transportation, and information are used to lower inventory costs. As the following chapter will illustrate, the key to achieving strategic fit across the supply chain is to structure the supply chain drivers appropriately to provide the desired level of responsiveness.

Before we discuss each of the six drivers in detail, we put these drivers into a framework that helps to clarify the role of each driver in improving supply chain performance.

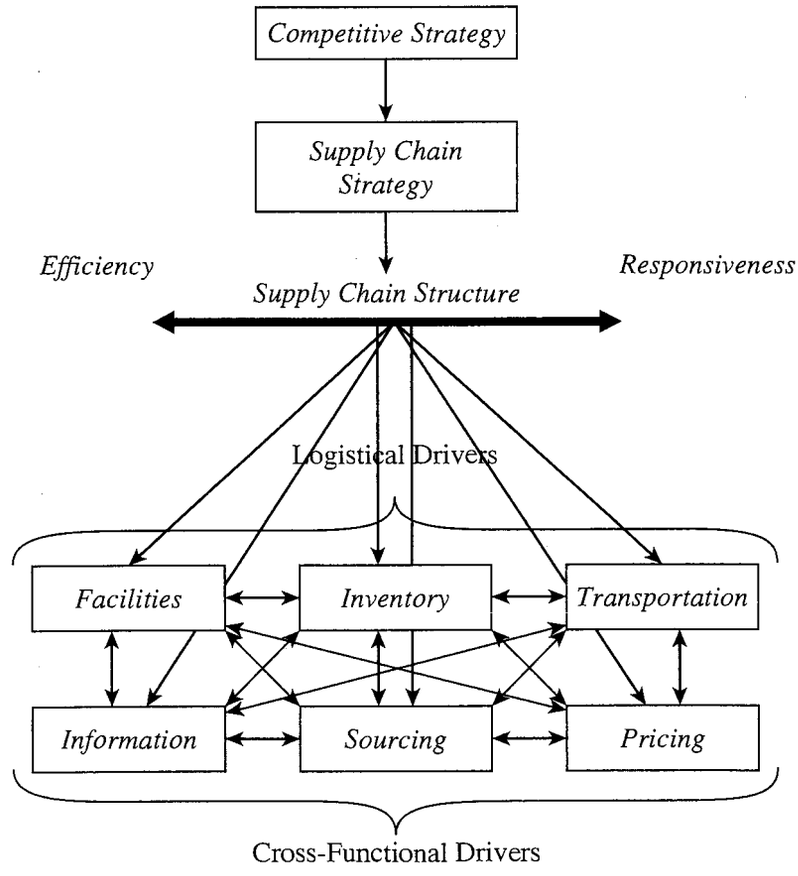
3.2 FRAMEWORK FOR STRUCTURING DRIVERS

Recall from Chapter 2 that the goal of a supply chain strategy is to strike the balance between responsiveness and efficiency that fits with the competitive strategy. To reach this goal, a company must structure the right combination of the three logistical and three cross-functional drivers discussed earlier. For each of the individual drivers, supply chain managers must make a trade-off between efficiency and responsiveness based on interaction with the other drivers. The combined impact of these drivers then determines the responsiveness and the profits of the entire supply chain.

We provide a visual framework for supply chain decision making in Figure 3-1. Most companies begin with a competitive strategy and then decide what their supply chain strategy ought to be. The supply chain strategy determines how the supply chain should perform with respect to efficiency and responsiveness. The supply chain must then use the three logistical and three cross-functional drivers to reach the performance level the supply chain strategy dictates and maximize the supply chain profits. Although this framework is generally viewed from the top down, in many instances, a study of the six drivers may indicate the need to change the supply chain and potentially even the competitive strategy.

Consider this framework using Wal-Mart as an example. Wal-Mart's competitive strategy is to be a reliable, low-cost retailer for a wide variety of mass-consumption

FIGURE 3-1 Supply Chain Decision-Making Framework



goods. This strategy dictates that the ideal supply chain will emphasize efficiency but also maintain an adequate level of responsiveness. Wal-Mart uses the three logistical and three cross-functional drivers effectively to achieve this type of supply chain performance. With the inventory driver, Wal-Mart maintains an efficient supply chain by keeping low levels of inventory. For instance, Wal-Mart pioneered cross-docking, a system in which inventory is not stocked in a warehouse but rather is shipped to stores from the manufacturer. These shipments make only brief stops at distribution centers (DCs), where they are transferred to trucks that make deliveries to stores. This significantly lowers inventory because products are stocked only at stores, not at both stores and warehouses. With respect to inventory, Wal-Mart favors efficiency over responsiveness. On the transportation front, Wal-Mart runs its own fleet, to keep responsiveness high. This increases transportation cost, but the benefits in terms of reduced inventory and improved product availability justify this cost in Wal-Mart's case. In the case of facilities, Wal-Mart uses centrally located DCs within its network of stores to decrease the number of facilities and increase efficiency at each DC. Wal-Mart builds retail stores only where the demand is sufficient to justify having several of them supported by a DC, thereby increasing efficiency of its transportation assets. To utilize information in the supply chain, Wal-Mart has invested significantly more than its competitors in information technology. As a result, Wal-Mart is a leader in its use of the information driver to improve responsiveness and decrease inventory investment. Wal-Mart feeds demand information across the supply chain to suppliers who manufacture only what is being demanded. The supply chain's ability to share demand information has

required large investments, but the result is an improved supply chain in terms of both responsiveness and efficiency. With regard to the sourcing driver, Wal-Mart identifies efficient sources for each product it sells. Wal-Mart feeds them large orders, allowing them to be efficient by exploiting economies of scale. Finally, for the pricing driver, Wal-Mart practices "every day low pricing" (EDLP) for its products. This ensures that customer demand stays steady and does not fluctuate with price variations. The entire supply chain then focuses on meeting this demand in an efficient manner. Wal-Mart uses all the supply chain drivers to achieve the right balance between responsiveness and efficiency so that its competitive strategy and supply chain strategy are in harmony.

We devote the next six sections to a detailed discussion of each of the three logistical and three cross-functional drivers and their roles in the supply chain.

3.3 FACILITIES

In this section, we discuss the role that facilities play in the supply chain as well as critical facility-related decisions that supply chain managers need to make.

ROLE IN THE SUPPLY CHAIN

If we think of inventory as *what* is being passed along the supply chain and transportation as *how* it is passed along, then facilities are the *where* of the supply chain. They are the locations to or from which the inventory is transported. Within a facility, inventory is either transformed into another state (manufacturing) or it is stored (warehousing).

ROLE IN THE COMPETITIVE STRATEGY

Facilities are a key driver of supply chain performance in terms of responsiveness and efficiency. For example, companies can gain economies of scale when a product is manufactured or stored in only one location; this centralization increases efficiency. The cost reduction, however, comes at the expense of responsiveness, as many of a company's customers may be located far from the production facility. The opposite is also true. Locating facilities close to customers increases the number of facilities needed and consequently reduces efficiency. If the customer demands and is willing to pay for the responsiveness that having numerous facilities adds, however, then this facilities decision helps meet the company's competitive strategy goals.

Example 3-1: **Toyota and Honda**
Both Toyota and Honda use facilities decisions to be more responsive to their customers. These companies have an end goal of opening manufacturing facilities in every major market that they enter. While there are other benefits to opening local facilities, such as protection from currency fluctuation and trade barriers, the increase in responsiveness plays a large role in Toyota and Honda's decision to place facilities in their local markets.

COMPONENTS OF FACILITIES DECISIONS

Decisions regarding facilities are a crucial part of supply chain design. We now identify components of facilities decisions that companies must analyze.

Role

For production facilities, firms must decide whether they will be flexible, dedicated, or a combination of the two. Flexible capacity can be used for many types of products but

is often less efficient, whereas dedicated capacity can be used for only a limited number of products but is more efficient. Firms must also decide whether to design a facility with a product focus or a functional focus. A product-focused facility performs many different functions (e.g., fabrication and assembly) in producing a single type of product. A functional-focused facility performs few functions (e.g., only fabrication or only assembly) on many types of products. A product focus tends to result in more expertise about a particular type of product at the expense of the functional expertise that comes from a functional methodology.

For warehouses and DCs, firms must decide whether they will be primarily cross-docking facilities or storage facilities. At cross-docking facilities, inbound trucks from suppliers are unloaded; the product is broken into smaller lots, and is quickly loaded onto store-bound trucks. Each store-bound truck carries a variety of products, some from each inbound truck. For storage facilities, firms must decide on the products to be stored at each facility.

Location

Deciding where a company will locate its facilities constitutes a large part of the design of a supply chain. A basic trade-off here is whether to centralize in order to gain economies of scale or to decentralize to become more responsive by being closer to the customer. Companies must also consider a host of issues related to the various characteristics of the local area in which the facility is situated. These include macroeconomic factors, quality of workers, cost of workers, cost of facility, availability of infrastructure, proximity to customers, the location of that firm's other facilities, tax effects, and other strategic factors.

Capacity

Companies must also determine a facility's capacity to perform its intended function or functions. A large amount of excess capacity allows the facility to be very flexible and to respond to wide swings in the demands placed on it. Excess capacity, however, costs money and therefore can decrease efficiency. A facility with little excess capacity will likely be more efficient per unit of product it produces than one with a lot of unused capacity. The high-utilization facility, however, will have difficulty responding to demand fluctuations. Therefore, a company must make a trade-off to determine the right amount of capacity to have at each of its facilities.

Facility-Related Metrics

A manager should track the following facility-related metrics that influence supply chain performance.

- ***Capacity*** measures the maximum amount a facility can process.
- ***Utilization*** measures the fraction of capacity that is currently being used in the facility. Utilization affects both the unit cost of processing and the associated delays. Unit costs tend to decline and delays increase with increasing utilization.
- ***Theoretical flow/cycle time of production*** measures the time required to process a unit if there are absolutely no delays at any stage.
- ***Actual average flow/cycle time*** measures the average actual time taken for all units processed over a specified duration such as a week or month. The actual flow/cycle time includes the theoretical time and any delays.
- ***Flow time efficiency*** is the ratio of the theoretical flow time to the actual average flow time.
- ***Product variety*** measures the number of products/product families processed in a facility. Processing costs and flow times are likely to increase with product variety.

- ***Volume contribution of top 20 percent SKUs and customers*** measures the fraction of total volume processed by a facility that comes from the top 20 percent SKUs or customers. An 80/20 outcome in which the top 20 percent contribute 80 percent of volume indicates likely benefits from focusing the facility where separate processes are used to process the top 20 percent and the remaining 80 percent.
- ***Processing/setup/down/idle time*** measure the fraction of time that the facility was processing units, being set up to process units, unavailable because it was down, or idle because it had no units to process.
- ***Average production batch size*** measures the average amount produced in each production batch. Large batch sizes will decrease production cost but increase inventories in the supply chain.
- ***Production service level*** measures the fraction of production orders completed on time and in full.

OVERALL TRADE-OFF: RESPONSIVENESS VERSUS EFFICIENCY

The fundamental trade-off that managers face when making facilities decisions is between the cost of the number, location, and type of facilities (efficiency) and the level of responsiveness that these facilities provide the company's customers. Increasing the number of facilities increases facility and inventory costs but decreases transportation costs and reduces response time. Increasing the flexibility of a facility increases facility costs but decreases inventory costs and response time.

3.4 INVENTORY

In this section we discuss the role that inventory plays in the supply chain and how managers use inventory to drive supply chain performance.

ROLE IN THE SUPPLY CHAIN

Inventory exists in the supply chain because of a mismatch between supply and demand. This mismatch is intentional at a steel manufacturer, where it is economical to manufacture in large lots that are then stored for future sales. The mismatch is also intentional at a retail store where inventory is held in anticipation of future demand. An important role that inventory plays in the supply chain is to increase the amount of demand that can be satisfied by having the product ready and available when the customer wants it. Another significant role that inventory plays is to reduce cost by exploiting economies of scale that may exist during production and distribution.

Inventory is held throughout the supply chain in the form of raw materials, work in process, and finished goods. Inventory is a major source of cost in a supply chain and has a huge impact on responsiveness. If we think of the responsiveness spectrum discussed in Chapter 2, the location and quantity of inventory can move the supply chain from one end of the spectrum to the other. For example, an apparel supply chain with high inventory levels at the retail stage has a high level of responsiveness because a consumer can walk into a store and walk out with the shirt he or she was looking for. In contrast, an apparel supply chain with little inventory could be very efficient but would make customers wait several weeks or even months for their clothes.

Inventory also has a significant impact on the material flow time in a supply chain. *Material flow time* is the time that elapses between the point at which material enters

the supply chain to the point at which it exits. For a supply chain, *throughput* is the rate at which sales occur. If inventory is represented by I, flow time by T, and throughput by D, the three can be related using Little's law as follows:

$$I = DT \quad \textbf{(3.1)}$$

For example, if the flow time of an auto assembly process is 10 hours and the throughput is 60 units an hour, Little's law tells us that the inventory is $60 \times 10 = 600$ units. If we were able to reduce inventory to 300 units while holding throughput constant, we would reduce our flow time to five hours (300/60). We note that in this relationship, inventory and throughput must have consistent units.

The logical conclusion here is that inventory and flow time are synonymous in a supply chain because throughput is often determined by customer demand. Managers should use actions that lower the amount of inventory needed without increasing cost or reducing responsiveness, because reduced flow time can be a significant advantage in a supply chain.

ROLE IN THE COMPETITIVE STRATEGY

Inventory plays a significant role in a supply chain's ability to support a firm's competitive strategy. If a firm's competitive strategy requires a very high level of responsiveness, a company can achieve this responsiveness by locating large amounts of inventory close to the customer. Conversely, a company can also use inventory to become more efficient by reducing inventory through centralized stocking. The latter strategy would support a competitive strategy of being a low-cost producer. The trade-off implicit in the inventory driver is between the responsiveness that results from more inventory and the efficiency that results from less inventory.

Example 3-2: **Nordstrom**
Nordstrom's competitive strategy targets upper-end customers with high responsiveness requirements. These customers are willing to pay a premium to have the products they want when they want them. To support this competitive strategy, Nordstrom uses inventory; the company stocks a large variety and quantity of products to ensure a high level of availability. In fact, Nordstrom stocks a significantly larger amount of inventory than other department stores. Nordstrom incurs higher costs because of its large inventory, but it gains extra margin from its customers, who are willing to pay for the level of service that Nordstrom's inventory makes possible.

COMPONENTS OF INVENTORY DECISIONS

We now identify major inventory-related decisions that supply chain managers must make to effectively create more responsive and more efficient supply chains.

Cycle Inventory

Cycle inventory is the average amount of inventory used to satisfy demand between receipts of supplier shipments. The size of the cycle inventory is a result of the production, transportation, or purchase of material in large lots. Companies produce or purchase in large lots to exploit economies of scale in the production, transportation, or purchasing process. With the increase in lot size, however, also comes an increase in carrying costs. As an example of a cycle stock decision, consider an online book retailer. This retailer's sales average around 10 truckloads of books a month. The cycle inventory decisions the retailer must make are how much to order for replenishment and how often to place these orders. The e-retailer could order 10 truckloads once each month or it could order one truckload every three days. The basic

trade-off supply chain managers face is the cost of holding larger lots of inventory (when cycle inventory is high) versus the cost of ordering product frequently (when cycle inventory is low).

Safety Inventory

Safety inventory is inventory held in case demand exceeds expectation; it is held to counter uncertainty. If the world were perfectly predictable, only cycle inventory would be needed. Because demand is uncertain and may exceed expectations, however, companies hold safety inventory to satisfy an unexpectedly high demand. Managers face a key decision when determining how much safety inventory to hold. For example, a toy retailer such as Toys "R" Us must calculate its safety inventory for the holiday buying season. If it has too much safety inventory, toys go unsold and may have to be discounted after the holidays. If the company has too little safety inventory, however, then Toys "R" Us loses sales, along with the margin those sales would have brought. Therefore, choosing safety inventory involves making a trade-off between the costs of having too much inventory and the costs of losing sales due to not having enough inventory.

Seasonal Inventory

Seasonal inventory is built up to counter predictable variability in demand. Companies using seasonal inventory build up inventory in periods of low demand and store it for periods of high demand when they will not have the capacity to produce all that is demanded. Managers face key decisions in determining whether to build seasonal inventory, and if they do build it, in deciding how much to build. If a company can rapidly change the rate of its production system at very low cost, then it may not need seasonal inventory, because the production system can adjust to a period of high demand without incurring large costs. However, if changing the rate of production is expensive (e.g., when workers must be hired or fired), then a company would be wise to establish a smooth production rate and build up its inventory during periods of low demand. Therefore, the basic trade-off supply chain managers face in determining how much seasonal inventory to build is the cost of carrying the additional seasonal inventory versus the cost of having a more flexible production rate.

Level of Product Availability

Level of product availability is the fraction of demand that is served on time from product held in inventory. A high level of product availability provides a high level of responsiveness but increases cost because a lot of inventory is held but rarely used. In contrast, a low level of product availability lowers inventory holding cost but results in a higher fraction of customers who are not served on time. The basic trade-off when determining the level of product availability is between the cost of inventory to increase product availability and the loss from not serving customers on time.

Inventory-Related Metrics

A manager should track the following inventory-related metrics that influence supply chain performance.

- ***Average inventory*** measures the average amount of inventory carried. Average inventory should be measured in units, days of demand, and financial value.
- ***Products with more than a specified number of days of inventory*** identifies the products for which the firm is carrying a high level of inventory. This metric can be used to identify products that are in oversupply or identify reasons that justify the high inventory, such as price discounts, or being a very slow mover.
- ***Average replenishment batch size*** measures the average amount in each replenishment order. The batch size should be measured by SKU in terms of both units

and days of demand. It can be estimated by averaging over time the difference between the maximum and the minimum inventory (measured in each replenishment cycle) on hand.

- ***Average safety inventory*** measures the average amount of inventory on hand when a replenishment order arrives. Average safety inventory should be measured by SKU in both units and days of demand. It can be estimated by averaging over time the minimum inventory on hand in each replenishment cycle.
- ***Seasonal inventory*** measures the amount of both cycle and safety inventory that is purchased solely due to seasonal changes in demand.
- ***Fill rate*** measures the fraction of orders/demand that were met on time from inventory. Fill rate should not be averaged over time but over a specified number of units of demand (say, every thousand, million, etc.).
- ***Fraction of time out of stock*** measures the fraction of time that a particular SKU had zero inventory. This fraction can be used to estimate the demand during the stock out period.

Overall Trade-Off: Responsiveness Versus Efficiency

The fundamental trade-off that managers face when making inventory decisions is between responsiveness and efficiency. Increasing inventory generally makes the supply chain more responsive to the customer. A higher level of inventory also facilitates a reduction in production and transportation costs because of improved economies of scale in both functions. This choice, however, increases inventory holding cost.

3.5 TRANSPORTATION

In this section we discuss the role that transportation plays in the supply chain, as well as key transportation-related decisions that supply chain managers must make.

ROLE IN THE SUPPLY CHAIN

Transportation moves product between different stages in a supply chain. Like the other supply chain drivers, transportation has a large impact on both responsiveness and efficiency. Faster transportation allows a supply chain to be more responsive but reduces its efficiency. The type of transportation a company uses also affects the inventory and facility locations in the supply chain. Dell, for example, flies some components from Asia because doing so allows the company to lower the level of inventory it holds. Clearly, such a practice also increases responsiveness but decreases transportation efficiency because it is more costly than transporting parts by ship.

ROLE IN THE COMPETITIVE STRATEGY

The role of transportation in a company's competitive strategy figures prominently in the company's consideration of the target customer's needs. If a firm's competitive strategy targets a customer who demands a very high level of responsiveness, and that customer is willing to pay for this responsiveness, then a firm can use transportation as one driver for making the supply chain more responsive. The opposite holds true as well. If a company's competitive strategy targets customers whose main decision criterion is price, then the company can use transportation to lower the cost of the product at the expense of responsiveness. Because a company may use both inventory and transportation to increase responsiveness or efficiency, the optimal decision for the company often means finding the right balance between the two.

Example 3-3: **Laura Ashley**
Laura Ashley sells clothing and other household items through a mail-order catalog and uses transportation as part of its competitive strategy. Laura Ashley's customers are willing to pay a premium price for a high level of responsiveness. To meet this level of responsiveness, the company has located its main warehouse near the FedEx hub in Memphis, Tennessee, to better utilize the responsive transportation that FedEx offers. When an order is placed, the goods are easily and quickly sent from the Laura Ashley warehouse to the FedEx hub, where they are sent overnight to the customer. This transportation policy enables Laura Ashley's customers to order their goods later than they can at other companies and still receive them next day.

COMPONENTS OF TRANSPORTATION DECISIONS

We now identify key components of transportation that companies must analyze when designing and operating a supply chain.

Design of Transportation Network

The transportation network is the collection of transportation modes, locations, and routes along which product can be shipped. A company must decide whether transportation from a supply source will be direct to the demand point or will go through intermediate consolidation points. Design decisions also include whether multiple supply or demand points will be included in a single run or not. Finally, companies must also decide on the set of transportation modes that will be used.

Choice of Transportation Mode

The mode of transportation is the manner in which a product is moved from one location in the supply chain network to another. Companies can choose between air, truck, rail, sea, and pipeline as modes of transport for products. Today, information goods can also be sent via the Internet. Each mode has different characteristics with respect to the speed, size of shipments (individual parcels to pallets to full trucks to entire ships), cost of shipping, and flexibility that lead companies to choose one particular mode over the others.

Transportation-Related Metrics

A manager should track the following transportation-related metrics that influence supply chain performance.

- ***Average inbound transportation cost*** typically measures the cost of bringing product into a facility as a percentage of sales or cost of goods sold (COGS). Ideally, this cost should be measured per unit brought in, but this can be difficult. The inbound transportation cost is generally included in COGS. It is useful to separate this cost by supplier.
- ***Average incoming shipment size*** measures the average number of units or dollars in each incoming shipment at a facility.
- ***Average inbound transportation cost per shipment*** measures the average transportation cost of each incoming delivery. Along with the incoming shipment size, this metric identifies opportunities for greater economies of scale in inbound transportation.
- ***Average outbound transportation cost*** measures the cost of sending product out of a facility to the customer. Ideally, this cost should be measured per unit shipped, but it is often measured as a percentage of sales. It is useful to separate this metric by customer.
- ***Average outbound shipment size*** measures the average number of units or dollars on each outbound shipment at a facility.

- ***Average outbound transportation cost per shipment*** measures the average transportation cost of each outgoing delivery. Along with the outgoing shipment size, this metric identifies opportunities for greater economies of scale in outbound transportation.
- ***Fraction transported by mode*** measures the fraction of transportation (in units or dollars) using each mode of transportation. This metric can be used to estimate if certain modes are overused or underutilized.

Overall Trade-Off: Responsiveness Versus Efficiency

The fundamental trade-off for transportation is between the cost of transporting a given product (efficiency) and the speed with which that product is transported (responsiveness). Using fast modes of transport raises responsiveness and transportation cost but lowers the inventory holding cost.

3.6 INFORMATION

In this section we discuss the role that information plays in the supply chain, as well as key information-related decisions that supply chain managers must make.

ROLE IN THE SUPPLY CHAIN

Information deeply affects every part of the supply chain. Its impact is easy to underestimate, as information affects a supply chain in many different ways. Consider the following:

1. Information serves as the connection between various stages of a supply chain, allowing them to coordinate and maximize total supply chain profitability.
2. Information is also crucial to the daily operations of each stage in a supply chain. For instance, a production scheduling system uses information on demand to create a schedule that allows a factory to produce the right products in an efficient manner. A warehouse management system uses information to create visibility of the warehouse's inventory. The company can then use this information to determine whether new orders can be filled.

ROLE IN THE COMPETITIVE STRATEGY

Information is an important driver that companies have used to become both more efficient and more responsive. The tremendous growth of the importance of information technology is a testimony to the impact that information can have on improving a company. Like all the other drivers, however, even with information, companies reach a point when they must make the trade-off between efficiency and responsiveness.

Another key decision involves what information is most valuable in reducing cost and improving responsiveness within a supply chain. This decision will vary depending on the supply chain structure and the market segments served. Some companies, for example, target customers who require customized products that carry a premium price tag. These companies might find that investments in information allow them to respond more quickly to their customers. The following examples illustrate this type of investment.

Example 3-4: Andersen Windows

Andersen Windows, a major manufacturer of residential wood windows located in Bayport, Minnesota, has invested in an information system that enables the company to bring customized products to the market rapidly. This system, called "Window of Knowledge," allows distributors and customers to design windows to custom-fit their needs. Users can

select from a library of over 50,000 components that can be combined in any number of ways. The system immediately gives the customer price quotes and automatically sends the order to the factory if the customer decides to buy. This information investment not only gives the customer a much wider variety of products, it allows Andersen to be much more responsive to the customer, as it gets the customer's order to the factory as soon as the order is placed.

Example 3-5: **Dell**
Dell takes orders directly from consumers over the phone and via the Internet. Building this direct channel required an investment because of the added functions Dell must perform. A large part of that cost can be attributed to information. With the direct channel model, however, Dell is able to view the actual consumer demand much sooner than most PC manufacturers. Therefore, the company can respond more quickly to changes in consumer needs. Dell can then modify its product offerings to meet these new needs. Dell is not the low-cost provider. The company is, however, the cheapest for its level of responsiveness, and a large part of its responsiveness is due to the information flow between Dell and its customers, and Dell and its suppliers, that is made possible by its investment in information.

COMPONENTS OF INFORMATION DECISIONS

We now consider key components of information that a company must analyze to increase efficiency and improve responsiveness within its supply chain.

Push Versus Pull

When designing processes of the supply chain, managers must determine whether these processes are part of the push or pull phase in the chain. We discuss this distinction in Chapter 1, but we mention it again because different types of systems require different types of information. Push systems generally require information in the form of elaborate *material requirements planning* (MRP) systems to take the master production schedule and roll it back, creating schedules for suppliers with part types, quantities, and delivery dates. Pull systems require information on actual demand to be transmitted extremely quickly throughout the entire chain so that production and distribution of products may reflect the real demand accurately.

Coordination and Information Sharing

Supply chain coordination occurs when all stages of a supply chain work toward the objective of maximizing total supply chain profitability based on shared information. Lack of coordination can result in a significant loss of supply chain profit. Coordination among different stages in a supply chain requires each stage to share appropriate information with other stages. For example, if a supplier is to produce the right parts in a timely manner for a manufacturer in a pull system, the manufacturer must share demand and production information with the supplier. Information sharing is thus crucial to the success of a supply chain.

Forecasting and Aggregate Planning

Forecasting is the art and science of making projections about what future demand and conditions will be. Obtaining forecasting information frequently means using sophisticated techniques to estimate future sales or market conditions. Managers must decide how they will make forecasts and to what extent they will rely on forecasts to make decisions. Companies often use forecasts both on a tactical level to schedule production and on a strategic level to determine whether to build new plants or even whether to enter a new market.

Once a company creates a forecast, the company needs a plan to act on this forecast. *Aggregate planning* transforms forecasts into plans of activity to satisfy the projected demand. A key decision managers face is how to collaborate on aggregate planning

throughout the entire supply chain. The aggregate plan becomes a critical piece of information to be shared across the supply chain because it affects both the demand on a firm's suppliers and the supply to its customers.

Enabling Technologies

Many technologies exist to share and analyze information in the supply chain. Managers must decide which technologies to use and how to integrate these technologies into their companies and their partners' companies. The consequences of these decisions are becoming more and more important as the capabilities of these technologies grow. Some of these technologies include the following.

1. Electronic data interchange (EDI) allows companies to place instantaneous, paperless purchase orders with suppliers. EDI is not only efficient, it also decreases the time needed to get products to customers because transactions are faster and more accurate than when they are paper based. Although EDI is a bit outdated and has limited capabilities, it still offers efficiency and responsiveness gains for some firms.
2. The Internet has critical advantages over EDI with respect to information sharing. The Internet conveys much more information and therefore offers much more visibility than EDI. Better visibility improves decisions across the supply chain. Internet communication among stages in the supply chain is also easier because a standard infrastructure (the World Wide Web) already exists. Thanks to the Internet, e-commerce has become a major force in the supply chain.
3. Enterprise resource planning (ERP) systems provide the transactional tracking and global visibility of information from within a company and across its supply chain. This real-time information helps a supply chain to improve the quality of its operational decisions. ERP systems keep track of the information, whereas the Internet provides one method with which to view this information. A more detailed discussion of ERP systems is in Chapter 17.
4. Supply chain management (SCM) software uses the information in ERP systems to provide analytical decision support in addition to the visibility of information. ERP systems show a company what is going on, while SCM systems help a company decide what it should do. A more detailed discussion of SCM systems is in Chapter 17.
5. Radio frequency identification (RFID) consists of an active or passive radio frequency (RF) tag applied to the item being tracked and an RF reader/emitter. A passive tag draws energy from the reader, whereas an active tag has its own battery and draws power from there. Wal-Mart has mandated the use of RFID technology by its top 100 suppliers at the case level. RFID has many potential uses. It can be used in manufacturing to check availability of the entire bill of materials. The technology can make the receiving of a truck much faster and cheaper. Full implementation of RFID could eliminate the need for manual counting and barcode scanning at the receiving dock. It can also be used to get an exact count of incoming items and items in storage. RFID technology, however, has yet to reach 100 percent accuracy, and its cost per unit is still high enough to make global acceptance difficult, even at the case level.

Information-Related Metrics

A manager should track the following information-related metrics that influence supply chain performance.

- ***Forecast horizon*** identifies how far in advance of the actual event a forecast is made. The forecast horizon must equal the lead time of the decision that is driven by the forecast.

- ***Frequency of update*** identifies how frequently each forecast is updated. The forecast should be updated somewhat more frequently than a decision will be revisited, so that large changes can be flagged and corrective action taken.
- ***Forecast error*** measures the difference between the forecast and actual demand. The forecast error is a measure of uncertainty and drives all responses to uncertainty such as safety inventory or excess capacity.
- ***Seasonal factors*** measure the extent to which the average demand in a season is above or below the average in the year.
- ***Variance from plan*** identifies the difference between the planned production/inventories and the actual values. These variances can be used to raise flags that identify shortages and surpluses.
- ***Ratio of demand variability to order variability*** measures the standard deviation of incoming demand and supply orders placed. A ratio less than one potentially indicates the existence of the bullwhip effect.

Overall Trade-Off: Responsiveness Versus Efficiency

Good information can help a firm improve both its responsiveness and efficiency. The information driver is used to improve the performance of other drivers, and the use of information is based on the strategic position the other drivers support. Accurate information can help a firm improve efficiency by decreasing inventory and transportation costs. Accurate information can improve responsiveness by helping a supply chain better match supply and demand.

3.7 SOURCING

In this section we discuss the role that sourcing plays in the supply chain and key sourcing related decisions that managers need to make.

ROLE IN THE SUPPLY CHAIN

Sourcing is the set of business processes required to purchase goods and services. Managers must first decide which tasks will be outsourced and those that will be performed within the firm. For each outsourced task, the manager must decide whether to source from a single supplier or a portfolio of suppliers. If a portfolio of multiple suppliers is to be carried, then the role of each supplier in the portfolio must be clarified. The next step is to identify the set of criteria that will be used to select suppliers and measure their performance. Managers then select suppliers and negotiate contracts with them. Contracts define the role of each supply source and should be structured to improve supply chain performance and minimize information distortion from one stage to the next. Once suppliers and contracts are in place, procurement processes that facilitate the placement and delivery of orders play a major role.

ROLE IN THE COMPETITIVE STRATEGY

Sourcing decisions are crucial because they affect the level of efficiency and responsiveness the supply chain can achieve. In some instance, firms outsource to responsive third parties if it is too expensive for them to develop this responsiveness on their own. An example is the outsourcing of next-day delivery by all firms to a few package carriers because it is too expensive for a firm to develop next-day delivery capability on its own. In other instances firms have kept the responsive process in-house, to maintain control. An example of this is Benetton, which keeps the dyeing of knit garments

in-house so it can respond quickly to orders as they arrive. Firms also outsource for efficiency if the third party can achieve significant economies of scale or has a lower underlying cost structure for other reasons. Outsourcing decisions should be driven by the desire for growth in total supply chain profitability.

Example 3-6: **Cisco**
Cisco has outsourced almost all of its manufacturing. It does, however, have a sourcing strategy that varies by product type. For low-end products such as routers for home networks, Cisco aims for efficiency. These routers are produced and packed in China and shipped in bulk for sale in the United States. Cisco aims for the lowest-cost manufacturing location and economies of scale in transportation because the targeted market segment values low cost. For high-end products, in contrast, Cisco outsources to contract manufacturers in the United States. These manufacturers are not cheap but they are responsive and can serve the rapidly evolving needs of the high-end market.

COMPONENTS OF SOURCING DECISIONS

We now consider key sourcing decisions that are made within a firm.

In-House or Outsource

The most significant sourcing decision for a firm is whether to perform a task in-house or outsource it to a third party. This decision should be driven in part by its impact on the total supply chain profit. It is best to outsource if the growth in total supply chain profit is significant with little additional risk. Within a task such as transportation, managers must decide whether to outsource all of it, outsource only the responsive component, or outsource only the efficient component. Once again, the decision should be based in part on the growth in total supply chain profitability.

Supplier Selection

Managers must decide on the number of suppliers they will have for a particular activity. They must then identify the criteria along which suppliers will be evaluated and how they will be selected. For the selection process, managers must decide whether they will use direct negotiations or resort to an auction. If an auction is used, it must be structured to ensure the desired outcome.

Procurement

Procurement is the process in which the supplier sends product in response to customer orders. Managers must decide on the structure of procurement of direct as well as indirect materials, and strategic as well as general materials. In each case, it is important to identify the critical mechanism for increasing supply chain profits. For example, a firm should set up procurement for direct materials to ensure good coordination between the supplier and buyer. In contrast, the procurement of MRO products should be structured to ensure that transaction costs are low.

Sourcing-Related Metrics

A manager should track the following sourcing related metrics that influence supply chain performance.

- ***Days payable outstanding*** measures the number of days between when a supplier performed a supply chain task and when it was paid.
- ***Average purchase price*** measures the average price at which a good or service was purchased during the year. The average price should be weighted by the quantity purchased at each price.
- ***Range of purchase price*** measures the fluctuation in purchase price during a specified period. The goal is to identify if the quantity purchased correlated with the price.

- ***Average purchase quantity*** measures the average amount purchased per order. The goal is to identify whether a sufficient level of aggregation is occurring across locations when placing an order.
- ***Fraction on-time deliveries*** measures the fraction of deliveries from the supplier that were on time.
- ***Supply quality*** measures the quality of product supplied.
- ***Supply lead time*** measures the average time between when an order is placed and the product arrives.

Overall Trade-Off: Increase the Supply Chain Profits

Sourcing decisions should be made to increase the size of the total profit to be shared across the supply chain. The total profits are affected by the impact of sourcing on sales, service, production costs, inventory costs, transportation costs, and information costs. Outsourcing to a third party is meaningful if the third party raises the supply chain profits more than the firm can by its own. In contrast, a firm should keep a supply chain function in-house if the third party cannot increase the supply chain profits or if the risk associated with outsourcing is significant.

3.8 PRICING

In this section we discuss the role that pricing plays in the supply chain.

ROLE IN THE SUPPLY CHAIN

Pricing is the process by which a firm decides how much to charge customers for its goods and services. Pricing affects the customer segments that choose to buy the product, as well as the customer's expectations. This directly affects the supply chain in terms of the level of responsiveness required as well as the demand profile that the supply chain attempts to serve. Pricing is also a lever that can be used to match supply and demand. Short-term discounts can be used to eliminate supply surpluses or decrease seasonal demand spikes by moving some of the demand forward. In short, pricing is one of the most significant factors that affect the level and type of demand that the supply chain will face.

ROLE IN THE COMPETITIVE STRATEGY

Pricing is a significant attribute through which a firm executes its competitive strategy. For example, Costco, a membership-based wholesaler in the United States, has a policy that prices are kept steady but low. Customers expect low prices but are comfortable with a lower level of product availability. The steady prices also ensure that demand stays relatively stable. Costco serves a well-defined segment, and it can thus design an appropriate supply chain. The Costco supply chain aims to be very efficient, at the expense of some responsiveness. In contrast, some manufacturing and transportation firms use pricing that varies with the response time desired by the customer. Through their pricing, these firms are targeting a broader set of customers, some of whom need responsiveness while others need efficiency. In this case it becomes important for these firms to structure a supply chain that can meet the two divergent needs.

Example 3-7: **Amazon**

Amazon offers its customers a large menu of prices for products that are purchased from the company. For example, in November 2005, a person purchasing two books worth $30 could use standard shipping (ships in 3–5 business days) at a cost of $4.98, two-day shipping (ships in 2 business days) at a cost of $11.47, one-day shipping (ships in 1 business day) at a cost of $20.47 or use free shipping (ships in 7–14 business days). The pricing menu

allows Amazon to attract customers with varying levels of desired responsiveness. Whereas customers paying for one-day shipping impose a high degree of uncertainty on Amazon, customers opting for free shipping can be used to level out the workload at the warehouse over time. Amazon can thus use its pricing to provide responsiveness to those who value it while using those who want a low price to help it improve its efficiency. Amazon also uses pricing effectively to shift some of the Christmas peak to November, when it usually offers a discount on shipping. The discount moves some of the December demand forward, allowing it to reduce its December peak and improve its efficiency without giving up on responsiveness for those customers who do not want to order earlier.

COMPONENTS OF PRICING DECISIONS

We now describe key components of pricing decisions that affect supply chain performance.

Pricing and Economies of Scale

Most supply chain activities display economies of scale. Changeovers make small production runs more expensive per unit than large production runs. Loading and unloading costs make it cheaper to deliver a truckload to one location than four. In each case, the provider of the supply chain activity must decide how to price it appropriately to reflect these economies of scale. A commonly used approach is to offer quantity discounts. Care must be taken to ensure that quantity discounts offered are consistent with the economies of scale in the underlying process. Otherwise there is a danger of customer orders being driven primarily by the quantity discounts even though the underlying process does not have significant economies of scale.

Everyday Low Pricing Versus High–Low Pricing

A firm such as Costco practices everyday low pricing at its warehouse stores, keeping prices steady over time. Costco will go to the extent of not offering any discount on damaged books to ensure its everyday low pricing strategy. In contrast, most supermarkets practice high–low pricing and offer steep discounts on a subset of their product every week. The Costco pricing strategy results in relatively stable demand. The high–low pricing strategy results in a peak during the discount week, often followed by a steep drop in demand during the following weeks. The two pricing strategies lead to very different demand profiles that the supply chain must serve.

Fixed Price Versus Menu Pricing

A firm must decide whether it will charge a fixed price for its supply chain activities or have a menu with prices that vary with some other attribute, such as the response time or location of delivery. If marginal supply chain costs or the value to the customer vary significantly along some attribute, it is often effective to have a pricing menu. We have already discussed Amazon as an example of a firm offering a menu that is somewhat consistent with the cost of providing the particular supply chain service. An example where the pricing menu is somewhat inconsistent is seen at many MRO suppliers. They often allow customers to have their order shipped to them or to be picked up in person. A customer pays an additional shipping fee for home delivery but pays nothing for a personal pickup. The pick, pack, and deliver cost at the warehouse, however, is higher in the case of a personal pickup compared to home delivery. The pricing policy thus can lead to customer behavior that has a negative impact on profits.

Pricing-Related Metrics

A manager should track the following pricing-related metrics. With menu pricing, each metric should be tracked separately for each segment in the menu.

- ***Profit margin*** measures profit as a percentage of revenue. A firm needs to examine a wide variety of profit margin metrics to optimize its pricing, including dimensions

such as type of margin (gross, net, etc.), scope (SKU, product line, division, firm), customer type, and others.

- ***Days sales outstanding*** measures the average time between when a sale is made and when the cash is collected.
- ***Incremental fixed cost per order*** measures the incremental costs that are independent of the size of the order. These include changeover costs at a manufacturing plant or order processing or transportation costs that are incurred independent of shipment size at a mail-order firm.
- ***Incremental variable cost per unit*** measures the incremental costs that vary with the size of the order. These include picking costs at a mail-order firm or variable production costs at a manufacturing plant.
- ***Average sale price*** measures the average price at which a supply chain activity was performed in a given period. The average should be obtained by weighting the price with the quantity sold at that price.
- ***Average order size*** measures the average quantity per order. The average sale price, order size, incremental fixed cost per order, and incremental variable cost per unit help estimate the contribution from performing the supply chain activity.
- ***Range of sale price*** measures the maximum and the minimum of sale price per unit over a specified time horizon.
- ***Range of periodic sales*** measures the maximum and minimum of the quantity sold per period (day/week/month) during a specified time horizon. The goal is to understand any correlation between sales and price and any potential opportunity to shift sales by changing price over time.

Overall Trade-Off: Increase Firm Profits

All pricing decisions should be made with the objective of increasing firm profits. This requires an understanding of the cost structure of performing a supply chain activity and the value this activity brings to the supply chain. Strategies such as everyday low pricing may foster stable demand that allows for efficiency in the supply chain. Other pricing strategies may lower supply chain costs, defend market share, or even steal market share. Differential pricing may be used to attract customers with varying needs, as long as this strategy helps either increase revenues or shrink costs, preferably both.

In the next section, we discuss the main obstacles companies face when striving to achieve strategic fit.

3.9 OBSTACLES TO ACHIEVING STRATEGIC FIT

The key to achieving strategic fit is a company's ability to find a balance between responsiveness and efficiency that best matches the needs of its target customer. In deciding where this balance should be located on the responsiveness spectrum, companies face many obstacles. In this section we discuss some of the obstacles and also provide a feel for how the supply chain environment has changed over the years. On one hand, these obstacles have made it much more difficult for companies to create the ideal balance. On the other hand, they have afforded companies increased opportunities for improving supply chain management. Managers need a solid understanding of the impact of these obstacles because they are critical to a company's ability to reap the maximum profitability from its supply chain.

INCREASING VARIETY OF PRODUCTS

Product proliferation is rampant today. With customers demanding ever more customized products, manufacturers have responded with mass customization and even segment-of-one (companies view each customer as an independent market segment) views of the market. Products that were formerly quite generic are now custom-made for a specific consumer. For example, the number of running shoe styles sold in the United States went from five in the early 1970s to almost 300 by the late 1990s. The increase in product variety complicates the supply chain by making forecasting much more difficult. Increased variety tends to raise uncertainty, and increased uncertainty hurts both efficiency and responsiveness within the supply chain.

DECREASING PRODUCT LIFE CYCLES

In addition to the increasing variety of product types, the life cycle of products has been shrinking. Today there are products whose life cycles can be measured in months, compared to the old standard of years. These are not just niche products, either. PCs now have a life cycle of several months, and even some automobile manufacturers have lowered their product life cycles from five plus years to about three years. This decrease in product life cycles makes the job of achieving strategic fit more difficult, as the supply chain must constantly adapt to manufacture and deliver new products, in addition to coping with these products' demand uncertainty. Shorter life cycles increase uncertainty while reducing the window of opportunity within which the supply chain can achieve fit. Increased uncertainty combined with a smaller window of opportunity has put additional pressure on supply chains to coordinate and create a good match between supply and demand.

INCREASINGLY DEMANDING CUSTOMERS

Customers are constantly demanding improvements in delivery lead times, cost, and product performance. If they do not receive these improvements, they move on to new suppliers. Many companies had periodic, standard price increases—not due to a rise in demand or any other factor, but simply because raising prices was the way business was done. Now, one repeatedly sees companies that cannot force through *any* price increases without losing market share. Today's customers are demanding faster fulfillment, better quality, and better-performing products for the same price they paid years ago. This tremendous growth in customer *demands* (not necessarily *demand*) means that the supply chain must provide more just to maintain its business.

FRAGMENTATION OF SUPPLY CHAIN OWNERSHIP

Over the past several decades, most firms have become less vertically integrated. As companies have shed noncore functions, they have been able to take advantage of supplier and customer competencies that they themselves did not have. This new ownership structure, however, has also made managing the supply chain more difficult. With the chain broken into many owners, each with its own policies and interests, the chain is more difficult to coordinate. Potentially, this problem could cause each stage of a supply chain to work only toward its own objectives rather than the whole chain's, resulting in the reduction of overall supply chain profitability.

GLOBALIZATION

Supply chains today are more likely than ever to be global. Establishing a global supply chain creates many benefits, such as the ability to source from a global base of suppliers

who may offer better or cheaper goods than were available in a company's home nation. Globalization, however, also adds stress to the chain, because facilities within the chain are farther apart, making coordination much more difficult.

Globalization has also increased competition, as once-protected national players must compete with companies from around the world. In the past, with fewer companies satisfying customers' needs, customers were willing to tolerate longer response times. However, in most industries there are now many more firms aggressively pursuing their competitors' business. This competitive situation makes supply chain performance a key to maintaining and growing sales while also putting more strain on supply chains and thus forcing them to choose their trade-offs even more precisely.

DIFFICULTY EXECUTING NEW STRATEGIES

Creating a successful supply chain strategy is not easy. Once a good strategy is formulated, however, the execution of the strategy can be even more difficult. For instance, Toyota's production system, which is a supply chain strategy, has been widely known and understood. Yet this strategy has been a sustained competitive advantage for Toyota for more than two decades. Does Toyota have a brilliant strategy that no one else can figure out? Their strategy *is* brilliant, but many others have figured it out. The difficulty other firms have had is in executing that strategy. Many highly talented employees at all levels of the organization are necessary to make a supply chain strategy successful. Although we deal mostly with the formulation of strategy in this book, one should keep in mind that skillful execution of a strategy can be as important as the strategy itself.

All of the obstacles discussed earlier are making it more difficult for companies to achieve strategic fit in the supply chain. These obstacles also represent a tremendous opportunity in terms of untapped improvement within the supply chain. The increasing impact of these obstacles has led to supply chain management becoming a major factor in the success or failure of firms.

KEY POINT Many obstacles, such as rising product variety and shorter life cycles, have made it increasingly difficult for supply chains to achieve strategic fit. Overcoming these obstacles offers a tremendous opportunity for firms to use supply chain management to gain competitive advantage.

3.10 SUMMARY OF LEARNING OBJECTIVES

1. Identify the major drivers of supply chain performance.

   The major drivers of supply chain performance are facilities, inventory, transportation, information, sourcing, and pricing.

2. Discuss the role of each driver in creating strategic fit between the supply chain strategy and the competitive strategy.

   A company achieving strategic fit has found the right balance between responsiveness and efficiency. Each driver affects this balance. Having more facilities generally makes a chain more responsive, while having fewer, central facilities creates higher efficiency. Holding higher levels of inventory increases the responsiveness of a supply chain, while keeping inventory low increases the chain's efficiency. Using faster modes of transportation increases a chain's responsiveness, while using slower modes generally increases efficiency. Investing in information can vastly improve the supply chain performance on both dimensions. This investment, however, must be made based on the strategic position supported by

the other drivers. Appropriate sourcing decisions raise supply chain profits by assigning supply chain functions to the right party, who brings higher economies of scale or a higher level of aggregation of uncertainty. Pricing can be used to attract the right target customer segment. Differential pricing can be used to attract customers who value responsiveness as well as customers who want efficiency. The supply chain can then be structured to provide responsiveness to some customers while improving overall efficiency.

3. Define the key metrics that track the performance of the supply chain in terms of each driver.

   Facility-related metrics are capacity, utilization, theoretical flow/cycle time of production, actual flow/cycle time, flow time efficiency, product variety, volume contribution of top 20 percent SKUs/customers, processing/setup/down/idle time, and average production batch size. Inventory-related metrics are average inventory, products with more than a specified number of days of inventory, average replenishment batch size, average safety inventory, seasonal inventory, fill rate, and fraction of time out of stock. Transportation-related metrics are average inbound transportation cost, average incoming shipment size, average inbound transportation cost per shipment, average outbound transportation cost, average outbound shipment size, average outbound transportation cost per shipment, and fraction transported by mode. Information-related metrics are forecast horizon, forecast error, seasonal factors, variance from plan, and ratio of demand variability to order variability. Sourcing-related metrics are days payable outstanding, average purchase price, range of purchase price, average purchase quantity, fraction on-time deliveries, supply quality, and supply lead time. Pricing-related metrics are profit margin, days sales outstanding, incremental fixed cost per order, incremental variable cost per unit, average sale price, average order size, range of sale price, and range of periodic sales.

4. Describe the major obstacles that must be overcome to manage a supply chain successfully.

   Increasing product variety, decreasing product life cycles, demanding customers, and global competition all make creating supply chain strategies more difficult, as these factors can hamper supply chain performance. The increase in globalization of the supply chain and fragmentation of supply chain ownership has also made it more difficult to execute supply chain strategies.

Discussion Questions

1. How could a grocery retailer use inventory to increase the responsiveness of the company's supply chain?
2. How could an auto manufacturer use transportation to increase the efficiency of its supply chain?
3. How could a bicycle manufacturer increase responsiveness through its facilities?
4. How could an industrial supplies distributor use information to increase its responsiveness?
5. Motorola has gone from manufacturing all its cell phones in-house to almost completely outsourcing the manufacturing. What are the pros and cons of the two approaches?
6. How can a home-delivery company like Peapod use pricing of its delivery services to improve its profitability?
7. How has globalization made strategic fit even more important to a company's success?
8. What are some industries in which products have proliferated and life cycles have shortened? How have the supply chains in these industries adapted?
9. How can the full set of logistical and cross-functional drivers be used to create strategic fit for a PC manufacturer targeting both time-sensitive and price-conscious customers?

Bibliography

Hofman, Debra. "The Hierarchy of Supply Chain Metrics." *Supply Chain Management Review* (September 2004): 28–37.

Marien, Edward J. "The Four Supply Chain Enablers." *Supply Chain Management Review* (March–April 2000): 60–8.

CASE STUDY

SEVEN-ELEVEN JAPAN CO.

Established in 1973, Seven-Eleven Japan set up its first store in Koto-ku, Tokyo, in May 1974. The company was first listed on the Tokyo Stock Exchange in October 1979. In 2004 it was owned by the Ito-Yokado group, which also managed a chain of supermarkets in Japan and owned a majority share in Southland, the company managing Seven-Eleven in the United States. Seven-Eleven Japan realized a phenomenal growth between the years of 1985 and 2003. During that period, the number of stores increased from 2,299 to 10,303; annual sales increased from 386 billion to 2,343 billion yen; and net income increased from 9 billion to 91.5 billion yen. Additionally, the company's return on equity (ROE) averaged around 14 percent between 2000 and 2004. In 2004, Seven-Eleven Japan represented Japan's largest retailer in terms of operating income and number of stores. Customer visits to Seven-Eleven outlets totaled 3.6 billion that year, averaging almost 30 visits to a Seven-Eleven annually for every person in Japan.

COMPANY HISTORY AND PROFILE

Both Ito-Yokado and Seven-Eleven Japan were founded by Masatoshi Ito. He started his retail empire after World War II, when he joined his mother and elder brother and began to work in a small clothing store in Tokyo. By 1960 he was in sole control, and the single store had grown into a $3 million company. After a trip to the United States in 1961, Ito became convinced that superstores were the wave of the future. At that time, Japan was still dominated by Mom-and-Pop stores. Ito's chain of superstores in the Tokyo area was instantly popular and soon constituted the core of Ito-Yokado's retail operations.

In 1972, Ito first approached the Southland Corporation about the possibility of opening Seven-Eleven convenience stores in Japan. After rejecting his initial request, Southland agreed in 1973 to a licensing agreement. In exchange for 0.6 percent of total sales, Southland gave Ito exclusive rights throughout Japan. In May 1974, the first Seven-Eleven convenience store opened in Tokyo.

This new concept was an immediate hit in Japan, and Seven-Eleven Japan experienced tremendous growth. By 1979 there were already 591 Seven-Eleven stores in Japan; by 1984 there were 2,001. Rapid growth continued (see Table 3-1), resulting in 10,356 stores by 2004.

On October 24, 1990, the Southland Corporation entered into bankruptcy protection. Southland asked for Ito-Yokado's help, and on March 5, 1991, IYG Holding was formed by Seven-Eleven Japan (48 percent) and Ito-Yokado (52 percent). IYG acquired 70 percent of Southland's common stock for a total price of $430 million.

In 2004, convenience store operations from Seven-Eleven Japan and 7-Eleven Inc. in the United States contributed 48.2 percent of total revenues and 90.2 percent of total consolidated operating income for the Ito Yokado group. Seven-Eleven Japan contributed 87.6 percent of

TABLE 3-1 Stores and Annual Sales for Seven-Eleven Japan

Year	*Number of Stores*	*Annual Sales (billion yen)*	*Year*	*Number of Stores*	*Annual Sales (billion yen)*
1974	15	0.7	1989	3,954	780.3
1975	69	4.8	1990	4,270	931.9
1976	199	17.4	1991	4,629	1,081.8
1977	375	39.8	1992	5,058	1,194.9
1978	591	72.5	1993	5,475	1,281.9
1979	801	109.8	1994	5,905	1,392.3
1980	1,040	153.6	1995	6,373	1,477.1
1981	1,306	202.1	1996	6,875	1,609.0
1982	1,643	256.5	1997	7,314	1,740.9
1983	2,001	319.0	1998	7,732	1,848.1
1984	2,299	386.7	1999	8,153	1,963.9
1985	2,651	453.6	2000	8,602	2,046.6
1986	2,964	521.9	2001	9,060	2,114.0
1987	3,304	599.1	2002	9,690	2,213.2
1988	3,653	686.3	2003	10,303	2,343.2

the total income received from convenience stores by Ito Yokado. Effectively, Seven-Eleven Japan has become the dominant part of the Ito Yokado group.

THE CONVENIENCE STORE INDUSTRY AND SEVEN-ELEVEN IN JAPAN

In Japan, the convenience store sector was one of the few business areas that continued to grow during the prolonged 1990s downturn. From 1991 to 2002 the number of convenience stores in Japan increased from 19,603 to almost 42,000. As a percentage of all retail stores in Japan, this represented an increase from 1.2 percent to 3.2 percent. During that period, annual sales at convenience stores more than doubled, from just over 3 trillion to 6.7 trillion yen. As a percentage of all retail sales in Japan, this represented an increase from 2.2 percent to 5.0 percent.

Japan's convenience store sector gradually consolidated, with larger players growing and smaller operators shutting down. In 2004, the top 10 convenience store chains accounted for approximately 90 percent of Japan's convenience stores. As the chains improved their operating structures and better leveraged economies of scale, smaller operators found it hard to compete.

Seven-Eleven Japan had increased its share of the convenience store market since it opened. In 2002, Seven-Eleven was Japan's leading convenience store operator, accounting for 21.7 percent of all convenience stores and 31.5 percent of total sales. Seven-Eleven was very effective in terms of same-store sales. In 2004 average daily sales at the four major convenience store chains excluding Seven-Eleven Japan totaled 484,000 yen. Seven-Eleven stores, in contrast, had daily sales of 647,000 yen—more than 30 percent higher than the competition put together. In 2004, Seven-Eleven's operating income of 165.7 billion yen positioned it as a leader not only of the convenience store sector but also of Japan's retail industry as a whole. In terms of growth, its performance was even more impressive. In 2004 Seven-Eleven accounted for 60 percent of the total net increase in the number of stores among the top 10 convenience store chains in Japan. This growth had been very carefully planned, exploiting the core strengths that Seven-Eleven Japan had developed in the areas of information systems and distribution systems.

THE SEVEN-ELEVEN JAPAN FRANCHISE SYSTEM

Seven-Eleven Japan developed an extensive franchise network and performed a key role in the daily operations of this network. The Seven-Eleven Japan network included both company-owned stores and third-party-owned franchises. In 2004, franchise commissions accounted for over 68 percent of revenue from operations. To ensure efficiency, Seven-Eleven Japan based its fundamental network expansion policy on a market-dominance strategy. Entry into any new market was built around a cluster of 50 to 60 stores supported by a distribution center. Such clustering gave Seven-Eleven Japan a high-density market presence and allowed it to operate an efficient distribution system. Seven-Eleven Japan, in its 1994 annual report, listed the following six advantages of the market-dominance strategy:

- Boosted distribution efficiency
- Improved brand awareness
- Increased system efficiency
- Enhanced efficiency of franchise support services
- Improved advertising effectiveness
- Prevented competitors' entrance into the dominant area

Adhering to its dominant strategy, Seven-Eleven Japan opened the majority of its new stores in areas with existing clusters of stores. For example, the Aichi prefecture, where Seven-Eleven began opening stores in 2002, saw a large increase in 2004, with 108 new store openings. This represented more than 15 percent of the new Seven-Eleven stores opened in Japan that year.

Geographically, Seven-Eleven has a limited presence in Japan. In 2004 the company had stores in about 70 percent (32 of 47) of the prefectures within Japan. However, within prefectures where they were present, stores tended to be dense. As the 2004 annual report stated, "Filling in the entire map of Japan is not our priority. Instead, we look for demand where Seven-Eleven stores already exist, based on our fundamental area-dominance strategy of concentrating stores in specific areas."

With Seven-Eleven franchises being highly sought after, fewer than one of 100 applicants were awarded a franchise (a testament to store profitability). The franchise owner was required to put a significant amount of money up front. Half of this amount was used to prepare the store and train the owner. The rest was used for purchasing the initial stock for the store. In 1994, 45 percent of total gross profits at a store went to Seven-Eleven Japan, and the rest went to the store owner. The responsibilities of the two parties were as follows.

Seven-Eleven Japan responsibilities:

- Develop supply and merchandise
- Provide the ordering system
- Pay for the system operation
- Supply accounting services
- Provide advertising
- Install and remodel facilities
- Pay 80 percent of utility costs

Franchise owner responsibilities:

- Operate and manage store
- Hire and pay staff
- Order supplies
- Maintain store appearance
- Provide customer service

TABLE 3-2 Financial Figures for Seven-Eleven Japan (2000–2004)

For Fiscal Years Ending February 28/29	*2000*	*2001*	*2002*	*2003*	*2004*
Net sales (billion yen)	1,964.0	2,046.6	2,114.0	2,213.3	2,343.2
Revenue (billion yen)	327.0	346.9	365.9	400.7	445.4
Ordinary income (billion yen)	140.2	147.2	153.8	159.6	168.9
Net income (billion yen)	68.2	78.4	83.2	86.5	91.5
Number of stores	8,153	8,602	9,060	9,690	10,303

STORE INFORMATION AND CONTENTS

Seven-Eleven had 10,303 stores in Japan and Hawaii as of 2003 (see Table 3-2). In 2004, Seven-Eleven Japan changed the standard size of new stores from 125 square meters to 150 square meters, still significantly smaller than the size of most U.S. 7-Eleven stores. Daily sales at a store averaged 647,000 yen (about $6,100), which was about twice the average at a U.S. store.

Seven-Eleven Japan offered its stores a choice from a set of 5,000 SKUs (stock keeping units). Each store carried on average about 3,000 SKUs depending on local customer demand. Seven-Eleven emphasized regional merchandizing to cater precisely to local preferences. Each store carried food items, beverages, magazines, and consumer items such as soaps and detergents. Sales across product categories from 2002 to 2004 are given in Table 3-3.

The food items were classified in four broad categories: (1) chilled-temperature items including sandwiches, delicatessen products, and milk; (2) warm-temperature items including box lunches, rice balls, and fresh bread; (3) frozen items including ice cream, frozen foods, and ice cubes; (4) and room-temperature items including canned food, instant noodles, and seasonings. Processed food and fast-food items were big sellers for the stores. In 2004, processed and fast foods contributed about 60 percent of the total sales at each store. Over 1 billion rice balls were sold in 2004; this amounted to each Japanese citizen eating approximately eight Seven-Eleven rice balls a year. The top-selling products in the fast-food category were lunch boxes, rice balls, bread-based products, and pasta. As of February 2004, Seven-Eleven Japan had 290 dedicated manufacturing plants that produced only fast food for their stores.

Other products sold at Seven-Eleven stores included soft drinks, nutritional drinks, alcoholic beverages such as beer and wine, game software, music CDs, and magazines.

In 2004, Seven-Eleven was focused on increasing the number of original items that were available only at their stores. At that time, original items accounted for roughly 52 percent of total store sales. The company aimed to increase the percentage to 60 percent in the medium to long term.

STORE SERVICES

Besides products, Seven-Eleven Japan gradually added a variety of services that customers could obtain at its stores. The first service, added in October 1987, was the in-store payment of Tokyo Electric Power bills. The company later expanded the set of utilities for which customers could pay their bills in the stores to include gas, insurance premiums, and telephone. With more convenient operating hours and locations than banks or other financial institutions, the bill payment service attracted millions of additional customers every year. In April 1994, Seven-Eleven Japan began accepting installment payments on behalf of credit companies. It started selling ski-lift pass vouchers in November 1994. In 1995 it began to accept payment for mail-order purchases. This was expanded to include payment for Internet shopping in November 1999. In August 2000, a meal delivery service company, Seven-Meal Service Co. Ltd., was established to serve the aging Japanese population. In 2001, IYBank Co. was established through a joint investment with Ito Yokado. By April 2004, ATMs had been installed in about 75 percent of the total store network in Japan, with the goal to achieve 100 percent ATM installation.

Other services offered at stores include photocopying, ticket sales using multifunctional copiers, and being a pick-up location for parcel delivery companies that typically do not leave the parcel outside if the customer is not at home. The major thrust for offering these services was to make Seven-Eleven stores in Japan more convenient places to shop. Several of these services exploited the existing Total Information System (see text following) in the store.

In February 2000, Seven-Eleven Japan established 7dream.com, an e-commerce company. The goal was to exploit the existing distribution system and the fact that stores were easily accessible to most Japanese. Stores served as drop-off and collection points for Japanese customers. A survey by eSBook (a joint venture among Softbank, Seven-Eleven Japan, Yahoo!Japan, and Tohan, a publisher) discovered that 92 percent of its customers preferred to pick up their online purchases at the local convenience store, rather than have them delivered to their homes. This was understandable given the frequency with which Japanese customers visit their local convenience store. 7dream hoped to build on this

TABLE 3-3 Sales by Product Category Between 2002 and 2004

	2002				*2003*				*2004*			
	Sales (billion yen)	*Gross Margin (percent)*	*Percent of Total Sales*	*Percent Increase from Prior Year*	*Sales (billion yen)*	*Gross Margin (percent)*	*Percent of Total Sales*	*Percent Increase from Prior Year*	*Sales (billion yen)*	*Gross Margin (percent)*	*Percent of Total Sales*	*Percent Increase from Prior Year*
Processed foods	681.5	34.4	32.0	5.3	696.0	34.9	31.2	2.1	725.4	36.0	30.8	4.2
Fast foods	642.2	32.3	30.2	3.1	674.7	32.4	30.3	5.1	704.4	32.2	29.9	4.4
Fresh foods	264.9	30.5	12.4	3.3	284.0	30.9	12.7	7.2	305.0	31.1	12.9	7.4
Nonfoods	540.2	22.9	25.4	1.7	573.6	22.6	25.8	6.2	624.0	22.1	26.4	8.8
Total	2,128.7	30.4	100.0	3.5	2,228.2	30.5	100.0	4.7	2,358.8	30.6	100.0	5.9

preference along with the synergies from the existing distribution system.

SEVEN-ELEVEN JAPAN'S INTEGRATED STORE INFORMATION SYSTEM

From its start, Seven-Eleven Japan sought to simplify its operations by using advanced information technology. Seven-Eleven Japan attributed a significant part of its success to the Total Information System installed in every outlet and linked to headquarters, suppliers, and the Seven-Eleven distribution centers. The first online network linking the head office, stores, and vendors was established in 1979, though the company did not collect point-of-sales (POS) information at that time. In 1982, Seven-Eleven became the first company in Japan to introduce a POS system comprising POS cash registers and terminal control equipment. In 1985 the company developed, jointly with NEC, personal computers using color graphics that were installed at each store and linked to the POS cash registers. These computers were also on the network linking the store to the head office as well as the vendors. Until July 1991, head office, stores, distribution centers, and suppliers were linked only by a traditional analog network. At that time, an integrated services digital network (ISDN) was installed. Linking more than 5,000 stores, it became one of the world's largest ISDN systems at that time.

The two-way, high-speed, online communication capability of ISDN enabled Seven-Eleven Japan to collect, process, and feed back POS data quickly. Sales data gathered in each store by 11:00 P.M. were processed and ready for analysis the next morning. In 1997, Seven-Eleven Japan introduced its fifth generation of the Total Information System, which was still in use in 2004.

The hardware system at a 1994 Seven-Eleven store included the following:

- ***Graphic order terminal:*** This was a hand-held device with a wide-screen graphic display, used by the store owner or manager to place orders. The items were recorded and brought up in the order in which they were arranged on the shelves. The store manager/owner walked down the aisles and placed orders by item. When placing an order, the store manager had access (from the store computer) to detailed analysis of POS data related to the particular item. This included sales analysis of product categories and SKUs over time, analysis of waste, 10-week sales trends by SKU, 10-day sales trends by SKU, sales trends for new products, sales analysis by day and time, list of slow-moving items, analysis of sales and number of customers over time, contribution of product to sections in store display, and sales growth by product categories. The store manager used this information when placing his order, which was entered directly into the terminal. Once all the orders were placed, the terminal was returned to its slot, at which point the orders were relayed by the store computer to both the appropriate vendor and the Seven-Eleven distribution center.
- ***Scanner terminal:*** These scanners read bar codes and recorded inventory. They were used to receive products coming in from a distribution center. This was automatically checked against a previously placed order, and the two were reconciled. Before the scanner terminals were introduced, truck drivers waited in the store until the delivery was checked. Once they were introduced, the driver simply dropped the delivery in the store, and a store clerk received it at a suitable time when there were few customers. The scanner terminals were also used when examining inventory at stores.
- ***Store computer:*** This linked to the ISDN network, the POS register, the graphic order terminal, and the scanner terminal. It communicated among the various input sources, tracked store inventory and sales, placed orders, provided detailed analysis of POS data, and maintained and regulated store equipment.
- ***POS register:*** To better understand the functioning of this information network, one needs to consider a sampling of daily operations. As soon as a customer purchased an item and paid at the POS register, the item information was retrieved from the store computer and the time of sale was automatically recorded. In addition, the cashier recorded the age and sex of the customer. To do this, the cashier used five register keys for the categories: under-13, 13–19, 20–29, 30–49, and 50+. This POS data was automatically transmitted online to a host computer. All sales data collected by 11:00 P.M. were organized and ready for analysis by the next morning. The data were evaluated on a company-wide, district, and store basis.

The analyzed and updated data were then sent back to the Seven-Eleven Japan stores via the network. Each store computer automatically updated its product master file to analyze its recent sales and stock movements. The main objective of the analysis was to improve the ordering process. All this information was available on the graphic order terminal used for order placement.

The information system allowed Seven-Eleven stores to better match supply with demand. Store staff could adjust the merchandising mix on the shelves according to consumption patterns throughout the day. For example, popular breakfast items were stocked earlier during the day, while popular dinner items were stocked later in the evening. The identification of slow and nonmoving items allowed a store to convert shelf space to introduce new items. More than 50 percent of the items sold at a Seven-Eleven store changed in the

course of a year. This was due partly to seasonal demand and partly to new products. When a new product was introduced, the decision whether to continue stocking it was made within the first three weeks. Each item on the shelf contributed to sales and margin and did not waste valuable shelf space.

SEVEN-ELEVEN'S DISTRIBUTION SYSTEM

The Seven-Eleven distribution system tightly linked the entire supply chain for all product categories. The Seven-Eleven distribution centers and the information network played a key role in that regard. The major objective was to carefully track sales of items and offer short replenishment cycle times. This allowed a store manager to forecast sales corresponding to each order accurately.

From March 1987, Seven-Eleven, offered three-times-a-day store delivery of all rice dishes (which comprised most of the fast-food items sold). Bread and other fresh food were delivered twice a day. The distribution system was flexible enough to alter delivery schedules depending on customer demand. For example, ice cream was delivered daily during the summer but only three times a week at other times. The replenishment cycle time for fresh and fast-food items had been shortened to less than 12 hours. A store order for rice balls by 10:00 A.M. was delivered before the dinner rush.

As discussed earlier, the store manager used a graphic order terminal to place an order. All stores were given cutoff times for breakfast, lunch, and dinner ordering. When a store placed an order, it was immediately transmitted to the supplier as well as the distribution center. The supplier received orders from all Seven-Eleven stores and started production to fill the orders. The supplier then sent the orders by truck to the distribution center. Each store order was separated so the distribution center could easily assign it to the appropriate store truck using the order information it already had. The key to store delivery was what Seven-Eleven called the combined delivery system. At the distribution center, delivery of like products from different suppliers (for example, milk and sandwiches) was directed into a single temperature-controlled truck. There were four categories of temperature-controlled trucks: frozen foods, chilled foods, room-temperature processed foods, and warm foods. Each truck made deliveries to multiple retail stores. The number of stores per truck depended on the sales volume. All deliveries were made during off-peak hours and were received using the scanner terminals. The system worked on trust and did not require the delivery person to be present when the store personnel scanned in the delivery. That reduced the delivery time spent at each store.

This distribution system enabled Seven-Eleven to reduce the number of vehicles required for daily delivery service to each store, even though the delivery frequency of each item was quite high. In 1974, 70 vehicles visited each store every day. In 1994, only 11 were necessary. This dramatically reduced delivery costs and enabled rapid deliver of a variety of fresh foods.

As of February 2004, Seven-Eleven Japan had a total of 290 dedicated manufacturing plants throughout the country that produced only fast food for Seven-Eleven stores. These items were distributed through 293 dedicated distribution centers (DCs) that ensured rapid, reliable delivery. None of these DCs carried any inventory; they merely transferred inventory from supplier trucks to Seven-Eleven distribution trucks. The transportation was provided by Transfleet Ltd., a company set up by Mitsui and Co. for the exclusive use of Seven-Eleven Japan.

7-ELEVEN IN THE UNITED STATES

Seven-Eleven had expanded rapidly around the world (see Table 3-4). The major growth was in Asia, though the United States continued to be the second largest market for Seven-Eleven. Once Seven-Eleven Japan acquired Southland Corporation, it set about improving operations in the United States. In the initial years, several 7-Eleven stores in the United States were shut down. The number of stores started to grow beginning in 1998. Historically, the distribution structure in the United States was completely different from that of Japan. Stores in the United States were replenished using direct store delivery (DSD) by some manufacturers, with the remain-

TABLE 3-4 Global Store Distribution for Seven-Eleven in 2004

Country	*Stores*
Japan	10,615
United States	5,798
Taiwan	3,680
Thailand	2,861
South Korea	1,179
China	808
Mexico	491
Canada	488
Malaysia	460
Australia	345
Singapore	261
Philippines	257
Norway	78
Sweden	74
Turkey	65
Denmark	46
Puerto Rico	12
Guam	8
Total	27,526

ing products delivered by wholesalers. DSD accounted for about half the total volume, with the rest coming from wholesalers.

With the goal of introducing "fresh" products, 7-Eleven introduced the concept of combined distribution centers (CDCs) around 2000. By 2003, 7-Eleven had 23 CDCs located throughout North America supporting about 80 percent of the store network. CDCs delivered fresh items such as sandwiches, bakery products, bread, produce, and other perishables once a day. A variety of fresh-food suppliers sent product to the CDC throughout the day, where they were sorted for delivery to stores at night. Requests from store managers were sent to the nearest CDC, and by 10:00 P.M. the products were en route to the stores. Fresh-food sales in North America exceeded $450 million in 2003. During this period, DSD by manufacturers and wholesaler delivery to stores also continued.

This was a period when 7-Eleven worked very hard to introduce new fresh-food items with a goal of competing more directly with the likes of Starbucks than with traditional gas station food marts. 7-Eleven in the United States had over 68 percent of its sales from nongasoline products compared to the rest of the industry, for which this number was closer to 35 percent. The goal was to continue to increase sales in the fresh-food and fast-food categories.

In 2003 revenue in the United States and Canada totaled $10.9 billion, with about 69 percent coming from merchandise and the rest from the sale of gasoline. The North American inventory turnover rate in 2004 was about 19, compared to over 50 in Japan. This performance, however, represented a significant improvement in North American performance, where inventory turns in 1992 were around 12.

STUDY QUESTIONS

1. A convenience store chain attempts to be responsive and provide customers what they need, when they need it, where they need it. What are some different ways that a convenience store supply chain can be responsive? What are some risks in each case?
2. Seven-Eleven's supply chain strategy in Japan can be described as attempting to micro-match supply and demand using rapid replenishment. What are some risks associated with this choice?
3. What has Seven-Eleven done in its choice of facility location, inventory management, transportation, and information infrastructure to develop capabilities that support its supply chain strategy in Japan?
4. Seven-Eleven does not allow direct store delivery in Japan but has all products flow through its distribution center. What benefit does Seven-Eleven derive from this policy? When is direct store delivery more appropriate?
5. What do you think about the 7dream concept for Seven-Eleven Japan? From a supply chain perspective, is it likely to be more successful in Japan or the United States? Why?
6. Seven-Eleven is attempting to duplicate the supply chain structure that has succeeded in Japan in the United States with the introduction of CDCs. What are the pros and cons of this approach? Keep in mind that stores are also replenished by wholesalers and DSD by manufacturers.
7. The United States has food service distributors that also replenish convenience stores. What are the pros and cons to having a distributor replenish convenience stores versus a company like Seven-Eleven managing its own distribution function?

PART II

DESIGNING THE SUPPLY CHAIN NETWORK

CHAPTER 4
DESIGNING DISTRIBUTION NETWORKS AND APPLICATIONS TO E-BUSINESS

CHAPTER 5
NETWORK DESIGN IN THE SUPPLY CHAIN

CHAPTER 6
NETWORK DESIGN IN AN UNCERTAIN ENVIRONMENT

The goal of the chapters in Part II is to discuss a set of frameworks and tools used to design supply chain networks. Network design decisions are among the most important supply chain decisions, as their implications are significant and long lasting. In designing a supply chain, we need to consider how all supply chain drivers—facilities, transportation, inventory, information, sourcing, and pricing—should be used together to support the competitive strategy of a firm and maximize supply chain profits.

Chapter 4 explores how to design a distribution network. A variety of distribution network models are presented, along with an analysis of the pros and cons of each model. This chapter also includes an in-depth discussion of the design of distribution networks in the context of e-business. Chapter 5 considers facility-related decisions that firms must make when designing their supply chain network. A framework for facility decisions in a supply chain is developed, and methodologies for locating facilities and allocating capacity and markets to each facility are described. Chapter 6 highlights how uncertainties in demand and financial factors such as prices, exchange rates, and inflation should be accounted for in supply chain decisions. Methodologies for evaluation of network design decisions under uncertainty are discussed. These methodologies are then used to evaluate several network design decisions.

CHAPTER 4

DESIGNING DISTRIBUTION NETWORKS AND APPLICATIONS TO E-BUSINESS



Learning Objectives

After reading this chapter, you will be able to:

1. Identify the key factors to be considered when designing a distribution network.
2. Discuss the strengths and weaknesses of various distribution options.
3. Understand how e-business has affected the design of distribution networks in different industries.

In this chapter, we provide an understanding of the role of distribution within a supply chain and identify factors that should be considered when designing a distribution network. We identify several potential designs for distribution networks and evaluate the strengths and weaknesses of each option. We apply these ideas to discuss the evolution of distribution networks in various industries since the advent of e-business. Our goal is to provide managers with a logical framework for selecting the appropriate distribution network given product, competitive, and market characteristics.

4.1 THE ROLE OF DISTRIBUTION IN THE SUPPLY CHAIN

Distribution refers to the steps taken to move and store a product from the supplier stage to a customer stage in the supply chain. Distribution occurs between every pair of stages in the supply chain. Raw materials and components are moved from suppliers to manufacturers, whereas finished products are moved from the manufacturer to the end consumer. Distribution is a key driver of the overall profitability of a firm because it affects both the supply chain cost and the customer experience directly. Distribution-related costs make up about 10.5 percent of the U.S. economy and about 20 percent of the cost of manufacturing. For commodity products, distribution forms an even higher fraction of the product cost. In India, the outbound distribution cost of cement is about 30 percent of the cost of producing and selling cement.

It would be no exaggeration to state that two of the world's most profitable companies, Wal-Mart and Seven-Eleven Japan, have built the success of their entire business around outstanding distribution design and operation. In the case of Wal-Mart, distribution allows the company to provide high availability levels of relatively common products at a very low cost. In the case of Seven-Eleven Japan, effective distribution provides a very high level of customer responsiveness at a reasonable cost.

The appropriate distribution network can be used to achieve a variety of supply chain objectives ranging from low cost to high responsiveness. As a result, companies in the same industry often select very different distribution networks. Next, we discuss

industry examples that highlight the variety of distribution network choices and the issues that arise when selecting among these options.

Dell distributes its PCs directly to end consumers, whereas companies such as HP distribute through resellers. Dell customers wait several days to get a PC, whereas customers can walk away with an HP PC from a reseller. Gateway opened Gateway Country stores, where customers could examine the products and have salespeople help them configure a PC that suited their needs. Gateway, however, chose to sell no products at the stores; all PCs were shipped directly from the factory to the customer. In 2001, Gateway closed several of these stores because of their poor financial performance. Apple Computer, in contrast, has opened many retail stores where computers are sold. These PC companies have chosen different distribution models. How can we evaluate this wide range of distribution choices? Which ones serve the companies and their customers better?

P&G has chosen to distribute directly to large supermarket chains while obligating smaller players to buy P&G products from distributors. Products move directly from P&G to the larger chains, but move through an additional stage when going to smaller supermarkets. Texas Instruments, which once used only direct sales, now sells about 30 percent of its volume to 98 percent of its customers through distributors, while serving the remaining 2 percent of customers with 70 percent of the volume directly.[1] What value do these distributors provide? When should a distribution network include an additional stage such as a distributor? Proponents of e-business had predicted the death of intermediaries such as distributors. Why were they proved wrong in many industries? Distributors play a much more significant role for consumer goods distribution in a country such as India compared to the United States. Why might this be the case?

W.W. Grainger stocks about 100,000 SKUs that can be sent to customers within a day of order placement. The remaining, slower-moving products are not stocked but instead are shipped directly from the manufacturer when a customer places an order. It takes several days for the customer to receive the product in this case. Are these distribution choices appropriate? How can they be justified?

As the preceding examples illustrate, firms can make many different choices when designing their distribution network. A poor distribution network can hurt the level of service that customers receive while increasing the cost. An inappropriate network can have a significant negative effect on the profitability of the firm, as evident in the failure of many business-to-consumer (B2C) companies such as Webvan. The appropriate choice of distribution network results in customer needs being satisfied at the lowest possible cost.

In the next section, we identify performance measures that need to be considered when designing the distribution network.

4.2 FACTORS INFLUENCING DISTRIBUTION NETWORK DESIGN

At the highest level, performance of a distribution network should be evaluated along two dimensions:

1. Customer needs that are met
2. Cost of meeting customer needs

[1] *A Tale of Two Electronic Component Distributors,* Ananth Raman and Bharat P. Rao, Harvard Business School Case 9–697–064, 1997.

Thus, a firm must evaluate the impact on customer service and cost as it compares different distribution network options. The customer needs that are met influence the company's revenues, which along with cost decide the profitability of the delivery network.

Although customer service consists of many components, we focus on those measures that are influenced by the structure of the distribution network. These include:

- Response time
- Product variety
- Product availability
- Customer experience
- Time to market
- Order visibility
- Returnability

Response time is the amount of time it takes for a customer to receive an order. Product variety is the number of different products/configurations that are offered by the distribution network. Product availability is the probability of having a product in stock when a customer order arrives. Customer experience includes the ease with which customers can place and receive orders as well as the extent to which this experience is customized. It also includes purely experiential aspects, such as the possibility of getting a cup of coffee and the value that the sales staff provides. Time to market is the time it takes to bring a new product to the market. Order visibility is the ability of customers to track their orders from placement to delivery. Returnability is the ease with which a customer can return unsatisfactory merchandise and the ability of the network to handle such returns.

It may seem at first that a customer always wants the highest level of performance along all these dimensions. In practice, however, this is not the case. Customers ordering a book at Amazon.com are willing to wait longer than those who drive to a nearby Borders store to get the same book. In contrast, customers can find a much larger variety of books at Amazon compared to the Borders store. Thus, Amazon customers trade off fast response times for high levels of variety.

Firms that target customers who can tolerate a long response time require only a few locations that may be far from the customer. These companies can focus on increasing the capacity of each location. In contrast, firms that target customers who value short response times need to locate facilities close to them. These firms must have many facilities, each with a low capacity. Thus, a decrease in the response time customers desire increases the number of facilities required in the network, as shown in Figure 4-1.

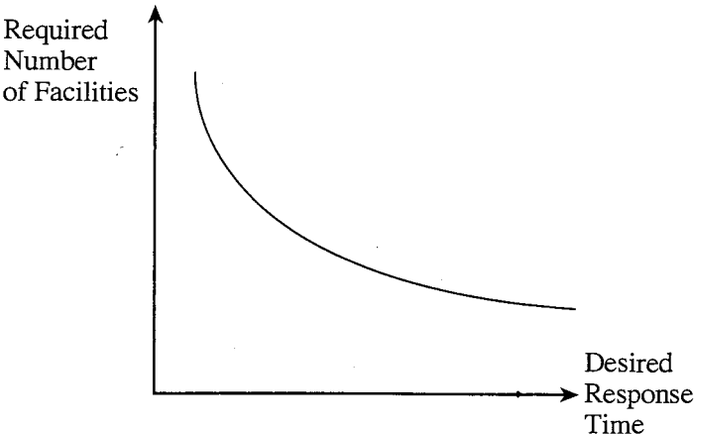
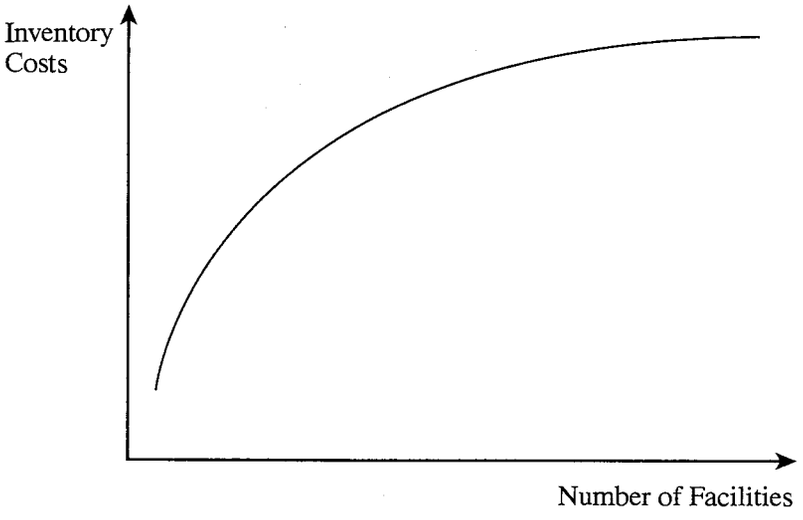


FIGURE 4-1
Relationship Between Desired Response Time and Number of Facilities

FIGURE 4-2 Relationship Between Number of Facilities and Inventory Costs



For example, Borders provides its customers with books on the same day but requires about 400 stores to achieve this goal for most of the United States. Amazon, in contrast, takes about a week to deliver a book to its customers, but uses only about six locations to store its books.

Changing the distribution network design affects the following supply chain costs (notice that these are four of the six supply chain drivers we discussed earlier):

- Inventories
- Transportation
- Facilities and handling
- Information

The other two drivers, sourcing and pricing, also affect the choice of the distribution system; the link will be discussed when relevant. As the number of facilities in a supply chain increases, the inventory and resulting inventory costs also increase (see Chapter 11), as shown in Figure 4-2.

To decrease inventory costs, firms try to consolidate and limit the number of facilities in their supply chain network. For example, with fewer facilities, Amazon is able to turn its inventory about 12 times a year, whereas Borders, with about 400 facilities, achieves only about two turns per year.

Inbound transportation costs are the costs incurred in bringing material into a facility. *Outbound transportation costs* are the costs of sending material out of a facility. Outbound transportation costs per unit tend to be higher than inbound costs because inbound lot sizes are typically larger. For example, the Amazon warehouse receives full truckload shipments of books on the inbound side, but ships out small packages with only a few books per customer on the outbound side. Increasing the number of warehouse locations decreases the average outbound distance to the customer and makes outbound transportation distance a smaller fraction of the total distance traveled by the product. Thus, as long as inbound transportation economies of scale are maintained, increasing the number of facilities decreases total transportation cost, as shown in Figure 4-3. If the number of facilities is increased to a point where inbound lot sizes

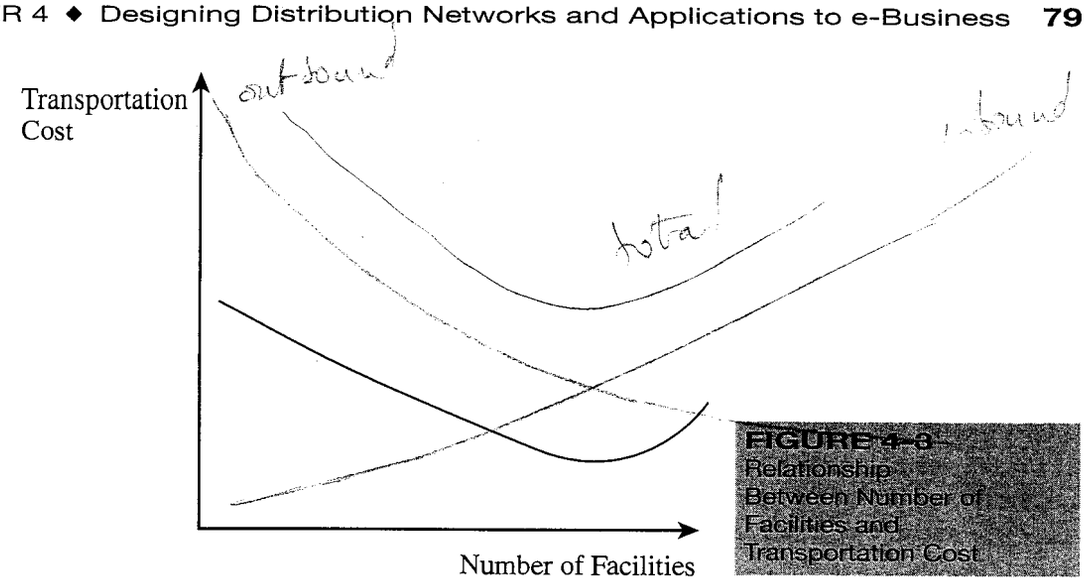


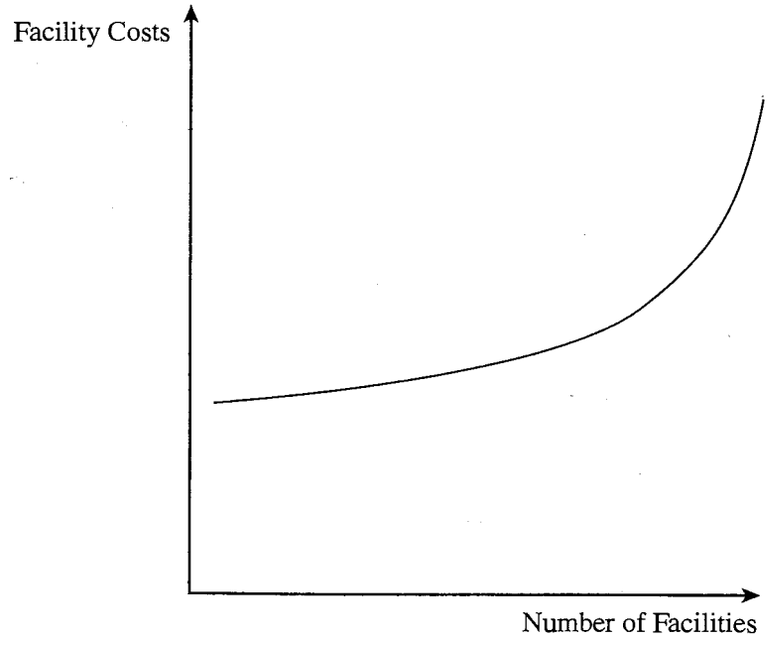
FIGURE 4-3 Relationship Between Number of Facilities and Transportation Cost

are also very small and result in a significant loss of economies of scale in inbound transportation, increasing the number of facilities increases total transportation cost, as shown in Figure 4-3.

Facility costs decrease as the number of facilities is reduced, as shown in Figure 4-4, because a consolidation of facilities allows a firm to exploit economies of scale.

Total logistics costs are the sum of inventory, transportation, and facility costs for a supply chain network. As the number of facilities increases, total logistics costs first decrease and then increase as shown in Figure 4-5. Each firm should have *at least* the number of facilities that minimize total logistics costs. For example, Amazon has more

FIGURE 4-4 Relationship Between Number of Facilities and Facility Costs



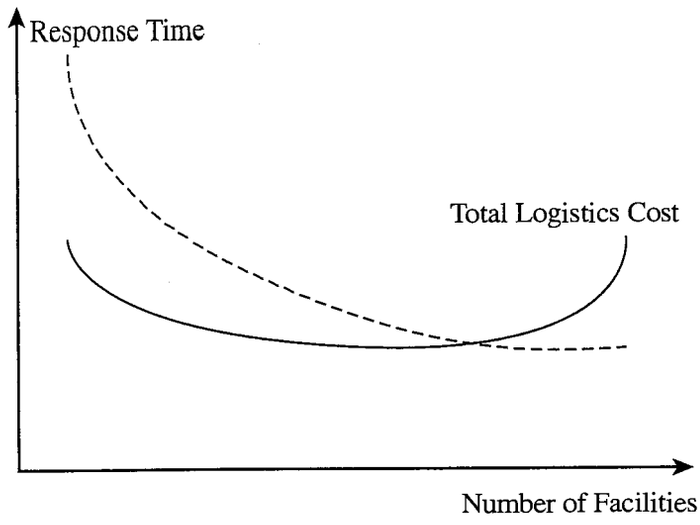


FIGURE 4-5 Variation in Logistics Cost and Response Time with Number of Facilities

than one warehouse primarily to reduce its logistics costs (and improve response time). As a firm wants to reduce the response time to its customers further, it may have to increase the number of facilities beyond the point that minimizes logistics costs. A firm should add facilities beyond the cost-minimizing point only if managers are confident that the increase in revenues because of better responsiveness is greater than the increase in costs because of the additional facilities.

The customer service and cost components listed earlier are the primary measures used to evaluate different delivery network designs. In general, no distribution network will outperform others along all dimensions. Thus, it is important to ensure that the strengths of the distribution network fit with the strategic position of the firm.

In the next section, we discuss various distribution networks and their relative strengths and weaknesses.

4.3 DESIGN OPTIONS FOR A DISTRIBUTION NETWORK

In this section, we discuss distribution network choices from the manufacturer to the end consumer. When considering distribution between any other pair of stages, such as supplier to manufacturer or even a service company serving its customers through a distribution network, many of the same options still apply. Managers must make two key decisions when designing a distribution network:

1. Will product be delivered to the customer location or picked up from a preordained site?
2. Will product flow through an intermediary (or intermediate location)?

Based on the firm's industry and the answers to these two questions, one of six distinct distribution network designs may be used to move products from factory to customer, which are classified as follows:

1. Manufacturer storage with direct shipping
2. Manufacturer storage with direct shipping and in-transit merge
3. Distributor storage with package carrier delivery

4. Distributor storage with last-mile delivery
5. Manufacturer/distributor storage with costumer pickup
6. Retail storage with customer pickup

Next we describe each distribution option and discuss its strengths and weaknesses.

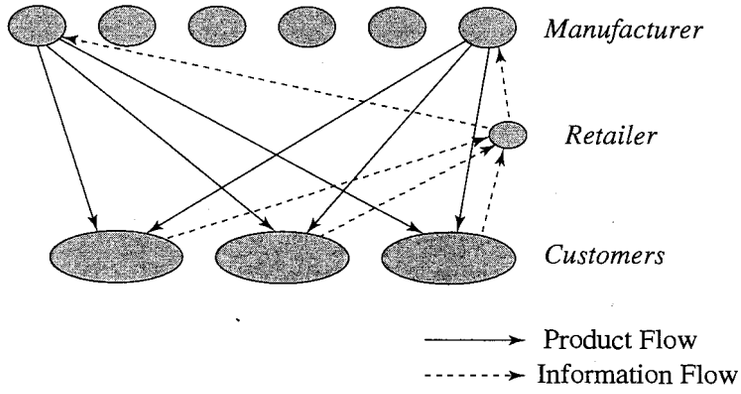
MANUFACTURER STORAGE WITH DIRECT SHIPPING

In this option, product is shipped directly from the manufacturer to the end customer, bypassing the retailer (who takes the order and initiates the delivery request). This option is also referred to as drop-shipping, with product delivered directly from the manufacturer to the customer. The retailer, if independent of the manufacturer, carries no inventories. Information flows from the customer, via the retailer, to the manufacturer, and product is shipped directly from the manufacturer to customers as shown in Figure 4-6. Online retailers such as eBags and Nordstrom.com use drop-shipping to deliver goods to the end consumer. eBags holds few bags in inventory. Nordstrom carries some products in inventory and uses the drop-ship model for slow-moving footwear. W.W. Grainger also uses drop-shipping to deliver slow-moving items to customers.

The biggest advantage of drop-shipping is the ability to centralize inventories at the manufacturer. A manufacturer can aggregate demand across all retailers that it supplies. As a result, the supply chain is able to provide a high level of product availability with lower levels of inventory. A key issue with regard to drop-shipping is the ownership structure of the inventory at the manufacturer. If specified portions of inventory at the manufacturer are allocated to individual retailers, there is little benefit of aggregation even though the inventory is physically aggregated. Benefit of aggregation is achieved only if the manufacturer can allocate at least a portion of the available inventory across retailers on an as-needed basis. The benefits from centralization are highest for high-value, low-demand items with unpredictable demand. The decision of Nordstrom to drop-ship low-demand shoes satisfies these criteria. Similarly, bags sold by eBags tend to have high value and relatively low demand per SKU. The inventory benefits of aggregation are small for items with predictable demand and low value. Thus, drop-shipping does not offer a significant inventory advantage to an online grocer selling a staple item such as detergent. For slow-moving items, inventory turns can increase by a factor of 6 or higher if drop-shipping is used instead of storage at retail stores.

Drop-shipping also offers the manufacturer the opportunity to postpone customization until after a customer has placed an order. Postponement, if implemented,

FIGURE 4-6 Manufacturer Storage with Direct Shipping



further lowers inventories by aggregating to the component level. Build-to-order companies such as Dell hold inventories as common components and postpone product customization, thus lowering the level of inventory carried.

Although inventory costs are typically low with drop-shipping, transportation costs are high because the average outbound distance to the end consumer is large, and package carriers are used to ship the product. Package carriers have high shipping costs per unit compared to truckload or less-than-truckload carriers. With drop-shipping, a customer order including items from several manufacturers will involve multiple shipments to the customer. This loss in aggregation of outbound transportation increases cost.

Supply chains save on the fixed cost of facilities when using drop-shipping because all inventories are centralized at the manufacturer. This eliminates the need for other warehousing space in the supply chain. There can be some savings of handling costs as well, because the transfer from manufacturer to retailer no longer occurs. Handling cost savings must be evaluated carefully, however, because the manufacturer is now required to transfer items to the factory warehouse in full cases and then ship out from the warehouse in single units. The inability of a manufacturer to develop single-unit delivery capabilities can have a significant negative effect on handling cost and response time. Handling costs can be reduced significantly if the manufacturer has the capability to ship orders directly from the production line.

A good information infrastructure is needed between the retailers and the manufacturer so that the retailer can provide product availability information to the customer, even though the inventory is located at the manufacturer. The customer should also have visibility into order processing at the manufacturer, even with the order being placed with the retailer. Drop-shipping generally requires significant investment in information infrastructure. The information infrastructure requirement is somewhat simpler for direct sellers like Dell because two stages (retailer and manufacturer) do not need to be integrated.

Response times tend to be long when drop-shipping is used because the order has to be transmitted from the retailer to the manufacturer and shipping distances are generally longer from the manufacturer's centralized site. eBags, for example, states that order processing may take from one to five days and ground transportation after that may take from three to 11 business days. This implies that customer response time at eBags will be four to 16 days using ground transportation and drop-shipping.

Another issue is that the response time need not be identical for every manufacturer that is part of a customer order. Given an order containing products from several sources, the customer will receive multiple partial shipments over time, making receiving more complicated for the customer.

Manufacturer storage allows a high level of product variety to be available to the customer. With a drop-shipping model, every product at the manufacturer can be made available to the customer without any limits imposed by shelf space. W.W. Grainger is able to offer hundreds of thousands of slow-moving items from thousands of manufacturers using drop-shipping. This would be impossible if each product had to be stored by W.W. Grainger. Drop-shipping allows a new product to be available to the market the day the first unit is produced.

Drop-shipping provides a good customer experience in the form of delivery to the customer location. The experience, however, suffers when a single order containing products from several manufacturers is delivered in partial shipments.

Order visibility is very important in the context of manufacturer storage, because two stages in the supply chain are involved in every customer order. Failure to provide this capability is likely to have a significant negative effect on customer satisfaction.

Order tracking, however, becomes harder to implement in a drop-ship system because it requires complete integration of information systems at both the retailer and the manufacturer. For direct sellers such as Dell, order visibility is simpler to provide.

A manufacturer storage network is likely to have difficulty handling returns, hurting customer satisfaction. The handling of returns is more expensive under drop-shipping because each order may involve shipments from more than one manufacturer. There are two ways that returns can be handled. One is for the customer to return the product directly to the manufacturer. The second approach is for the retailer to set up a separate facility (across all manufacturers) to handle returns. The first approach incurs high transportation and coordination costs, whereas the second approach requires investment in a facility to handle returns.

The performance characteristics of drop-shipping along various dimensions are summarized in Table 4-1.

Given its performance characteristics, manufacturer storage with direct shipping is best suited for a large variety of low-demand, high-value items for which customers are willing to wait for delivery and accept several partial shipments. Manufacturer storage is also suitable if it allows the manufacturer to postpone customization, thus reducing inventories. For drop-shipping to be effective, there should be few sourcing locations per order. It is thus ideal for direct sellers that are able to build-to-order. Drop-shipping will be hard to implement if there are more than 20 or 30 sourcing locations that have to ship directly to customers on a regular basis. For products with very low demand, however, drop-shipping may be the only option.

TABLE 4-1 Performance Characteristics of Manufacturer Storage with Direct Shipping Network

Cost Factor	*Performance*
Inventory	Lower costs because of aggregation. Benefits of aggregation are highest for low-demand, high-value items. Benefits are very large if product customization can be postponed at the manufacturer.
Transportation	Higher transportation costs because of increased distance and disaggregate shipping.
Facilities and handling	Lower facility costs because of aggregation. Some saving on handling costs if manufacturer can manage small shipments or ship from production line.
Information	Significant investment in information infrastructure to integrate manufacturer and retailer.
Service Factor	***Performance***
Response time	Long response time of one to two weeks because of increased distance and two stages for order processing. Response time may vary by product, thus complicating receiving.
Product variety	Easy to provide a very high level of variety.
Product availability	Easy to provide a high level of product availability because of aggregation at manufacturer.
Customer experience	Good in terms of home delivery but can suffer if order from several manufacturers is sent as partial shipments.
Time to market	Fast, with the product available as soon as the first unit is produced.
Order visibility	More difficult but also more important from a customer service perspective.
Returnability	Expensive and difficult to implement.

MANUFACTURER STORAGE WITH DIRECT SHIPPING AND IN-TRANSIT MERGE

Unlike pure drop-shipping, under which each product in the order is sent directly from its manufacturer to the end customer, in-transit merge combines pieces of the order coming from different locations so that the customer gets a single delivery. Information and product flows for the in-transit merge network are as shown in Figure 4-7. In-transit merge has been used by direct sellers such as Dell and can be used by companies implementing drop-shipping. When a customer orders a PC from Dell along with a Sony monitor, the package carrier picks up the PC from the Dell factory and the monitor from the Sony factory; it then merges the two together at a hub before making a single delivery to the customer.

As with drop-shipping, the ability to aggregate inventories and postpone product customization is a significant advantage of in-transit merge. In-transit merge allows Dell and Sony to hold all their inventories at the factory. This approach has the greatest benefits for products with high value whose demand is difficult to forecast, particularly if product customization can be postponed.

In most cases, transportation costs are lower than with drop-shipping because of the merge that takes place at the carrier hub before delivery to the customer, although an increase in coordination is required. An order with products from three manufacturers thus requires only one delivery to the customer, compared to three that would be required with drop-shipping. Fewer deliveries save transportation cost and simplify receiving.

Facility and processing costs for the manufacturer and the retailer are similar to those for drop-shipping. The party performing the in-transit merge has higher facility costs because of the merge capability required. Receiving costs at the customer are lower because a single delivery is received. Overall supply chain facility and handling costs are somewhat higher than with drop-shipping.

A very sophisticated information infrastructure is needed to allow in-transit merge. In addition to information, operations at the retailer, manufacturers, and the carrier must be coordinated. The investment in information infrastructure is higher than for drop-shipping.

Response times, product variety, availability, and time to market are similar to drop-shipping. Response times may be marginally higher because of the need to perform the merge. Customer experience is likely to be better than with drop-shipping, because the customer receives only one delivery for an order instead of many partial

FIGURE 4-7 In-Transit Merge Network

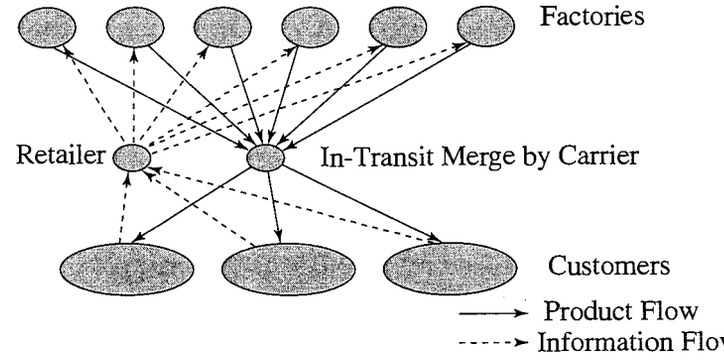


TABLE 4-2 Performance Characteristics of In-Transit Merge

Cost Factor	*Performance*
Inventory	Similar to drop-shipping.
Transportation	Somewhat lower transportation costs than drop-shipping.
Facilities and handling	Handling costs higher than drop-shipping at carrier; receiving costs lower at customer.
Information	Investment is somewhat higher than for drop-shipping.
Service Factor	***Performance***
Response time	Similar to drop-shipping; may be marginally higher.
Product variety	Similar to drop-shipping.
Product availability	Similar to drop-shipping.
Customer experience	Better than drop-shipping because a single delivery has to be received.
Time to market	Similar to drop-shipping
Order visibility	Similar to drop-shipping.
Returnability	Similar to drop-shipping.

shipments. Order visibility is a very important requirement. Although the initial setup is difficult because it requires integration of manufacturer, carrier, and retailer, tracking itself becomes easier given the merge that occurs at the carrier hub. Up to the point of merge, the order from each manufacturer is tracked separately. After that, the order can be tracked as a single unit.

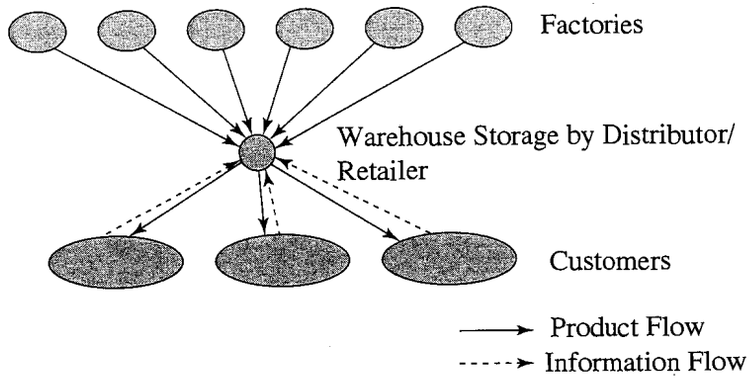
Returnability is similar to that with drop-shipping. Problems in handling returns are very likely, and the reverse supply chain will continue to be expensive and difficult to implement, as with drop-shipping.

The performance of factory storage with in-transit merge is compared with that of drop-shipping in Table 4-2. The main advantages of in-transit merge over drop-shipping are lower transportation cost and improved customer experience. The major disadvantage is the additional effort during the merge itself. Given its performance characteristics, manufacturer storage with in-transit merge is best suited for low- to medium-demand, high-value items the retailer is sourcing from a limited number of manufacturers. Compared to drop-shipping, in-transit merge requires a higher demand from each manufacturer (not necessarily each product) in order to be effective. When there are too many sources, in-transit merge can be very difficult to coordinate and implement. In-transit merge is best implemented if there are no more than four or five sourcing locations. The in-transit merge of a Dell PC with a Sony monitor is appropriate because product variety is high but there are few sourcing locations with relatively large total demand from each sourcing location.

DISTRIBUTOR STORAGE WITH CARRIER DELIVERY

Under this option, inventory is not held by manufacturers at the factories but is held by distributors/retailers in intermediate warehouses, and package carriers are used to transport products from the intermediate location to the final customer. Amazon, as well as industrial distributors such as W.W. Grainger and McMaster-Carr, have used this approach combined with drop-shipping from a manufacturer (or distributor). Information and product flows when using distributor storage with delivery by a package carrier are shown in Figure 4-8.

FIGURE 4-8 Distributor Storage with Carrier Delivery



Relative to manufacturer storage, distributor storage requires a higher level of inventory, as the distributor/retailer warehouse generally aggregates demand uncertainty at a lower level than the manufacturer that is able to aggregate demand across all distributors/retailers. From an inventory perspective, distributor storage makes sense for products with somewhat higher demand. This is seen in the operations of both Amazon and W.W. Grainger. They stock only the medium- to fast-moving items at their warehouses, with slower-moving items stocked farther upstream. In some instances, postponement can be implemented with distributor storage, but it does require that the warehouse develop some assembly capability. Distributor storage, however, requires much less inventory than a retail network. Amazon achieves about 12 turns of inventory annually using warehouse storage, whereas Borders achieves about two turns using retail stores.

Transportation costs are somewhat lower for distributor storage compared to manufacturer storage because an economic mode of transportation (e.g., truckloads) can be employed for inbound shipments to the warehouse, which is closer to the customer. Unlike manufacturer storage, under which multiple shipments may need to go out for a single customer order with multiple items, distributor storage allows outbound orders to the customer to be bundled into a single shipment, further reducing transportation cost. Distributor storage provides savings on the transportation of faster-moving items relative to manufacturer storage.

Compared to manufacturer storage, facility costs (of warehousing) are somewhat higher with distributor storage because of a loss of aggregation. Processing and handling costs are comparable to manufacturer storage unless the factory is able to ship to the end customer directly from the production line. In that case, distributor storage has higher processing costs. From a facility cost perspective, distributor storage is not appropriate for extremely slow-moving items.

The information infrastructure needed with distributor storage is significantly less complex than that needed with manufacturer storage. The distributor warehouse serves as a buffer between the customer and the manufacturer, decreasing the need to coordinate the two completely. Real-time visibility between customers and the warehouse is needed, whereas real-time visibility between the customer and the manufacturer is not. Visibility between the distributor warehouse and manufacturer can be achieved at a much lower cost than real-time visibility between the customer and manufacturer.

Response time under distributor storage is better than under manufacturer storage because distributor warehouses are, on average, closer to customers and the entire

TABLE 4-3 Performance Characteristics of Distributor Storage with Carrier Delivery

Cost Factor	*Performance*
Inventory	Higher than manufacturer storage. Difference is not large for faster-moving items.
Transportation	Lower than manufacturer storage. Reduction is highest for faster-moving items.
Facilities and handling	Somewhat higher than manufacturer storage. The difference can be large for very slow-moving items.
Information	Simpler infrastructure compared to manufacturer storage.
Service Factor	***Performance***
Response time	Faster than manufacturer storage.
Product variety	Lower than manufacturer storage.
Product availability	Higher cost to provide the same level of availability as manufacturer storage.
Customer experience	Better than manufacturer storage with drop-shipping.
Time to market	Higher than manufacturer storage.
Order visibility	Easier than manufacturer storage.
Returnability	Easier than manufacturer storage.

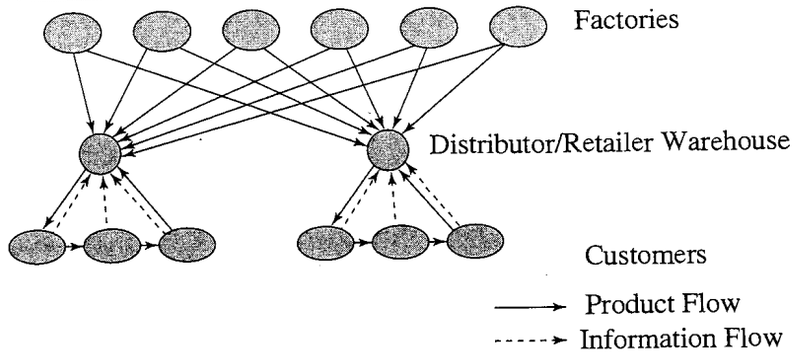
order is aggregated at the warehouse before being shipped. Amazon, for example, processes most warehouse-stored items within a day and then it takes three to seven business days using ground transportation for the order to reach the customer. W.W. Grainger processes customer orders on the same day and has enough warehouses to deliver most orders the next day using ground transport. Warehouse storage limits to some extent the variety of products that can be offered. W.W. Grainger does not store very-low-demand items at its warehouse, relying on manufacturers to drop-ship those products to the customer. Customer convenience is high with distributor storage because a single shipment reaches the customer in response to an order. Time to market under distributor storage is somewhat higher than under manufacturer storage because of the need to stock another stage in the supply chain. Order visibility becomes easier than with manufacturer storage because there is a single shipment from the warehouse to the customer and only one stage of the supply chain is involved directly in filling the customer order. Returnability is better than with manufacturer storage because all returns can be processed at the warehouse itself. The customer also has to return only one package, even if the items are from several manufacturers.

The performance of distributor storage with carrier delivery is summarized in Table 4-3. Distributor storage with carrier delivery is well suited for medium- to fast-moving items. Distributor storage also makes sense when customers want delivery faster than is offered by manufacturer storage but do not need it immediately. Distributor storage can handle somewhat lower variety than manufacturer storage but can handle a much higher level of variety than a chain of retail stores.

DISTRIBUTOR STORAGE WITH LAST-MILE DELIVERY

Last-mile delivery refers to the distributor/retailer delivering the product to the customer's home instead of using a package carrier. Webvan, Peapod, and Albertsons have used last-mile delivery in the grocery industry. Companies such as Kozmo and Urbanfetch tried to set up home-delivery networks for a variety of products but failed

FIGURE 4-9 Distributor Storage with Last-Mile Delivery



to survive. Unlike package carrier delivery, last-mile delivery requires the distributor warehouse to be much closer to the customer. Given the limited radius that can be served with last-mile delivery, more warehouses are required compared to the case when package delivery is used. The warehouse storage with last-mile delivery network is as shown in Figure 4-9.

Distributor storage with last-mile delivery requires higher levels of inventory than the other options (except for retail stores) because it has a lower level of aggregation. From an inventory perspective, warehouse storage with last-mile delivery is suitable for relatively fast-moving items for which disaggregation does not lead to a significant increase of inventory. Staple items in the grocery industry fit this description.

Among all the distribution networks, transportation costs are highest for last-mile delivery. This is because package carriers aggregate delivery across many retailers and are able to obtain better economies of scale than are available to a distributor/retailer attempting last-mile delivery. Delivery costs (including transportation and processing) can be about $30 to $40 per home delivery in the grocery industry. Last-mile delivery may be somewhat less expensive in large, dense cities. Transportation costs may also be justifiable for bulky products for which the customer is willing to pay for home delivery. Home delivery of water and large bags of rice has proved quite successful in China, where the high population density has helped decrease delivery costs.

Facility and processing costs are very high using this option, given the large number of facilities required. Facility costs are somewhat lower than for a network with retail stores but much higher than for either manufacturer storage or distributor storage with package carrier delivery. Processing costs, however, are much higher than for a network of retail stores because all customer participation is eliminated. A grocery store using last-mile delivery performs all the processing until the product is delivered to the customer's home, unlike a supermarket, where there is much more customer participation.

The information infrastructure with last-mile delivery is similar to that for distributor storage with package carrier delivery. However, it requires the additional capability of scheduling deliveries.

Response times are faster than using package carriers. Kozmo and Urbanfetch tried to provide same-day delivery, whereas online grocers typically provide next-day delivery. Product variety is generally lower than for distributor storage with carrier delivery. The cost of providing product availability is higher than for every option other than retail stores. The customer experience can be very good using this

TABLE 4-4 Performance Characteristics of Distributor Storage with Last-Mile Delivery

Cost Factor	*Performance*
Inventory	Higher than distributor storage with package carrier delivery.
Transportation	Very high cost given minimal scale economies. Higher than any other distribution option.
Facilities and handling	Facility costs higher than manufacturer storage or distributor storage with package carrier delivery, but lower than a chain of retail stores.
Information	Similar to distributor storage with package carrier delivery.
Service Factor	***Performance***
Response time	Very quick. Same day to next-day delivery.
Product variety	Somewhat less than distributor storage with package carrier delivery but larger than retail stores.
Product availability	More expensive to provide availability than any other option except retail stores.
Customer experience	Very good, particularly for bulky items.
Time to market	Slightly higher than distributor storage with package carrier delivery.
Order traceability	Less of an issue and easier to implement than manufacturer storage or distributor storage with package carrier delivery.
Returnability	Easier to implement than other options. Harder and more expensive than a retail network.

option, particularly for bulky, hard-to-carry items. Time to market is even higher than for distributor storage with package carrier delivery because the new product has to penetrate deeper before it is available to the customer. Order visibility is less of an issue given that deliveries are made within 24 hours. The order-tracking feature does become important to handle exceptions in case of incomplete or undelivered orders. Of all the options discussed, returnability is best with last-mile delivery, because trucks making deliveries can also pick up returns from customers. Returns are still more expensive to handle than at a retail store, where a customer can bring the product back.

The performance characteristics of distributor storage with last-mile delivery are summarized in Table 4-4. In areas with high labor costs, it is very hard to justify distributor storage with last-mile delivery on the basis of efficiency or improved margin. It can only be justified if there is a large enough customer segment willing to pay for this convenience. In that case, an effort should be made to couple last-mile delivery with an existing distribution network to exploit economies of scale and improve utilization. An example is Albertsons' use of existing grocery store facilities and labor to provide home delivery. A portion of the grocery store serves as a fulfillment center for online orders as well as a replenishment center for the grocery store itself. This helps improve utilization and lower the cost of providing this service. Last-mile delivery may be justifiable if customer orders are large enough to provide some economies of scale. Peapod has changed its pricing policies to reflect this idea. Minimum order sizes are for $50 (with a delivery charge of $9.95), and free delivery is no longer provided for orders of any size. Peapod offers discounts for deliveries during slower periods based on what its schedule looks like. To be profitable, home delivery companies almost definitely have to eliminate free delivery.

MANUFACTURER OR DISTRIBUTOR STORAGE WITH CUSTOMER PICKUP

In this approach, inventory is stored at the manufacturer or distributor warehouse but customers place their orders online or on the phone and then travel to designated pickup points to collect their merchandise. Orders are shipped from the storage site to the pickup points as needed. Examples include 7dream.com, operated by Seven-Eleven Japan, which allows customers to pick up online orders at a designated store. A business-to-business (B2B) example is W.W. Grainger, whose customers can pick up their orders at one of the W.W. Grainger retail outlets. In the case of 7dream.com, the order is delivered from a manufacturer or distributor warehouse to the pickup location. In the case of W.W. Grainger, some items are stored at the pickup location, whereas others may come from a central location. The information and product flows in the network for Seven-Eleven Japan are as shown in Figure 4-10.

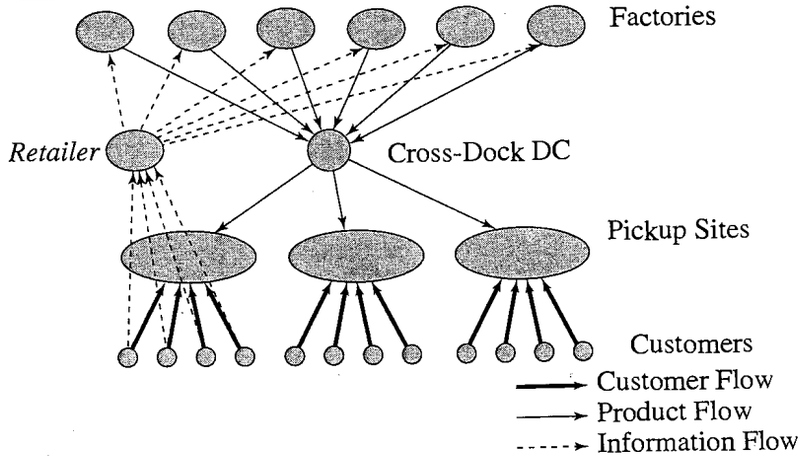
Seven-Eleven has distribution centers where product from manufacturers is cross-docked and sent to retail outlets on a daily basis. A retailer delivering an online order can be treated as one of the manufacturers, with deliveries cross-docked and sent to the appropriate Seven-Eleven outlet. Serving as an outlet for online orders allows Seven-Eleven to improve utilization of its existing logistical assets.

Inventory costs using this approach can be kept low, with either manufacturer or distributor storage to exploit aggregation. W.W. Grainger keeps its inventory of fast-moving items at pickup locations, whereas slow-moving items are stocked at a central warehouse, or in some cases at the manufacturer.

Transportation cost is lower than for any solution using package carriers because significant aggregation is possible when delivering orders to a pickup site. This allows the use of truckload or less-than-truckload carriers to transport orders to the pickup site. For a company such as Seven-Eleven Japan, the marginal increase in transportation cost is small because trucks are already making deliveries to the stores and their utilization can be improved by including online orders.

Facility costs are high if new pickup sites have to be built. A solution using existing sites can lower the additional facility costs. This, for example, is the case with 7dream.com and W.W. Grainger, for which the stores already exist. Processing costs at the manufacturer or the warehouse are comparable to those of other solutions. Processing costs at the pickup site are high because each order must be matched with a specific customer when

FIGURE 4-10 Manufacturer or Distributor Warehouse Storage with Consumer Pickup



he or she arrives. Creating this capability can increase processing costs significantly if appropriate storage and information systems are not provided. Increased processing cost at the pickup site is the biggest hurdle to the success of this approach.

A significant information infrastructure is needed to provide visibility of the order until the customer picks it up. Very good coordination is needed among the retailer, the storage location, and the pickup location.

In this case, a response time comparable to that using package carriers can be achieved. Variety and availability comparable to any manufacturer or distributor storage option can be provided. There is some loss of customer experience, because unlike the other options discussed, customers must pick up their own orders. On the other hand, customers who do not want to pay online can pay by cash using this option. In countries like Japan, where Seven-Eleven has more than 10,000 outlets, it can be argued that the loss of customer convenience is small, because most customers are close to a pickup site and can collect an order at their convenience. In some cases, this option is considered more convenient because it does not require the customer to be at home at the time of delivery. Time to market for new products can be as short as with manufacturer storage.

Order visibility is extremely important for customer pickups. The customer must be informed when the order has arrived, and the order should be easily identified once the customer arrives to pick it up. Such a system is hard to implement because it requires integration of several stages in the supply chain. Returns can potentially be handled at the pickup site. The problem with some existing sites such as Seven-Eleven stores is that they are not equipped to accept and process returns for products not sold at the stores. From a transportation perspective, however, return flows can be handled using the delivery trucks. For customers, returning a product is easy because they have a physical location to bring it to. Overall, returnability is fairly good using this option.

The performance characteristics of manufacturer or distributor storage with consumer pickup sites are summarized in Table 4-5. The main advantages of a network

TABLE 4-5 Performance Characteristics of Network with Consumer Pickup Sites

Cost Factor	*Performance*
Inventory	Can match any other option, depending on the location of inventory.
Transportation	Lower than the use of package carriers, especially if using an existing delivery network.
Facilities and handling	Facility costs can be very high if new facilities have to be built. Costs are lower if existing facilities are used. The increase in handling cost at the pickup site can be significant.
Information	Significant investment in infrastructure required
Service Factor	***Performance***
Response time	Similar to package carrier delivery with manufacturer or distributor storage. Same-day delivery possible for items stored locally at pickup site.
Product variety	Similar to other manufacturer or distributor storage options.
Product availability	Similar to other manufacturer or distributor storage options.
Customer experience	Lower than other options because of the lack of home delivery. In areas with high density of population, loss of convenience may be small.
Time to market	Similar to manufacturer storage options.
Order visibility	Difficult but essential.
Returnability	Somewhat easier given that pickup location can handle returns.

with consumer pickup sites is that it can lower the delivery cost and expand the set of products sold as well as customers served online. The major hurdle is the increased handling cost at the pickup site. Such a network is likely to be most effective if existing locations such as coffee shops, convenience stores, or grocery stores are used as pickup sites, because this type of network improves the economies from existing infrastructure. Unfortunately, such sites are typically designed to allow the customer to do the picking and need to develop the capability of picking a customer-specific order.

RETAIL STORAGE WITH CUSTOMER PICKUP

In this option, often viewed as the most traditional type of supply chain, inventory is stored locally at retail stores. Customers walk into the retail store or place an order online or by phone and pick it up at the retail store. Examples of companies that offer multiple options of order placement include Albertsons, which uses part of the facility as a grocery store and part of the facility as an online fulfillment center. Customers can walk into the store or order online. A B2B example is W.W. Grainger: Customers can order online, by phone, or in person and pick up their order at one of W.W. Grainger's retail outlets. Albertsons keeps its inventory at the pickup location itself. W.W. Grainger stores some items at the pickup locations whereas others may come from a central location.

Local storage increases inventory costs because of the lack of aggregation. For very fast-moving items, however, there is marginal increase in inventory even with local storage. Albertsons uses local storage because most of its products are relatively fast moving and are stocked at the supermarket in any case. Similarly, W.W. Grainger keeps its inventory of fast-moving items at pickup locations, whereas slow-moving items are stocked at a central warehouse.

Transportation cost is much lower than with other solutions because inexpensive modes of transport can be used to replenish product at the retail store. Facility costs are high because many local facilities are required. A minimal information infrastructure is needed if customers walk into the store and place orders. For online orders, however, a significant information infrastructure is needed to provide visibility of the order until the customer picks it up.

Very good response times can be achieved with this system because of local storage. For example, both Albertsons and W.W. Grainger offer same-day pickup from their retail locations. Product variety stored locally is lower than under other options. It is more expensive than with all other options to provide a high level of product availability. Customer experience depends on whether the customer likes to shop or not. Time to market is the highest with this option because the new product has to penetrate through the entire supply chain before it is available to customers. Order visibility is extremely important for customer pickups when orders are placed online or by phone. Returns can be handled at the pickup site. Overall, returnability is fairly good using this option.

The performance characteristics of a network with customer pickup sites and local storage (such as retail stores) are summarized in Table 4-6. The main advantage of a network with local storage is that it can lower delivery costs and provide a faster response than other networks. The major disadvantage is the increased inventory and facility costs. Such a network is best suited for fast-moving items or items for which customers value rapid response.

SELECTING A DISTRIBUTION NETWORK DESIGN

A network designer needs to consider product characteristics as well as network requirements when deciding on the appropriate delivery network. The various networks

TABLE 4-6 Performance Characteristics of Local Storage at Consumer Pickup Sites

Cost Factor	*Performance*
Inventory	Higher than all other options.
Transportation	Lower than all other options.
Facilities and handling	Higher than other options. The increase in handling cost at the pickup site can be significant for online and phone orders.
Information	Some investment in infrastructure required for online and phone orders.
Service Factor	***Performance***
Response time	Same-day (immediate) pickup possible for items stored locally at pickup site.
Product variety	Lower than all other options.
Product availability	More expensive to provide than all other options.
Customer experience	Related to whether shopping is viewed as a positive or negative experience by customer.
Time to market	Highest among distribution options.
Order visibility	Trivial for in-store orders. Difficult, but essential, for online and phone orders.
Returnability	Easier than other options given that pickup location can handle returns.

considered earlier have different strengths and weaknesses. In Table 4-7, the various delivery networks are ranked relative to each other along different performance dimensions. A ranking of 1 indicates the best performance along a given dimension; as the relative performance worsens, the ranking number increases.

Only niche companies end up using a single distribution network. Most companies are best served by a combination of delivery networks. The combination used depends on product characteristics as well as the strategic position that the firm is targeting. The

TABLE 4-7 Comparative Performance of Delivery Network Designs

	Retail Storage with Customer Pickup	*Manufacturer Storage with Direct Shipping*	*Manufacturer Storage with In-Transit Merge*	*Distributor Storage with Package Carrier Delivery*	*Distributor Storage with Last-Mile Delivery*	*Manufacturer Storage with Pickup*
Response time	1	4	4	3	2	4
Product variety	4	1	1	2	3	1
Product availability	4	1	1	2	3	1
Customer experience	Varies from 1 to 5	4	3	2	1	5
Time to market	4	1	1	2	3	1
Order visibility	1	5	4	3	2	6
Returnability	1	5	5	4	3	2
Inventory	4	1	1	2	3	1
Transportation	1	4	3	2	5	1
Facility and handling	6	1	2	3	4	5
Information	1	4	4	3	2	5

Key: 1 corresponds to the strongest performance and 6 the weakest performance.

TABLE 4-8 Performance of Delivery Networks for Different Product/Customer Characteristics

	Retail Storage with Customer Pickup	*Manufacturer Storage with Direct Shipping*	*Manufacturer Storage with In-Transit Merge*	*Distributor Storage with Package Carrier Delivery*	*Distributor Storage with Last-Mile Delivery*	*Manufacturer Storage with Pickup*
High-demand product	+2	−2	−1	0	+1	−1
Medium-demand product	+1	−1	0	+1	0	0
Low-demand product	−1	+1	0	+1	−1	+1
Very low-demand product	−2	+2	+1	0	−2	+1
Many product sources	+1	−1	−1	+2	+1	0
High product value	−1	+2	+1	+1	0	+12
Quick desired response	+2	−2	−2	−1	+1	−2
High product variety	−1	+2	0	+1	0	+2
Low customer effort	−2	+1	+2	+2	+2	−1

Key: +2 = very suitable; +1 = somewhat suitable; 0 = neutral; −1 = somewhat unsuitable; −2 = very unsuitable.

suitability of different delivery designs (from a supply chain perspective) in various situations is shown in Table 4-8.

An excellent example of a hybrid network is that of W.W. Grainger, which combines all the aforementioned options in its distribution network. The network, however, is tailored to match the characteristics of the product and the needs of the customer. Fast-moving and emergency items are stocked locally, and customers can either pick them up or have them shipped, depending on the urgency. Slower-moving items are stocked at a national DC and shipped to the customer within a day or two. Very-slow-moving items are typically drop-shipped from the manufacturer and carry a longer lead time. Another hybrid network is used by Amazon, which stocks some items at its warehouses. Other slow-moving items may be drop-shipped from distributors or publishers.

We can now revisit the examples from the computer industry discussed at the beginning of the chapter. Gateway's decision to create a network of retail stores without exploiting any of the supply chain advantages such a network offers was flawed. To fully exploit the benefits of the retail network, Gateway should have stocked its standard configurations (likely to have high demand) at the retail stores, with all other configurations drop-shipped from the factory (perhaps with local pickup at the retail stores if it was economical). Instead, they drop-shipped all configurations from the factory. Apple has opened some retail stores and actually carries products for sale at these stores. This makes sense given the lower level of customization on most Apple products and the high demand for some of their products such as iPods. In fact, Apple has seen consistent growth in sales and profits through its retail outlets.

4.4 E-BUSINESS AND THE DISTRIBUTION NETWORK

In this section we use ideas discussed earlier in the chapter to see how the advent of e-business in the late 1990s affected the structure and performance of various distribution networks. The goal is to understand what drove the successful introduction of e-business in some networks and not others, and how these networks should evolve.

Similar to our consideration with distribution networks, we build a scorecard based on how e-business affects a supply chain's ability to meet customer needs and the cost of meeting those needs. We now detail the contents of each scorecard category.

IMPACT OF E-BUSINESS ON CUSTOMER SERVICE

As with distribution networks considered earlier, we start by studying how e-business affects customer service elements such as response time, product variety, availability, customer experience, time to market, visibility, and returnability. We also look at factors such as direct sales and the ability to offer flexible pricing that help e-business.

Response Time to Customers

In selling physical products that cannot be downloaded, an e-business without a physical retail outlet takes longer to fulfill a customer request than a retail store because of the shipping time involved. Thus, customers who require a short response time may not use the Internet to order a product. There is no such delay, however, for products that can be downloaded. Going online may offer a time advantage in many cases. For example, a mutual fund prospectus or music can be downloaded from the Web. A physical mailing of these products or even making a trip to a music store takes much longer.

Product Variety

An e-business finds it easier to offer a large selection of products than a bricks-and-mortar store. For example, Amazon.com offers a much larger selection of books than a typical bookstore. Offering the same selection at a retail store would require a huge location with a correspondingly large amount of inventory.

Product Availability

An e-business can greatly increase the speed with which information on customer demand is disseminated throughout the supply chain, giving rise to more accurate forecasts. These improved forecasts and the more accurate view of customer demand leads to a better match between supply and demand. On the inventory front, this translates into having more of the inventory that customers demand and less of the inventory they do not. An e-business also allows for aggregation of inventory that improves product availability.

Customer Experience

An e-business affects customer experience in terms of access, customization, and convenience. Unlike most retail stores that are open only during business hours, an e-business allows access to customers who may not be able to place orders during regular business hours. For example, a customer can place an order at Grainger.com even though the W.W. Grainger store where he will pick up his order is closed. In fact, W.W. Grainger has observed a surge in online orders after their bricks-and-mortar stores close. An e-business also allows a firm to access customers who are geographically distant. For example, a small specialty retail store located near Chicago can reach customers all over the United States, or even the world, by setting up an e-business. Without an e-business, only the customers located near the store are likely to shop there. Access to an e-business is limited only by the customers' access to the Internet.

The Internet offers an opportunity to create a personalized buying experience for each customer. For example, Amazon displays products that are related to what customers have recently purchased or browsed. Firms that focus on mass customization can use the Internet to help customers select a product that suits their needs. For example, Dell allows customers to customize their computers by using the options available on the Dell Web site.

For both consumers and companies, e-business can increase the ease with which one does business. For instance, customers have the convenience of not needing to leave home or work to make a purchase. An e-business can also help automate the

purchasing process, increasing the speed of conducting business as well as decreasing the costs of placing orders. For example, many e-businesses use data from past purchases to speed up the current purchase.

Faster Time to Market

A firm can use e-business to introduce new products much more quickly than a firm that uses physical channels. A firm that sells PCs through physical channels must produce enough units to stock the shelves at its distributors and retailers before it starts to see revenue from the new product. An e-business, in contrast, introduces a new product by making it available on the Web site—a distribution lag to fill the physical channels is not present. A new product can be made available as soon as the first unit is ready to be produced. This is evident in the computer industry, in which Dell often introduces new products earlier than its competitors that use traditional channels.

Order Visibility

The Internet makes it possible to provide visibility of order status. From a customer's perspective, it is crucial to provide this visibility because an online order has no physical equivalent to a customer shopping for an item at a retail store.

Returnability

Returnability is harder with online orders, which typically arrive from a centralized location. It is much easier to return a product purchased at a retail store. The proportion of returns is also likely to be much higher for online orders because customers are unable to touch and feel the product before their purchase. Going online thus increases the cost of reverse flows.

Direct Sales to Customers

An e-business allows manufacturers and other members of the supply chain that do not have direct contact with customers in traditional channels to enhance revenues by bypassing intermediaries and selling directly to customers, thereby collecting the intermediary's incremental revenue. For example, Dell sells PCs online direct to customers. As a result, Dell is able to increase revenue and enhance margins because it shares no part of the revenue with a distributor or retailer. In contrast, HP, which sells through retailers, must share some of the product revenue with the distributor and retailer, resulting in lower revenue and margins for HP.

Flexible Pricing, Product Portfolio, and Promotions

An e-business can easily alter prices by changing one entry in the database linked to its Web site. This ability allows an e-business to maximize revenues by setting prices based on current inventories and demand. The airlines provide a good example of this ability—they make last-minute, low-cost fares available on the Web on routes with unsold seats. Dell also changes prices for different PC configurations regularly, based on demand and component availability. Firms can change prices at an e-business much more easily than most traditional channels can. If Dell or L.L.Bean were to use paper catalogs to convey a discount in prices, they would have to print new catalogs and mail them to potential customers. With an e-business, however, they only have to update the price on their Web site. Similarly, an e-business can easily alter the product portfolio that it offers as well as the promotions it is running.

Efficient Funds Transfer

An e-business can enhance revenues by speeding up collection. An excellent example shows how e-business affects areas even outside the business world. Within 48 hours of John McCain's 2000 Presidential primary victory in New Hampshire, Senator

McCain's campaign collected $1 million through his Web site. In contrast, it would have taken much more time and effort to process all the payments if the campaign was receiving checks by mail.

IMPACT OF E-BUSINESS ON COST

On the cost side, e-business affects inventory, facilities, transportation, and information costs. It is important to observe that the impact in each case is not necessarily positive.

Inventory

An e-business can lower inventory levels and inventory cost by improving supply chain coordination and creating a better match between supply and demand. Additionally, e-business enables a firm to aggregate inventories far from customers if most customers are willing to wait for delivery of online orders. As a result of geographic aggregation, an e-business requires less inventory. For example, Amazon.com is able to aggregate its inventory of books and music at a few warehouses. Borders and Barnes&Noble, in contrast, need more inventory because they must carry a significant portion of their stock at retail stores. A key point to note is that the relative benefit of aggregation is small for high-demand items with low variability but large for low-demand items with high variability.

An e-business can significantly lower its inventories if it can postpone the introduction of variety until after the customer order is received. The time lag between when a customer places the order and when he expects delivery offers an e-business a window of opportunity to implement postponement. For example, Dell keeps its inventory as components and assembles its PCs after receiving the customer order. The amount of component inventory required is much lower than it would be if Dell kept its inventories in the form of assembled PCs. Its e-business thus allows Dell to hold less inventory relative to a firm carrying its inventory at retail stores in finished-goods form.

Facilities

Two basic types of facilities costs must be included in the analysis: costs related to the number and location of facilities in a network, and costs associated with the operations that take place in these facilities. An e-business can reduce network facility costs by centralizing operations, thereby decreasing the number of facilities required. For example, Amazon.com is able to satisfy demand from a few warehouses, whereas Borders and Barnes&Noble must incur facility costs for all the retail outlets they operate.

With regard to ongoing operating costs, customer participation in selection and order placement allows an e-business to lower its resource costs. For example, when a customer goes to the Lands' End Web site, she makes the effort to check on product availability and then place her order. When the same customer phones in an order, the firm incurs the additional cost of its employees checking product availability and placing the order. An e-business can lower its order fulfillment costs because it does not have to fill an order as soon as it arrives. A retail store or supermarket must staff its sales counters so that more cashiers are available when more customers are shopping. As a result, these stores require greater staffing during weekends and at times when people are not at work. At an e-business, if a reasonable buffer of unfilled orders is maintained, the rate of order fulfillment can be made significantly smoother than the rate at which orders arrive, which reduces the peak load for order fulfillment and thus reduces resource requirements and cost.

Additionally, operating costs can be decreased for a manufacturer using e-business to sell direct to customers because fewer supply chain stages touch the product as it makes its way to a customer, thereby reducing handling costs.

On the downside, however, for some products, such as groceries, an e-business has to perform tasks currently performed by the customer at retail stores, affecting both handling costs and transportation costs. In such situations, an e-business will incur higher handling and delivery costs than a retail store. For example, whereas a customer picks out the required items at a grocery store, an e-business such as Peapod incurs higher handling costs because its employees must pick a customer's order from the warehouse shelves and deliver it to the customer's home.

Transportation

If a firm can put its product in a form that can be downloaded, the Internet will allow it to save on the cost and time for delivery. For example, downloadable music and software offer an opportunity to eliminate all costs associated with transporting compact discs. For nondigital products, aggregating inventories increases outbound transportation relative to inbound transportation. Compared to a business with many retail outlets, an e-business with aggregated inventories tends to have higher transportation costs (across the entire supply chain) per unit because of the increased outbound costs.

Information

An e-business can share demand information throughout its supply chain to improve visibility. The Internet may also be used to share planning and forecasting information within the supply chain, further improving coordination. This helps reduce overall supply chain costs and better match supply and demand. Here we see that information is an enabler of many of the benefits of e-business discussed so far.

An e-business incurs additional information costs, however. The cost of software and hardware to set up an e-business can often be significant. These costs need to be weighed against the benefits that will be derived. Keep in mind that much of the information technology (IT) infrastructure for e-business may already be in place to operate the regular bricks-and-mortar business. This can greatly reduce the incremental cost needed for e-business.

The blank B2C e-business scorecard shown in Table 4-9 can be used by a firm to summarize the impact of e-business on each of the areas identified earlier.

The value of setting up an e-business is not the same in every industry. Whereas Dell has seen its profits increase after going online, Webvan and many other online

TABLE 4-9 The e-Business Scorecard

Area	*Impact*
Response time	
Product variety	
Product availability	
Customer experience	
Time to market	
Order visibility	
Direct sales	
Flexible pricing, portfolio, promotions	
Efficient funds transfer	
Inventory	
Facilities	
Transportation	
Information	

Key: +2 = very positive; +1 = positive; 0 = neutral; −1 = negative; −2 = very negative.

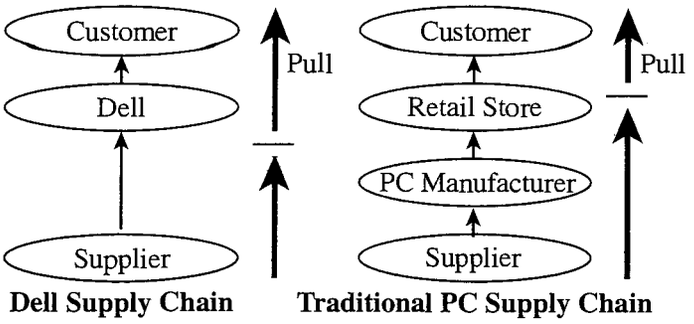


FIGURE 4-11 Supply Chains for Dell and a Traditional PC Manufacturer

grocers have gone out of business. The scorecard in Table 4-9 can be used to understand how e-business affects the performance of different supply chain networks. In the next section, we apply the e-business scorecard to several examples.

USING E-BUSINESS TO SELL PCs: DELL

The PC industry in general—and Dell in particular—has used e-business effectively to improve performance of supply chain networks. As shown in Figure 4-11, Dell sells PCs directly to customers, both companies and consumers, and starts assembly after receiving a customer order (shown by the fact that Dell is above the push/pull boundary). Traditional PC manufacturers, in contrast, assemble the PC in the push phase of the supply chain because they must maintain assembled products available for purchase at a retail store.

Impact of e-Business on Customer Service in the PC Industry

The main disadvantage for Dell of selling PCs over the Internet is that customers who are unwilling to wait five to 10 days to receive their order cannot be attracted. A PC, however, is usually a planned purchase; most people are willing to wait for its delivery. Dell also does not attract customers who need a lot of help when selecting a PC. However, the segment of people who are comfortable selecting their own PC and are willing to wait for its delivery is quite large and still growing. Dell and other PC manufacturers who sell over the Internet target this group of customers.

Dell is able to exploit most of the responsiveness-enhancing opportunities offered by an e-business. The company uses the Internet to offer a very wide variety of different PC configurations. Customers are allowed to select recommended PC configurations or customize them to have the desired processor, memory, hard drive, and other components. Customization allows Dell to satisfy customers by giving them a product that is close to their specific requirements. The customization options are very easy to display over the Internet, allowing Dell to attract customers who value this choice. Dell also uses customized Web pages to enable large business customers to place orders.

The Internet allows Dell to bring new products to market more quickly than competitors who sell through retail stores. This is particularly important because products in the PC industry have short life cycles of a few months. Competing firms that sell through distributors and retailers need to fill shelves at their distributors and retailers before a product reaches the customer. Dell, in contrast, introduces a new product to customers on the Internet as soon as the first PC of that model is ready to be assembled. As a result, Dell can offer new components in its products as soon as they are available. It takes PC manufacturers who sell through distributors and retailers much longer to bring new components to market.

Although the company cannot compete with a retailer in terms of response time for a PC the retailer has in stock, Dell is one of the fastest at providing customers with customized PCs. The company has designed its products and assembly process to assemble the customized PC after a customer order arrives. Without the direct interaction between the consumer and Dell that e-business affords, Dell's reaction would be slower, and the company could not be as responsive with customized products. Decreasing the response time by a few days allows Dell to attract more time-sensitive customers.

Dell also uses the price flexibility the Internet offers to increase revenues. The salespeople at Dell change prices and delivery time daily, based on demand and supply of components, in order to maximize the revenue that can be extracted from available resources. To spur sales, the company lowers prices on configurations that contain components with excess inventory.

By using the Internet to sell PCs directly to customers, Dell is able to eliminate distributor and retailer margins and increase its own margin. The Internet allows Dell customers to place orders at any time of the day. Relative to other channels, the Internet makes it much cheaper to provide access by decreasing the workforce required. Computer stores, for example, would find it very expensive to stay open all the time.

Having an e-business allows Dell to collect payment for its PCs in a matter of days after they are sold. Dell, however, pays its suppliers according to the more traditional schedules in which payment is due in weeks (e.g., 30 days). Given its low levels of inventory, Dell is able to operate its business with negative working capital because it receives payment for its PCs about 30 days before it pays its suppliers for their components. A PC supply chain including distributors and retailers cannot achieve these results.

Impact of e-Business on Cost in the PC Industry

Inventory Costs. Its e-Business offers Dell the ability to reduce its inventories by aggregating them in a few geographic locations, whereas a chain of retail stores selling computers must carry inventory in each store. Dell is able to further reduce inventories by exploiting the time that elapses from the point at which an online order arrives to the point at which it must be shipped. Dell products and assembly lines are designed so that all components on which customers are offered customization can be assembled in a very short period of time. This allows Dell to postpone assembly until after the customer order has been placed. As a result, Dell holds all inventories in the form of components that are common across multiple finished products. Postponement, coupled with component commonality, allows Dell to reduce inventories significantly.

A PC manufacturer that sells through distributors and retailers finds it difficult to implement postponement. As a result, traditional PC manufacturers often find that they are stuck with PC configurations that are not selling while simultaneously being out of the configurations that are selling. Dell, in contrast, is better able to match supply and demand.

Facility Costs. Its e-Business allows the Dell supply chain to lower facility costs because the company has no physical distribution or retail outlets. Dell incurs only the cost of the manufacturing facility and warehousing space for components. A PC supply chain selling through retail stores must pay for the distribution warehouses and retail stores as well.

Its e-Business also allows Dell to take advantage of customer participation in order placement and thus decrease processing costs at its facility. Dell saves on the cost of call center representatives because customers do all the work when they place an order online.

Transportation Costs. As a result of e-business, total transportation costs in the Dell supply chain are higher than in a supply chain selling PCs through distributors and retailers. Dell sends individual PCs to customers from its factories, whereas a manufacturer selling through distributors and retailers sends large shipments on trucks to warehouses and to retailers. The Dell supply chain thus has higher outbound transportation costs. Relative to the price of a high-end PC, however, the outbound transportation cost is low (typically 2 to 3 percent) and thus it does not have a major impact on the overall cost.

Information Costs. Although Dell has made a significant investment in information technology to implement its build-to-order model, these costs are more than made up for by the benefits discussed earlier. Additionally, the majority of these IT costs would be incurred regardless of Dell's e-business status. Therefore, e-business does add incrementally to Dell's information costs, but this is not a significant factor given the benefits.

Impact of e-Business on Performance at Dell

As summarized in the e-business scorecard in Table 4-10, e-business allows Dell to significantly improve its performance in terms of both responsiveness and cost. As a result, customers are happier while Dell is able to reduce costs. Dell, to the delight of its shareholders, has exploited every advantage that the Internet offers to improve performance.

A Supply Chain Network for PCs Using Retail Stores and the Internet

It may seem at first glance that all PC manufacturers should structure their networks as Dell does. A careful study, however, indicates that a traditional PC manufacturer, selling through distributors and retailers, can gain a lot by incorporating the Internet into its existing network. This issue becomes more significant as hardware becomes more of a commodity. The PC manufacturer should use an e-business to sell new products or customized PC configurations whose demand is hard to forecast and let the retail channel sell standard configurations whose demand is easier to forecast. Manufacturers should introduce new models on the Internet, and as demand for some of them grows, these models should be added to the retail channel. Another option is to

TABLE 4-10 Impact of e-Business on Performance at Dell

Area	*Impact*
Response time	−1
Product variety	+2
Product availability	+1
Customer experience	+2
Time to market	+2
Order visibility	+1
Direct sales	+2
Flexible pricing, portfolio, promotions	+2
Efficient funds transfer	+2
Inventory	+2
Facilities	+2
Transportation	−1
Information	0

Key: +2 = very positive; +1 = positive; 0 = neutral; −1 = negative; −2 = very negative.

introduce recommended configurations of new models at retail stores, while selling all customized configurations on the Internet. The manufacturer is thus able to decrease inventories by aggregating all high-variability production and satisfying that demand online. These models should be built to order using as many common components as is feasible. The standard models can be produced using a low-cost approach even if it involves longer lead time. Selling standardized models through distributors and retail stores allows the supply chain to save on transportation costs, which are likely to be more significant for these low-cost configurations. Retailers can be allowed to participate in the e-business by having kiosks where customers can configure models of their choice or order standardized models that are out of stock. It is important that traditional PC manufacturers give retailers a chance to participate in any e-business to avoid damaging existing channel relationships.

A traditional manufacturer can use the two-pronged approach outlined earlier to utilize both the strengths of e-business and those of traditional retail and distribution channels. Gateway failed in its effort with retail stores because it did not use any of the supply chain strengths of the bricks-and-mortar channel. Instead of just helping people with configuration at their retail stores, Gateway would have served its customers better by also carrying recommended configurations of their PCs in the stores. This would immediately satisfy customers who wanted the recommended configuration, while allowing Gateway to produce the more customized configurations efficiently.

USING E-BUSINESS TO SELL BOOKS: AMAZON

Book supply chains have been transformed with the advent of e-business and the launching of Amazon.com in July 1995. Since 1995, Amazon.com has added music, toys, electronics, software, and home improvement equipment to its product offerings. It is fair to state, however, that the growth in profitability that the Internet has brought to the book industry has been less than in the PC industry.

Impact of e-Business on Customer Service in the Book Industry

There are several reasons why e-business has not helped profits in the book industry to the same extent as in the PC industry. Unlike the PC industry, in which e-business facilitates direct sales by manufacturers, e-business has not shortened supply chains in the book industry.

As is the case with Dell, customers wanting a book quickly cannot shop at Amazon.com. Thus Amazon.com can only attract customers who are willing to wait a few days to get a book. Amazon.com also cannot attract customers who value the ability to leaf through books. The company tries to counter this problem by providing reviews and other information on books to allow customers to get a feel for the book online.

To counter these drawbacks, Amazon.com has exploited several opportunities on the Internet to attract customers and increase revenues. Amazon.com attracts many customers by offering a wide selection of millions of books. Customers can search for hard-to-find books or those of special interest. A large physical bookstore, in contrast, can carry fewer than a hundred thousand titles. Amazon.com also uses the Internet to recommend books to customers based on their purchase history. Customers are sent e-mails informing them of new titles that match their interests. Amazon.com also provides reviews and comments from other customers on the titles available. New titles are quickly introduced and made available online, whereas in a bricks-and-mortar bookstore chain, all retail stores have to be stocked.

Amazon.com uses the Internet to allow customers to order a book at any time from the comfort of their own home. If customers know the books they want, they can

place the order online and the books will be delivered to their door. There is no need to leave the house and spend an hour or two going to a physical bookstore. This fact allows Amazon.com to attract customers who value this convenience and are willing to wait for delivery.

Cost Impact of e-Business on the Book Industry

Amazon.com also uses e-business to lower its inventory and some of its facility costs. Transportation costs, however, increase as a result of selling books online.

Inventory Costs. Amazon.com is able to decrease inventories by aggregating inventories in a few geographical locations. A bookstore chain, in contrast, has higher inventories because titles are carried at every store. The reduction of inventories from aggregation is most significant for low-demand books with high demand uncertainty. The benefit is less significant for best-sellers with demand that is more predictable. Amazon.com carries high-demand titles in inventory, whereas it purchases low-demand titles from a distributor in response to a customer order. This allows the Amazon.com supply chain to further reduce inventories of low-demand titles because distributors are able to aggregate across other booksellers in addition to Amazon.

Facility Costs. Its e-business allows Amazon.com to lower facility costs because it does not need the retail infrastructure that a bookstore chain such as Borders or Barnes&Noble must have. Initially, Amazon.com did not have a warehouse, purchasing all books from distributors. When demand volumes were low, the distributor was a better location to carry inventories because it aggregated demand across other booksellers besides Amazon.com. As demand has grown, however, Amazon.com has opened its own warehouses, where it stocks high-demand books. Amazon.com now purchases high-demand books directly from publishers and goes to distributors for lower-demand books only. Thus, facility costs at Amazon.com are growing, though they are still much lower than the facility costs for a bookstore chain because Amazon.com has no retail sites.

Transportation Costs. The Amazon.com supply chain incurs higher transportation costs than a bookstore chain selling through retail stores. Local bookstores do not have the cost of individually shipping books to customers. Amazon.com, in contrast, incurs the cost of shipping books to its customers from warehouses. The shipping cost from an Amazon.com warehouse represents a significant fraction of the cost of a book (it can be even higher than 100 percent for an inexpensive book). As demand has grown, Amazon.com has opened several warehouses in an effort to get closer to customers, decrease its transportation costs, and improve response time.

Information Costs. As with Dell, setting up an e-business takes some additional investment in IT, but this is not incrementally significant compared with the IT that is required to run a bricks-and-mortar business. Therefore, IT costs for e-business are somewhat higher, but not prohibitively so.

Impact of e-Business on Performance at Amazon

Amazon's e-business scorecard is summarized in Table 4-11. A comparison of Tables 4-10 and 4-11 shows that e-business offers far greater advantages when selling PCs than when selling books. Some key differences between the two products are that (1) product differentiation in PCs can be postponed until after the customer has placed an order, whereas books are currently published well in advance of a sale; and (2) transportation cost represents a much higher portion of the cost of books and a relatively small portion of the cost of PCs. If books become downloadable, Amazon.com will be able to exploit all the advantages that Dell currently exploits, along with being able to

TABLE 4-11 Impact of e-Business on Performance at Amazon.com

Area	*Impact*
Response time	−1
Product variety	+2
Product availability	+1
Customer experience	+1
Time to market	+1
Order visibility	0
Direct sales	0
Flexible pricing, portfolio, promotions	+1
Efficient funds transfer	0
Inventory	+1
Facilities	+1
Transportation	−2
Information	−1

Key: +2 = very positive; +1 = positive; 0 = neutral; −1 = negative; −2 = very negative.

ship its products over the Internet. As a result, many of Amazon's current disadvantages would disappear.

Other potentially downloadable products that Amazon.com currently sells include software and music. In both instances, Amazon.com can increase the benefit of e-business if it either creates compact discs in response to a customer order or allows customers to download these products. For other products, such as toys and hand tools, limited possibilities exist for postponement. The advantages of e-business for Amazon.com in those product categories will continue to be small compared to physical retail outlets.

A Supply Chain Network for Books Using Retail Stores and the Internet

The performance of traditional bookstore supply chains can be improved significantly by combining the strengths of the retail and online channels. It is important to realize that the benefits of aggregation are most significant for low-demand books whose demand is hard to forecast. The book supply chains should be structured so that retail outlets carry many copies of best-sellers for customer purchase and one copy of low-demand books to encourage customers to browse and make impulse purchases. Terminals or Internet kiosks should be provided so that customers wanting to order low-demand books can place their orders online. The presence of kiosks increases the variety of books that the bookstore can offer. This approach allows the supply chain to reduce inventories by aggregating low-demand books sold online while keeping transportation costs low for best-sellers sold at retails stores.

USING E-BUSINESS TO SELL GROCERIES: PEAPOD

The grocery industry saw a spurt in new e-businesses in 1998 and 1999, although virtually all have gone out of business. Peapod, one of the oldest online grocers, is one of the few left. Given this industry's poor track record, one might surmise that this is an industry not well suited for e-business. Let us take a look with our scorecard to see whether this is the case.

Peapod started by supplying orders using employees at grocery stores to pick and deliver orders. The company has now moved to supplying orders from centralized fulfillment centers and also some large supermarkets. Each fulfillment center is much larger than a supermarket and is comparable to a warehouse. The Peapod and supermarket supply chains are comparable except that for a supermarket, some products come from a warehouse whereas the rest come directly from suppliers.

Impact of e-Business on Customer Service in the Grocery Industry

Peapod and other online groceries have tried to sell convenience and the time savings they offer customers. For many people, grocery shopping is a chore that is time consuming and rarely enjoyable. Peapod allows customers to place orders at any time and have them delivered at home, eliminating a trip to the supermarket. This can be a significant convenience, especially in urban areas, where customers have to walk to a supermarket and carry all their groceries home. In a suburban area, the benefit is smaller because people can drive to supermarkets with relative ease. The convenience of saving time, however, remains quite valuable.

The convenience factor related to access is even more significant if a specialty-food provider goes online. For example, ethnic food stores are not as accessible as supermarkets and people often drive long distances to reach them. Offering ethnic foods on the Internet provides easy access to customers and saves a long drive. Ethnicgrocer.com is an e-business that specializes in, as the name suggests, ethnic groceries and products. Peapod, however, does not offer significantly more variety than a typical supermarket. Most large supermarkets offer sufficiently large variety to cover the needs of most households.

Peapod is able to increase revenues by creating a personalized shopping experience for customers and delivering customized, one-to-one advertising and promotions. This is done using extensive member profiles that Peapod creates based on online shopping behavior, purchase histories, and surveys. Unlike a supermarket, where the store does not know what customers have selected until they check out, Peapod can guide online customers based on what they purchase. For example, if a customer buys some pasta, Peapod can suggest a type of pasta sauce or some Parmesan cheese. Over longer periods, Peapod can collect shopping patterns and suggest products that match a customer's preferences. Such suggestions enhance revenues by increasing customers' impulse purchases.

Peapod also adds to its revenues by giving consumer goods companies a forum for targeted interactive advertising and electronic coupons. Peapod increases revenues by selling data on consumer choices to product manufacturers. Consumer choice data available to an online grocer is more valuable than scanner data from a supermarket because scanner data only reveals the customer's final purchases. An online grocer, in contrast, can record the customer's decision process. For example, an online grocer can record a customer's substitution patterns for items that are out of stock. With scanner data, a supermarket cannot record substitutions because it has no way of finding out if the customer looked for something that is out of stock.

Impact of e-Business on Costs in the Grocery Industry

Peapod and other online grocers use e-business to lower some facility costs and, to an extent, inventory costs. Picking costs and transportation costs, however, are much higher than for traditional supermarkets.

Inventory Costs. Compared to a supermarket chain, an online grocer such as Peapod can lower inventories by aggregating the inventory in a few large replenishment centers. The degree of aggregation, however, is less than that achieved by

Amazon.com or Dell, because Peapod needs fulfillment centers in every urban area it serves to get food to customers in acceptable condition.

The benefits of aggregation are further diminished by the fact that the majority of products sold at a supermarket are staple items with steady demand. Thus, aggregation provides a marginal benefit in terms of improved forecast accuracy and reduced inventories (see Chapter 11). The benefits of aggregation are higher for specialty, low-demand items with high demand uncertainty. These products constitute a small fraction of overall sales at a supermarket. Thus, aggregation allows e-grocers to lower their inventory costs only marginally compared to a typical supermarket. If online grocers focused primarily on specialty items such as ethnic foods, the inventory benefits of aggregation would be larger.

Facility Costs. Peapod's e-business allows it to lower facility costs because it needs only warehouse facilities and can save on the cost of retail outlets such as supermarkets. Processing costs at Peapod to fulfill an order, however, are significantly higher than those for a supermarket, and overwhelm the savings from needing fewer facilities. Peapod saves on checkout clerks compared to a supermarket but must pick the customer order, a task the customer performs at a supermarket and one that is much more time consuming than checkout. Thus, e-business results in a loss of customer participation compared to a supermarket and raises overall facility costs.

Transportation. An online grocer such as Peapod has significantly higher transportation costs than a supermarket. Supermarkets have the advantage of having to bear only inbound transportation cost for products, with customers providing transportation from the supermarket to their homes. Inbound transportation costs tend to be low because supermarkets have large deliveries that enable them to exploit economies of scale in transportation. Peapod, in contrast, has to bear inbound transportation cost to its fulfillment centers and then outbound delivery costs from the fulfillment centers to customer homes. Outbound delivery costs are high, because individual orders must be delivered to each customer's home. The task becomes all the more problematic given the different temperature requirements for different types of food.

Compared to computers and even books, groceries have a low value-to-weight/volume ratio. For example, paper towels and bathroom tissues have very low value but occupy a lot of space in a truck. Thus, transportation costs are a significant fraction of the cost incurred by online grocers. This makes it very difficult for an online grocer to compete with a supermarket on prices.

Information Costs. Again, the IT infrastructure required for an e-business increases costs. In the case of an e-grocer, this is somewhat more significant than with the other e-businesses we have been discussing, because an e-grocer takes on a wider range of functions that shoppers do themselves. Therefore, IT costs are higher for an e-grocer. As in the other examples, however, IT costs are not a deal breaker for this business model.

Impact of e-Business on Performance at Peapod

An e-business offers some revenue-enhancement opportunities in the grocery industry. Costs, however, are significantly higher for an online grocer than for a supermarket, as we can see from Table 4-12. A comparison of Tables 4-10, 4-11, and 4-12 shows that e-business offers fewer benefits when selling groceries compared to books and PCs. Supermarkets are large enough to enjoy most of the inventory benefits that aggregation offers, without having the additional delivery cost incurred by an online grocer. Online grocers cannot compete with supermarkets on price, and can succeed only if

TABLE 4-12 Impact of e-Business on Performance at Peapod

Area	*Impact*
Response time	−1
Product variety	0
Product availability	0
Customer experience	+1
Time to market	0
Order visibility	−1
Direct sales	0
Flexible pricing, portfolio, promotions	+1
Efficient funds transfer	0
Inventory	0
Facilities	−1
Transportation	−2
Information	−1

Key: +2 = very positive; +1 = positive; 0 = neutral; −1 = negative; −2 = very negative.

there are enough people willing to pay a premium for the convenience of home delivery. Online grocers, however, can provide some cost advantage when selling specialty groceries, whose demand tends to be low and uncertain.

Value of e-Business to a Traditional Grocery Chain

Traditional supermarket chains can benefit by using an e-business to complement the strengths of their existing network. The e-business can be used to offer convenience to customers who are willing to pay for it. Supermarkets can be used to target customers who value lower prices.

A supermarket chain with an e-business has the opportunity to offer an entire array of services at differing prices based on the amount of work the customer does. The cheapest service involves customers walking into the supermarket and shopping for the products they want. In this case, the customer picks the order from the shelves and provides outbound transportation for it. For an additional charge, a supermarket might allow customers to place orders online to be picked up at a later time. The supermarket personnel would pick the order from the shelf, but the customer would provide outbound transportation. The most expensive service is when the customer places orders online for home delivery. In this case the supermarket chain is responsible for both picking the order from the shelf and delivering it to the customer's home. The varying services and prices would allow supermarket chains to efficiently satisfy the needs of a variety of customers.

Among the supermarket chains, Albertsons has taken the lead in combining e-business with physical supermarkets. It has renamed some of its stores Albertsons.com. Half the store remains a traditional supermarket, while the other half is used to fulfill online grocery orders. This allows the firm to exploit economies of scale on inbound transportation while keeping delivery distances to customers short on the outbound side. Customers are allowed to pick up their orders at the store or have the order delivered to their home. Based on our analysis, the Albertsons model is likely to be the most effective method for combining e-business with existing supermarkets in the grocery industry, whereas pure online grocers are likely to be less effective.

As we have mentioned earlier, the online channel is also more effective for specialty grocers. In fact, Amazon.com has set up a specialty grocery area on its Web site to go after this market.

USING E-BUSINESS TO SELL MRO SUPPLIES: GRAINGER.COM

W.W. Grainger is a B2B distributor of MRO supplies, selling more than 200,000 different products ranging from consumables such as machine lubricants to hardware items such as nuts and bolts. W.W. Grainger has traditionally sold its products using a paper catalog. Customers place orders on the phone or walk up to one of about 400 branches (similar to large retail stores) in the United States. Orders placed over the phone are either picked up at a branch or shipped to the customer using a package carrier. In 1995, W.W. Grainger established an e-business when it set up Grainger.com, allowing customers to place orders online. Such businesses have grown rapidly in the MRO supplies industry, with competitors such as McMaster-Carr having also built e-businesses.

Impact of e-business on Customer Service for W.W. Grainger

W.W. Grainger is in a position to exploit several opportunities offered by the Internet. Grainger.com gives a customer access to all the 220,000 products that W.W. Grainger sells, whereas the catalog offers only about 80,000 products. Compared to a catalog, searching for a product is simpler on the Internet using search engines that W.W. Grainger has developed. The increased variety allows W.W. Grainger to attract more customers and satisfy more needs of existing customers. The Internet allows W.W. Grainger to enhance revenues by introducing a new product as soon as it becomes available. With directmail marketing, W.W. Grainger had to wait for a new catalog to be shipped before customers were informed about new products. An e-business also allows W.W. Grainger to offer promotions and change prices easily without having to send out new catalogs.

Grainger.com allows customers to place orders and check their status at any time. This is a significant benefit to customers, who can use this ability to improve their MRO purchase process. For example, a customer's night-shift personnel can use the Internet to place and check on orders for supplies they need. They no longer have to wait for people from the day shift to place their order. This improves the accuracy of orders and reduces the time needed to process them. A study by the Aberdeen Group indicates that online purchases decrease the duration of the order and fulfillment cycle from an average of 7.3 days to an average of 2 days. The decreased order-fulfillment times allow W.W. Grainger to attract more orders through its e-business. A study by W.W. Grainger Consulting estimates that MRO distributors could see incremental sales gains of 10 to 20 percent by selling online.

Product margins, however, are likely to drop as a result of e-business in the MRO supply industry. With customers able to compare prices easily over the Internet, the growth in e-business has put pressure on MRO supply companies to lower price.

Impact of e-Business on Costs at W.W. Grainger

W.W. Grainger uses e-business to lower its order processing costs and to some extent its facility costs. Notably, W.W. Grainger customers also see a significant reduction in order processing costs as a result of e-business.

Inventory Costs. With an increase in Internet orders that are shipped by package carrier, W.W. Grainger is able to aggregate more of it's inventories, resulting in some inventory reduction. W.W. Grainger will achieve further inventory reduction if online sales grow large enough to enable the company to close some of its branches.

The inventory benefits, however, are likely to be small, because W.W. Grainger's existing supply chain network is well suited to online sales. Customers also save on inventory costs as a result of e-business because replenishment lead times over the Internet are lower than with traditional procurement methods.

Facility Costs. W.W. Grainger's facility costs will come down to some extent if more Internet sales are shipped using package carriers and some branches are closed. W.W. Grainger will see a bigger reduction in processing costs from online sales. Customers placing orders over the Internet perform all order placement activities. This allows W.W. Grainger to decrease the number of customer service representatives in its call centers.

Customers also save on order processing costs as a result of e-business. An e-business is a convenient way for corporations to place content-rich catalogs in the hands of end users of MRO supplies. As a result, companies no longer require people to process MRO purchase orders. An e-business offers many companies a quick and convenient chance to get away from inefficient manual methods of procurement. The Aberdeen Group estimates that online purchase of MRO supplies saves about $30 per order in administrative costs.

Transportation Costs. Transportation costs in the W.W. Grainger supply chain are unlikely to change significantly as a result of e-business. Transportation costs may increase if more Internet orders are shipped using package carriers rather than being picked up at branches. Overall, however, the costs are likely to remain unchanged, as the method of ordering should not have a large impact on how a customer wants an order delivered.

Information Costs. Information costs increase to fund the creation of the Grainger.com storefront, but beyond that there is little additional cost.

Impact of e-Business on Performance at W.W. Grainger. MRO distributors such as W.W. Grainger are likely to find e-business a somewhat attractive proposition, as summarized in Table 4-13. Most of the gains from e-business come from a

TABLE 4-13 Impact of e-Business on W.W. Grainger Performance

Area	*Impact*
Response time	0
Product variety	+2
Product availability	0
Customer experience	+1
Time to market	+1
Order visibility	+1
Direct sales	0
Flexible pricing, portfolio, promotions	+1
Efficient funds transfer	0
Inventory	0
Facilities	+1
Transportation	0
Information	−1

Key: +2 = very positive; +1 = positive; 0 = neutral; −1 = negative; −2 = very negative.

decrease in order taking and processing costs. Some gains are also achieved because of the ability to display a wider variety of products and increased customer convenience in product search. The structure of the MRO supply chain, however, is not significantly different for online orders compared to phone orders. Thus, gains from an improved supply chain structure are minimal.

4.5 DISTRIBUTION NETWORKS IN PRACTICE

1. ***The ownership structure of the distribution network can have as big an impact as the type of distribution network.*** The bulk of this chapter deals with different types of physical networks and subsequent flows to distribute products successfully. However, equally important is who owns each stage in the distribution network. Distribution networks that have exactly the same physical flow but different ownership structures can have vastly different performance. For example, a manufacturer that owns its distribution network can control the network's actions. However, if the manufacturer does not own the distribution network, as is more often the case, a wide variety of issues need to be taken into account to optimize over the network. Obviously, an independent distributor wants to optimize its own enterprise, not necessarily the entire supply chain. Attempting to optimize over a distribution network with multiple enterprises requires great skill in coordinating the incentives of each of the players and in creating the right relationships. Be sure to consider the impact of both the physical flows and the ownership structure when designing a distribution network.

2. ***The choice of a distribution network has very long-term consequences.*** The structure of the distribution network is one of the most difficult decisions to change. The impact often lasts for decades, amplifying the importance of the choice. For example, in the United States, auto manufacturers sell virtually all of their vehicles to consumers through a network of independent dealers set up decades ago. Because dealers are the interface between the consumer and the automotive supply chain, auto manufacturers are very interested in influencing dealers to ensure that this is a positive relationship. However, given that dealers are independent, they have a somewhat different set of goals that is not necessarily consistent with the manufacturers. Further complicating this is the fact that dealers often have relationships with more than one manufacturer and have successfully encouraged legislation that makes it very difficult for manufacturers to use any other distribution channel. Although automakers have tried to implement alternative distribution channels for several years, the dealers have kept the manufacturers captive, remaining the only channel through which cars are sold.

Another example of long-term consequences is seen within the PC industry. In the early days, manufacturers sold through independent distributors and retailers. Dell's emergence was a clear example of how the direct model was often superior to the traditional model. Other PC manufacturers, such as HP, made forays into selling PCs directly. However, their existing distribution channels reacted quite negatively to this—as you might expect, given that it would cannibalize their business. Because distributors often sold other companies' PCs, manufacturers were hesitant to promote their direct efforts aggressively, for fear of their distributors retaliating by promoting competitors' products. These PC manufacturers therefore ended up with minimal direct business. The manufacturers were essentially shackled by their legacy distribution network. The only way to go direct was a clean break—a move that was

just too costly given that their distributors owned the relationship with their customers. These examples illustrate the long-term implications of choosing the right distribution network.

3. ***Consider whether an exclusive distribution strategy is advantageous.*** Another important choice is whether to distribute exclusively or not. For instance, a manufacturer of consumer electronics such as Sony could choose to have relationships with many distributors such as Best Buy, Circuit City, and Wal-Mart. In this case, Sony would be interested in increasing the availability of its products to customers and would certainly not mind if its distributors competed with each other to sell Sony products to customers. An alternative, which is more plausible for a manufacturer of very-high-end stereo equipment, is to form an exclusive relationship with a distributor. In this case, customers can buy this brand's products only from a single retailer. The retailer can garner higher margins, as it doesn't have to battle over price with a nearby store. But what's in it for the manufacturer? The manufacturer can often increase its sales significantly, because its exclusive distributor will be much more interested in marketing the manufacturer's goods, as there is a higher margin and less competition.

4. ***Product price, commoditization, and criticality affect the type of distribution system preferred by customers.*** Interactions between a buyer and a seller take time and resources. Many buyers would like to establish a relationship with a single enterprise that can deliver a full line of products. This can be accomplished by a manufacturer with a broad line of products. However, this is often accomplished more effectively by a distributor carrying products from many manufacturers. A customer's desire for a one-stop shop depends not just on the convenience of the relationship, but also on the type of product he or she is buying. The more differentiated an item is, the more likely that a customer will be willing to have a relationship solely around that particular product.

For example, a consumer may well be content to buy a PC directly from a manufacturer. However, very few consumers are willing to order pens direct from a pen manufacturer, paper directly from a paper manufacturer, and staples directly from a staple manufacturer. Most consumers much prefer a stationary store that carries a very wide range of different manufacturers' products. Even if a pen manufacturer could economically deliver individual pens to customers' homes, the hassle for the consumer of dealing with different entities for each type of office product would be prohibitive.

5. ***Integrate the Internet with the existing physical network.*** To extract maximum benefit from e-business, firms should integrate it with their existing supply chain networks. Separating the two networks often results in inefficiencies within the supply chain. This coupling of e-business with the existing physical network has been referred to as clicks-and-mortar.

Alberstons use of its physical assets to satisfy both online orders and people who want to shop in a supermarket is an effective integration of e-business within a supply chain network. Another example of an effective clicks-and-mortar strategy is The Gap, which allows customers to place online orders through computers placed in the stores and also return items purchased online at retail stores. The Internet is used to expand the variety available to customers at a Gap store. Gap stores stock popular items, whereas customers can order online the colors or sizes that may not be available in the store. This allows the Gap to centralize low-demand items while increasing the variety available to customers and extracting the maximum benefit from integrating its e-business with its physical network.

4.6 SUMMARY OF LEARNING OBJECTIVES

1. Identify factors to be considered when designing the distribution network.

   A manager must consider the customer needs to be met and the cost of meeting these needs when designing the distribution network. Some key customer needs to be considered include response time, product variety/availability, convenience, order visibility, and returnability. Important costs that managers must consider include inventories, transportation, facilities and handling, and information. Increasing the number of facilities decreases the response time and transportation cost but increases inventory and facility cost.
2. Discuss the strengths and weaknesses of various distribution options.

   Distribution networks that ship directly to the customer are better suited for a large variety of high-value products that have low and uncertain demand. These networks carry low levels of inventory but incur high transportation cost and provide a slow response time. Distribution networks that carry local inventory are suitable for products with high demand, especially if transportation is a large fraction of total cost. These networks incur higher inventory cost but lower transportation cost and provide a faster response time.
3. Understand how e-business has affected the design of distribution networks in various industries.

   The rise of e-businesses has affected both customer service and costs in supply chains. An e-business allows a firm to offer greater product variety and improve product availability by centralizing inventories. This is especially beneficial for low-volume, high-variety products. An e-business also improves the customer experience by providing 24-hour access and allowing a more customized experience. Selling a product online, however, increases the response time relative to a retail store. An e-business reduces facility costs if there is no significant loss of customer participation. Transportation costs increase, however, and this is particularly significant for low-value products with predictable demand. An e-business has been most effective for high-value products with uncertain demand, when customers are willing to wait some time before delivery.

Discussion Questions

1. What differences in the retail environment may justify the fact that the fast-moving consumer goods supply chain in India has far more distributors than in the United States?
2. A specialty chemical company is considering expanding its operations into Brazil, where five companies dominate the consumption of specialty chemicals. What sort of distribution network should this company utilize?
3. A distributor has heard that one of the major manufacturers from which it buys is considering going direct to the consumer. What can the distributor do about this? What advantages can it offer the manufacturer that the manufacturer is unlikely to be able to reproduce?
4. What types of distribution networks are typically best suited for commodity items?
5. What type of networks are best suited to highly differentiated products?
6. In the future, do you see the value added by distributors decreasing, increasing, or staying about the same?
7. Why has e-business been more successful in the PC industry compared to the grocery industry? In the future, how valuable is e-business likely to be in the PC industry?
8. Is e-business likely to be more beneficial in the early part or the mature part of a product's life cycle? Why?
9. Consider the sale of home improvement products at Home Depot or a chain of hardware stores such as Tru-Value. Who can extract the greatest benefit from going online? Why?
10. Amazon.com sells books, music, electronics, software, toys, and home improvement products online. In which product category does e-business offer the greatest advantage compared to

a retail store chain? In which product category does e-business offer the smallest advantage (or a potential cost disadvantage) compared to a retail store chain? Why?

11. Why should an e-business such as Amazon.com build more warehouses as its sales volume grows?

Bibliography

Business Trade & Technology Strategies, The Forrester Report (August 1998).

Chopra, Sunil. "Designing the Delivery Network for a Supply Chain." *Transportation Research, Part E* (2003): 39: 123–40.

Chopra, Sunil, and Jan Van Mieghem. "Which e-Business Is Right for Your Supply Chain?" *Supply Chain Management Review* (July–August 2000): 32–40.

Evans, Philip, and Thomas S. Wurster. "Getting Real About Virtual Commerce." *Harvard Business Review* (November–December 1999): 84–94.

Hanson, Ward. *Principles of Internet Marketing.* Cincinnati, OH: South-West College Publishing, 2000.

Lee, Hau L., and Seungjin Whang. " Winning the Last Mile of e-Commerce." *Sloan Management Review* (Summer 2001): 54–62.

Mastering Commerce Logistics, The Forrester Report (August 1999).

Poirier, Charles C. "The Convergence of Business & Technology." *Supply Chain Management Review* (Fall 1999): 52–8.

Raman, Ananth, and Bharat P. Rao. *A Tale of Two Electronic Component Suppliers.* Harvard Business School Case 9–697–064, 1997.

Retail's Growth Spiral, The Forrester Report (November 1998).

Ricker, Fred R., and Ravi Kalakota. "Order Fulfillment: The Hidden Key to e-Commerce Success." *Supply Chain Management Review* (Fall 1999): 60–70.

Salcedo, Simon, and Ann Grackin. "The e-Value Chain." *Supply Chain Management Review* (Winter 2000): 63–70.

Willcocks, Leslie P., and Robert Plant. "Pathways to e-Business Leadership: Getting from Bricks to Clicks." *Sloan Management Review* (Spring 2001): 50–9.

Shapiro, Carl, and Hal R. Varian. *Information Rules: A Strategic Guide to the Network Economy.* Boston: Harvard Business School Press, 1999.

"The e-Enabled Supply Chain." Global Supplement, *Supply Chain Management Review* (Fall 1999).

Turban, Efraim, Jae Lee, David King, and H. Michael Chung. *Electronic Commerce: A Managerial Perspective.* Upper Saddle River, NJ: Prentice Hall, 2000.

CHAPTER 5
NETWORK DESIGN IN THE SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of network design in a supply chain.
2. Identify factors influencing supply chain network design decisions.
3. Develop a framework for making network design decisions.
4. Use optimization for facility location and capacity allocation decisions.

In this chapter, we start with the broad supply chain design discussed in Chapter 4 and provide an understanding of the role of network design within a supply chain. After assigning the role of each facility as discussed in Chapter 4 and the beginning of this chapter, we focus on the fundamental questions of facility location, capacity allocation, and market allocation within a supply chain network. We identify and discuss the various factors that influence the facility location, capacity, and market allocation decisions. We then establish a framework and discuss various solution methodologies for network design decisions in a supply chain.

5.1 THE ROLE OF NETWORK DESIGN IN THE SUPPLY CHAIN

Supply chain *network design decisions* include the assignment of facility role, location of manufacturing, storage, or transportation-related facilities, and the allocation of capacity and markets to each facility. Supply chain network design decisions are classified as follows.

1. ***Facility role:*** What role should each facility play? What processes are performed at each facility?
2. ***Facility location:*** Where should facilities be located?
3. ***Capacity allocation:*** How much capacity should be allocated to each facility?
4. ***Market and supply allocation:*** What markets should each facility serve? Which supply sources should feed each facility?

Network design decisions have a significant impact on performance because they determine the supply chain configuration and set constraints within which the other supply chain drivers can be used either to decrease supply chain cost or to increase responsiveness. All network design decisions affect each other and must be made taking this fact into consideration. Decisions concerning the role of each facility are significant because they determine the amount of flexibility the supply chain has in changing the way it meets demand. For example, Toyota has plants located

worldwide in each market that it serves. Before 1997, each plant was capable of serving only its local market. This hurt Toyota when the Asian economy went into a recession in the late 1990s. The local plants in Asia had idle capacity that could not be used to serve other markets that were experiencing excess demand. Toyota has added flexibility to each plant to be able to serve markets other than the local one. This additional flexibility helps Toyota deal more effectively with changing global market conditions.

Facility location decisions have a long-term impact on a supply chain's performance because it is very expensive to shut down a facility or move it to a different location. A good location decision can help a supply chain be responsive while keeping its costs low. Toyota, for example, built its first U.S. assembly plant in Lexington, Kentucky, in 1988 and has used the plant since then. The Lexington plant proved very profitable for Toyota when the yen strengthened and cars produced in Japan were too expensive to be cost competitive with cars produced in the United States. The Lexington plant allowed Toyota to be responsive to the U.S. market while keeping costs low.

In contrast, a poorly located facility makes it very difficult for a supply chain to perform close to the efficient frontier. For example, Amazon.com found it very difficult to be cost effective in supplying books throughout the United States when it had a single warehouse in Seattle. As a result, the company has added warehouses in other parts of the country.

Capacity allocation decisions also have a significant impact on supply chain performance. Whereas capacity allocation can be altered more easily than location, capacity decisions do tend to stay in place for several years. Allocating too much capacity to a location results in poor utilization, and as a result, higher costs. Allocating too little capacity results in poor responsiveness if demand is not satisfied, or high cost if demand is filled from a distant facility.

The allocation of supply sources and markets to facilities has a significant impact on performance because it affects total production, inventory, and transportation costs incurred by the supply chain to satisfy customer demand. This decision should be reconsidered on a regular basis so that the allocation can be changed as market conditions or plant capacities change. Of course, the allocation of markets and supply sources can only be changed if the facilities are flexible enough to serve different markets and receive supply from different sources. As we mentioned earlier, Amazon.com has built new warehouses and changed the markets supplied by each warehouse as its customer base has grown. As a result, it has lowered costs and improved responsiveness.

Network design decisions must be revisited as a firm grows or when two companies merge. Because of the redundancies and differences in markets served by either of the two separate firms, consolidating some facilities and changing the location and role of others can often help reduce cost and improve responsiveness.

We focus on developing a framework as well as methodologies that can be used for network design in a supply chain. In the next section, we identify various factors that influence network design decisions.

5.2 FACTORS INFLUENCING NETWORK DESIGN DECISIONS

In this section we examine a wide variety of factors that influence network design decisions in supply chains.

STRATEGIC FACTORS

A firm's competitive strategy has a significant impact on network design decisions within the supply chain. Firms that focus on cost leadership tend to find the lowest-cost location for their manufacturing facilities, even if that means locating very far from the markets they serve. For example, in the early 1980s, many apparel producers moved all their manufacturing out of the United States to countries with lower labor costs, in hope of lowering costs. With the drop in apparel quotas in 2005, most of the manufacturing is now moving to low-cost countries such as China.

Firms that focus on responsiveness tend to locate facilities closer to the market and may select a high-cost location if this choice allows the firm to react quickly to changing market needs. Zara, the Spanish apparel manufacturer, has a large fraction of its production capacity in Portugal and Spain despite the higher cost there. The local capacity allows the company to respond quickly to changing fashion trends in Europe. Its responsiveness to changing fashion trends has allowed Zara to become one of the fastest-growing apparel retailers in the world.

Convenience store chains aim to provide easy access to customers as part of their competitive strategy. Convenience store networks thus include many stores that cover an area, with each store being relatively small. In contrast, discount stores such as Sam's Club use a competitive strategy that focuses on providing low prices. Thus, their networks have very large stores and customers often have to travel many miles to get to one. The geographic area covered by one Sam's Club store may include dozens of convenience stores.

Global supply chain networks can best support their strategic objectives with facilities in different countries playing different roles. For example, Nike has production facilities located in many Asian countries. Its facilities in China and Indonesia focus on cost and produce mass-market lower-priced shoes for Nike. In contrast, facilities in Korea and Taiwan focus on responsiveness and produce higher-priced new designs. This differentiation allows Nike to satisfy a wide variety of demands in the most profitable manner.

It is important for a firm to identify the mission or strategic role of each facility when designing its global network. Kasra Ferdows (1997) suggests the following classification of possible strategic roles for various facilities in a global supply chain network.

1. ***Offshore facility: low-cost facility for export production.*** An offshore facility serves the role of being a low-cost supply source for markets located outside the country where the facility is located. The location selected for an offshore facility should have low labor and other costs to facilitate low-cost production. Given that many Asian developing countries waive import tariffs if all the output from a factory is exported, they are preferred sites for offshore manufacturing facilities.

2. ***Source facility: low-cost facility for global production.*** A source facility also has low cost as its primary objective, but its strategic role is broader than that of an offshore facility. A source facility is often a primary source of product for the entire global network. Source facilities tend to be located in places where production costs are relatively low, infrastructure is well developed, and a skilled workforce is available. Good offshore facilities migrate over time into source facilities. Many Chinese and Indian apparel manufacturers are attempting to transform into source facilities since the drop in apparel quotas in 2005.

3. ***Server facility: regional production facility.*** A server facility's objective is to supply the market where it is located. A server facility is built because of tax incentives, local content requirement, tariff barriers, or high logistics cost to supply the region from

elsewhere. In the late 1970s, Suzuki partnered with the Indian government to set up Maruti Udyog. Initially, Maruti was set up as a server facility and produced cars only for the Indian market. The Maruti facility allowed Suzuki to overcome the high tariffs on imported cars in India.

4. ***Contributor facility: regional production facility with development skills.*** A contributor facility serves the market where it is located but also assumes responsibility for product customization, process improvements, product modifications, or product development. Most well-managed server facilities become contributor facilities over time. The Maruti facility in India today develops many new products for both the Indian and the overseas markets and has moved from being a server to a contributor facility in the Suzuki network.

5. ***Outpost facility: regional production facility built to gain local skills.*** An outpost facility is located primarily to obtain access to knowledge or skills that may exist within a certain region. Given its location, it also plays the role of a server facility. The primary objective remains one of being a source of knowledge and skills for the entire network. Many global firms have set up outpost production facilities in Japan despite the high operating costs.

6. ***Lead facility: facility that leads in development and process technologies.*** A lead facility creates new products, processes, and technologies for the entire network. Lead facilities are located in areas with good access to a skilled workforce and technological resources.

TECHNOLOGICAL FACTORS

Characteristics of available production technologies have a significant impact on network design decisions. If production technology displays significant economies of scale, a few high-capacity locations are most effective. This is the case in the manufacture of computer chips, for which factories require a very large investment. As a result, most semiconductor companies build few high-capacity facilities.

In contrast, if facilities have lower fixed costs, many local facilities are preferred because this helps lower transportation costs. For example, bottling plants for Coca-Cola do not have a very high fixed cost. To reduce transportation costs, Coca-Cola sets up many bottling plants all over the world, each serving its local market.

Flexibility of the production technology affects the degree of consolidation that can be achieved in the network. If the production technology is very inflexible and product requirements vary from one country to another, a firm has to set up local facilities to serve the market in each country. Conversely, if the technology is flexible, it becomes easier to consolidate manufacturing in a few large facilities.

MACROECONOMIC FACTORS

Macroeconomic factors include taxes, tariffs, exchange rates, and other economic factors that are not internal to an individual firm. As global trade has increased, macroeconomic factors have had a significant influence on the success or failure of supply chain networks. Thus, it is imperative that firms take these factors into account when making network design decisions.

Tariffs and Tax Incentives

Tariffs refer to any duties that must be paid when products and/or equipment are moved across international, state, or city boundaries. Tariffs have a strong influence on location decisions within a supply chain. If a country has very high tariffs, companies either do not

serve the local market or set up manufacturing plants within the country to save on duties. High tariffs lead to more production locations within a supply chain network, with each location having a lower allocated capacity. As tariffs have come down with the World Trade Organization, and regional agreements such as NAFTA (North America), the European Union, and MERCOSUR (South America), firms can now supply the market within a country from a plant located outside that country without incurring high duties. As a result, firms have begun to consolidate their global production and distribution facilities. For global firms, a decrease in tariffs has led to a decrease in the number of manufacturing facilities and an increase in the capacity of each facility built.

Tax incentives are a reduction in tariffs or taxes that countries, states, and cities often provide to encourage firms to locate their facilities in specific areas. Many countries vary incentives from city to city to encourage investments in areas with lower economic development. Such incentives are often a key factor in the final location decision for many plants. General Motors built its Saturn facility in Tennessee primarily because of the tax incentives offered by the state. Similarly, BMW built its U.S. factory in Spartanburg, South Carolina, mainly because of the tax incentives offered by that state.

Developing countries often create *free trade zones* in which duties and tariffs are relaxed as long as production is used primarily for export. This creates a strong incentive for global firms to set up plants in these countries to be able to exploit their low labor costs. In China, for example, the establishment of a free trade zone near GuangZhou led to many global firms locating facilities there in the 1990s.

A large number of developing countries also provide additional tax incentives based on training, meals, transportation, and other facilities offered to the workforce. Tariffs may also vary based on the product's level of technology. China, for example, waives tariffs entirely for "high-tech" products, in an effort to encourage companies to locate there and bring in state-of-the-art technology. Motorola located a large chip manufacturing plant in China to take advantage of the reduced tariffs and other incentives available to high-tech products.

Many countries also place minimum requirements on local content and limits on imports. Such policies lead companies to set up many facilities and source from local suppliers. For example, until 2004, the United States limited the import of apparel from various countries. As a result, companies developed suppliers in many countries to avoid reaching the limit from any one country. The end of quotas in 2005 has led to some consolidation of apparel manufacturing in China, India, and a handful of other countries.

Exchange Rate and Demand Risk

Fluctuations in exchange rates are common and have a significant impact on the profits of any supply chain serving global markets. For example, the dollar fluctuated between 102 and 132 yen in the three years from 2002 to 2004. A firm that sells its product in the United States with production in Japan is exposed to the risk of appreciation of the yen. The cost of production is incurred in yen, whereas revenues are obtained in dollars. Thus, an increase in the value of the yen increases the production cost in dollars, decreasing the firm's profits. In the 1980s, many Japanese manufacturers faced this problem when the yen appreciated in value because most of their production capacity was located in Japan. The appreciation of the yen decreased their revenues (in terms of yen) from large overseas markets and they saw their profits decline. Most Japanese manufacturers have responded by building production facilities all over the world.

Exchange rate risks may be handled using financial instruments that limit, or hedge against, the loss due to fluctuations. Suitably designed supply chain networks, however, offer the opportunity to take advantage of exchange-rate fluctuations and increase profits. An effective way to do this is to build some overcapacity into the

network and make the capacity flexible so that it can be used to supply different markets. This flexibility allows the firm to react to exchange-rate fluctuations by altering production flows within the supply chain to maximize profits.

Companies must also take into account fluctuations in demand caused by changes in the economies of different countries. For example, firms with little production flexibility experienced unutilized capacity in their Asian plants when Asian economies slowed down between 1996 and 1998. Firms with greater flexibility in their manufacturing facilities were able to use the extra capacity in their Asian plants to meet the needs of other countries where demand was high. As mentioned earlier in the chapter, in 1997 Toyota had assembly plants in Asia that were only capable of producing for the local market. The Asian financial crisis motivated Toyota to make the plants more flexible to be able to supply demand from other countries.

When designing supply chain networks, companies must build appropriate flexibility to help counter fluctuations in exchange rates and demand across different countries.

POLITICAL FACTORS

The political stability of the country under consideration plays a significant role in location choice. Companies prefer to locate facilities in politically stable countries where the rules of commerce and ownership are well defined. Countries with independent and clear legal systems allow firms to feel that they have recourse in the courts should they need it. This makes it easier for companies to invest in facilities in these countries. As with any factor that is hard to quantify, a firm makes a subjective evaluation of this factor when designing its supply chain network.

INFRASTRUCTURE FACTORS

The availability of good infrastructure is an important prerequisite to locating a facility in a given area. Poor infrastructure adds to the cost of doing business from a given location. Global companies have located their factories in China near Shanghai, Tianjin, or GuangZhuo—even though these locations do not have the lowest labor or land costs—because there is good infrastructure at these locations. Key infrastructure elements to be considered during network design include availability of sites, labor availability, proximity to transportation terminals, rail service, proximity to airports and seaports, highway access, congestion, and local utilities.

COMPETITIVE FACTORS

Companies must consider competitors' strategy, size, and location when designing their supply chain networks. A fundamental decision firms make is whether to locate their facilities close to competitors or far from them. The form of competition and factors such as raw material or labor availability influence this decision.

Positive Externalities Between Firms

Positive externalities are instances where the collocation of multiple firms benefits all of them. Positive externalities lead to competitors locating close to each other. For example, gas stations and retail stores tend to locate close to each other because doing so increases the overall demand, thus benefiting all parties. By locating together in a mall, competing retail stores make it more convenient for customers, who need only drive to one location to find everything they are looking for. This increases the total number of customers who visit the mall, increasing demand for all stores located there.

Another example of positive externality is when the presence of a competitor leads to the development of appropriate infrastructure in a developing area. In India,

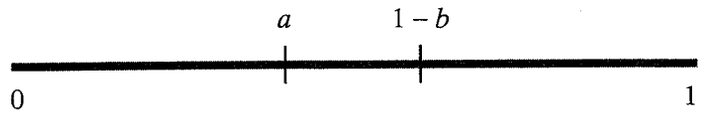


FIGURE 5-1 Two Firms Locating on a Line

for example, Suzuki was the first foreign auto manufacturer to set up a manufacturing facility. The company went to considerable effort and built a local supplier network. Given the well-established supplier base in India, Suzuki's competitors have also built assembly plants there, because they now find it more effective to build cars in India rather than import them to the country.

Locating to Split the Market

When there are no positive externalities, firms locate to be able to capture the largest possible share of the market. A simple model first proposed by Hotelling explains the issues behind this decision.[1]

When firms do not control price but compete on distance from the customer, they can maximize market share by locating close to each other and splitting the market. Consider a situation in which customers are uniformly located along the line segment between 0 and 1 and two firms compete based on their distance from the customer as shown in Figure 5-1. A customer goes to the closest firm and customers that are equidistant from the two firms are evenly split between them.

If total demand is 1, Firm 1 locates at point a, and Firm 2 locates at point $1 - b$, the demand at the two firms, d_1 and d_2, is given by

$$d_1 = a + \frac{1 - b - a}{2} \quad \text{and} \quad d_2 = \frac{1 + b - a}{2}$$

Both firms maximize their market share if they move closer to each other and locate at $a = b = 1/2$.

Observe that when both firms locate in the middle of the line segment, the average distance that customers have to travel is 1/4. If one firm locates at 1/4 and the other at 3/4, the average distance customers have to travel drops to 1/8. This set of locations, however, is not an equilibrium because it gives both firms an incentive to try and increase market share by moving to the middle. The result of competition is for both firms to locate close together even though doing so increases the average distance to the customer.

If the firms compete on price and incur the transportation cost to the customer, it may be optimal for the two firms to locate as far apart as possible,[2] with Firm 1 locating at 0 and Firm 2 locating at 1. Locating far from each other minimizes price competition and helps the firms split the market and maximize profits.

CUSTOMER RESPONSE TIME AND LOCAL PRESENCE

Firms that target customers who value a short response time must locate close to them. For example, customers are unlikely to come to a convenience store if they have to travel a long distance to get there. It is thus best for a convenience store chain to have many stores distributed in an area so that most people have a convenience store close to them. In contrast, customers shop for larger amounts of goods at supermarkets and

[1] Jean Tirole, *The Theory of Industrial Organization* (Cambridge, MA: The MIT Press, 1997:279).
[2] Ibid.

are willing to travel longer distances to get to one. Thus, supermarket chains tend to have stores that are larger than convenience stores and not as densely distributed. Most towns have fewer supermarkets than convenience stores. Discounters such as Sam's Club target customers who are even less time sensitive. These stores are even larger than supermarkets and there are fewer of them in an area. W.W. Grainger uses about 350 facilities all over the United States to provide same-day delivery of maintenance and repair supplies to many of its customers. McMaster-Carr, a competitor, targets customers who are willing to wait for next-day delivery. McMaster-Carr has only six facilities throughout the United States and is able to provide next-day delivery to a large number of customers.

If a firm is delivering its product to customers, use of a rapid means of transportation allows it to build fewer facilities and still provide a short response time. This option, however, increases transportation cost. Moreover, there are many situations in which the presence of a facility close to a customer is important. For example, a coffee shop is likely to attract customers who live or work nearby. No faster mode of transport can serve as a substitute and be used to attract customers that are far away from the coffee shop.

LOGISTICS AND FACILITY COSTS

Logistics and facility costs incurred within a supply chain change as the number of facilities, their location, and capacity allocation is changed. Companies must consider inventory, transportation, and facility costs when designing their supply chain networks.

Inventory and facility costs increase as the number of facilities in a supply chain increase. Transportation costs decrease as the number of facilities is increased. If the number of facilities increases to a point where inbound economies of scale are lost, then transportation cost increases. For example, with few facilities Amazon.com has lower inventory and facility costs than Borders, which has about 450 stores. Borders, however, has lower transportation costs.

The supply chain network design is also influenced by the transformation occurring at each facility. When there is a significant reduction in material weight or volume as a result of processing, it may be better to locate facilities closer to the supply source rather than the customer. For example, when iron ore is processed to make steel, the amount of output is a small fraction of the amount of ore used. Locating the steel factory close to the supply source is preferred because it reduces the distance that the large quantity of ore has to travel.

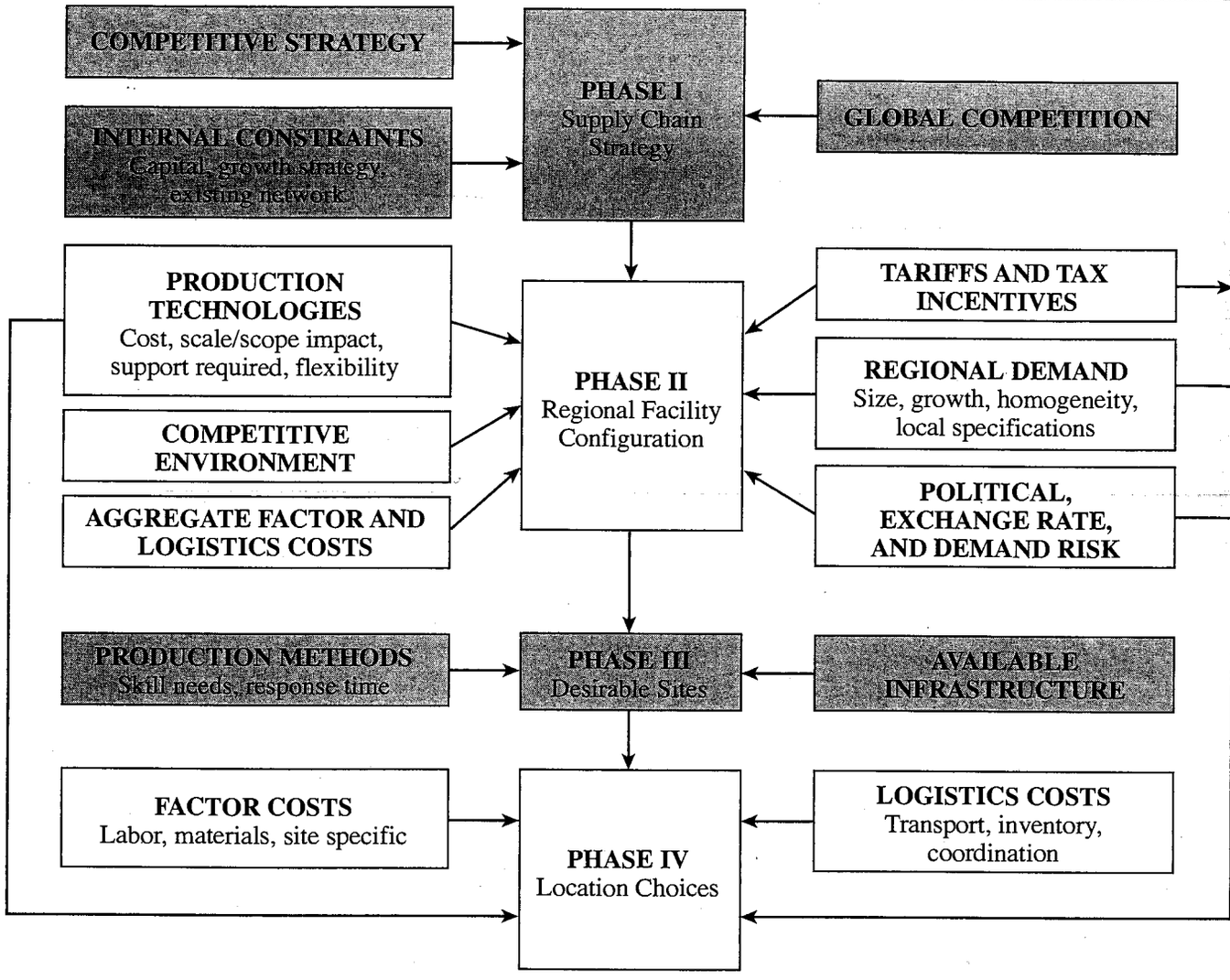
Total logistics costs are a sum of the inventory, transportation, and facility costs. The facilities in a supply chain network should at least equal the number that minimizes total logistics cost. A firm may increase the number of facilities beyond this point to improve the response time to its customers. This decision is justified if the revenue increase from improved response outweighs the increased cost from additional facilities.

In the next section we discuss a framework for making network design decisions.

5.3 FRAMEWORK FOR NETWORK DESIGN DECISIONS

The goal when designing a supply chain network is to maximize the firm's profits while satisfying customer needs in terms of demand and responsiveness. To design an effective network a manager must consider all the factors described in Section 5.2 as well as

FIGURE 5-2 Framework for Network Design Decisions



those discussed in Chapter 4. Global network design decisions are made in four phases as shown in Figure 5-2. We describe each phase in greater detail.

PHASE I: DEFINE A SUPPLY CHAIN STRATEGY/DESIGN

The objective of the first phase of network design is to define a firm's broad supply chain design. This includes determining the stages in the supply chain, and whether each supply chain function will be performed in-house or outsourced (see Chapter 4).

Phase I starts with a clear definition of the firm's competitive strategy as the set of customer needs that the supply chain aims to satisfy. The supply chain strategy then specifies what capabilities the supply chain network must have to support the competitive strategy (see Chapter 2). Next, managers must forecast the likely evolution of global competition and whether competitors in each market will be local or global players. Managers must also identify constraints on available capital and whether growth will be accomplished by acquiring existing facilities, building new facilities, or partnering.

Based on the competitive strategy of the firm, its resulting supply chain strategy, an analysis of the competition, any economies of scale or scope, and any constraints, managers must determine the supply chain design for the firm.

PHASE II: DEFINE THE REGIONAL FACILITY CONFIGURATION

The objective of the second phase of network design is to identify regions where facilities will be located, their potential roles, and their approximate capacity.

An analysis of Phase II starts with a forecast of the demand by country. Such a forecast must include a measure of the size of the demand as well as a determination of whether the customer requirements are homogenous or variable across different countries. Homogenous requirements favor large consolidated facilities, whereas requirements that vary across countries favor smaller, localized facilities.

The next step is for managers to identify whether economies of scale or scope can play a significant role in reducing costs, given available production technologies. If economies of scale or scope are significant, it may be better to have a few facilities serving many markets. For example, semiconductor manufacturers such as Advanced Micro Devices have very few plants for their global markets, given the economies of scale in production. If economies of scale or scope are not significant, it may be better for each market to have its own facility.

Next, managers must identify demand risk, exchange-rate risk, and political risk associated with different regional markets. They must also identify regional tariffs, any requirements for local production, tax incentives, and any export or import restrictions for each market. The tax and tariff information is used to identify the best location to extract a major share of the profits. In general, it is best to obtain the major share of profits at the location with the lowest tax rate.

Managers must identify competitors in each region and make a case for whether a facility needs to be located close to or far from a competitor's facility. The desired response time for each market and logistics costs at an aggregate level in each region must also be identified.

Based on all this information, managers identify the regional facility configuration for the supply chain network using network design models discussed in the next section. The regional configuration defines the approximate number of facilities in the network, regions where facilities will be set up, and whether a facility will produce all products for a given market or a few products for all markets in the network.

PHASE III: SELECT A SET OF DESIRABLE POTENTIAL SITES

The objective of Phase III is to select a set of desirable potential sites within each region where facilities are to be located. Sites should be selected based on an analysis of infrastructure availability to support the desired production methodologies. *Hard infrastructure requirements* include the availability of suppliers, transportation services, communication, utilities, and warehousing infrastructure. *Soft infrastructure requirements* include the availability of skilled workforce, workforce turnover, and the community receptivity to business and industry.

PHASE IV: LOCATION CHOICES

The objective of Phase IV is to select a precise location and capacity allocation for each facility. Attention is restricted to the desirable potential sites selected in Phase III. The network is designed to maximize total profits taking into account the expected margin and demand in each market, various logistics and facility costs, and the taxes and tariffs at each location.

In the next section we discuss methodologies for making facility location and capacity allocation decisions during Phases II to IV.

5.4 MODELS FOR FACILITY LOCATION AND CAPACITY ALLOCATION

A manager's goal when locating facilities and allocating capacity should be to maximize the overall profitability of the resulting supply chain network while providing customers with the appropriate responsiveness. Revenues come from the sale of product, whereas costs arise from facilities, labor, transportation, material, and inventories. The profits of the firm are also affected by taxes and tariffs. Ideally, profits after tariffs and taxes should be maximized when designing a supply chain network.

A manager must consider many trade-offs during network design. For example, building many facilities to serve local markets reduces transportation cost and provides a fast response time, but it increases the facility and inventory costs incurred by the firm.

Managers use network design models in two different situations. First, these models are used to decide on locations where facilities will be established and the capacity to be assigned to each facility. Managers must make this decision considering a time horizon over which locations and capacities will not be altered (typically in years). Second, these models are used to assign current demand to the available facilities and identify lanes along which product will be transported. Managers must consider this decision at least on an annual basis as demand, prices, exchange rates, and tariffs change. In both cases, the goal is to maximize the profit while satisfying customer needs. The following information ideally is available in making the design decision:

- Location of supply sources and markets
- Location of potential facility sites
- Demand forecast by market
- Facility, labor, and material costs by site
- Transportation costs between each pair of sites
- Inventory costs by site and as a function of quantity
- Sale price of product in different regions
- Taxes and tariffs
- Desired response time and other service factors

Given this information, either gravity models or network optimization models may be used to design the network. We organize the models according to the phase of the network design framework at which each model is likely to be useful.

PHASE II: NETWORK OPTIMIZATION MODELS

During Phase II of the network design framework (see Figure 5-2), a manager considers regional demand, tariffs, economies of scale, and aggregate factor costs to decide the regions in which facilities are to be located. As an example, consider SunOil, a manufacturer of petrochemical products with worldwide sales. The Vice President of Supply Chain can consider several different options to meet demand. One possibility is to set up a facility in each region. The advantage of such an approach is that it lowers transportation cost and also helps avoids duties that may be imposed if product is imported from other regions. The disadvantage of this approach is that plants are sized to meet local demand and may not fully exploit economies of scale. An alternative approach is to consolidate plants in just a few regions. This improves economies of scale but increases transportation

FIGURE 5-3 Cost and Demand Data for SunOil

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region*								
		Production and Transportation Cost per 1,000,000 Units					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				

cost and duties. During Phase II, the manager must consider these quantifiable trade-offs along with nonquantifiable factors such as the competitive environment and political risk.

Network optimization models are useful for managers considering regional configuration during Phase II. The first step is to collect the data in a form that can be used for a quantitative model. For SunOil, the Vice President of Supply Chain decides to view the worldwide demand in terms of five regions—North America, South America, Europe, Africa, and Asia. The data collected are shown in Figure 5-3.

Annual demand for each of the five regions is shown in cells B9:F9. Cells B4:F8 contain the variable production, inventory, and transportation cost (including tariffs and duties) of producing in one region to meet demand in each individual region. For example, as shown in cell C4, it costs $92,000 (including duties) to produce 1 million units in North America and sell them in South America. Observe that the data collected at this stage are at a fairly aggregate level.

There are fixed as well as variable costs associated with facilities, transportation, and inventories at each facility. Fixed costs are those that are incurred no matter how much is produced or shipped from a facility. Variable costs are those that are incurred in proportion to the quantity produced or shipped from a given facility. Facility, transportation, and inventory costs generally display economies of scale and the marginal cost decreases as the quantity produced at a facility increases. In the models we consider, however, all variable costs grow linearly with the quantity produced or shipped.

SunOil is considering two different plant sizes in each location. Low-capacity plants can produce 10 million units a year, whereas high-capacity plants can produce 20 million units a year, as shown in cells H4:H8 and J4:J8, respectively. High-capacity plants exhibit some economies of scale and have fixed costs that are less than twice the fixed cost of a low-capacity plant, as shown in cells I4:I8. All fixed costs are annualized. The vice president wants to know what the lowest cost network should look like. To answer this question, we next discuss the capacitated plant location model, which can be used in this setting.

The Capacitated Plant Location Model

The capacitated plant location network optimization model requires the following inputs:

n = number of potential plant locations/capacity (each level of capacity will count as a separate location)
m = number of markets or demand points
D_j = annual demand from market j
K_i = potential capacity of plant i
f_i = annualized fixed cost of keeping factory i open
c_{ij} = cost of producing and shipping one unit from factory i to market j (cost includes production, inventory, transportation, and tariffs)

The supply chain team's goal is to decide on a network design that maximizes profits after taxes. For the sake of simplicity, however, we assume that all demand must be met and taxes on earnings are ignored. The model thus focuses on minimizing the cost of meeting global demand. It can, however, be modified to include profits and taxes. Define the following decision variables:

$y_i = 1$ if plant i is open, 0 otherwise
x_{ij} = quantity shipped from plant i to market j

The problem is then formulated as the following integer program:

$$Min \quad \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = D_j \qquad \text{for} \qquad j = 1, \ldots, m \tag{5.1}$$

$$\sum_{j=1}^{m} x_{ij} \leq K_i y_i \qquad \text{for} \qquad i = 1, \ldots, n \tag{5.2}$$

$$y_i \in \{0, 1\} \qquad \text{for} \qquad i = 1, \ldots, n, x_{ij} \geq 0 \tag{5.3}$$

The objective function minimizes the total cost (fixed + variable) of setting up and operating the network. The constraint in Equation 5.1 requires that the demand at each regional market be satisfied. The constraint in Equation 5.2 states that no plant can supply more than its capacity. (Clearly, the capacity is 0 if the plant is closed and K_i if it is open. The product of terms, $K_i y_i$, captures this effect.) The constraint in Equation 5.3 enforces that each plant is either open ($y_i = 1$) or closed ($y_i = 0$). The solution identifies the plants that are to be kept open, their capacity, and the allocation of regional demand to these plants.

The model is solved using the Solver tool in Excel. Given the data, the next step in Excel is to identify cells corresponding to each decision variable as shown in Figure 5-4.

FIGURE 5-4 Spreadsheet Area for Decision Variables for SunOil

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region*								
		Production and Transportation Cost per 1,000,000 Units					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (1000 Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0	0	0	0	0	0	0		

Cells B14:F18 correspond to the decision variables x_{ij} and determine the amount produced in a supply region and shipped to a demand region. Cells G14:G18 contain the decision variables y_i corresponding to the low-capacity plants and cells H14:H18 contain the decision variables y_i corresponding to the high-capacity plants. Initially, all decision variables are set to be 0.

The next step is to construct cells for the constraints in Equations 5.1 and 5.2 and the objective function. The constraint cells and objective function are shown in Figure 5-5. Cells B22:B26 contain the capacity constraints in Equation 5.2 and cells B28:F28 contain the demand constraints in Equation 5.1. The objective function is shown in cell B31 and measures the total fixed cost plus the variable cost of operating the network.

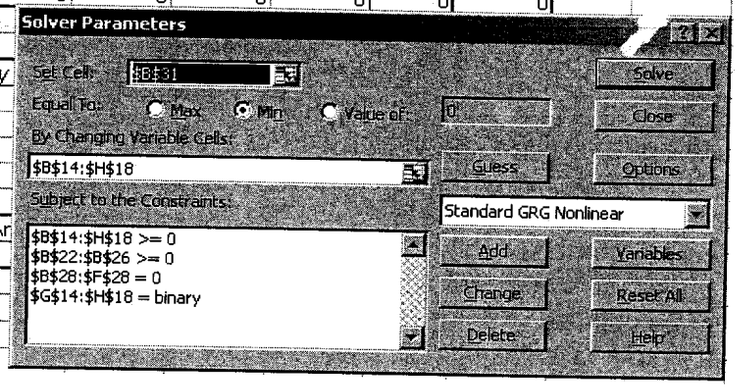
FIGURE 5-5 Spreadsheet Area for Constraints and Objective Function for SunOil

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region*								
3	*Supply Region*	*Production and Transportation Cost per 1,000,000 Units* N. America	S. America	Europe	Asia	Africa	**Fixed Cost ($)**	**Low Capacity**	**Fixed Cost ($)**	**High Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (1000 Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0	0	0	0	0	0	0		
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacity*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	0								
27		N. America	S. America	Europe	Asia	Africa				
28	*Unmet Demand*	12	8	14	16	7				
29										
30	***Objective Function***									
31	***Cost =***	$ -								

Cell	Cell Formula	Equation	Copied to
B28	=B9 - SUM(B14:B18)	5.1	B28:F28
B22	=G14*H4 + H14*J4 - SUM(B14:F14)	5.2	B22:B26
B31	=SUMPRODUCT(B14:F18,B4:F8) + SUMPRODUCT(G14:G18,G4:G8) + SUMPRODUCT(H14:H18,I4:I8)	Objective Function	—

FIGURE 5-6 Using Solver to Set Regional Configuration for SunOil

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region*								
		Production and Transportation Cost per 1,000,000 Units					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (1000 Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	0	0	0	0	0	0	0		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	0	0	0	0	0		
18	Africa	0	0	0	0	0	0	0		
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacity*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	0								
27		N. America	S. Ar							
28	*Unmet Demand*	12								
29										
30	***Objective Function***									
31	***Cost =***	$ -								
32										



The next step is to use Tools | Solver to invoke Solver as shown in Figure 5-6. Within Solver the goal is to minimize the total cost in cell B31. The variables are in cells B14:H18. The constraints are as follows:

$$\text{B14:H18} \geq 0 \quad \{\text{All decision variables are nonnegative}\}$$

$$\text{B22:B26} \geq 0 \quad \left\{K_i y_i - \sum_{j=1}^{m} x_{ij} \geq 0 \qquad \text{for} \qquad i = 1, \ldots, 5\right\}$$

$$\text{B28:F28} = 0 \quad \left\{D_j - \sum_{i=1}^{n} x_{ij} = 0 \qquad \text{for} \qquad j = 1, \ldots, 5\right\}$$

$$\text{G14:H18 } \textit{binary} \quad \{\text{Location variables } y_i \text{ are binary; that is, 0 or 1}\}$$

Within the *Solver parameters* dialog box, click on *Solve* to obtain the optimal solution as shown in Figure 5-7. From Figure 5-7, the supply chain team concludes that the lowest-cost network will have facilities located in South America, Asia, and Africa. Further, a high-capacity plant should be planned in each region. The plant in South America meets the North American demand, whereas the European demand is met from plants in Asia and Africa.

The model discussed earlier can be modified to account for strategic imperatives that require locating a plant in some region. For example, if SunOil decides to locate a plant in Europe for strategic reasons, we can modify the model by adding a constraint

FIGURE 5-7 Optimal Regional Network Configuration for SunOil

	A	B	C	D	E	F	G	H	I	J
1	***Inputs - Costs, Capacities, Demands***									
2		*Demand Region*								
		Production and Transportation Cost per 1,000,000 Units					**Fixed**	**Low**	**Fixed**	**High**
3	*Supply Region*	N. America	S. America	Europe	Asia	Africa	**Cost ($)**	**Capacity**	**Cost ($)**	**Capacity**
4	N. America	81	92	101	130	115	6,000	10	9,000	20
5	S. America	117	77	108	98	100	4,500	10	6,750	20
6	Europe	102	105	95	119	111	6,500	10	9,750	20
7	Asia	115	125	90	59	74	4,100	10	6,150	20
8	Africa	142	100	103	105	71	4,000	10	6,000	20
9	*Demand*	12	8	14	16	7				
10										
11	***Decision Variables***									
12		*Demand Region - Production Allocation (1000 Units)*					Plants	Plants		
13	*Supply Region*	N. America	S. America	Europe	Asia	Africa	(1=open)	(1=open)		
14	N. America	0	0	0	0	0	0	0		
15	S. America	12	8	0	0	0	0	1		
16	Europe	0	0	0	0	0	0	0		
17	Asia	0	0	4	16	0	0	1		
18	Africa	0	0	10	0	7	0	1		
19										
20	***Constraints***									
21	*Supply Region*	*Excess Capacity*								
22	N. America	0								
23	S. America	0								
24	Europe	0								
25	Asia	0								
26	Africa	3								
27		N. America	S. America	Europe	Asia	Africa				
28	*Unmet Demand*	0	0	0	0	0				
29										
30	***Objective Function***									
31	***Cost =***	$ 23,751								

that requires one plant to be located in Europe. At this stage, the costs associated with a variety of options incorporating different combinations of strategic concerns such as local presence should be evaluated. A suitable regional configuration is then selected.

Next we consider a model that can be useful during Phase III.

PHASE III: GRAVITY LOCATION MODELS

During Phase III (see Figure 5-2), a manager identifies potential locations in each region where the company has decided to locate a plant. As a preliminary step, the manager needs to identify the geographic location where potential sites may be considered. Gravity location models can be useful when identifying suitable geographic locations within a region. Gravity models are used to find locations that minimize the cost of transporting raw materials from suppliers and finished goods to the markets served. Next, we discuss a typical scenario in which gravity models can be used.

Consider, for example, Steel Appliances (SA), a manufacturer of high-quality refrigerators and cooking ranges. SA has one assembly factory located near Denver, from which it has supplied the entire United States. Demand has grown rapidly and the CEO of SA has decided to set up another factory to serve its eastern markets. The supply chain manager is asked to find a suitable location for the new factory. Three parts plants located in Buffalo, Memphis, and St. Louis will supply parts to the new factory, which will serve markets in Atlanta, Boston, Jacksonville, Philadelphia, and New York. The coordinate location, the demand in each market, the required supply from each parts plant, and the shipping cost for each supply source or market are shown in Table 5-1.

TABLE 5-1 Locations of Supply Sources and Markets for Steel Appliances

Sources/Markets	Transportation Cost $/Ton Mile ($F_n$)	Quantity in Tons (D_n)	Coordinates x_n	Coordinates y_n
Supply sources				
Buffalo	0.90	500	700	1,200
Memphis	0.95	300	250	600
St. Louis	0.85	700	225	825
Markets				
Atlanta	1.50	225	600	500
Boston	1.50	150	1,050	1,200
Jacksonville	1.50	250	800	300
Philadelphia	1.50	175	925	975
New York	1.50	300	1,000	1,080

Gravity models assume that both the markets and the supply sources can be located as grid points on a plane. All distances are calculated as the geometric distance between two points on the plane. These models also assume that the transportation cost grows linearly with the quantity shipped. We discuss a gravity model for locating a single facility that receives raw material from supply sources and ships finished product to markets. The basic inputs to the model are as follows:

x_n, y_n: coordinate location of either a market or supply source n
F_n: cost of shipping one unit for one mile between the facility and either market or supply source n
D_n: quantity to be shipped between facility and market or supply source n

If (x, y) is the location selected for the facility, the distance d_n between the facility at location (x, y) and the supply source or market n is given by

$$d_n = \sqrt{(x - x_n)^2 + (y - y_n)^2} \tag{5.4}$$

the total transportation cost (TC) is given by

$$TC = \sum_{n=1}^{k} d_n D_n F_n \tag{5.5}$$

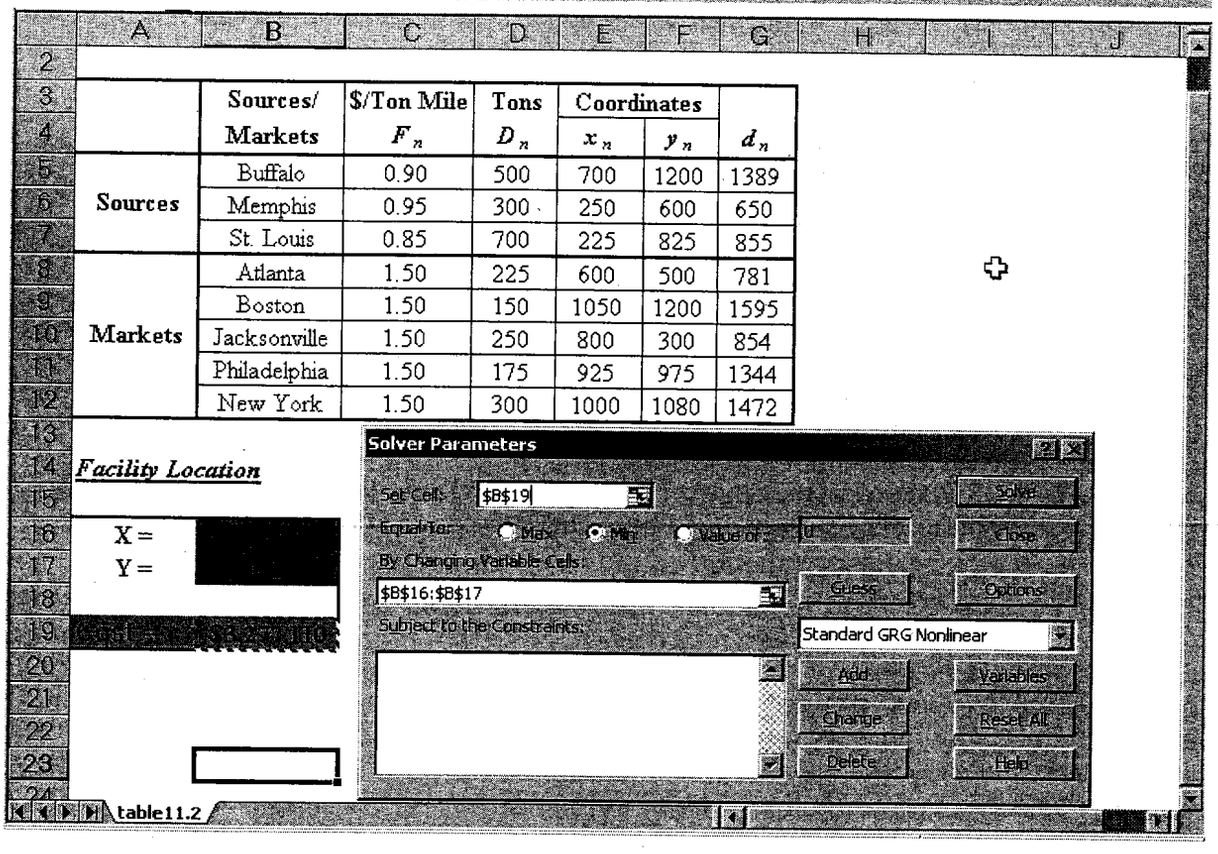
The optimal location is one that minimizes the total TC in Equation 5.5. The optimal solution for SA is obtained using the Solver tool in Excel as shown in Figure 5-8. The first step is to enter the problem data as shown in cells B5:G12. Next, we set the decision variables (x, y) corresponding to the location of the new facility in cells B16 and B17, respectively. In cells G5:G12, we then calculate the distance d_n from the facility location (x, y) to each source or market using Equation 5.4. The total TC is then calculated in cell B19 using Equation 5.5.

The next step is to use the Tools/Solver to invoke Solver. Within the Solver parameters dialog box (see Figure 5-8), the following information is entered to represent the problem.

Set Target Cell: B19
Equal to: Select *Min*
By Changing Cells: B16:B17

Click on the Solve button. The optimal solution is returned in cells B16 and B17.

FIGURE 5-8 Using Solver to Optimize Location for Steel Appliances



	Sources/ Markets	$/Ton Mile F_n	Tons D_n	Coordinates x_n	y_n	d_n
Sources	Buffalo	0.90	500	700	1200	1389
	Memphis	0.95	300	250	600	650
	St. Louis	0.85	700	225	825	855
Markets	Atlanta	1.50	225	600	500	781
	Boston	1.50	150	1050	1200	1595
	Jacksonville	1.50	250	800	300	854
	Philadelphia	1.50	175	925	975	1344
	New York	1.50	300	1000	1080	1472

Cell	Cell Formula	Equation	Copied to
G5	=SQRT(($B$16-E5)^2+($B$17-F5)^2)	5.1	G5:G12
B19	=SUMPRODUCT(G5:G12,D5:D12,C5:C12)	5.2	—

The manager thus identifies the coordinates $(x, y) = (681, 882)$ as the location of the factory that minimizes total cost TC. From a map, these coordinates are close to the border of North Carolina and Virginia. The precise coordinates provided by the gravity model may not correspond to a feasible location. The manager should look for desirable sites close to the optimal coordinates that have the required infrastructure as well as the appropriate worker skills available.

The gravity model can also be solved using the following iterative procedure.

1. For each supply source or market n, evaluate d_n as defined in Equation 5.4.
2. Obtain a new location (x', y') for the facility, where

$$x' = \frac{\sum_{n=1}^{k} \frac{D_n F_n x_n}{d_n}}{\sum_{n=1}^{k} \frac{D_n F_n}{d_n}} \quad \text{and} \quad y' = \frac{\sum_{n=1}^{k} \frac{D_n F_n y_n}{d_n}}{\sum_{n=1}^{k} \frac{D_n F_n}{d_n}}$$

3. If the new location (x', y') is almost the same as (x, y) stop. Otherwise, set $(x, y) = (x', y')$ and go to step 1.

PHASE IV: NETWORK OPTIMIZATION MODELS

During Phase IV (see Figure 5-2), a manager decides on the location and capacity allocation for each facility. Besides locating the facilities, a manager also decides how markets are allocated to facilities. This allocation must account for customer service constraints in terms of response time. The demand allocation decision can be altered on a regular basis as costs change and markets evolve. When designing the network, both location and allocation decisions are made jointly.

We illustrate the relevant network optimization models using the example of two manufacturers of fiber-optic telecommunication equipment. Both TelecomOne and HighOptic are manufacturers of the latest generation of telecommunication equipment. TelecomOne has focused on the eastern half of the United States. It has manufacturing plants located in Baltimore, Memphis, and Wichita, and serves markets in Atlanta, Boston, and Chicago. HighOptic has targeted the western half of the United States and serves markets in Denver, Omaha, and Portland. HighOptic has plants located in Cheyenne and Salt Lake City.

Plant capacities, market demand, variable production and transportation cost per thousand units shipped, and fixed costs per month at each plant are shown in Table 5-2.

Allocating Demand to Production Facilities

From Table 5-2 we calculate that TelecomOne has a total production capacity of 71,000 units per month and a total demand of 30,000 units per month, whereas HighOptic has a production capacity of 51,000 units per month and a demand of 24,000 units per month. Each year, managers in both companies must decide how to allocate the demand to their production facilities as demand and costs change.

The demand allocation problem can be solved using a demand allocation model. The model requires the following inputs:

n = number of factory locations
m = number of markets or demand points
D_j = annual demand from market j
K_i = capacity of factory i
c_{ij} = cost of producing and shipping one unit from factory i to market j (cost includes production, inventory, and transportation)

The goal is to allocate the demand from different markets to the various plants to minimize the total cost of facilities, transportation, and inventory. Define the decision variables:

x_{ij} = quantity shipped from factory i to market j

TABLE 5-2 Capacity, Demand, and Cost Data for TelecomOne and HighOptic

	Demand City Production and Transportation Cost per Thousand Units (Thousand $)						*Monthly Capacity (Thousand Units) K_i*	*Monthly Fixed Cost (Thousand $) f_i*
Supply City	***Atlanta***	***Boston***	***Chicago***	***Denver***	***Omaha***	***Portland***		
Baltimore	1,675	400	685	1,630	1,160	2,800	18	7,650
Cheyenne	1,460	1,940	970	100	495	1,200	24	3,500
Salt Lake City	1,925	2,400	1,425	500	950	800	27	5,000
Memphis	380	1,355	543	1,045	665	2,321	22	4,100
Wichita	922	1,646	700	508	311	1,797	31	2,200
Monthly demand (thousand units) D_j	10	8	14	6	7	11		

TABLE 5-3 Optimal Demand Allocation for TelecomOne and HighOptic

		Atlanta	*Boston*	*Chicago*	*Denver*	*Omaha*	*Portland*
TelecomOne	Baltimore	0	8	2			
	Memphis	10	0	12			
	Wichita	0	0	0			
HighOptic	Salt Lake				0	0	11
	Cheyenne				6	7	0

The problem is formulated as the following linear program:

$$Min \quad \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = D_j \quad \text{for} \quad j = 1,\ldots,m \tag{5.6}$$

$$\sum_{j=1}^{m} x_{ij} \leq K_i \quad \text{for} \quad i = 1,\ldots,n \tag{5.7}$$

The constraints in Equation 5.6 ensure that all market demand is satisfied and the constraints in Equation 5.7 ensure that no factory produces more than its capacity.

For both TelecomOne and HighOptic, the demand allocation problem can be solved using the Solver tool within Excel. The optimal demand allocation is presented here in Table 5-3. Observe that it is optimal for TelecomOne not to produce anything in the Wichita facility even though the facility is operational and the fixed cost is incurred. With the demand allocation as shown in Table 5-3, TelecomOne incurs a monthly variable cost of $14,886,000 and a monthly fixed cost of $13,950,000 for a total monthly cost of $28,836,000. HighOptic incurs a monthly variable cost of $12,865,000 and a monthly fixed cost of $8,500,000 for a total monthly cost of $21,365,000.

Locating Plants: The Capacitated Plant Location Model

Management at both TelecomOne and HighOptic has decided to merge the two companies into a single entity to be called TelecomOptic. Management feels that significant benefits will result if the two networks are merged appropriately. TelecomOptic will have five factories from which to serve six markets. Management is debating whether all five factories are needed. They have assigned a supply chain team to study the network for the combined company and identify the plants that should be shut down.

The problem of selecting the optimal location and capacity allocation is very similar to the regional configuration problem we have already studied in Phase II. The only difference is that instead of using costs and duties that apply over a region, we now use location-specific costs and duties. The supply chain team thus decides to use the capacitated plant location model discussed earlier to solve the problem in Phase IV.

Ideally, the problem should be formulated to maximize total profits taking into account costs, taxes, and duties by location. Given that taxes and duties do not vary between locations, the supply chain team decides to locate factories and then allocate demand to the open factories to minimize the total cost of facilities, transportation, and inventory. Define the following decision variables:

y_i = 1 if factory i is open, 0 otherwise
x_{ij} = quantity shipped from factory i to market j

FIGURE 5-9 Spreadsheet Area for Decision Variables for TelecomOptic

	A	B	C	D	E	F	G	H	I
1	***Inputs - Costs, Capacities, Demands (for TelecomOptic)***								
2		*Demand City*							
		Production and Transportation Cost per 1000 Units						**Fixed**	
3	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Cost ($)**	**Capacity**
4	Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
5	Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
6	Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
7	Memphis	380	1,355	543	1,045	665	2,321	4,100	22
8	Wichita	922	1,646	700	508	311	1,797	2,200	31
9	*Demand*	10	8	14	6	7	11		
11	***Decision Variables***								
12		*Demand City - Production Allocation (1000 Units)*						**Plants**	
13	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)	
14	Baltimore	0	0	0	0	0	0	0	
15	Cheyenne	0	0	0	0	0	0	0	
16	Salt Lake	0	0	0	0	0	0	0	
17	Memphis	0	0	0	0	0	0	0	
18	Wichita	0	0	0	0	0	0	0	

Table11.4HighOptic / Table11.4TelecomOne / Produ

Recall that the problem is then formulated as the following integer program:

$$Min \quad \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

Subject to x and y satisfying the constraints in Equations 5.1, 5.2, and 5.3.

The capacity and demand data along with production, transportation, and inventory costs at different factories for the merged firm TelecomOptic are given in Table 5-2. The supply chain team decides to solve the plant location model using the Solver tool in Excel.

The first step in setting up the Solver model is to enter the cost, demand, and capacity information as shown in Figure 5-9. The fixed costs f_i for the five plants are entered in cells H4 to H8. The capacities K_i of the five plants are entered in cells I4 to I8. The variable costs from each plant to each demand city, c_{ij}, are entered in cells B4 to G8. The demands D_j of the six markets are entered in cells B9 to G9. Next, corresponding to decision variables x_{ij} and y_i, cells B14 through G18 and H14 to H18, respectively, are assigned as shown in Figure 5-9. Initially all variables are set to be 0.

The next step is to construct cells for each of the constraints in Equations 5.1 and 5.2. The constraint cells are as shown in Figure 5-10. Cells B22 to B26 contain the capacity constraints in Equation 5.7, whereas cells B29 to G29 contain the demand constraints in Equation 5.6. The constraint in cell B22 corresponds to the capacity constraint for the factory in Baltimore. The cell B29 corresponds to the demand constraint for the market in Atlanta. The capacity constraints require that the cell value be greater than or equal to ($\geq$) 0, whereas the demand constraints require the cell value be equal to 0.

The objective function measures the total fixed and variable cost of the supply chain network and is evaluated in Cell B32. The next step is to use Tools|Solver to invoke Solver as shown in Figure 5-11.

Within Solver, the goal is to minimize the total cost in cell B32. The variables are in cells B14:H18. The constraints are as follows:

B14:G18 $\geq$ 0 {All decision variables are nonnegative}

$$\text{B22:B26} \geq 0 \quad \left\{ K_i y_i - \sum_{j=1}^{m} x_{ij} \geq 0 \quad \text{for} \quad i = 1, \ldots, 5 \right\}$$

FIGURE 5-10 Spreadsheet Area for Constraints for TelecomOptic

	A	B	C	D	E	F	G	H	I
1	***Inputs - Costs, Capacities, Demands (for TelecomOptic)***								
2		*Demand City*							
3	*Supply City*	*Production and Transportation Cost per 1000 Units* Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Fixed Cost ($)**	**Capacity**
4	Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
5	Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
6	Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
7	Memphis	380	1,355	543	1,045	665	2,321	4,100	22
8	Wichita	922	1,646	700	508	311	1,797	2,200	31
9	*Demand*	10	8	14	6	7	11		
11	***Decision Variables***								
12		*Demand City - Production Allocation (1000 Units)*						**Plants**	
13	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)	
14	Baltimore	0	0	0	0	0	0	0	
15	Cheyenne	0	0	0	0	0	0	0	
16	Salt Lake	0	0	0	0	0	0	0	
17	Memphis	0	0	0	0	0	0	0	
18	Wichita	0	0	0	0	0	0	0	
20	***Constraints***								
21	*Supply City*	*Excess Capacity*							
22	Baltimore	0			*Total Available Capacity* 0				
23	Cheyenne	0							
24	Salt Lake	0			Solver				
25	Memphis	0							
26	Wichita	0							
28		Atlanta	Boston	Chicago	Denver	Omaha	Portland		
29	*Unmet Demand*	10	8	14	6	7	11		
31	***Objective Function***								
32	***Cost =***	$ -							

View Linear Program Formulation

Table11.4 HighOptic | Table11.4 TelecomOne | Produ

Cell	Formula	Equation	Copied to
B22	= I4*H14 - SUM(B14:G14)	5.6	B22:B26
B29	= B9 - SUM(B14:B18)	5.5	B29:G29
B32	= SUMPRODUCT(B4:G8, B14:G18) + SUMPRODUCT(H4:H8, H14:H18)	Objective function	—

$$\text{B29:G29} = 0 \quad \left\{ D_j - \sum_{i=1}^{n} x_{ij} = 0 \qquad \text{for} \qquad j = 1, \ldots, 6 \right\}$$

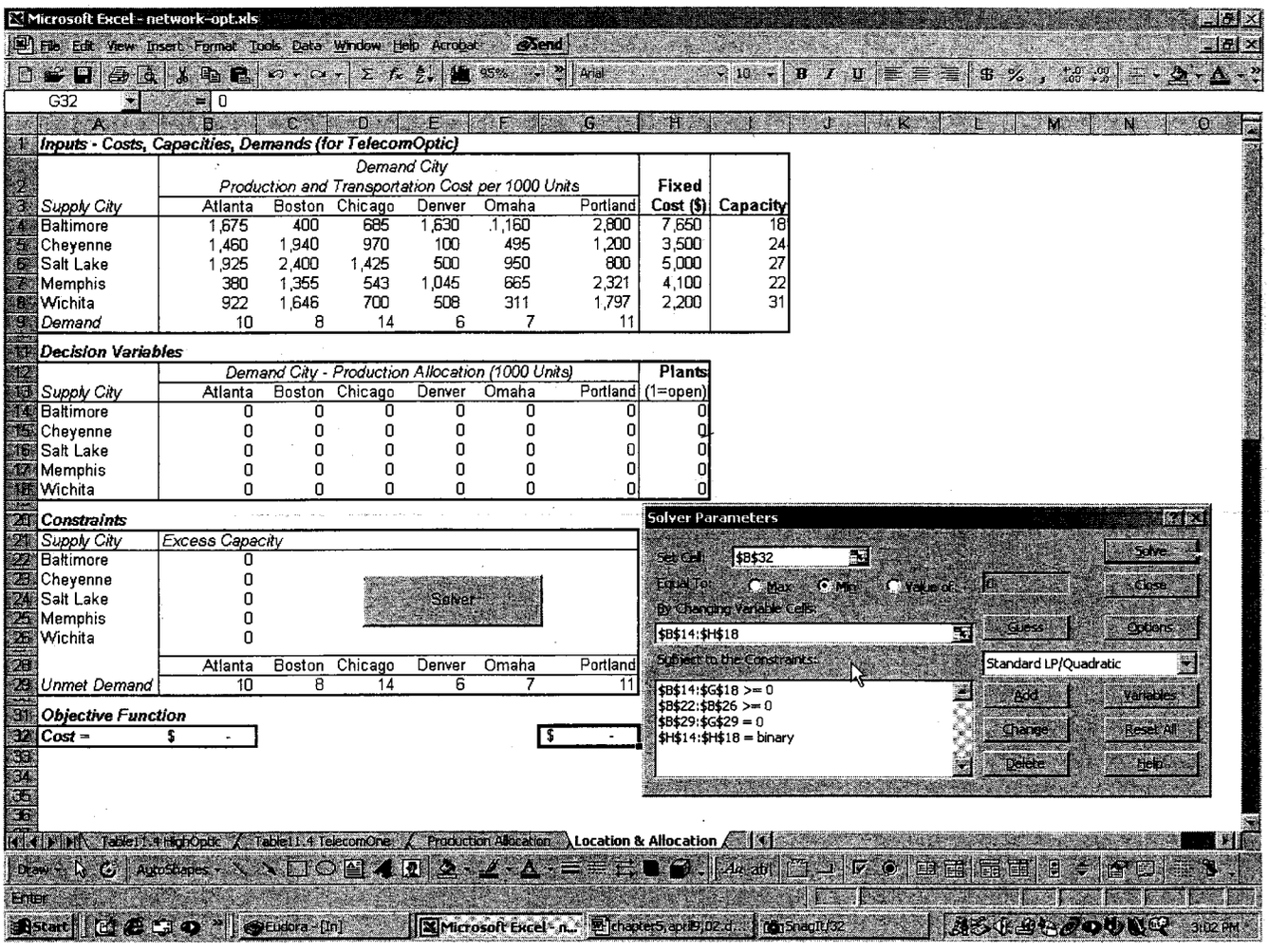
H14:H18 *binary* {Location variables y_i are binary; that is, 0 or 1}

Within the Solver parameters dialog box, click on Solve to obtain the optimal solution as shown in Figure 5-12. From Figure 5-12, the supply chain team concludes that it is optimal for TelecomOptic to close the plants in Salt Lake City and Wichita while keeping the plants in Baltimore, Cheyenne, and Memphis open. The total monthly cost of this network and operation is $47,401,000. This cost represents savings of about $3 million per month compared to the situation in which TelecomOne and HighOptic operate separate supply chain networks.

Locating Plants: The Capacitated Plant Location Model with Single Sourcing

In some cases, companies want to design supply chain networks in which a market is supplied from only one factory, referred to as a *single source.* Companies may impose

FIGURE 5-11 Solver Dialog Box for TelecomOptic



this constraint because it lowers the complexity of coordinating the network and requires less flexibility from each facility. The plant location model discussed earlier needs some modification to accommodate this constraint. The decision variables are redefined as follows:

$y_i = 1$ if factory is located at site i, 0 otherwise
$x_{ij} = 1$ if market j is supplied by factory i, 0 otherwise

The problem is formulated as the following integer program:

$$Min \quad \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} D_j c_{ij} x_{ij}$$

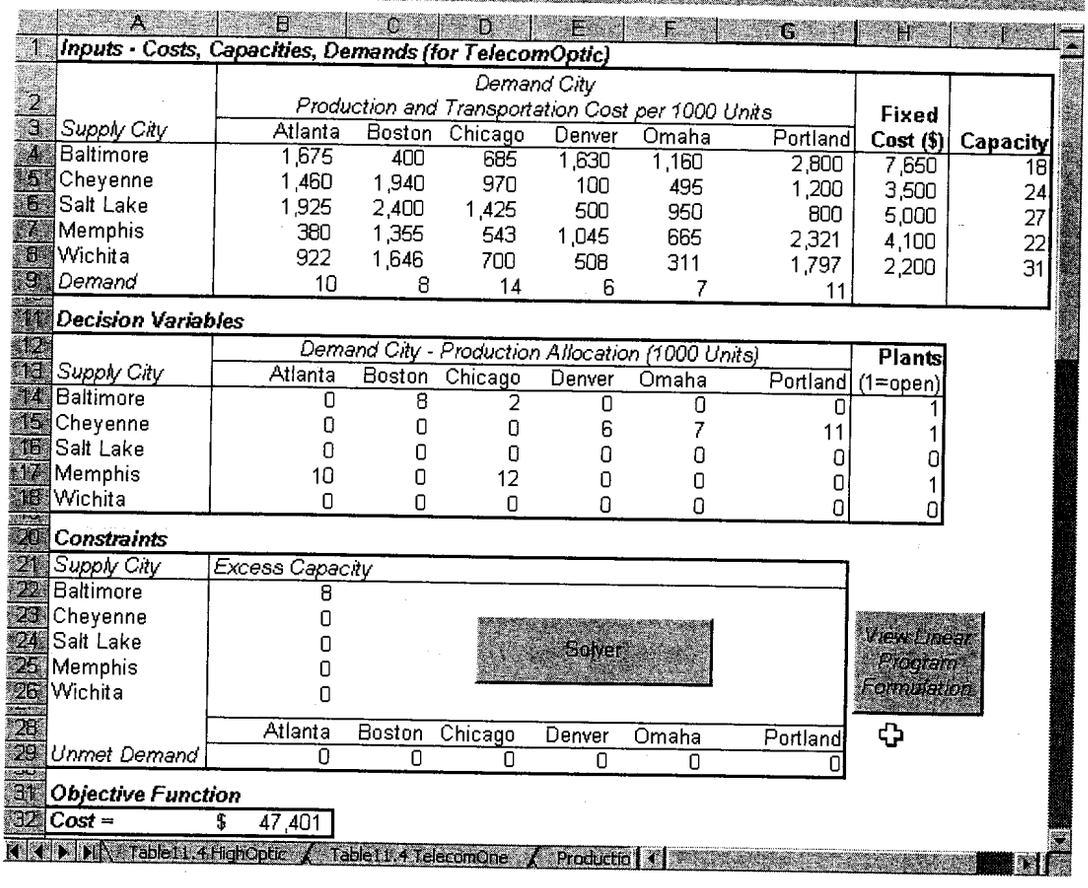
Subject to

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad \text{for} \qquad j = 1, \ldots, m \tag{5.8}$$

$$\sum_{j=1}^{m} D_j x_{ij} \leq K_i y_i \qquad \text{for} \qquad i = 1, \ldots, n \tag{5.9}$$

$$x_{ij}, y_i \in \{0,1\} \tag{5.10}$$

FIGURE 5-12 Optimal Network Design for TelecomOptic



	A	B	C	D	E	F	G	H	I
1	***Inputs - Costs, Capacities, Demands (for TelecomOptic)***								
2		*Demand City*							
3	*Supply City*	*Production and Transportation Cost per 1000 Units* Atlanta	Boston	Chicago	Denver	Omaha	Portland	**Fixed Cost ($)**	**Capacity**
4	Baltimore	1,675	400	685	1,630	1,160	2,800	7,650	18
5	Cheyenne	1,460	1,940	970	100	495	1,200	3,500	24
6	Salt Lake	1,925	2,400	1,425	500	950	800	5,000	27
7	Memphis	380	1,355	543	1,045	665	2,321	4,100	22
8	Wichita	922	1,646	700	508	311	1,797	2,200	31
9	*Demand*	10	8	14	6	7	11		
11	***Decision Variables***								
12		*Demand City - Production Allocation (1000 Units)*						**Plants**	
13	*Supply City*	Atlanta	Boston	Chicago	Denver	Omaha	Portland	(1=open)	
14	Baltimore	0	8	2	0	0	0	1	
15	Cheyenne	0	0	0	6	7	11	1	
16	Salt Lake	0	0	0	0	0	0	0	
17	Memphis	10	0	12	0	0	0	1	
18	Wichita	0	0	0	0	0	0	0	
20	***Constraints***								
21	*Supply City*	*Excess Capacity*							
22	Baltimore	8							
23	Cheyenne	0							
24	Salt Lake	0							
25	Memphis	0							
26	Wichita	0							
28		Atlanta	Boston	Chicago	Denver	Omaha	Portland		
29	*Unmet Demand*	0	0	0	0	0	0		
31	***Objective Function***								
32	***Cost =***	$ 47,401							

The constraints in Equations 5.8 and 5.10 enforce that each market is supplied by exactly one factory.

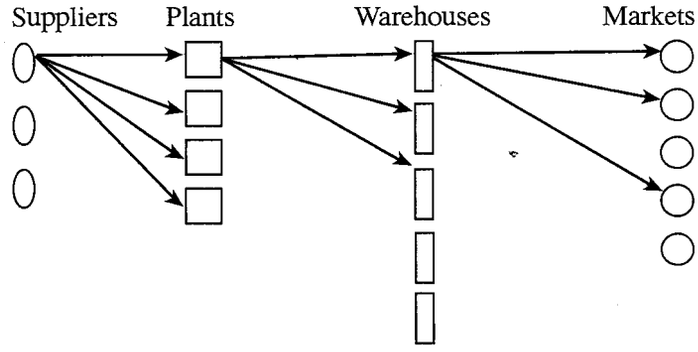
We do not describe the solution of the model in Excel because it is very similar to the model discussed earlier. The optimal network with single sourcing for TelecomOptic is as shown in Table 5-4.

If single sourcing is required, it is optimal for TelecomOptic to close the factories in Baltimore and Cheyenne. This is different from the result in Figure 5-12, in which factories in Salt Lake City and Wichita were closed. The monthly cost of operating the network in Table 5-4 is $49,717,000. This cost is about $2.3 million higher than the cost of the network in Figure 5-12, in which single sourcing was not required. The supply chain team thus concludes that single sourcing adds about $2.3 million per month to the cost of the supply chain network, although it makes coordination easier and requires less flexibility from the plants.

TABLE 5-4 Optimal Network Configuration for TelecomOptic with Single Sourcing

	Open/Closed	*Atlanta*	*Boston*	*Chicago*	*Denver*	*Omaha*	*Portland*
Baltimore	Closed	0	0	0	0	0	0
Cheyenne	Closed	0	0	0	0	0	0
Salt Lake	Open	0	0	0	6	0	11
Memphis	Open	10	8	0	0	0	0
Wichita	Open	0	0	14	0	7	0

FIGURE 5-13 Stages in a Supply Network



Locating Plants and Warehouses Simultaneously

A much more general form of the plant location model needs to be considered if the entire supply chain network from the supplier to the customer is to be designed. We consider a supply chain in which suppliers send material to factories that supply warehouses that supply markets as shown in Figure 5-13. Location and capacity allocation decisions have to be made for both factories and warehouses. Multiple warehouses may be used to satisfy demand at a market and multiple factories may be used to replenish warehouses. It is also assumed that units have been appropriately adjusted such that one unit of input from a supply source produces one unit of the finished product. The model requires the following inputs:

m = number of markets or demand points
n = number of potential factory locations
l = number of suppliers
t = number of potential warehouse locations
D_j = annual demand from customer j
K_i = potential capacity of factory at site i
S_h = supply capacity at supplier h
W_e = potential warehouse capacity at site e
F_i = fixed cost of locating a plant at site i
f_e = fixed cost of locating a warehouse at site e
c_{hi} = cost of shipping one unit from supply source h to factory i
c_{ie} = cost of producing and shipping one unit from factory i to warehouse e
c_{ej} = cost of shipping one unit from warehouse e to customer j

The goal is to identify plant and warehouse locations as well as quantities shipped between various points that minimize the total fixed and variable costs. Define the following decision variables:

y_i = 1 if factory is located at site i, 0 otherwise
y_e = 1 if warehouse is located at site e, 0 otherwise
x_{ej} = quantity shipped from warehouse e to market j
x_{ie} = quantity shipped from factory at site i to warehouse e
x_{hi} = quantity shipped from supplier h to factory at site i

The problem is formulated as the following integer program:

$$Min \quad \sum_{i=1}^{n} F_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n}\sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t}\sum_{j=1}^{m} c_{ej} x_{ej}$$

The objective function minimizes the total fixed and variable costs of the supply chain network subject to the following constraints:

$$\sum_{i=1}^{n} x_{hi} \leq S_h \quad \text{for} \quad h = 1, \ldots, l \tag{5.11}$$

The constraint in Equation 5.11 specifies that the total amount shipped from a supplier cannot exceed the supplier's capacity.

$$\sum_{h=1}^{l} x_{hi} - \sum_{e=1}^{t} x_{ie} \geq 0 \quad \text{for} \quad i = 1, \ldots, n \tag{5.12}$$

The constraint in Equation 5.12 states that the amount shipped out of a factory cannot exceed the quantity of raw material received.

$$\sum_{e=1}^{t} x_{ie} \leq K_i y_i \quad \text{for} \quad i = 1, \ldots, n \tag{5.13}$$

The constraint in Equation 5.13 enforces that the amount produced in the factory cannot exceed its capacity.

$$\sum_{i=1}^{n} x_{ie} - \sum_{j=1}^{m} x_{ej} \geq 0 \quad \text{for} \quad e = 1, \ldots, t \tag{5.14}$$

The constraint in Equation 5.14 specifies that the amount shipped out of a warehouse cannot exceed the quantity received from the factories.

$$\sum_{j=1}^{m} x_{ej} \leq W_e y_e \quad \text{for} \quad e = 1, \ldots, t \tag{5.15}$$

The constraint in Equation 5.15 specifies that the amount shipped through a warehouse cannot exceed its capacity.

$$\sum_{e=1}^{t} x_{ej} = D_j \quad \text{for} \quad j = 1, \ldots, m \tag{5.16}$$

The constraint in Equation 5.16 specifies that the amount shipped to a customer must cover the demand.

$$y_i, y_e \in \{0, 1\}, x_{ej}, x_{ie}, x_{hi} \geq 0 \tag{5.17}$$

The constraint in Equation 5.17 enforces that each factory or warehouse is either open or closed.

The model discussed earlier can be modified to allow direct shipments between factories and markets. All the models discussed previously can also be modified to accommodate economies of scale in production, transportation, and inventory costs. However, these requirements make the models more difficult to solve.

ACCOUNTING FOR TAXES, TARIFFS, AND CUSTOMER REQUIREMENTS

Network design models should be structured such that the resulting supply chain network maximizes profits after tariffs and taxes while meeting customer service requirements. The models discussed earlier can easily be modified to maximize profits accounting for taxes, even when revenues are in different currencies. If r_j is the revenue

from selling one unit in market j, the objective function of the capacitated plant location model can be modified to be

$$Max \quad \sum_{j=1}^{m} r_j \sum_{i=1}^{n} x_{ij} - \sum_{i=1}^{n} F_i y_i - \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

This objective function maximizes profits for the firm. When using a profit maximization objective function, a manager should modify the constraint in Equation 5.1 to be

$$\sum_{i=1}^{n} x_{ij} \leq D_j \quad \text{for} \quad j = 1, \ldots, m \tag{5.18}$$

The constraint in Equation 5.18 is more appropriate than the constraint in Equation 5.1 because it allows the network designer to identify the demand that can be satisfied profitably and the demand that is satisfied at a loss to the firm. The plant location model with Equation 5.18 instead of Equation 5.1 and a profit maximization objective function will only serve that portion of demand that is profitable to serve. This may result in some markets in which a portion of the demand is dropped, unless constrained otherwise, because it cannot be served profitably.

Customer preferences and requirements may be in terms of desired response time and the choice of transportation mode or transportation provider. Consider, for example, two modes of transportation available between plant location i and market j. Mode 1 may be sea and mode 2 may be air. The plant location model is modified by defining two distinct decision variables x_{ij}^1 and x_{ij}^2 corresponding to the quantity shipped from location i to market j using Modes 1 and 2, respectively. The desired response time using each transportation mode is accounted for by allowing shipments only when the time taken is less than the desired response time. For example, if the time from location i to market j using mode 1 (sea) is longer than would be acceptable to the customer, we simply drop the decision variable x_{ij}^1 from the plant location model. The option among several transportation providers can be modeled similarly.

5.5 THE ROLE OF IT IN NETWORK DESIGN

Even though it may seem at first glance that the strategic nature of the network design problem makes information technology systems less valuable, good IT systems can significantly improve the capability of a network designer. In this chapter, we discuss a variety of methodologies in Excel that can be used to solve network design problems. Even though the core models are the same, problems in practice tend to be much larger than the problems considered in the chapter. For much larger problems, there are four ways that an IT system can help with network design relative to the use of a general-purpose tool such as Excel.

1. A good network design IT system makes the modeling of the network design problems much easier than in a general-purpose tool such as Excel. These applications have many built-in tools that facilitate an accurate description of a large supply chain network and incorporate realistic features that would be time consuming and difficult to build in Excel.

2. An IT system contains high-performance optimization technologies, which deliver a high-quality solution for large problems in a reasonable amount of time. Although Excel's solver can be upgraded, there are many cases in which the size and complexity of the optimization require a more sophisticated system that a network design application can provide.

3. A good network design application also allows for an analysis of various "what if" scenarios. Given the uncertainty associated with forecasts, the ability to evaluate network designs in a variety of scenarios is a very powerful tool for a designer. A network designer may find it much more appropriate to select a design that gives very good costs in many likely scenarios rather than a design that is optimal in one scenario but very poor in another. The ease of modeling and speed of solution allows a good network design application to facilitate what-if analysis to a far greater extent than a general-purpose tool such as Excel.

4. Finally, network design applications are structured to interface easily with the planning and operational software used by firms, which contain much of the actual data required for network design. The ease of interfacing with the data source speeds up the creation and solution of a network design model.

Network design applications are often quite inexpensive relative to the other uses of IT we discuss. Network design applications, sometimes called *supply chain strategy modules*, are often thrown in for free on top of the much more expensive planning and execution modules. In fact, many companies have rights to these products without even realizing it, as a result of past software purchases.

There are some caveats, however, to the use of IT systems in network design. Network design decisions are strategic and involve many factors that are hard to quantify. When using a network design tool, it is easy to fall into the trap of allowing the application to make the decision based only on aspects that are quantifiable. Important factors such as culture, quality-of-life issues, and cost of coordination that are hard for IT to handle can be significant in making a network design decision. Thus, relevant nonquantifiable factors should be included with the output of IT systems when making network design decisions.

The software firms that produce network design software come from three groups (see Chapter 17 for more details). The first are the large enterprise resource planning (ERP) players who now dominate the supply chain software space. The two giants here are SAP and Oracle. There are also several best-of-breed supply chain vendors that have held on despite the gains of the ERP vendors in recent years. These firms include i2 Technologies and Manugistics. Finally, there is a group of small firms such as Optiant and SmartOps that focus exclusively on network design or supply chain strategy. These firms are more consultative than a pure software house.

In summary, although network design is an area that is not as closely tied to IT as many other supply chain areas we discuss, it is nonetheless one that can benefit from the power of IT at relatively little cost.

5.6 MAKING NETWORK DESIGN DECISIONS IN PRACTICE

Managers should keep the following issues in mind when making network design decisions for a supply chain.

Do not underestimate the life span of facilities. It is important to think through the long-term consequences of facility decisions because facilities last a long time and have an enduring impact on a firm's performance. Managers must consider not only future demand and costs but also scenarios in which technology may change. Otherwise, facilities may become useless within a few years. For example, an insurance company moved its clerical labor from a metropolitan location to a suburban location to lower costs. With increasing automation, the need for clerical labor decreased significantly and within a few years the facility was no longer needed. The company found it

very difficult to sell the facility given its distance from residential areas and airports.[3] Within most supply chains, production facilities are harder to change than storage facilities. Supply chain network designers must consider that any factories that they put in place will stay there for an extended period of a decade or more. Warehouses or storage facilities, particularly those that are not owned by the company, can be changed within a year of making the decision.

Do not gloss over the cultural implications. Network design decisions regarding facility location and facility role have a significant impact on the culture of each facility and the firm. The culture at a facility will be influenced by other facilities in its vicinity. Network designers can use this fact to influence the role of the new facility and the focus of people working there. For example, when Ford Motor Company introduced the Lincoln Mark VIII model, management was faced with a dilemma. At that time, the Mark VIII shared a platform with the Mercury Cougar. However, the Mark VIII is part of Ford's luxury Lincoln division. Locating the Mark VIII line with the Cougar would have obvious operational advantages because of shared parts and processes. However, Ford decided to locate the Mark VIII line in the Wixom, Michigan, plant, where other Lincoln cars were produced. The primary reason for doing so was to ensure that the focus on quality for the Mark VIII would be consistent with that of other Ford luxury cars that were produced in Wixom.

The location of a facility has a significant impact on the extent and form of communication that develops in the supply chain network. Locating a facility far from headquarters will likely give it more of a culture of autonomy. This may be beneficial if the firm is starting a new division that needs to function in a manner different from the rest of the company. In contrast, locating two facilities closer together is likely to encourage communication between them. Extensive communication can be very useful if decisions made at either facility have a strong impact on the performance of the other facility.

Do not ignore quality-of-life issues. The quality of life at selected facility locations has a significant impact on performance because it influences the workforce available and its morale. In many instances, a firm may be better off selecting a higher-cost location if it provides a much better quality of life. Failure to do so can have dire consequences. For example, an aerospace supplier decided to relocate an entire division to an area with a lower standard of living in order to reduce costs. Most of the marketing team, however, refused to relocate. As a result, customer relations deteriorated and the company had a very difficult transition. The effort to save costs hurt the company and effectively curtailed the firm's status as a major player in its market.[4]

Focus on tariffs and tax incentives when locating facilities. Managers making facility location decisions should consider tariffs and tax incentives carefully. When considering international locations, it is astounding how often tax incentives drive the choice of location, often overcoming all of the other cost factors combined. For instance, Ireland has developed a large high-tech industry by enticing companies with low taxes. Even within nations, local governments may offer generous packages of low to no taxes and free land when firms decide to locate facilities within their jurisdiction. Toyota, BMW, and Mercedes have all chosen their facility locations in the United States due in large part to tax incentives offered by different states.

[3]Charles F. Harding, "Quantifying Abstract Factors in Facility-Location Decisions," *Industrial Development* (May–June 1988): 24.

[4]Charles F. Harding, "Quantifying Abstract Factors in Facility-Location Decisions," *Industrial Development* (May–June 1988): 24.

5.7 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of network design decisions in supply chain.

   Network design decisions include identifying facility roles, locations, and capacities as well as allocating markets to be served by different facilities. These decisions define the physical constraints within which the network must be operated as market conditions change. Good network design decisions increase supply chain profits, whereas poor network design hurts profits.
2. Identify factors influencing supply chain network design decisions.

   Broadly speaking, network design decisions are influenced by strategic, technological, macroeconomic, political, infrastructure, competitive, and operational factors.
3. Develop a framework for making network design decisions.

   The goal of network design is to maximize the supply chain's long-term profitability. The process starts by defining the supply chain strategy, which must be aligned with the competitive strategy of the firm. The supply chain strategy, regional demand, costs, infrastructure, and the competitive environment are used to define a regional facility configuration. For regions where facilities are to be located, potentially attractive sites are then selected based on available infrastructure. The optimal configuration is determined from the potential sites using demand, logistics cost, factor costs, and margins in different markets.
4. Use optimization for facility location and capacity allocation decisions.

   Gravity location models identify a location that minimizes inbound and outbound transportation costs. They are simple to implement but do not account for other important costs. Network optimization models can include contribution margins, taxes, tariffs, production, transportation, and inventory costs and are used to maximize profitability. These models are useful when locating facilities, allocating capacity to facilities, and allocating markets to facilities.

Discussion Questions

1. How do the location and size of warehouses affect the performance of a firm such as Amazon.com? What factors should Amazon.com take into account when making this decision?
2. How do import duties and exchange rates affect the location decision in a supply chain?
3. What are different roles played by production facilities within a global network?
4. Amazon.com has built new warehouses as it has grown. How does this change affect various cost and response times in the Amazon.com supply chain?
5. McMaster-Carr sells maintenance, repair, and operations equipment from five warehouses in the United States. W.W. Grainger sells products from more than 350 retail locations, supported by several warehouses. In both cases, customers place orders using the Web or on the phone. Discuss the pros and cons of the two strategies.
6. Consider a firm such as Dell, with very few production facilities worldwide. List the pros and cons of this approach and why it may or may not be suitable for the computer industry.
7. Consider a firm such as Ford, with more than 150 facilities worldwide. List the pros and cons of having many facilities and why it may or may not be suitable for the automobile industry.

Exercises

1. SC Consulting, a supply chain consulting firm, must decide on the location of its home offices. Its clients are located primarily in the 16 states listed in Table 5-5. There are four potential sites for home offices: Los Angeles, Tulsa, Denver, and Seattle. The annual fixed cost of locating an office in Los Angeles is $165,428, Tulsa is $131,230, Denver is $140,000, and Seattle is $145,000. The expected number of trips to each state and the travel costs from each potential site are shown in Table 5-5.

TABLE 5-5 Travel Costs and Number of Trips for SC Consulting

	Travel Costs ($)				
State	*Los Angeles*	*Tulsa*	*Denver*	*Seattle*	*Number of Trips*
Washington	150	250	200	25	40
Oregon	150	250	200	75	35
California	75	200	150	125	100
Idaho	150	200	125	125	25
Nevada	100	200	125	150	40
Montana	175	175	125	125	25
Wyoming	150	175	100	150	50
Utah	150	150	100	200	30
Arizona	75	200	100	250	50
Colorado	150	125	25	250	65
New Mexico	125	125	75	300	40
North Dakota	300	200	150	200	30
South Dakota	300	175	125	200	20
Nebraska	250	100	125	250	30
Kansas	250	75	75	300	40
Oklahoma	250	25	125	300	55

Each consultant is expected to take at most 25 trips each year.

(a) If there are no restrictions on the number of consultants at a site and the goal is to minimize costs, where should the home offices be located and how many consultants should be assigned to each office? What is the annual cost in terms of the facility and travel?

(b) If, at most, 10 consultants are to be assigned to a home office, where should the offices be set up? How many consultants should be assigned to each office? What is the annual cost of this network?

(c) What do you think of a rule by which all consulting projects out of a given state are assigned to one home office? How much is this policy likely to add to cost compared to allowing multiple offices to handle a single state?

2. DryIce, Inc., is a manufacturer of air conditioners that has seen its demand grow significantly. The company anticipates nationwide demand for the year 2006 to be 180,000 units in the South, 120,000 units in the Midwest, 110,000 units in the East, and 100,000 units in the West. Managers at DryIce are designing the manufacturing network and have selected four potential sites—New York, Atlanta, Chicago, and San Diego. Plants could have a capacity of either 200,000 or 400,000 units. The annual fixed costs at the four locations are shown in Table 5-6,

TABLE 5-6 Production and Transport Costs for DryIce, Inc.

	New York	*Atlanta*	*Chicago*	*San Diego*
Annual fixed cost of 200,000 plant	$6 million	$5.5 million	$5.6 million	$6.1 million
Annual fixed cost of 400,000 plant	$10 million	$9.2 million	$9.3 million	$10.2 million
East	$211	$232	$238	$299
South	$232	$212	$230	$280
Midwest	$240	$230	$215	$270
West	$300	$280	$270	$225

TABLE 5-7 Capacity, Demand, Production, and Transportation Costs for Sunchem

	North America	*South America*	*Europe*	*Japan*	*Asia*	*Capacity Tons/Year*	*Production Cost/Ton*
United States	600	1,200	1,300	2,000	1,700	185	$10,000
Germany	1,300	1,400	600	1,400	1,300	475	15,000 marks
Japan	2,000	2,100	1,400	300	900	50	1,800,000 yen
Brazil	1,200	800	1,400	2,100	2,100	200	13,000 real
India	2,200	2,300	1,300	1,000	800	80	400,000 rupees
Demand (tons/year)	270	190	200	120	100		

TABLE 5-8 Anticipated Exchange Rates for 2006

	US$	*Mark*	*Yen*	*Real*	*Rupee*
US$	1.000	1.993	107.7	1.78	43.55
Mark	0.502	1	54.07	0.89	21.83
Yen	0.0093	0.0185	1	0.016	0.405
Real	0.562	1.124	60.65	1	24.52
Rupee	0.023	0.046	2.47	0.041	1

along with the cost of producing and shipping an air conditioner to each of the four markets. Where should DryIce build its factories and how large should they be?

3. Sunchem, a manufacturer of printing inks, has five manufacturing plants worldwide. Their locations and capacities are shown in Table 5-7 along with the cost of producing 1 ton of ink at each facility. The production costs are in the local currency of the country where the plant is located. The major markets for the inks are North America, South America, Europe, Japan, and the rest of Asia. Demand at each market is shown in Table 5-7. Transportation costs from each plant to each market in U.S. dollars are shown in Table 5-7. Management must come up with a production plan for 2006.
   (a) If exchange rates are expected as in Table 5-8, and no plant can run below 50 percent of capacity, how much should each plant produce and which markets should each plant supply?
   (b) If there are no limits on the amount produced in a plant, how much should each plant produce?
   (c) Can adding 10 tons of capacity in any plant reduce costs?
   (d) How should Sunchem account for the fact that exchange rates fluctuate over time?
4. Sleekfon and Sturdyfon are two major cell phone manufacturers that have recently merged. Their current market sizes are as shown in Table 5.9. All demand is in millions of units.

TABLE 5-9 Global Demand and Duties for Sleekfon and Sturdyfon

Market	*N. America*	*S. America*	*Europe (EU)*	*Europe (Non EU)*	*Japan*	*Rest of Asia/ Australia*	*Africa*
Sleekfon demand	10	4	20	3	2	2	1
Sturdyfon demand	12	1	4	8	7	3	1
Import duties (%)	3	20	4	15	4	22	25

TABLE 5-10 Plant Capacities and Costs for Sleekfon and Sturdyfon

		Capacity	*Fixed Cost/Year*	*Variable Cost/Unit*
Sleekfon	Europe (EU)	20	100	6.0
	N. America	20	100	5.5
	S. America	10	60	5.3
Sturdyfon	Europe (EU)	20	100	6.0
	N. America	20	100	5.5
	Rest of Asia	10	50	5.0

Sleekfon has three production facilities in Europe (EU), North America, and South America. Sturdyfon also has three production facilities in Europe (EU), North America, and Rest of Asia. The capacity (in millions of units), annual fixed cost (in millions of $), and variable production costs ($ per unit) for each plant are as shown in Table 5.10.

Transportation costs between regions are as shown in Table 5.11. All transportation costs are shown in $ per unit.

Duties are applied on each unit based on the fixed cost per unit capacity, variable cost per unit, and transportation cost. Thus a unit currently shipped from North America to Africa has a fixed cost per unit of capacity of $5.00, a variable production cost of $5.50, and a transportation cost of $2.20. The 25 percent import duty is thus applied on $12.70 (5.00 + 5.50 + 2.20) to give a total cost on import of $15.90. For the questions below, assume that market demand is as in Table 5.9.

The merged company has estimated that scaling back a 20-million-unit plant to 10 million units saves 30 percent in fixed costs. Variable costs at a scaled-back plant are unaffected. Shutting a plant down (either 10 million or 20 million units) saves 80 percent in fixed costs. Fixed costs are only partially recovered because of severance and other costs associated with a shutdown.

(a) What is the lowest cost achievable for the production and distribution network prior to the merger? Which plants serve which markets?

(b) What is the lowest cost achievable for the production and distribution network after the merger if none of the plants is shut down? Which plants serve which markets?

(c) What is the lowest cost achievable for the production and distribution network after the merger if plants can be scaled back or shut down in batches of 10 million units of capacity? Which plants serve which markets?

TABLE 5-11 Transportation Costs Between Regions ($ per Unit)

	N. America	*S. America*	*Europe (EU)*	*Europe (Non EU)*	*Japan*	*Rest of Asia/ Australia*	*Africa*
N. America	1.00	1.50	1.50	1.80	1.70	2.00	2.20
S. America	1.50	1.00	1.70	2.00	1.90	2.20	2.20
Europe (EU)	1.50	1.70	1.00	1.20	1.80	1.70	1.40
Europe (Non EU)	1.80	2.00	1.20	1.00	1.80	1.60	1.50
Japan	1.70	1.90	1.80	1.80	1.00	1.20	1.90
Rest of Asia/ Australia	2.00	2.20	1.70	1.60	1.20	1.00	1.80
Africa	2.20	2.20	1.40	1.50	1.90	1.80	1.00

(d) How is the optimal network configuration affected if all duties are reduced to 0?
(e) How should the merged network be configured?

5. Return to the Sleekfon and Sturdyfon data in Exercise 4. Management has estimated that demand in global markets is likely to grow. North America, Japan, and Europe (EU) are relatively saturated and expect no growth. South America, Africa, and Europe (Non EU) markets expect a growth of 20 percent. The rest of Asia/Australia anticipates a growth of 200 percent.
   (a) How should the merged company configure its network to accommodate the anticipated growth? What is the annual cost of operating the network?
   (b) There is an option of adding capacity at the plant in Rest of Asia/Australia. Adding 10 million units of capacity incurs additional fixed cost of $40 million per year. Adding 20 million units of additional capacity incurs additional fixed cost of $70 million per year. If shutdown costs and duties are as in Exercise 4, how should the merged company configure its network to accommodate anticipated growth? What is the annual cost of operating the new network?
   (c) If all duties are reduced to 0, how does your answer to Exercise 5(b) change?
   (d) How should the merged network be configured given the option of adding to the plant in Rest of Asia/Australia?
6. StayFresh, a manufacturer of refrigerators in India, has two plants—one in Mumbai and the other in Chennai. Each plant has a capacity of 300,000 units. The two plants serve the entire country, which is divided into four regional markets: the North, with a demand of 100,000 units; the West, with a demand of 150,000 units; the South, with a demand of 150,000 units; and the East, with a demand of 50,000 units. Two other potential sites for plants include Delhi and Kolkata. The variable production and transport costs (in thousands of rupees; 1 U.S. dollar is worth about 45 rupees) per refrigerator from each potential production site to each market are as shown in Table 5.12.

   StayFresh is anticipating a compounded growth in demand of 20 percent per year for the next five years and must plan its network investment decisions. Demand is anticipated to stabilize after five years of growth. Capacity can be added in increments of either 150,000 or 300,000 units. Adding 150,000 units of capacity incurs a one-time cost of 2 billion rupees, whereas adding 300,000 units of capacity incurs a one-time cost of 3.4 billion rupees. Assume that StayFresh plans to meet all demand (prices are sufficiently high) and that capacity for each year must be in place by the beginning of the year. Also assume that the cost for the fifth year will continue for the next 10 years, that is, years 6 to 15. The problem can now be solved for different discount factors. To begin with, assume a discount factor of 0.2, that is, 1 rupee spent next year is worth $1 - 0.2 = 0.8$ rupee this year.
   (a) How should the production network for the company evolve over the next five years?
   (b) How does your answer change if the anticipated growth is 15 percent? 25 percent?
   (c) How does your decision change for a discount factor of 0.25? 0.15?
   (d) What investment strategy do you recommend for the company?
7. Blue Computers, a major PC manufacturer in the United States, currently has plants in Kentucky and Pennsylvania. The Kentucky plant has a capacity of 1 million units a year and

TABLE 5-12 Production and Transport Cost ('000s Rupees) per Refrigerator

	North	*East*	*West*	*South*
Chennai	20	19	17	15
Delhi	15	18	17	20
Kolkata	18	15	20	19
Mumbai	17	20	15	17

TABLE 5-13 Variable Production and Shipping Costs for Blue Computers

	Variable Production and Shipping Cost ($/Unit)					*Annual Fixed Cost*
	Northeast	*Southeast*	*Midwest*	*South*	*West*	*(Million $)*
Kentucky	185	180	175	175	200	150
Pennsylvania	170	190	180	200	220	200
N. Carolina	180	180	185	185	215	150
California	220	220	195	195	175	150
Demand ('000 units/month)	700	400	400	300	600	

the Pennsylvania plant has a capacity of 1.5 million units a year. The firm divides the United States into five markets: Northeast, Southeast, Midwest, South, and West. Each PC sells for $1,000. The firm anticipates a 50 percent growth in demand (in each region) this year (after which demand will stabilize) and wants to build a plant with a capacity of 1.5 million units per year to accommodate the growth. Potential sites being considered are in North Carolina and California. Currently the firm pays federal, state, and local taxes on the income from each plant. Federal taxes are 20 percent of income, and all state and local taxes are 7 percent of income in each state. North Carolina has offered to reduce taxes for the next 10 years from 7 percent to 2 percent. Blue Computers would like to take the tax break into consideration when planning its network. Consider income over the next 10 years in your analysis. Assume that all costs remain unchanged over the 10 years. Use a discount factor of 0.1 for your analysis. Annual fixed costs, production and shipping costs per unit, and current regional demand (before the 50 percent growth) are shown in Table 5-13.

(a) If Blue Computers sets an objective of minimizing total fixed and variable costs, where should they build the new plant? How should the network be structured?

(b) If Blue Computers sets an objective of maximizing after-tax profits, where should they build the new plant? How should the network be structured?

8. Hot&Cold and CaldoFreddo are two European manufacturers of home appliances that have merged. Hot&Cold has plants in France, Germany, and Finland, whereas CaldoFreddo has plants in the United Kingdom and Italy. The European market is divided into four regions: North, East, West, and South. Plant capacities (millions of units per year), annual fixed costs (millions of euros per year), regional demand (millions of units), and variable production and shipping costs (euros per unit) are as shown in Table 5-14.

Each appliance sells for an average price of 300 euros. All plants are currently treated as profit centers, and the company pays taxes separately for each plant. Tax rates in the various countries are as follows: France, 0.25; Germany. 0.25; Finland, 0.3; U.K., 0.2; Italy, 0.35.

TABLE 5-14 Capacity, Cost, and Demand Data for Hot&Cold and CaldoFreddo

		Variable Production and Shipping Costs					*Annual*
		North	*East*	*South*	*West*	*Capacity*	*Fixed Cost*
Hot&Cold	France	100	110	105	100	50	1,000
	Germany	95	105	110	105	50	1,000
	Finland	90	100	115	110	40	850
Demand		30	20	20	35		
CaldoFreddo	U.K.	105	120	110	90	50	1,000
	Italy	110	105	90	115	60	1,150
Demand		15	20	30	20		

(a) Before the merger, what is the optimal network for each of the two firms if their goal is to minimize costs? What is the optimal network if the goal is to maximize after-tax profits?

(b) After the merger, what is the minimum cost configuration if none of the plants is shut down? What is the configuration that maximizes after-tax profits if none of the plants is shut down?

(c) After the merger, what is the minimum cost configuration if plants can be shut down (assume that a shutdown saves 100 percent of the annual fixed cost of the plant)? What is the configuration that maximizes after-tax profits?

Bibliography

Anderson, Kenneth E., Daniel P. Murphy, and James M. Reeve. "Smart Tax Planning for Supply Chain Facilities." *Supply Chain Management Review* (November–December 2002): 46–52.

Ballou, Ronald H. *Business Logistics Management.* Upper Saddle River, NJ: Prentice Hall, 1999.

Daskin, Mark S. *Network and Discrete Location.* New York: Wiley, 1995.

Ferdows, Kasra. "Making the Most of Foreign Factories." *Harvard Business Review* (March–April 1997): 73–88.

Harding, Charles F. "Quantifying Abstract Factors in Facility-Location Decisions." *Industrial Development* (May–June 1988): 24.

Korpela, Jukka, Antti Lehmusvaara, and Markku Tuominen. "Customer Service Based Design of the Supply Chain." *International Journal of Production Economics* (2001) 69: 193–204.

MacCormack, Alan D., Lawrence J. Newman III, and Donald B. Rosenfield. "The New Dynamics of Global Manufacturing Site Location." *Sloan Management Review* (Summer 1994): 69–79.

Note on Facility Location. Harvard Business School Note 9–689–059, 1989.

Robeson, James F., and William C. Copacino, eds. *The Logistics Handbook.* New York: Free Press, 1994.

Tayur, Sridhar, Ram Ganeshan, and Michael Magazine, eds. *Quantitative Models for Supply Chain Management.* Boston: Kluwer Academic Publishers, 1999.

Tirole, Jean. *The Theory of Industrial Organization.* Cambridge, MA: The MIT Press, 1997.

CASE STUDY

MANAGING GROWTH AT SPORTSTUFF.COM

In December 2000, Sanjay Gupta and his management team were busy evaluating the performance at SportStuff.com over the previous year. Demand had grown by 80 percent. This growth, however, was a mixed blessing. The venture capitalists supporting the company were very pleased with the growth in sales and the resulting increase in revenue. Sanjay and his team, however, could clearly see that costs would grow faster than revenues if demand continued to grow and the supply chain network was not redesigned. They decided to analyze the performance of the current network to see how it could be redesigned to best cope with the rapid growth anticipated over the next three years.

SPORTSTUFF.COM

Sanjay Gupta founded SportStuff.com in 1996 with a mission of supplying parents with more affordable sports equipment for their children. Parents complained about having to discard expensive skates, skis, jackets, and shoes because children outgrew them rapidly. Sanjay's initial plan was for the company to purchase used equipment and jackets from families and any surplus equipment from manufacturers and retailers and sell these over the Internet. The idea was very well received in the marketplace, demand grew rapidly, and by the end of 1996, the company had sales of $0.8 million. By this time a variety of new and used products were being sold and the company received significant venture capital support.

In June 1996, Sanjay leased part of a warehouse in the outskirts of St. Louis to manage the large amount of product being sold. Suppliers sent their product to the warehouse. Customer orders were packed and shipped by UPS from there. As demand grew, SportStuff.com leased more space within the warehouse. By 1999, SportStuff.com leased the entire warehouse and orders were being shipped to customers all over the United States. Management divided the United States into six customer zones for planning purposes. Demand from each customer zone in 1999 was as shown in Table 5-15. Sanjay estimated that the next three years would see a growth rate of about 80 percent per year, after which demand would level off.

THE NETWORK OPTIONS

Sanjay and his management team could see that they needed more warehouse space to cope with the anticipated growth. One option was to lease more warehouse space in St. Louis itself. Other options included leasing warehouses all over the country. Leasing a warehouse involved fixed costs based on the size of the warehouse and variable costs that varied with the quantity shipped through the warehouse. Four potential locations for warehouses were identified in Denver, Seattle, Atlanta, and Philadelphia. Warehouses leased could be either small (about 100,000 sq. ft.) or large (200,000 sq. ft.). Small warehouses could handle a flow of up to 2 million units per year, whereas large warehouses could handle a flow of up to 4 million units per year. The current warehouse in St. Louis was small. The fixed and variable costs of small and large warehouses in different locations are shown in Table 5-16.

TABLE 5-15 Regional Demand at SportStuff.com for 1999

Zone	*Demand in 1999*	*Zone*	*Demand in 1999*
Northwest	320,000	Lower Midwest	220,000
Southwest	200,000	Northeast	350,000
Upper Midwest	160,000	Southeast	175,000

TABLE 5-16 Fixed and Variable Costs of Potential Warehouses

	Small Warehouse		*Large Warehouse*	
Location	*Fixed Cost ($/year)*	*Variable Cost ($/Unit Flow)*	*Fixed Cost ($/year)*	*Variable Cost ($/Unit Flow)*
Seattle	300,000	0.20	500,000	0.2
Denver	250,000	0.20	420,000	0.2
St. Louis	220,000	0.20	375,000	0.2
Atlanta	220,000	0.20	375,000	0.2
Philadelphia	240,000	0.20	400,000	0.2

TABLE 5-17 UPS Charges per Shipment (Four Units)

	Northwest	*Southwest*	*Upper Midwest*	*Lower Midwest*	*Northeast*	*Southeast*
Seattle	$2.00	$2.50	$3.50	$4.00	$5.00	$5.50
Denver	$2.50	$2.50	$2.50	$3.00	$4.00	$4.50
St. Louis	$3.50	$3.50	$2.50	$2.50	$3.00	$3.50
Atlanta	$4.00	$4.00	$3.00	$2.50	$3.00	$2.50
Philadelphia	$4.50	$5.00	$3.00	$3.50	$2.50	$4.00

Sanjay estimated that the inventory holding costs at a warehouse (excluding warehouse expense) was about $\$600\sqrt{F}$, where F is the number of units flowing through the warehouse per year. Thus, a warehouse handling 1,000,000 units per year incurred an inventory holding cost of $600,000 in the course of the year. If your version of Excel has problems solving the nonlinear objective function, use the following inventory costs:

Range of *F*	**Inventory Cost**
0–2 million	$\$250{,}000 + 0.310F$
2–4 million	$\$530{,}000 + 0.170F$
4–6 million	$\$678{,}000 + 0.133F$
Over 6 million	$\$798{,}000 + 0.113F$

If you can handle only a single linear inventory cost, you should use $\$475{,}000 + 0.165F$.

SportStuff.com charged a flat fee of $3 per shipment sent to a customer. An average customer order contained four units. SportStuff.com in turn contracted with UPS to handle all its outbound shipments. UPS charges were based on both the origin and the destination of the shipment and are shown in Table 5-17. Management estimated that inbound transportation costs for shipments from suppliers were likely to remain unchanged, no matter what warehouse configuration was selected.

QUESTIONS

1. What is the cost SportStuff.com incurs if all warehouses leased are in St. Louis?
2. What supply chain network configuration do you recommend for SportStuff.com?

CHAPTER 6
NETWORK DESIGN IN AN UNCERTAIN ENVIRONMENT



Learning Objectives

After reading this chapter, you will be able to:

1. Identify uncertainties that influence supply chain performance and network design.
2. Understand the methodologies used to evaluate supply chain design decisions under uncertainty.
3. Analyze supply chain network design decisions in an uncertain environment.

In previous chapters, we emphasized that network design decisions have a long-term impact on a supply chain's performance. As a result, managers must account for demand, macroeconomic, and financial uncertainties over the long term when designing a supply chain network. In this chapter, we discuss the methodologies used to evaluate network design decisions under uncertainty and show how they improve supply chain decisions.

6.1 THE IMPACT OF UNCERTAINTY ON NETWORK DESIGN

Supply chain design decisions such as the number and size of plants to build, the size and scope of a distribution system, and whether to buy or lease one's facilities involve significant investment. These decisions, once made, cannot be altered in the short term. They remain in place for several years and define the constraints within which the supply chain must compete. Thus, it is important that these decisions be evaluated as accurately as possible.

Over the life of a supply chain network, a company experiences fluctuations in demand, prices, exchange rates, and the competitive environment. A decision that looks very good under the current environment may be quite poor if the situation changes. For example, long-term contracts for warehousing are more attractive if the demand and price of warehousing do not change in the future or if the price of warehousing goes up. In contrast, a short-term contract is more attractive if either demand or the price of warehousing drops in the future. The degree of demand and price uncertainty has a significant influence on the appropriate portfolio of long- and short-term warehousing space that a firm should carry.

Uncertainty of demand and price drives the value of building flexible production capacity at a plant. If price and demand do vary over time in a global network, flexible production capacity can be reconfigured to maximize profits in the new environment. In the late 1990s, Toyota made its global assembly plants more flexible so that each plant could supply multiple markets. One of the main benefits of this flexibility is that

it allows Toyota to react to fluctuations in demand, exchange rates, and local prices by altering production to maximize profits. A firm may choose to build a flexible global supply chain even in the presence of little demand or supply uncertainty if uncertainty exists in exchange rates or prices. Thus, supply, demand, and financial uncertainty must be considered when making network design decisions.

In the next section we discuss a methodology for evaluating any supply chain decision that will be in place for an extended duration.

6.2 DISCOUNTED CASH FLOW ANALYSIS

Supply chain design decisions should be evaluated as a sequence of cash flows over the duration of time that they will be in place. The present value of a stream of cash flows is what that stream is worth in today's dollars. *Discounted cash flow* (DCF) analysis evaluates the present value of any stream of future cash flows and allows management to compare two streams of cash flows in terms of their financial value. DCF analysis is based on the fundamental premise that "a dollar today is worth more than a dollar tomorrow" because a dollar today may be invested and earn a return in addition to the dollar invested. This premise provides the basic tool for comparing the relative value of future cash flows that will arrive during different time periods.

The present value of future cash flow is found by using a discount factor. If a dollar today can be invested and earn a rate of return k over the next period, an investment of \$1 today will result in $1 + k$ dollars in the next period. An investor will therefore be indifferent between obtaining \$1 in the next period or $\$1/(1 + k)$ in the current period. Thus, \$1 in the next period is discounted by the

$$\text{Discount factor} = \frac{1}{1 + k} \tag{6.1}$$

to obtain its present value.

The rate of return k is also referred to as the discount rate, hurdle rate, or opportunity cost of capital. Given a stream of cash flows $C_0, C_1, \ldots, C_T$ over the next T periods, and a rate of return k, the net present value (NPV) of this cash flow stream is given by

$$\text{NPV} = C_0 + \sum_{t=1}^{T} \left(\frac{1}{1 + k}\right)^t C_t \tag{6.2}$$

The NPV of different options should be compared when making supply chain decisions. A negative NPV for an option indicates that the option will lose money for the supply chain. The decision with the highest NPV provides a supply chain with the highest financial return.

Consider Trips Logistics, a third-party logistics firm that provides warehousing and other logistics services. The general manager at Trips Logistics must decide the amount of space to lease for the upcoming three-year period. He has forecast that Trips Logistics will need to handle a demand of 100,000 units for each of the three years. Historically, Trips Logistics has required 1,000 sq. ft. of warehouse space for every 1,000 units of demand. For the purposes of this discussion, the only cost Trips Logistics faces is the cost for the warehouse.

Trips Logistics receives revenue of \$1.22 for each unit of demand. The general manager must decide whether to sign a three-year lease or obtain warehousing space on the spot market each year. The three-year lease costs \$1 per square foot per year

and the spot market rate is expected to be \$1.20 per square foot per year for each of the three years. Trips Logistics has a discount rate of $k = 0.1$.

The general manager decides to compare the NPV of signing a three-year lease for 100,000 sq. ft. of warehouse space with obtaining the space from the spot market each year.

If the general manager obtains warehousing space from the spot market each year, Trips Logistics earns \$1.22 for each unit and pays \$1.20 for each square foot of warehouse space required. The expected annual profit for Trips Logistics in this case is determined as follows:

$$\text{Expected annual profit if warehousing space is obtained from spot market} = 100{,}000 \times \$1.22 - 100{,}000 \times \$1.20 = \$2{,}000$$

Obtaining warehouse space from the spot market provides Trips Logistics with an expected positive cash flow of \$2,000 in each of the three years. The NPV is evaluated as follows:

$$\text{NPV(No lease)} = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2} = 2{,}000 + \frac{2{,}000}{1.1} + \frac{2{,}000}{1.1^2} = \$5{,}471$$

If the general manager leases 100,000 sq. ft. of warehouse space for the next three years, Trips Logistics pays \$1 per square foot of space leased each year. The expected annual profit for Trips Logistics in this case is given by the following:

$$\text{Expected annual profit with three-year lease} = 100{,}000 \times \$1.22 - 100{,}000 \times \$1.00 = \$22{,}000$$

Signing a lease for three years provides Trips Logistics with a positive cash flow of \$22,000 in each of the three years. The NPV is evaluated as follows:

$$\text{NPV(Lease)} = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2} = 22{,}000 + \frac{22{,}000}{1.1} + \frac{22{,}000}{1.1^2} = \$60{,}182$$

The NPV of signing the lease is \$60,182 − \$5,471 = \$54,711 higher than obtaining warehousing space on the spot market. Based on this simple analysis, a manager may opt to sign the lease. However, this does not tell the whole story, as we have not yet valued the greater flexibility to adjust to uncertainty that the spot market gives us. Later in the chapter, we discuss how the inclusion of uncertainty of future demand and costs may cause the manager to rethink the decision.

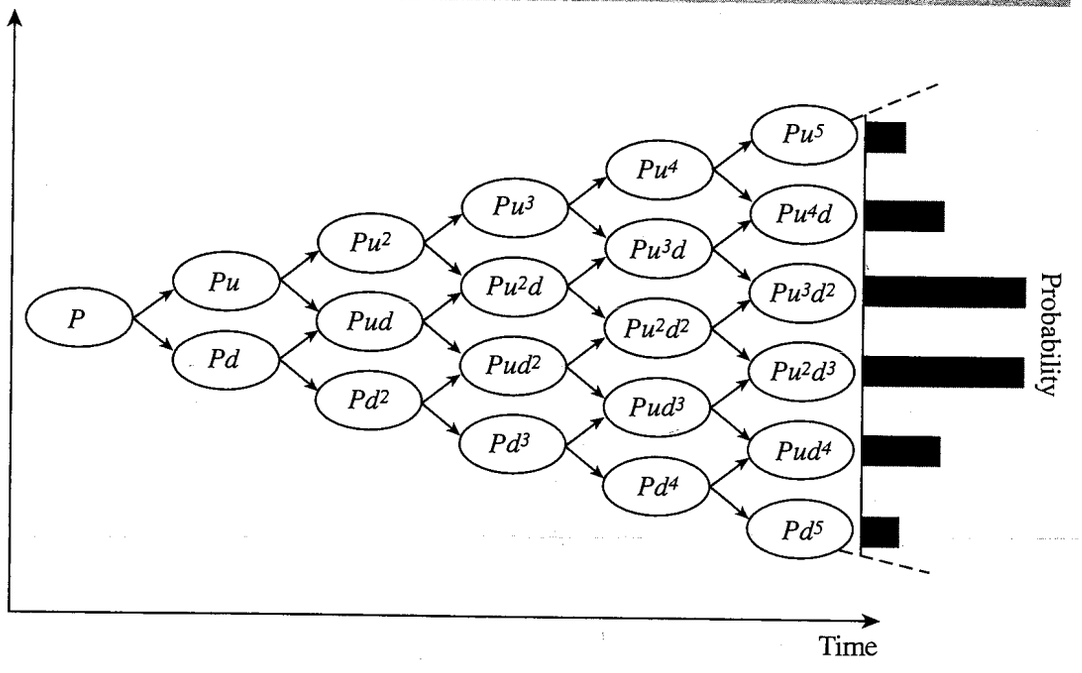
6.3 REPRESENTATIONS OF UNCERTAINTY

The manager at Trips Logistics considers both future demand and spot market prices to be predictable. In reality, demand and prices are highly uncertain and are likely to fluctuate during the life of any supply chain decision. For a global supply chain, exchange rates and inflation are also likely to vary over time in different locations. Supply chain managers must incorporate these uncertainties when making network design decisions. Next we discuss some models that can be used to represent uncertainty in factors such as demand, price, and exchange rate.

BINOMIAL REPRESENTATION OF UNCERTAINTY

The binomial representation of uncertainty is based on the assumption that when moving from one period to the next, the value of the underlying factor (such as demand or

FIGURE 6-1 The Multiplicative Binomial Tree



price) has only two possible outcomes—up or down. In the commonly used multiplicative binomial, it is assumed that the underlying factor either moves up by a factor $u > 1$ with probability p, or down by a factor $d < 1$ with probability $1 - p$. Given a price P in Period 0, the possible outcomes in future periods are as follows:

Period 1: Pu, Pd
Period 2: Pu^2, Pud, Pd^2
Period 3: Pu^3, Pu^2d, Pud^2, Pd^3
Period 4: $Pu^4, Pu^3d, Pu^2d^2, Pud^3, Pd^4$

In general, Period T has all possible outcomes $Pu^t d^{(T-t)}$, for $t = 0, 1, \ldots, T$. From a state $Pu^a d^{(T-a)}$ in Period t, the price may move to either $Pu^{a+1}d^{(T-a)}$ with probability p or $Pu^a d^{(T-a)+1}$ with probability $(1 - p)$ in Period $t + 1$. This is represented as the binomial tree shown in Figure 6-1.

In the additive binomial, it is assumed that the underlying factor increases by u in a given period with probability p and decreases by d with probability $1 - p$. The additive binomial has the following states in a given period:

Period 1: $P + u, P - d$
Period 2: $P + 2u, P + u - d, P - 2d$
Period 3: $P + 3u, P + 2u - d, P + u - 2d, P - 3d$
Period 4: $P + 4u, P + 3u - d, P + 2u - 2d, P + u - 3d, P - 4d$

In general, Period T has all possible outcomes $P + tu - (T - t)d$, for $t = 0, 1, \ldots, T$.

The multiplicative binomial cannot take on negative values and can be used for factors such as demand, price, and exchange rates that cannot become negative. It also has the advantage of the growth or decline in the given factor being proportional to the current value of the factor. For example, a product with a unit price of \$10 is much less likely to see a fluctuation in price of \$5 than a product with a unit price of \$100. This fact is better captured by the multiplicative binomial.

A logical objection to both the multiplicative and additive binomials is the fact that the underlying factor takes on only one of two possible values at the end of each period. Certainly a price can change to more than just two values. But by making the period short enough, this assumption may be justified. The time period selected depends on the factor under consideration and the frequency with which decision making occurs. For example, if a decision is made monthly, the time period should be no longer than a month. A time period that is shorter than a month may be justified to allow more than two outcomes at the end of each month.

As the number of periods increases, the probability distribution among the end states of the multiplicative binomial becomes smoother and begins to resemble the normal distribution. Observe that as we go further into the future, the range of possible outcomes increases. This is a common property of all binomial distributions and is a reasonable assumption for many factors such as demand, price, or exchange rates.

OTHER REPRESENTATIONS OF UNCERTAINTY

In the valuation of options, the underlying asset price is often allowed to vary continuously over time. A commonly used process to describe the evolution of the asset price is the log-normal diffusion process. A key feature of this process is that the price never drops below zero. Another feature of the log-normal diffusion process that is similar to the binomial is that the variance of the asset price grows with time. In fact, the variance grows proportionally to the length of the time horizon.

Another common representation of the evolution of a financial factor is the mean reverting process. The idea here is that the factor fluctuates around a mean and experiences shocks. When the factor deviates, it is pulled back toward the mean over time. The farther from the mean that the factor strays, the stronger it is pulled back toward the mean.

6.4 EVALUATING NETWORK DESIGN DECISIONS USING DECISION TREES

A manager makes several different decisions when designing a supply chain network. For instance:

- Should the firm sign a long-term contract for warehousing space or get space from the spot market as needed?
- What should the firm's mix of long-term and spot market be in the portfolio of transportation capacity?
- How much capacity should various facilities have? What fraction of this capacity should be flexible?

If uncertainty is ignored, a manager will always sign long-term contracts (because they are typically cheaper) and avoid all flexible capacity (because it is more expensive). Such decisions, however, can hurt the firm if future demand or prices are not as forecast at the time of the decision.

For example, until around 1990, all production capacity in the pharmaceutical industry was dedicated. Dedicated capacity was cheaper than flexible capacity but could only be used for the drug it was designed for. Pharmaceutical companies, however, have found it very difficult to forecast the demand and price for drugs in the marketplace. Thus, a large fraction of the dedicated capacity can go unused if the forecast

demand does not materialize. Today, pharmaceutical companies have a strategy of carrying a portfolio of dedicated and flexible capacity. Most products are introduced in a flexible facility and are moved to a dedicated facility only when a reasonably accurate forecast of future demand is available.

During network design, managers thus need a methodology that allows them to estimate the uncertainty in their forecast of demand and price and then incorporate this uncertainty in the decision-making process. Such a methodology is most important for network design decisions because these decisions are hard to change in the short term. In this section we describe such a methodology and show that accounting for uncertainty can have a significant impact on the value of network design decisions.

A *decision tree* is a graphic device used to evaluate decisions under uncertainty. Decision trees with DCFs can be used to evaluate supply chain design decisions given uncertainty in prices, demand, exchange rates, and inflation.

The first step in setting up a decision tree is to identify the number of time periods into the future that will be considered when making the decision. The decision maker should also identify the duration of a period—which could be a day, a month, a quarter, or any other time period. The duration of a period should be the minimum period of time over which factors affecting supply chain decisions may change by a *significant* amount. "Significant" is hard to define, but in most cases it is appropriate to use the duration over which an aggregate plan holds as a period. If planning is done monthly, we set the duration of a period at a month. In the following discussion, T will represent the number of time periods over which the supply chain decision is to be evaluated.

The next step is to identify factors that will affect the value of the decision and are likely to fluctuate over the next T periods. These factors include demand, price, exchange rate, and inflation, among others. Having identified the key factors, the next step is to identify probability distributions that define the fluctuation of each factor from one period to the next. If, for instance, demand and price are identified as the two key factors that affect the decision, the probability of moving from a given value of demand and price in one period to any other value of demand and price in the next period must be defined.

The next step is to identify a periodic discount rate k to be applied to future cash flows. It is not essential that the same discount rate apply to each period or even at every node in a period. The discount rate should take into account the inherent risk associated with the investment. In general, a higher discount rate should apply to investments with higher risk.

The decision is now evaluated using a decision tree, which contains the present and T future periods. Within each period a node must be defined for every possible combination of factor values (say, demand and price) that can be achieved. Arrows are drawn from origin nodes in Period i to end nodes in Period $i + 1$. The probability on an arrow is referred to as the transition probability and is the probability of transitioning from the origin node in Period i to the end node in Period $i + 1$.

The decision tree is evaluated starting from nodes in Period T and working back to Period 0. For each node, the decision is optimized taking into account current and future values of various factors. The analysis is based on *Bellman's principle,* which states that for any choice of strategy in a given state, the optimal strategy in the next period is the one that is selected if the entire analysis is assumed to begin in the next period. This principle allows the optimal strategy to be solved in a backward fashion starting at the last period. Expected future cash flows are discounted back and included in the decision currently under consideration. The value of the node in

Period 0 gives the value of the investment as well as the decisions made during each time period. Tools such as *Treeplan* are available that help solve decision trees on spreadsheets.

The decision tree analysis methodology is summarized as follows:

1. Identify the duration of each period (month, quarter, etc.) and the number of periods T over which the decision is to be evaluated.
2. Identify factors such as demand, price, and exchange rate whose fluctuation will be considered over the next T periods.
3. Identify representations of uncertainty for each factor; that is, determine what distribution to use to model the uncertainty.
4. Identify the periodic discount rate k for each period.
5. Represent the decision tree with defined states in each period as well as the transition probabilities between states in successive periods.
6. Starting at period T, work back to Period 0 identifying the optimal decision and the expected cash flows at each step. Expected cash flows at each state in a given period should be discounted back when included in the previous period.

We illustrate the decision tree analysis methodology by using the lease decision facing the general manager at Trips Logistics. The manager must decide whether to lease warehouse space for the coming three years and the quantity to lease. The long-term lease is currently cheaper than the spot market rate for warehouse space. The manager anticipates uncertainty in demand and spot prices for warehouse space over the coming three years. The long-term lease is cheaper but could go unused if demand is lower than anticipated. The long-term lease may also end up being more expensive if future spot market prices come down. In contrast, spot market rates are high and warehouse space from the spot market will be expensive if future demand is high. The manager is considering three options:

1. Get all warehousing space from the spot market as needed.
2. Sign a three-year lease for a fixed amount of warehouse space and get additional requirements from the spot market.
3. Sign a flexible lease with a minimum charge that allows variable usage of warehouse space up to a limit with additional requirement from the spot market.

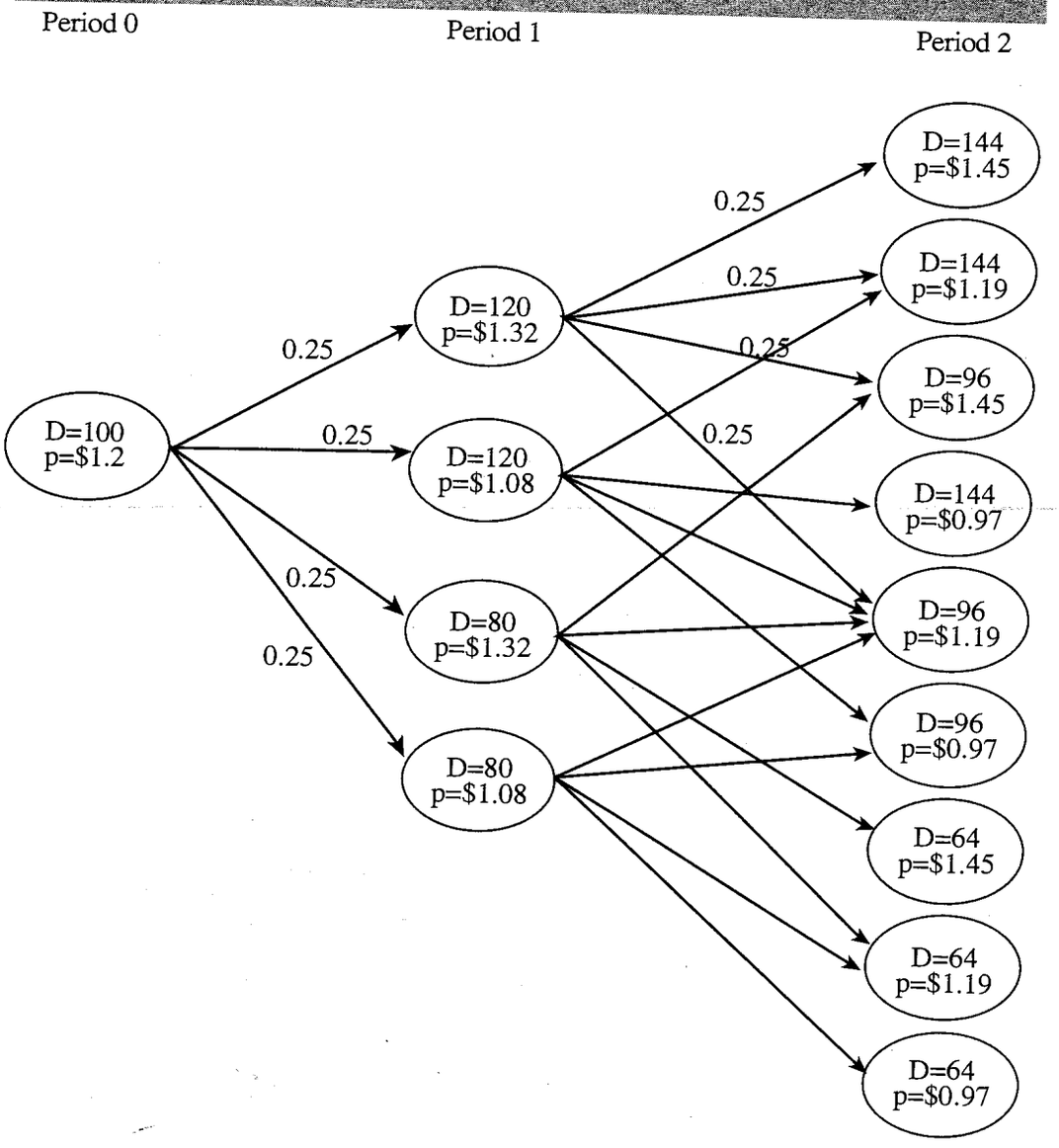
We now discuss how the manager can make the appropriate decision, taking uncertainty into account.

One thousand square feet of warehouse space is required for every 1,000 units of demand, and the current demand at Trips Logistics is for 100,000 units per year. The manager decides to use a multiplicative binomial representation of uncertainty for both demand and price. From one year to the next, demand may go up by 20 percent with a probability of 0.5 or go down by 20 percent with a probability of 0.5. The probabilities of the two outcomes are unchanged from one year to the next.

The general manager can sign a three-year lease at a price of $1 per square foot per year. Warehouse space is currently available on the spot market for $1.20 per square foot per year. From one year to the next, spot prices for warehouse space may go up by 10 percent with probability 0.5 or go down by 10 percent with probability 0.5 according to a binomial process. The probabilities of the two outcomes are unchanged from one year to the next.

The general manager feels that prices of warehouse space and demand for the product fluctuate independently. Each unit Trips Logistics handles results in revenue of $1.22 and Trips Logistics is committed to handling all demand that arises. Trips Logistics uses a discount rate of $k = 0.1$ for each of the three years.

FIGURE 6-2 Decision Tree for Trips Logistics Considering Demand and Price Fluctuation



The general manager assumes that all costs are incurred at the beginning of each year and thus constructs a decision tree with $T = 2$. The decision tree is shown in Figure 6-2, with each node representing demand (D) in thousands of units and price (p) in dollars. The probability of each transition is 0.25 because price and demand fluctuate independently.

The manager first analyzes the option of not signing a lease and obtaining all warehouse space from the spot market. He starts with Period 2 and evaluates the profit for Trips Logistics at each node. At the node $D = 144, p = \$1.45$, Trips Logistics must satisfy a demand of 144,000 and faces a spot price of $1.45 per square foot for warehouse space in Period 2. The cost incurred by Trips Logistics in Period 2 at the node $D = 144$, $p = \$1.45$ is represented by $C(D = 144, p = 1.45, 2)$ and is given by

$$C(D = 144, p = 1.45, 2) = 144{,}000 \times 1.45 = \$208{,}800$$

TABLE 6-1 Period 2 Calculations for Spot Market Option

	Revenue	*Cost* $C(D =, p =, 2)$	*Profit* $P(D =, p =, 2)$
$D = 144, p = 1.45$	$144{,}000 \times 1.22$	$144{,}000 \times 1.45$	−$33,120
$D = 144, p = 1.19$	$144{,}000 \times 1.22$	$144{,}000 \times 1.19$	$4,320
$D = 144, p = 0.97$	$144{,}000 \times 1.22$	$144{,}000 \times 0.97$	$36,000
$D = 96, p = 1.45$	$96{,}000 \times 1.22$	$96{,}000 \times 1.45$	−$22,080
$D = 96, p = 1.19$	$96{,}000 \times 1.22$	$96{,}000 \times 1.19$	$2,880
$D = 96, p = 0.97$	$96{,}000 \times 1.22$	$96{,}000 \times 0.97$	$24,000
$D = 64, p = 1.45$	$64{,}000 \times 1.22$	$64{,}000 \times 1.45$	−$14,720
$D = 64, p = 1.19$	$64{,}000 \times 1.22$	$64{,}000 \times 1.19$	$1,920
$D = 64, p = 0.97$	$64{,}000 \times 1.22$	$64{,}000 \times 0.97$	$16,000

The profit at Trips Logistics in Period 2 at the node $D = 144, p = \$1.45$ is represented by $P(D = 144, p = 1.45, 2)$ and is given by

$$P(D = 144, p = 1.45, 2) = 144{,}000 \times 1.22 - C(D = 144, p = 1.45, 2)$$
$$= 175{,}680 - 208{,}800 = -\$33{,}120$$

The profit for Trips Logistics at each of the other nodes in Period 2 is evaluated similarly, as shown in Table 6-1.

The manager next evaluates the expected profit at each node in Period 1 to be the profit during Period 1 plus the present value (in Period 1) of the expected profit in Period 2. The expected profit $EP(D =, p =, 1)$ at a node is the expected profit over all four nodes in Period 2 that may result from this node. $PVEP(D =, p =, 1)$ represents the present value of this expected profit and $P(D =, p =, 1)$, the total expected profit, is the sum of the profit in Period 1 and the present value of the expected profit in Period 2. From the node $D = 120$, $p = \$1.32$ in Period 1, there are four possible states in Period 2. The manager thus evaluates the expected profit in Period 2 over all four states possible from the node $D = 120$, $p = \$1.32$ in Period 1 to be $EP(D = 120, p = 1.32, 1)$, where

$$EP(D = 120, p = 1.32, 1) = 0.25 \times [P(D = 144, p = 1.45, 2) + P(D = 144,$$
$$p = 1.19, 2) + P(D = 96, p = 1.45, 2) + P(D = 96, p = 1.19, 2)]$$
$$= 0.25 \times [-33{,}120 + 4{,}320 - 22{,}080 + 2{,}880] = -\$12{,}000$$

The present value of this expected value in Period 1 is given by

$$PVEP(D = 120, p = 1.32, 1) = EP(D = 120, p = 1.32, 1)/(1 + k)$$
$$= -12{,}000/1.1 = -\$10{,}909$$

The manager obtains the total expected profit $P(D = 120, p = 1.32, 1)$ at node $D = 120, p = 1.32$ in Period 1 to be the sum of the profit in Period 1 at this node and the present value of future expected profits.

$$P(D = 120, p = 1.32, 1) = 120{,}000 \times 1.22 - 120{,}000 \times 1.32 + PVEP(D = 120,$$
$$p = 1.32, 1) = -\$12{,}000 - \$10{,}909 = -\$22{,}909$$

The total expected profit for all other nodes in Period 1 is evaluated as shown in Table 6-2.

For Period 0, the total profit $P(D = 100, p = 1.20, 0)$ is the sum of the profit at Period 0 and the present value of the expected profit over the four nodes in Period 1.

$$EP(D = 100, p = 1.20, 0) = 0.25 \times [P(D = 120, p = 1.32, 1) + P(D = 120,$$
$$p = 1.08, 1) + P(D = 96, p = 1.32, 1) + P(D = 96, p = 1.08, 1)]$$
$$= 0.25 \times [-22{,}909 + 32{,}073 - 15{,}273 + 21{,}382] = \$3{,}818$$

TABLE 6-2 Period 1 Calculations for Spot Market Option

Node	$EP(D =, p =, 1)$	$P(D =, p =, 1) = D \times 1.22 - D \times p + EP(D =, p =, 1)/(1 + k)$
$D = 120, p = 1.32$	−$12,000	−$22,909
$D = 120, p = 1.08$	$16,800	$32,073
$D = 80, p = 1.32$	−$8,000	−$15,273
$D = 80, p = 1.08$	$11,200	$21,382

$$PVEP(D = 100, p = 1.20, 1) = EP(D = 100, p = 1.20, 0)/(1 + k) = 3{,}818/1.1 = \$3{,}471$$

$$P(D = 100, p = 1.20, 0) = 100{,}000 \times 1.22 - 100{,}000 \times 1.20 + PVEP(D = 100, p = 1.20, 0) = \$2{,}000 + \$3{,}471 = \$5{,}471$$

Thus, the expected NPV of not signing the lease and obtaining all warehousing space from the spot market is given by

$$\text{NPV(Spot Market)} = \$5{,}471$$

The manager next evaluates the alternative where the lease for 100,000 sq. ft. of warehouse space is signed. The evaluation procedure is very similar to the previous case, but the outcome in terms of profit changes. For example, at the node $D = 144, p = 1.45$, the manager will require 44,000 sq. ft. of warehouse space from the spot market at $1.45 per square foot because only 100,000 sq. ft. has been leased at $1 per square foot. If demand happens to be less than 100,000 units, Trips Logistics still has to pay for the entire 100,000 sq. ft. of leased space. For Period 2 the manager obtains the profit at each of the nine nodes as shown in Table 6-3.

The manager next evaluates the total expected profit for each node in Period 1. Again, the expected profit $EP(D =, p =, 1)$ at a node is the expected profit of all four nodes in Period 2 that may result from this node (see Figure 6-2), and $P(D =, p =, 1)$ is the total expected profit from both Periods 1 and 2. The manager thus obtains the results in Table 6-4.

For Period 0, the expected profit $EP(D = 100, p = 1.20, 0)$ over the four nodes in Period 1 is given by

$$EP(D = 100, p = 1.20, 0) = 0.25 \times [P(D = 120, p = 1.32, 1) + P(D = 120, p = 1.08, 1) + P(D = 96, p = 1.32, 1) + P(D = 96, p = 1.08, 1)] = 0.25 \times [35{,}782 + 45{,}382 - 4{,}582 - 4{,}582] = \$18{,}000$$

TABLE 6-3 Period 2 Profit Calculations at Trips Logistics for Lease Option

Node	*Leased Space*	*Warehouse Space at Spot Price (S)*	*Profit* $P(D =, p =, 2) = D \times 1.22 - (100{,}000 \times 1 + S \times p)$
$D = 144, p = 1.45$	100,000 sq. ft.	44,000 sq. ft.	$11,880
$D = 144, p = 1.19$	100,000 sq. ft.	44,000 sq. ft.	$23,320
$D = 144, p = 0.97$	100,000 sq. ft.	44,000 sq. ft.	$33,000
$D = 96, p = 1.45$	100,000 sq. ft.	0 sq. ft.	$17,120
$D = 96, p = 1.19$	100,000 sq. ft.	0 sq. ft.	$17,120
$D = 96, p = 0.97$	100,000 sq. ft.	0 sq. ft.	$17,120
$D = 64, p = 1.45$	100,000 sq. ft.	0 sq. ft.	−$21,920
$D = 64, p = 1.19$	100,000 sq. ft.	0 sq. ft.	−$21,920
$D = 64, p = 0.97$	100,000 sq. ft.	0 sq. ft.	−$21,920

TABLE 6-4 Period 1 Profit Calculations at Trips Logistics for Lease Option

Node	*EP(D =, p =, 1)*	*Warehouse Space at Spot Price (S)*	*P(D =, p =, 1) = D × 1.22 − (100,000 × 1 + S × p) + EP(D =, p =, 1)/(1 + k)*
$D = 120$, $p = 1.32$	$0.25 \times [P(D = 144, p = 1.45, 2) + P(D = 144, p = 1.19, 2) + P(D = 96, p = 1.45, 2) + P(D = 96, p = 1.19, 2)] = 0.25 \times (11{,}880 + 23{,}320 + 17{,}120 + 17{,}120) = \$17{,}360$	20,000	\$35,782
$D = 120$, $p = 1.08$	$0.25 \times (23{,}320 + 33{,}000 + 17{,}120 + 17{,}120) = \$22{,}640$	20,000	\$45,382
$D = 80$, $p = 1.32$	$0.25 \times (17{,}120 + 17{,}120 - 21{,}920 - 21{,}920) = -\$2{,}400$	0	−\$4,582
$D = 80$, $p = 1.08$	$0.25 \times (17{,}120 + 17{,}120 - 21{,}920 - 21{,}920) = -\$2{,}400$	0	−\$4,582

The present value of the expected profit in Period 0 is given by

$$PVEP(D = 100, p = 1.20, 0) = EP(D = 100, p = 1.20, 0)/(1 + k) = 18{,}000/1.1 = \$16{,}364$$

The total expected profit is obtained as the sum of the profit in Period 0 and the present value of the expected profit over all four nodes in Period 1. It is

$$P(D = 100, p = 1.20, 0) = 100{,}000 \times 1.22 - 100{,}000 \times 1 + PVEP(D = 100, p = 1.20, 0) = \$22{,}000 + \$16{,}364 = \$38{,}364$$

The NPV of signing a three-year lease for 100,000 sq. ft. of warehouse space is thus

$$\text{NPV(Lease)} = \$38{,}364$$

Observe that the NPV of the lease option under uncertainty is considerably less than when uncertainty is ignored (\$60,182). This is because the lease is a fixed decision and Trips Logistics is unable to react to market conditions by leasing less space if demand is lower. Rigid contracts are less attractive in the presence of uncertainty.

The presence of uncertainty in demand and price reduces the value of the lease but does not affect the value of the spot market option. The manager, however, still prefers to sign the three-year lease for 100,000 sq. ft. because this option has a higher expected profit.

KEY POINT Uncertainty in demand and economic factors should be included in the financial evaluation of supply chain design decisions. The inclusion of uncertainty may have a significant impact on this evaluation.

EVALUATING FLEXIBILITY USING DECISION TREES

The decision tree analysis methodology is very useful when evaluating flexibility within a supply chain. We now consider the evaluation of flexibility with decision trees in the context of warehousing choices for Trips Logistics.

The general manager at Trips Logistics has been offered a contract in which, for an up-front payment of \$10,000, Trips Logistics will have the flexibility of using between 60,000 sq. ft. and 100,000 sq. ft. of warehouse space at \$1 per square foot per year. Trips

TABLE 6-5 Period 2 Profit Calculations at Trips Logistics with Flexible Lease Contract

Node	*Warehouse Space at \$1 (W)*	*Warehouse Space at Spot Price (S)*	*Profit P(D =, p =, 2) = D × 1.22 − (W × 1 + S × p)*
$D = 144, p = 1.45$	100,000 sq. ft.	44,000 sq. ft.	\$11,880
$D = 144, p = 1.19$	100,000 sq. ft.	44,000 sq. ft.	\$23,320
$D = 144, p = 0.97$	100,000 sq. ft.	44,000 sq. ft.	\$34,200
$D = 96, p = 1.45$	96,000 sq. ft.	0 sq. ft.	\$21,120
$D = 96, p = 1.19$	96,000 sq. ft.	0 sq. ft.	\$21,120
$D = 96, p = 0.97$	96,000 sq. ft.	0 sq. ft.	\$22,200
$D = 64, p = 1.45$	64,000 sq. ft.	0 sq. ft.	\$14,080
$D = 64, p = 1.19$	64,000 sq. ft.	0 sq. ft.	\$14,080
$D = 64, p = 0.97$	64,000 sq. ft.	0 sq. ft.	\$14,200

Logistics must pay \$60,000 per year for the first 60,000 sq. ft. and can then use up to another 40,000 sq. ft. on demand at \$1 per square foot. The general manager decides to use decision trees to evaluate whether this flexible contract is preferable to a fixed contract for 100,000 sq. ft.

The underlying decision tree for evaluating the flexible contract is exactly as in Figure 6-2. The profit at each node, however, changes because of the flexibility. If demand is larger than 100,000 units, Trips Logistics uses all 100,000 sq. ft. of warehouse space even under the flexible contract. If demand is between 60,000 and 100,000 units, Trips Logistics pays only for the exact amount of warehouse space used rather than the entire 100,000 sq. ft. under the contract without flexibility. The profit at all nodes where demand is 100,000 or higher remains the same as in Table 6-3. The profit in Period 2 at all nodes where demand is less than 100,000 units increases as shown in Table 6-5.

The general manager evaluates the expected profit $EP(D =, p =, 1)$ from Period 2 and the total expected profit for each node in Period 1 as discussed earlier. The results are shown in Table 6-6.

The total expected profit in Period 0 is the sum of the profit in Period 0 and the present value of the expected profit in Period 1. The manager thus obtains

$$EP(D = 100, p = 1.20, 0) = 0.25 \times [P(D = 120, p = 1.32, 1) + P(D = 120, p = 1.08, 1) + P(D = 96, p = 1.32, 1) + P(D = 96, p = 1.08, 1)]$$
$$= 0.25 \times [37{,}600 + 47{,}718 + 33{,}600 + 33{,}873] = \$38{,}198$$

TABLE 6-6 Period 1 Profit Calculations at Trips Logistics with Flexible Lease Contract

Node	*EP(D =, p =, 1)*	*Warehouse Space at \$1 (W)*	*Warehouse Space at Spot Price (S)*	*P(D =, p =, 1) = D × 1.22 − (W × 1 + S × p) + EP(D =, p =, 1)/(1 + k)*
$D = 120, p = 1.32$	0.25 × (11,880 + 23,320 + 21,120 + 21,120) = \$19,360	100,000	20,000	\$37,600
$D = 120, p = 1.08$	0.25 × (23,320 + 34,200 + 21,120 + 22,200) = \$25,210	100,000	20,000	\$47,718
$D = 80, p = 1.32$	0.25 × (21,120 + 21,120 + 14,080 + 14,080) = \$17,600	80,000	0	\$33,600
$D = 80, p = 1.08$	0.25 × (21,120 + 22,200 + 14,080 + 14,200) = \$17,900	80,000	0	\$33,873

TABLE 6-7 Comparison of Different Lease Options for Trips Logistics

Option	*Value*
All warehouse space from the spot market	$5,471
Lease 100,000 sq. ft. for three years	$38,364
Flexible lease to use between 60,000 and 100,000 sq. ft.	$46,725

$$PVEP(D = 100, p = 1.20, 1) = EP(D = 100, p = 1.20, 0)/(1 + k)$$
$$= 38{,}198/1.1 = \$34{,}725$$

$$P(D = 100, p = 1.20, 0) = 100{,}000 \times 1.22 - 100{,}000 \times 1 + PVEP(D = 100,$$
$$p = 1.20, 0) = \$22{,}000 + \$34{,}725 = \$56{,}725$$

With an up-front payment of $10,000, the net profit is $46,725 under the flexible lease. The value of flexibility may now be obtained as the difference between the expected present values of the two contracts. Accounting for uncertainty, the manager at Trips Logistics values the three options as shown in Table 6-7.

The flexible contract is thus beneficial for Trips Logistics because it is $8,361 more valuable than the rigid contract for three years.

KEY POINT Flexibility should be valued by taking into account uncertainty in demand and economic factors. In general, the value of flexibility increases with an increase in uncertainty.

6.5 AM TIRES: EVALUATION OF SUPPLY CHAIN DESIGN DECISIONS UNDER UNCERTAINTY

In this section we discuss a supply chain design decision at AM Tires, a tire manufacturer, to illustrate the power of the decision tree analysis methodology for making decisions under uncertainty. AM tires faces a plant location decision in a global network with fluctuating exchange rates and demand uncertainty.

AM Tires sells its products in both Mexico and the United States. Demand in the United States is currently 100,000 tires per year, and that in Mexico is 50,000 tires per year. From one year to the next, demand in either country may increase by 20 percent with probability 0.5 or decrease by 20 percent with probability 0.5. Demand fluctuations in the two countries are independent.

A tire sells for $30 in the United States and 240 pesos in Mexico. The current exchange rate is $1 US = 9 pesos. Exchange rates are expected to fluctuate according to the binomial distribution. From one year to the next, the peso may rise 25 percent or drop 25 percent, each with a probability of 0.5. Exchange-rate fluctuations are independent of demand fluctuations.

AM Tires is designing its manufacturing network, which will be in place for two years. The company is planning to build a 100,000-unit plant in the United States and a 50,000-unit plant in Mexico. The plants may be dedicated, in which case they can only supply the local market, or flexible, in which case they can supply either market. The fixed and variable costs for each option are shown in Table 6-8.

Observe that the fixed costs are given per year rather than up front with a future salvage value. Transportation costs between the United States and Mexico are $1 per tire

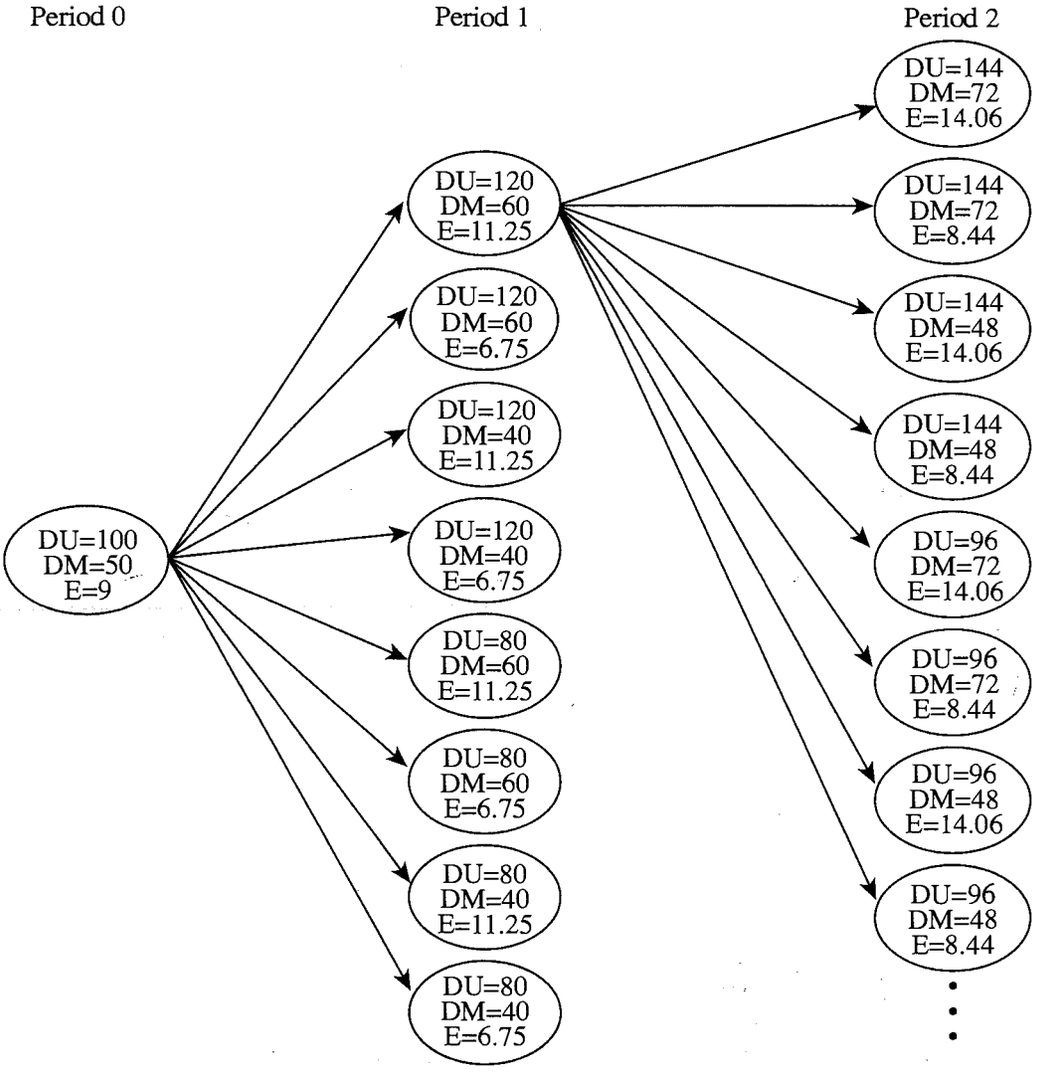
TABLE 6-8 Fixed and Variable Production Costs for AM Tires

	Dedicated Plant		*Flexible Plant*	
Plant	***Fixed Cost***	***Variable Cost***	***Fixed Cost***	***Variable Cost***
US 100,000	$1 million/year	$15/tire	$1.1 million/year	$15/tire
Mexico 50,000	4 million pesos/year	110 pesos/tire	4.2 million pesos/year	110 pesos/tire

either way. The plant decision has to stay in place over the next two years and the discount rate used by AM Tires is $k = 0.1$. The vice president of operations at AM Tires is working with the CEO to decide on the type of facility to build in each location. The company is bound by agreements (with each local government) to build a plant in each country.

The vice president constructs a decision tree as shown in Figure 6-3. Each node in a given period leads to eight possible nodes in the next period because demand in each country and the exchange rate may go up or down. The detailed links in Period 2 for one node in Period 1 are shown in Figure 6-3. The transition probability between each pair of

FIGURE 6-3 Partial Decision Tree for AM Tires



linked nodes is $0.5 \times 0.5 \times 0.5 = 0.125$ because demand and exchange rate fluctuations are independent and take place with a probability of 0.5 each. Demand is in thousands and is represented by DU for the United States and DM for Mexico. The exchange rate is represented by E, where E is the number of pesos to a US$.

There are four possible capacity and flexibility combinations between plants in Mexico and the United States. The vice president at AM Tires first evaluates the case in which a dedicated capacity of 100,000 is installed in the United States and a dedicated capacity of 50,000 is installed in Mexico.

DEDICATED CAPACITY OF 100,000 IN THE UNITED STATES AND 50,000 IN MEXICO

The vice president starts by evaluating profits at each node in Period 2. Each node is represented by the corresponding value of DU, DM, and E. At each node, given the demand in each market, the existing exchange rate, and the degree of flexibility, demand is allocated between plants to maximize profits (see Chapter 5).

Period 2 Evaluation

The detailed analysis for the node $DU = 144$, $DM = 72$, $E = 14.06$ is as follows. All 100,000 of the U.S. capacity and all 50,000 of the Mexican capacity is used for the local markets because capacity is dedicated and demand exceeds capacity in both markets. Revenues and costs are evaluated as follows.

1. ***Revenues for DU = 144, DM = 72, E = 14.06.*** The revenues in the United States and Mexico are evaluated as follows:

$$\text{U.S. revenue from manufacture and sale of 100,000 tires} = 100{,}000 \times \$30 = \$3{,}000{,}000$$

$$\text{Mexico revenue from manufacture and sale of 50,000 tires} = 50{,}000 \times 240 = 12{,}000{,}000 \text{ pesos} = \$12{,}000{,}000/E = 12{,}000{,}000/14.06 = \$853{,}485$$

$$\text{Total revenue} = \$3{,}853{,}485$$

2. ***Costs for DU = 144, DM = 72, E = 14.06.*** The costs in the United States and Mexico are evaluated from the data in Table 6-8. They are

$$\text{Fixed cost of U.S. plant} = \$1{,}000{,}000$$

$$\text{Variable production cost at U.S. plant} = 100{,}000 \times 15 = \$1{,}500{,}000$$

$$\text{Fixed cost of Mexico plant} = 4{,}000{,}000 \text{ pesos} = \$4{,}000{,}000/E = 4{,}000{,}000/14.06 = \$284{,}495$$

$$\text{Variable production cost at Mexico plant} = 50{,}000 \times 110 = 5{,}500{,}000 \text{ pesos} = \$5{,}500{,}000/E = 5{,}500{,}000/14.06 = \$391{,}181$$

$$\text{Total cost} = 1{,}000{,}000 + 1{,}500{,}000 + 284{,}495 + 391{,}181 = \$3{,}175{,}676$$

The total profit for AM Tires at the node $DU = 144, DM = 72, E = 14.06$, is thus given by

$$P(DU = 144, DM = 72, E = 14.06, 2) = 3{,}853{,}485 - 3{,}175{,}676 = \$677{,}809$$

Using the same approach, the vice president evaluates the profit in each of the 27 states in Period 2 as shown in Table 6-9. Each state in Period 2 is represented by the corresponding value of DU, DM, and E. The amount produced in each plant is the minimum of plant capacity and local demand because both plants are assumed to be dedicated.

TABLE 6-9 Period 2 Profits for Dedicated Capacity in Both United States and Mexico

			United States			*Mexico*			
DU	*DM*	*E*	*Production*	*Revenue ($)*	*Variable Cost ($)*	*Production*	*Revenue (pesos)*	*Variable Cost (pesos)*	*Profit ($)*
144	72	14.06	100,000	3,000,000	1,500,000	50,000	12,000,000	5,500,000	677,809
144	72	8.44	100,000	3,000,000	1,500,000	50,000	12,000,000	5,500,000	796,209
144	72	5.06	100,000	3,000,000	1,500,000	50,000	12,000,000	5,500,000	994,071
144	48	14.06	100,000	3,000,000	1,500,000	48,000	11,520,000	5,280,000	659,317
144	48	8.44	100,000	3,000,000	1,500,000	48,000	11,520,000	5,280,000	765,403
144	48	5.06	100,000	3,000,000	1,500,000	48,000	11,520,000	5,280,000	942,688
144	32	14.06	100,000	3,000,000	1,500,000	32,000	7,680,000	3,520,000	511,380
144	32	8.44	100,000	3,000,000	1,500,000	32,000	7,680,000	3,520,000	518,957
144	32	5.06	100,000	3,000,000	1,500,000	32,000	7,680,000	3,520,000	531,621
96	72	14.06	96,000	2,880,000	1,440,000	50,000	12,000,000	5,500,000	617,809
96	72	8.44	96,000	2,880,000	1,440,000	50,000	12,000,000	5,500,000	736,209
96	72	5.06	96,000	2,880,000	1,440,000	50,000	12,000,000	5,500,000	934,071
96	48	14.06	96,000	2,880,000	1,440,000	48,000	11,520,000	5,280,000	599,317
96	48	8.44	96,000	2,880,000	1,440,000	48,000	11,520,000	5,280,000	705,403
96	48	5.06	96,000	2,880,000	1,440,000	48,000	11,520,000	5,280,000	882,688
96	32	14.06	96,000	2,880,000	1,440,000	32,000	7,680,000	3,520,000	451,380
96	32	8.44	96,000	2,880,000	1,440,000	32,000	7,680,000	3,520,000	458,957
96	32	5.06	96,000	2,880,000	1,440,000	32,000	7,680,000	3,520,000	471,621
64	72	14.06	64,000	1,920,000	960,000	50,000	12,000,000	5,500,000	137,809
64	72	8.44	64,000	1,920,000	960,000	50,000	12,000,000	5,500,000	256,209
64	72	5.06	64,000	1,920,000	960,000	50,000	12,000,000	5,500,000	454,071
64	48	14.06	64,000	1,920,000	960,000	48,000	11,520,000	5,280,000	119,317
64	48	8.44	64,000	1,920,000	960,000	48,000	11,520,000	5,280,000	225,403
64	48	5.06	64,000	1,920,000	960,000	48,000	11,520,000	5,280,000	402,688
64	32	14.06	64,000	1,920,000	960,000	32,000	7,680,000	3,520,000	(28,620)
64	32	8.44	64,000	1,920,000	960,000	32,000	7,680,000	3,520,000	(21,043)
64	32	5.06	64,000	1,920,000	960,000	32,000	7,680,000	3,520,000	(8,379)

Period 1 Evaluation

In Period 1 there are eight outcome nodes to be analyzed. A detailed analysis for one of the nodes $DU = 120, DM = 60, E = 11.25$ is presented here. In addition to the revenue and cost at this node, we also need to consider the present value of the expected profit in Period 2 from the eight nodes that may result. The transition probability into each of the eight nodes is 0.125. The expected profit in Period 2 from the node $DU = 120, DM = 60, E = 11.25$ is thus given by

$$EP(DU = 120, DM = 60, E = 11.25, 1) = 0.125 \times [P(DU = 144, DM = 72, E = 14.06, 2) + P(DU = 144, DM = 72, E = 8.44, 2) + P(DU = 144, DM = 48, E = 14.06, 2) + P(DU = 144, DM = 48, E = 8.44, 2) + P(DU = 96, DM = 72, E = 14.06, 2) + P(DU = 96, DM = 72, E = 8.44, 2) + P(DU = 96, DM = 48, E = 14.06, 2) + P(DU = 96, DM = 48, E = 8.44, 2)]$$

From Table 6-9 we thus obtain

$$EP(DU = 120, DM = 60, E = 11.25, 1) = 0.125 \times [677{,}809 + 796{,}209 + 659{,}317 + 765{,}403 + 617{,}809 + 736{,}209 + 599{,}317 + 705{,}403] = \$694{,}685$$

The present value of the expected profit in Period 2 discounted to Period 1 is given by

$$PVEP(DU = 120, DM = 60, E = 11.25, 1) = EP(DU = 120, DM = 60, E = 11.25, 1)/(1 + k) = 694{,}685/1.1 = \$631{,}531$$

1. ***Revenues for DU = 120, DM = 60, E = 11.25.*** Given that both plants are dedicated, the U.S. plant will produce 100,000 tires for the local market and the Mexican plant will produce 50,000 tires for the market there. The revenues in the United States and Mexico are evaluated as follows:

$$\text{U.S. revenue from manufacture and sale of 100,000 tires} = 100{,}000 \times \$30 = \$3{,}000{,}000$$

$$\text{Mexico revenue from manufacture and sale of 50,000 tires} = 50{,}000 \times 240 = 12{,}000{,}000 \text{ pesos} = \$12{,}000{,}000/E = 12{,}000{,}000/11.25 = \$1{,}066{,}667$$

$$\text{Total revenue} = \$4{,}066{,}667$$

2. ***Costs for DU = 120, DM = 60, E = 11.25.*** The costs in the United States and Mexico are evaluated from the data in Table 6-8 as follows:

$$\text{Fixed cost of U.S. plant} = \$1{,}000{,}000$$

$$\text{Variable production cost at U.S. plant} = 100{,}000 \times 15 = \$1{,}500{,}000$$

$$\text{Fixed cost of Mexico plant} = 4{,}000{,}000 \text{ pesos} = \$4{,}000{,}000/E = 4{,}000{,}000/11.25 = \$355{,}556$$

$$\text{Variable production cost at Mexico plant} = 50{,}000 \times 110 = 5{,}500{,}000 \text{ pesos} = \$5{,}500{,}000/E = 5{,}500{,}000/11.25 = \$488{,}889$$

$$\text{Total cost} = 1{,}000{,}000 + 1{,}500{,}000 + 355{,}556 + 488{,}889 = \$3{,}344{,}445$$

The expected profit for AM Tires at the node $DU = 120$, $DM = 60$, $E = 11.25$ is given by

$$P(DU = 120, DM = 60, E = 11.25, 1) = 4{,}066{,}667 - 3{,}344{,}445 + PVEP(DU = 120, DM = 60, E = 11.25, 1) = 686{,}667 + 597{,}057 = \$1{,}353{,}754$$

The expected profit for all nodes in Period 1 is given in Table 6-10.

Period 0 Evaluation

In Period 0 the demand and exchange rate are given by $DU = 100$, $DM = 50$, $E = 9$. In addition to the revenue and cost at this node, we also need to consider the expected profit from the eight nodes in Period 1. The expected profit is given by

$$\begin{aligned} EP(DU = 100, DM = 50, E = 9, 0) = 0.125 \times [&P(DU = 120, DM = 60, E = 11.25, 1) \\ &+ P(DU = 120, DM = 60, E = 6.75, 1) + P(DU = 120, DM = 40, E = 11.25, 1) \\ &+ P(DU = 120, DM = 40, E = 6.75, 1) + P(DU = 80, DM = 60, E = 11.25, 1) \\ &+ P(DU = 80, DM = 60, E = 6.75, 1) + P(DU = 80, DM = 40, E = 11.25, 1) \\ &+ P(DU = 80, DM = 40, E = 6.75, 1)] \end{aligned}$$

From Table 6-10 we thus obtain

$$EP(DU = 100, DM = 50, E = 9, 0) = 0.125 \times (1{,}353{,}754 + 1{,}683{,}182 + 1{,}137{,}361 + 1{,}277{,}475 + 808{,}299 + 1{,}092{,}728 + 591{,}907 + 732{,}021) = \$1{,}078{,}966$$

TABLE 6-10 Period 1 Profits for Dedicated Capacity in Both United States and Mexico

				United States			Mexico			
DU	*DM*	*E*	*Expected Profit in Period 2 EP($)*	*Production*	*Revenue ($)*	*Variable Cost ($)*	*Production*	*Revenue (pesos)*	*Variable Cost (pesos)*	*Profit ($)*
120	60	11.25	656763	100,000	3,000,000	1,500,000	50,000	12,000,000	5,500,000	1,353,754
120	60	6.75	781370	100,000	3,000,000	1,500,000	50,000	12,000,000	5,500,000	1,638,182
120	40	11.25	545843	100,000	3,000,000	1,500,000	40,000	9,600,000	4,400,000	1,137,361
120	40	6.75	596445	100,000	3,000,000	1,500,000	40,000	9,600,000	4,400,000	1,277,475
80	60	11.25	386763	80,000	2,400,000	1,200,000	50,000	12,000,000	5,500,000	808,299
80	60	6.75	511370	80,000	2,400,000	1,200,000	50,000	12,000,000	5,500,000	1,092,728
80	40	11.25	275843	80,000	2,400,000	1,200,000	40,000	9,600,000	4,400,000	591,907
80	40	6.75	326445	80,000	2,400,000	1,200,000	40,000	9,600,000	4,400,000	732,021

The present value of the Period 1 profit discounted to Period 0 is given by

$$PVEP(DU = 100, DM = 50, E = 9, 0) = EP(DU = 100, DM = 50, E = 9, 0)/(1 + k) = 1{,}078{,}966/1.1 = \$980{,}878$$

1. ***Revenues for DU = 100, DM = 50, E = 9.*** In this case the U.S. plant produces 100,000 tires for the local market whereas the Mexican plant produces 50,000 tires for the market there. The revenues in Period 0 are given by

$$\text{U.S. revenue from manufacture and sale of 100,000 tires} = 100{,}000 \times \$30 = \$3{,}000{,}000$$

$$\text{Mexico revenue from manufacture and sale of 50,000 tires} = 50{,}000 \times 240 = 12{,}000{,}000 \text{ pesos} = \$12{,}000{,}000/E = 12{,}000{,}000/9 = \$1{,}333{,}333$$

$$\text{Total revenue} = \$4{,}333{,}333$$

2. ***Costs for DU = 100, DM = 50, E = 9.*** The costs in Period 0 are given by

$$\text{Fixed cost of U.S. plant} = \$1{,}000{,}000$$

$$\text{Variable production cost at U.S. plant} = 100{,}000 \times 15 = \$1{,}500{,}000$$

$$\text{Fixed cost of Mexico plant} = 4{,}000{,}000 \text{ pesos} = \$4{,}000{,}000/E = 4{,}000{,}000/9 = \$444{,}444$$

$$\text{Variable production cost at Mexico plant} = 50{,}000 \times 110 = 5{,}500{,}000 \text{ pesos} = \$5{,}500{,}000/E = 5{,}500{,}000/9 = \$611{,}111$$

$$\text{Total cost} = 1{,}000{,}000 + 1{,}500{,}000 + 444{,}444 + 611{,}111 = \$3{,}555{,}555$$

The expected profit for AM Tires from installing 100,000 units of dedicated capacity in the United States and 50,000 units of dedicated capacity in Mexico is given by

$$P(DU = 100, DM = 50, E = 9, 0) = 4{,}333{,}333 - 3{,}555{,}555 + 895{,}985 = \$1{,}758{,}656$$

The vice president of AM Tires thus obtains

$$\text{NPV(dedicated 100,000 unit capacity in the United States and 50,000 in Mexico)} = \$1{,}758{,}656$$

FLEXIBLE CAPACITY OF 100,000 IN UNITED STATES AND 50,000 IN MEXICO

The vice president next evaluates the NPV of installing flexible capacity in both the United States and Mexico. Flexible capacity may be used to produce tires for either country, depending on the profit from doing so. The decision tree in this case is as in Figure 6-3, but the profit at each node changes. The vice president first evaluates the profit at each node in Period 2.

Period 2 Evaluation

The detailed analysis for the node $DU = 144, DM = 72, E = 14.06$ for Period 2 is as follows. The vice president first evaluates the margin contribution of producing a tire in one place and selling in each of the two markets as shown in Table 6-11.

From Table 6-11 it is clear that, under the given conditions, both U.S. and Mexican production should first be used to satisfy U.S. demand of 144,000. The remaining 6,000 tires are sold in the Mexican market because this action maximizes profits for AM Tires. The example considered here is simple enough for the optimal demand allocation to be obtained by observation. In general, a demand allocation model (see Chapter 5) must be solved at each node of the decision tree.

1. ***U.S. production contribution for DU = 144, DM = 72, E = 14.06.*** Given a demand in the United States of 144,000 units, all 100,000 units of U.S. production are sent to the local market. Given a margin of $15 per unit, the vice president obtains

$$\text{Contribution margin from U.S. production} = 100{,}000 \times \$15 = \$1{,}500{,}000$$

$$\text{Fixed cost of U.S. plant} = \$1{,}100{,}000$$

$$\text{Profit from U.S. production} = \$400{,}000$$

2. ***Mexican production contribution for DU = 144, DM = 72, E = 14.06.*** Given that there is a higher margin of $21.2 per tire from selling Mexican tires in the United States, 44,000 tires from Mexico are sent to the United States. The remaining 6,000 tires are sold in Mexico, with each tire contributing $9.20. Thus

$$\text{Contribution margin from Mexican production} = 44{,}000 \times \$21.2 + 6{,}000 \times \$9.2 = \$988{,}000$$

$$\text{Fixed cost of Mexican plant} = 4{,}200{,}000 \text{ pesos} = \$298{,}720$$

$$\text{Profit from Mexican production} = \$689{,}280$$

The total profit for AM Tires is the sum of the profit from U.S. and Mexican production and is given by

$$P(DU = 144, DM = 72, E = 14.06, 2) = \$400{,}000 + \$675{,}055 = \$1{,}089{,}280$$

Compare the profit at this node with and without flexibility. Flexible capacity gives a profit of $1,089,280, whereas dedicated capacity results in a profit of $677,809. The

TABLE 6-11 Source/Destination Margins for $DU = 144, DM = 72, E = 14.06$

Source	*Destination*	*Variable Cost*	*Shipping Cost*	*E*	*Sale Price*	*Margin ($)*
U.S.	U.S.	$15	0	14.06	$30	$15
U.S.	Mexico	$15	$1	14.06	240 pesos	$1.1
Mexico	U.S.	110 pesos	$1	14.06	$30	$21.2
Mexico	Mexico	110 pesos	0	14.06	240 pesos	$9.2

TABLE 6-12 Period 2 Profits with Flexible Capacity in Both United States and Mexico

			Contribution Margin ($/unit)				U.S. Production		Profit in	Mexico Production		Mexico Profit	Total Profit
DU	*DM*	*E*	*U.S./ U.S.*	*U.S./ Mex*	*Mex/ U.S.*	*Mex/ Mex*	*For U.S.*	*For Mexico*	*U.S. ($)*	*For U.S.*	*For Mexico*	*($)*	*($)*
144	72	14.06	15	1.1	21.2	9.2	100,000	—	400,000	44,000	6,000	689,280	1,089,280
144	72	8.44	15	12.4	16.0	15.4	100,000	—	400,000	44,000	6,000	297,327	697,327
144	72	5.06	15	31.4	7.3	25.7	78,000	22,000	761,478	—	50,000	454,545	1,216,024
144	48	14.06	15	1.1	21.2	9.2	100,000	—	400,000	—	48,000	145,092	545,092
144	48	8.44	15	12.4	16.0	15.4	100,000	—	400,000	—	48,000	241,706	641,706
144	48	5.06	15	31.4	7.3	25.7	100,000	—	400,000	2,000	48,000	417,684	817,684
144	32	14.06	15	1.1	21.2	9.2	100,000	—	400,000	44,000	6,000	688,518	1,088,518
144	32	8.44	15	12.4	16.0	15.4	100,000	—	400,000	44,000	6,000	297,327	697,327
144	32	5.06	15	31.4	7.3	25.7	100,000	—	400,000	18,000	32,000	122,791	522,791
96	72	14.06	15	1.1	21.2	9.2	96,000	4,000	344,279	—	50,000	163,585	507,863
96	72	8.44	15	12.4	16.0	15.4	96,000	4,000	389,744	—	50,000	272,512	662,256
96	72	5.06	15	31.4	7.3	25.7	96,000	4,000	465,723	—	50,000	454,545	920,269
96	48	14.06	15	1.1	21.2	9.2	96,000	—	340,000	—	48,000	145,092	485,092
96	48	8.44	15	12.4	16.0	15.4	96,000	—	340,000	—	48,000	241,706	581,706
96	48	5.06	15	31.4	7.3	25.7	96,000	—	340,000	—	48,000	403,162	743,162
96	32	14.06	15	1.1	21.2	9.2	96,000	—	340,000	—	32,000	(2,845)	337,155
96	32	8.44	15	12.4	16.0	15.4	96,000	—	340,000	—	32,000	(4,739)	335,261
96	32	5.06	15	31.4	7.3	25.7	96,000	—	340,000	—	32,000	(7,905)	332,095
64	72	14.06	15	1.1	21.2	9.2	64,000	22,000	(116,467)	—	50,000	163,585	47,118
64	72	8.44	15	12.4	16.0	15.4	64,000	22,000	133,592	—	50,000	272,512	406,104
64	72	5.06	15	31.4	7.3	25.7	64,000	36,000	991,510	—	36,000	94,862	1,086,372
64	48	14.06	15	1.1	21.2	9.2	64,000	—	(140,000)	—	48,000	145,092	5,092
64	48	8.44	15	12.4	16.0	15.4	64,000	—	(140,000)	—	48,000	241,706	101,706
64	48	5.06	15	31.4	7.3	25.7	64,000	36,000	991,510	—	12,000	(521,736)	469,771
64	32	14.06	15	1.1	21.2	9.2	64,000	—	(140,000)	—	32,000	(2,845)	(142,845)
64	32	8.44	15	12.4	16.0	15.4	64,000	—	(140,000)	—	32,000	(4,739)	(144,739)
64	32	5.06	15	31.4	7.3	25.7	64,000	32,000	865,787	—	—	(830,040)	35,747

production flexibility allows AM Tires to exploit exchange-rate fluctuations and increase profit by adjusting the markets being served by each plant.

The vice president of operations repeats the aforementioned analysis for each of the 27 nodes in Period 2. The results are shown in Table 6-12.

Period 1 Evaluation

In Period 1 there are eight outcome nodes to be analyzed. The detailed analysis for the node $DU = 120, DM = 60, E = 11.25$ is provided. In addition to the revenue and cost at this node, we also need to consider the present value of the expected profit from the eight nodes in Period 2 that may result from this node. The transition probability to each of the eight nodes is 0.125. The expected profit is thus given by

$$\begin{aligned} EP(DU = 120, DM = 60, E = 11.25, 1) = 0.125 \times [&P(DU = 144, DM = 72, \\ &E = 14.06, 2) + P(DU = 144, DM = 72, E = 8.44, 2) + P(DU = 144, \\ &DM = 48, E = 14.06, 2) + P(DU = 144, DM = 48, E = 8.44, 2) \\ &+ P(DU = 96, DM = 72, E = 14.06, 2) + P(DU = 96, DM = 72, E = 8.44, 2) \\ &+ P(DU = 96, DM = 48, E = 14.06, 2) + P(DU = 96, DM = 48, E = 8.44, 2)] \end{aligned}$$

TABLE 6-13 Source/Destination Margins for $DU = 120$, $DM = 60$, $E = 11.25$

Source	*Destination*	*Variable Cost*	*Shipping Cost*	*E*	*Sale Price*	*Margin ($)*
U.S.	U.S.	$15	0	11.25	$30	$15
U.S.	Mexico	$15	$1	11.25	240 pesos	$5.3
Mexico	U.S.	110 pesos	$1	11.25	$30	$19.2
Mexico	Mexico	110 pesos	0	11.25	240 pesos	$11.6

From Table 6-12 the vice president thus obtains

$$EP(DU = 120, DM = 60, E = 11.25, 1) = 0.125 \times [1{,}089{,}280 + 697{,}327 + 545{,}092 + 641{,}706 + 507{,}863 + 662{,}256 + 485{,}092 + 581{,}706] = \$651{,}290$$

The present value of the expected profit discounted to Period 1 is given by

$$PVEP(DU = 120, DM = 60, E = 11.25, 1) = EP(DU = 120, DM = 60, E = 11.25, 1)/(1 + k) = 651{,}290/1.1 = \$592{,}082$$

The next step is to evaluate the margin contribution of producing a tire in one place and selling in each of the two markets with an exchange rate of $E = 11.25$. The details are contained in Table 6-13.

The next step is to evaluate the profit contribution from each plant by solving a demand allocation problem. Given the simple example, the evaluation is done directly in this case.

1. ***U.S. production contribution for DU = 120, DM = 60, E = 11.25.*** Given that there is a higher margin from selling U.S. production in the United States, all 100,000 U.S. tires are sent to the local market. Thus

$$\text{Contribution margin from U.S. production} = 100{,}000 \times \$15 = \$1{,}500{,}000$$

$$\text{Fixed cost of U.S. plant} = \$1{,}100{,}000$$

$$\text{Profit from U.S. production} = \$400{,}000$$

2. ***Mexican production contribution for DU = 120, DM = 60, E = 11.25.*** Given that there is a higher margin from selling Mexican production in the United States, 20,000 tires from Mexico are sent to the United States, while 30,000 tires are sold in Mexico. Given the margins in Table 6-13, the vice president thus obtains

$$\text{Contribution margin from Mexican plant} = 20{,}000 \times \$19.2 + 30{,}000 \times \$11.6 = \$732{,}000$$

$$\text{Fixed cost of Mexican plant} = 4{,}200{,}000 \text{ pesos} = \$373{,}333$$

$$\text{Profit from Mexican plant} = \$358{,}667$$

The total expected profit for AM Tires for $DU = 120, DM = 60, E = 11.25$ in Period 1 is thus given by

$$P(DU = 120, DM = 60, E = 11.25, 1) = \$400{,}000 + \$358{,}667 + PVEP(DU = 120, DM = 60, E = 11.25, 1) = \$400{,}000 + \$358{,}667 + \$574{,}845 = \$1{,}350{,}749$$

The expected profit for all other nodes in Period 1 is calculated as earlier and is shown in Table 6-14.

Period 0 Evaluation

In Period 0 the demand and exchange rate are given by $DU = 100, DM = 50, E = 9$. In addition to the revenue and cost at this node, we also need to consider the present

TABLE 6-14 Period 1 Profits with Flexible Capacity in Both the United States and Mexico

				Contribution Margin ($/unit)				*U.S. Production*			*Mexico Production*			
DU	*DM*	*E*	*Expected Profit in Period 1 EP ($)*	*U.S./ U.S.*	*U.S./ Mex*	*Mex/ U.S.*	*Mex/ Mex*	*For U.S.*	*For Mexico*	*Profit in U.S. ($)*	*For U.S.*	*For Mexico*	*Profit in Mexico ($)*	*Total Profit ($)*
120	60	11.25	632,330	15	5.3	19.2	11.6	100,000	—	400,000	20,000	30,000	358,667	1,350,749
120	60	6.75	753,405	15	19.6	12.7	19.3	90,000	10,000	446,000	—	50,000	342,778	1,502,429
120	40	11.25	570,022	15	5.3	19.2	11.6	90,000	—	250,000	30,000	20,000	434,667	1,220,105
120	40	6.75	552,355	15	19.6	12.7	19.3	100,000	—	400,000	10,000	40,000	276,778	1,207,656
80	60	11.25	330,657	15	5.3	19.2	11.6	80,000	—	100,000	20,000	30,000	358,667	776,500
80	60	6.75	589,807	15	19.6	12.7	19.3	90,000	10,000	446,000	—	50,000	342,778	1,353,703
80	40	11.25	175,843	15	5.3	19.2	11.6	60,000	—	(200,000)	20,000	30,000	358,667	335,761
80	40	6.75	275,227	15	19.6	12.7	19.3	80,000	20,000	492,000	—	20,000	(236,222)	534,722

value of the expected profit from all nodes in Period 1. Given a transition probability of 0.125 to each node, the expected profit from Period 1 is given by

$$EP(DU = 100, DM = 50, E = 9, 0) = 0.125 \times [P(DU = 120, DM = 60, E = 11.25, 1) + P(DU = 120, DM = 60, E = 6.75, 1) + P(DU = 120, DM = 40, E = 11.25, 1) + P(DU = 120, DM = 40, E = 6.75, 1) + P(DU = 80, DM = 60, E = 11.25, 1) + P(DU = 80, DM = 60, E = 6.75, 1) + P(DU = 80, DM = 40, E = 11.25, 1) + P(DU = 80, DM = 40, E = 6.75, 1)]$$

From Table 6-14 the vice president thus obtains

$$EP(DU = 100, DM = 50, E = 9, 0) = 0.125 \times (1{,}350{,}749 + 1{,}502{,}429 + 1{,}220{,}105 + 1{,}207{,}656 + 776{,}500 + 1{,}353{,}703 + 335{,}761 + 534{,}722) = \$1{,}035{,}203$$

The present value of the expected profit in Period 1 discounted to Period 0 is given by

$$PVEP(DU = 100, DM = 50, E = 9, 0) = EP(DU = 100, DM = 50, E = 9, 0)/(1 + k) = 1{,}035{,}203/1.1 = \$941{,}094$$

The next step is to evaluate the margin contribution of producing a tire in one place and selling in each of the two markets in Period 0. The details are contained in Table 6-15.

The vice president next evaluates the profit contribution from each plant.

1. ***U.S. production contribution for DU = 100, DM = 50, E = 9.*** All 100,000 units produced in the United States are sold locally because the U.S. market provides a higher margin. Thus,

   Contribution margin from U.S. production = 100,000 × \$15 = \$1,500,000

   Fixed cost of U.S. plant = \$1,100,000

   Profit from U.S. production = \$400,000

2. ***Mexican production contribution for DU = 100, DM = 50, E = 9.*** All of the Mexican capacity is used to satisfy Mexican demand because there is no unmet demand in the United States. Thus, 50,000 tires are sold in Mexico.

   Contribution margin from Mexican production = 50,000 × \$14.4 = \$720,000

   Fixed cost of Mexican plant = 4,200,000 pesos = \$466,667

   Profit from Mexican production = \$253,333

The total expected profit for AM Tires in Period 0 is thus given by

$$P(DU = 100, DM = 50, E = 9, 0) = \$400{,}000 + \$253{,}333 + PVEP(DU = 100, DM = 50, E = 9, 0) = \$400{,}000 + \$253{,}333 + \$941{,}094 = \$1{,}594{,}427$$

TABLE 6-15 Source/Destination Margins for *DU* = 100, *DM* = 50, *E* = 9

Source	*Destination*	*Variable Cost*	*Shipping Cost*	*E*	*Sale Price*	*Margin ($)*
U.S.	U.S.	\$15	0	9	\$30	\$15
U.S.	Mexico	\$15	\$1	9	240 pesos	\$10.7
Mexico	U.S.	110 pesos	\$1	9	\$30	\$16.8
Mexico	Mexico	110 pesos	0	9	240 pesos	\$14.4

TABLE 6-16 NPV of Various Plant Configurations for AM Tires

Plant Configuration		
United States	*Mexico*	*NPV*
Dedicated	Dedicated	$1,758,656
Flexible	Dedicated	$1,514,322
Dedicated	Flexible	$1,787,115
Flexible	Flexible	$1,594,427

The vice president thus obtains the following:

$$\text{NPV(Flexible 100,000 unit capacity in United States and 50,000 in Mexico)} = \$1,594,427$$

The option of having both plants be flexible yields a lower expected NPV compared to both plants being dedicated. This is because the cost of building flexibility is higher than the value it provides under the various possible exchange rate and demand outcomes. A similar analysis can be used to evaluate the cases in which one of the two plants is flexible. The results for the four options are shown in Table 6-16.

The results in Table 6-16 indicate that although flexibility in Mexico is beneficial, flexibility in the U.S. plant ends up costing money. The CEO of AM Tires decides to build a dedicated plant in the United States and a flexible plant in Mexico because this configuration has the highest expected profits.

When underlying decision trees are very complex and explicit solutions for the underlying decision tree are difficult to obtain, firms should use simulation for evaluating decisions (see Chapter 12). In a complex decision tree, thousands or even millions of possible paths may arise from the first period to the last. Transition probabilities are used to generate probability-weighted random paths within the decision tree. For each path, the stage-by-stage decision as well as the present value of the payoff is evaluated. The paths are generated in such a way that the probability of a path being generated during the simulation is the same as the probability of the path in the decision tree. After generating many paths and evaluating the payoffs in each case, the payoffs obtained during the simulation are used as a representation of the payoffs that would result from the decision tree. The expected payoff is then found by averaging the payoffs obtained in the simulation.

Simulation methods are very good at evaluating a decision when the path itself is not decision dependent—in other words, when transition probabilities from one period to the next are not dependent on the decision taken during a period. They can also take into account real-world constraints as well as complex decision rules. In addition, they can easily handle different forms of uncertainty even in instances in which uncertainty between different factors is correlated.

Simulation models require a higher setup cost to start and operate compared to decision tree tools. However, their main advantage is that they can provide high-quality evaluations of complex situations.

6.6 RISK MANAGEMENT AND NETWORK DESIGN

A global supply chain network is exposed to a variety of risks, including supply disruption, supply delays, demand fluctuations, price fluctuations, and exchange-rate fluctuations. If appropriate mitigation plans are not in place, these risks can significantly

TABLE 6-17 Supply Chain Risks to Be Considered During Network Design

Category	*Risk Drivers*
Disruptions	Natural disaster, war, terrorism Labor disputes Supplier bankruptcy
Delays	High capacity utilization at supply source Inflexibility of supply source Poor quality or yield at supply source
Systems risk	Information infrastructure breakdown System integration or extent of systems being networked
Forecast risk	Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base Bullwhip effect or information distortion
Intellectual property risk	Vertical integration of supply chain Global outsourcing and markets
Procurement risk	Exchange-rate risk Fraction purchased from a single source Industry-wide capacity utilization
Receivables risk	Number of customers Financial strength of customers
Inventory risk	Rate of product obsolescence Inventory holding cost Product value Demand and supply uncertainty
Capacity risk	Cost of capacity Capacity flexibility

Source: Adapted from "Managing Risk to Avoid Supply Chain Breakdown." Sunil Chopra and Manmohan S. Sodhi, *Sloan Management Review* (Fall 2004): 53–61.

hurt supply chain performance. For example, contamination at one of the two suppliers of flu vaccine to the United States led to a severe shortage at the beginning of the 2004 flu season. This shortage led to rationing in most states and severe price gouging in some cases. Similarly, the significant strengthening of the euro has hurt firms that have most of their supply sources located in Western Europe. Table 6-17 contains a categorization of supply chain risks and their drivers that must be considered during network design.

Good network design can play a significant role in mitigating supply chain risk. For instance, having multiple suppliers mitigates the risk of disruption from any one supply source. An excellent example is the difference in impact on Nokia and Ericsson when a plant owned by Royal Phillips Electronics, located in Albuquerque, New Mexico, caught fire in March 2000. Nokia adjusted to the disruption quickly using several other supply plants in its network. In contrast, Ericsson had no backup source in its network and was unable to react. Ericsson estimated that it lost revenues of $400 million as a result. Similarly, having flexible capacity mitigates the risks of global demand, price, and exchange-rate fluctuations. For example, Hino Trucks uses flexible capacity at its plants to change production levels for different products by shifting workforce between lines. As a result, the company keeps a constant workforce in the plant even though the production at each line varies to best match supply and demand. As illustrated by these examples, designing mitigation strategies into the network significantly improves a supply chain's ability to deal with risk.

Every mitigation strategy, however, comes at a price and may increase other risks. For example, increasing inventory mitigates the risk of delays but increases the risk of

TABLE 6-18 Tailored Risk Mitigation Strategies During Network Design

Risk Mitigation Strategy	*Tailored Strategies*
Increase capacity	Focus on low cost, decentralized capacity for predictable demand. Build centralized capacity for unpredictable demand. Increase decentralization as cost of capacity drops.
Get redundant suppliers	More redundant supply for high-volume products, less redundancy for low-volume products. Centralize redundancy for low-volume products in a few flexible suppliers.
Increase responsiveness	Favor cost over responsiveness for commodity products. Favor responsiveness over cost for short-life-cycle products.
Increase inventory	Decentralize inventory of predictable, lower-value products. Centralize inventory of less predictable, higher-value products.
Increase flexibility	Favor cost over flexibility for predictable, high-volume products. Favor flexibility for unpredictable, low-volume products. Centralize flexibility in a few locations if it is expensive.
Pool or aggregate demand	Increase aggregation as unpredictability grows.
Increase source capability	Prefer capability over cost for high-value, high-risk products. Favor cost over capability for low-value commodity products. Centralize high capability in flexible source if possible.

Source: Adapted from "Managing Risk to Avoid Supply Chain Breakdown." Sunil Chopra and Manmohan S. Sodhi, *Sloan Management Review* (Fall 2004): 53–61.

obsolescence. Acquiring multiple suppliers mitigates the risk of disruption but increases costs because each supplier may have difficulty achieving economies of scale. Thus, it is very important to develop tailored mitigation strategies during network design that achieve a good balance between the amount of risk mitigated and the increase in cost. Some tailored mitigation strategies are outlined in Table 6-18. Most of these strategies are discussed in greater detail later in the book.

6.7 MAKING SUPPLY CHAIN DESIGN DECISIONS UNDER UNCERTAINTY IN PRACTICE

Managers should consider the following ideas to help them make better network design decisions under uncertainty.

1. ***Combine strategic planning and financial planning during network design.*** In most organizations, financial planning and strategic planning are performed independently. Strategic planning tries to prepare for future uncertainties but often without rigorous quantitative analysis, whereas financial planning performs quantitative analysis but assumes a predictable or well-defined future. This chapter presents methodologies that allow integration of financial and strategic planning. Decision makers should design supply chain networks considering a portfolio of strategic options—the option to wait, build excess capacity, build flexible capacity, sign long-term contracts, purchase from the spot market, and so forth. The various options should be evaluated in the context of future uncertainty.

2. ***Use multiple metrics to evaluate supply chain networks.*** As one metric can give only part of the picture, it is beneficial to examine network design decisions using multiple metrics such as firm profits, supply chain profits, customer service levels, and response times. Good decisions perform well along most relevant metrics.

3. ***Use financial analysis as an input to decision making, not as the decision-making process.*** Financial analysis is a great tool in the decision-making process, as it often produces an answer and an abundance of quantitative data to back up that answer. However, financial methodologies alone do not provide a complete picture of the alternatives, and other nonquantifiable inputs should also be considered.

4. ***Use estimates along with sensitivity analysis.*** Many of the inputs into financial analysis are difficult, if not impossible, to obtain accurately. This can cause financial analysis to be a long and drawn-out process. One of the best ways to speed the process along and arrive at a good decision is to use estimates of inputs when it appears that finding a very accurate input would take an inordinate amount of time. As we discuss in some of the other practice-oriented sections, using estimates is fine when the estimates are backed up by sensitivity analysis. It is almost always easier to come up with a range for an input than it is to come up with a single point. By performing sensitivity analysis on the input's range, managers can often show that no matter where the true input lies within the range, the decision remains the same. When this is not the case, they have highlighted a key variable to making the decision and it likely deserves more attention to arrive at a more accurate answer. In summary, to make supply chain design decisions effectively, managers need to make estimates of inputs and then test all recommendations with sensitivity analysis.

6.8 SUMMARY OF LEARNING OBJECTIVES

1. Identify uncertainties that influence supply chain performance and network design.

   The main financial measurement for evaluating supply chain alternatives is the present value of the stream of cash flows generated by each alternative. These streams are affected by uncertainty of demand, price, exchange rates, and other economic factors. These uncertainties and any flexibility in the supply chain network must be taken into account when valuing the cash flows.

2. Understand the methodologies used to evaluate supply chain decisions under uncertainty.

   When valuing the streams of cash flows, decision trees are a basic approach to valuing alternatives under uncertainty. Incorporating a binomial representation of uncertainty allows the decision tree to value alternatives given uncertainty. When decision trees become too complex to solve reasonably, simulation can be used to perform financial evaluations on the decision alternatives.

3. Analyze supply chain network design decisions in an uncertain environment.

   The basic steps in analyzing network design decisions involve gathering financial data on the alternatives, determining what the uncertainties affecting the decision are, quantifying the cash flows for each alternative in each time period, quantifying the uncertainties' impact on the cash flows, and using one of the methodologies to calculate a financial valuation for the different alternatives.

Discussion Questions

1. Why is it important to consider uncertainty when evaluating supply chain design decisions?
2. What are the major sources of uncertainty that can affect the value of supply chain decisions?
3. Describe the basic principle of DCFs and how it can be used to compare different streams of cash flows.
4. How does the binomial representation of uncertainty relate to the normal distribution?
5. Summarize the basic steps in the decision tree analysis methodology.

6. What are the major financial uncertainties faced by an electronic components manufacturer deciding whether to build a plant in Thailand or the United States?
7. What are some major nonfinancial uncertainties that a company should consider when making decisions on where to source product?

Exercises

1. Moon Micro is a small manufacturer of servers that currently builds all of its product in Santa Clara, California. As the market for servers has grown dramatically, the Santa Clara plant has reached capacity of 10,000 servers per year. Moon is considering two options to increase its capacity. The first option is to add 10,000 units of capacity to the Santa Clara plant at an annualized fixed cost of $10,000,000 plus $500 labor per server. The second option is to have Molectron, an independent assembler, manufacture servers for Moon at a cost of $2,000 for each server (excluding raw materials cost). Raw materials cost $8,000 per server, and Moon sells each server for $15,000.

   Moon must make this decision for a two-year time horizon. During each year, demand for Moon servers has an 80 percent chance of increasing 50 percent from the year before and a 20 percent chance of remaining the same as the year before. Molectron's prices may change as well. They are fixed for the first year but have a 50 percent chance of increasing 20 percent in the second year and a 50 percent chance of remaining where they are.

   Use a decision tree to determine whether Moon should add capacity to its Santa Clara plant or if it should outsource to Molectron. What are some other factors that would affect this decision that we have not discussed?
2. Unipart, a manufacturer of auto parts, is considering two different B2B marketplaces to purchase its MRO supplies. Both marketplaces offer a full line of supplies at very similar prices for products and shipping. Both provide very similar service levels and lead times.

   However, their fee structures are quite different. The first marketplace, Parts4u.com, sells all of its products with a 5 percent commission tacked on top of the price of the product (not including shipping). AllMRO.com's pricing is based on a subscription fee of $10 million that must be paid up front for a two-year period and a commission of 1 percent on each transaction's product price.

   Unipart spends about $150 million on MRO supplies each year, although this varies with their utilization. Next year will likely be a strong year, in which high utilization will keep MRO spending at $150 million. However, there is a 25 percent chance that spending will drop by 10 percent. The second year, there is a 50 percent chance that the spending level will stay where it was in the first year and a 50 percent chance that it will drop by another 10 percent. Unipart uses a discount rate of 20 percent. Assume all costs are incurred at the beginning of each year (so Year 1's costs are incurred now and Year 2 costs are incurred in a year).

   Which B2B marketplace should Unipart buy its parts from?
3. Alphacap, a manufacturer of electronic components, is trying to select a single supplier for the raw materials that go into its main product, the doublecap. This is a new capacitor that is used by cellular phone manufacturers to protect microprocessors from power spikes. Two companies can provide the necessary materials—MultiChem and Mixemat.

   MultiChem has a very solid reputation for its products and charges a higher price on account of its reliability of supply and delivery. MultiChem dedicates plant capacity to each customer, and therefore supply is assured. This allows MultiChem to charge $1.20 for the raw materials used in each doublecap.

   Mixemat is a small raw materials supplier that has limited capacity but charges only $0.90 for a unit's worth of raw materials. Its reliability of supply, however, is in question. Mixemat does not have enough capacity to supply all of its customers all the time. This

means that orders to Mixemat are not guaranteed. In a year of high demand for raw materials, Mixemat will have 90,000 units available for Alphacap. In low-demand years, all product will be delivered.

If Alphacap does not get raw materials from suppliers, it needs to buy them on the spot market to supply its customers. Alphacap relies on one major cell phone manufacturer for the majority of its business. Failing to deliver could lead to losing this contract, essentially putting the firm at risk. Therefore, Alphacap will buy raw material on the spot market to make up for any shortfall. Spot prices for single-lot purchases (such as Alphacap would need) are $2.00 when raw materials demand is low and $4.00 when demand is high.

Demand in the raw materials market has a 75 percent chance of being high in the market each of the next two years. Alphacap sold 100,000 doublecaps last year and expects to sell 110,000 this year. However, there is a 25 percent chance they will sell only 100,000. Next year, the demand has a 75 percent chance of rising 20 percent over this year and a 25 percent chance of falling 10 percent. Alphacap uses a discount rate of 20 percent. Assume all costs are incurred at the beginning of each year (Year 1's costs are incurred now and Year 2 costs are incurred in a year) and that Alphacap must make a decision with a two-year horizon. Only one supplier can be chosen, as these two suppliers refuse to supply someone who works with their competitor.

Which supplier should Alphacap choose? What other information would you like to have to make this decision?

4. Bell Computer is reaching a crossroads. This PC manufacturer has been growing at a rapid rate, causing problems for its operations as it tries to keep up with the surging demand. Bell executives can plainly see that within the next half-year, the systems used to coordinate its supply chain are going to fall apart because they will not be able to handle the volume of Bell projects they will have.

   To solve this problem, Bell has brought in two supply chain software companies that have made proposals on systems that could cover the volume and the complexity of tasks Bell needs to have handled. These two software companies are offering very different types of products, however.

   The first company, SCSoftware, proposes a system for which Bell will purchase a license. This will allow Bell to use the software as long as it wants. However, Bell will be responsible for maintaining this software, which will require significant resources.

   The second company, SC–ASP, proposes that Bell pay a subscription fee on a monthly basis for SC–ASP to host Bell's supply chain applications on SC–ASP's machines. Bell employees will access information and analysis via a Web browser. Information will be fed automatically from the ASP servers to the Bell servers whenever necessary. Bell will continue to pay the monthly fee for the software, but all maintenance will be performed by SC–ASP.

   How should Bell go about making a decision regarding which software company to choose? What are the specific pieces of information that Bell needs to know (both about the software and about the future conditions Bell will experience) in order to make a decision? What are some of the qualitative issues Bell must think about when making this decision?

5. Reliable is a cell phone manufacturer serving the Asian and North American markets. Current annual demand of their product in Asia is 2,000,000, whereas the demand in North America is 4,000,000. Over the next two years, demand in Asia is expected to go up by 50 percent with a probability of 0.7, or go up by 20 percent with a probability of 0.3. Over the same period, demand in North America is expected to go up by 10 percent with a probability of 0.5, or go down 10 percent with a probability of 0.5. Reliable currently has a production facility in Asia with a capacity of 2,400,000 units per year and a facility in North America with a capacity of 4,200,000 per year. The variable production cost per phone in Asia is $15 and the variable cost per phone in North America is $17. It costs $3 to ship a phone between the two markets. Each phone sells for $40 in both markets.

Reliable is debating whether to add 2,000,000 units or 1,500,000 units of capacity to the Asian plant. The larger plant increase will cost $18,000,000, whereas the smaller addition will cost $15,000,000. What do you recommend? Assume that reliable uses a discount factor of 10 percent.

6. A European apparel manufacturer has production facilities in Italy and China to serve its European market, where annual demand is for 1.9 million units. Demand is expected to stay at the same level over the foreseeable future. Each facility has a capacity of 1 million units per year. With the current exchange rates, the production and distribution cost from Italy is 10 euros per unit, whereas the production and distribution cost from China is 7 euros. Over each of the next three years, the Chinese currency could rise relative to the euro by 15 percent with a probability of 0.5, or drop by 5 percent with a probability of 0.5. An option being considered is to shut down 0.5 million units of capacity in Italy and move it to China at a one-time cost of 2 million euros. Do you recommend this option? Assume a discount factor of 10 percent over the three years.
7. A chemical manufacturer is setting up capacity in Europe and North America for the next three years. Annual demand in each market is 2 million kilograms (kg) and is likely to stay at that level. The two choices under consideration are whether to build 4 million units of capacity in North America or 2 million units of capacity in each of the two locations. Building two plants will incur an additional one-time cost of $2 million. The variable cost of production in North America (for either a large or a small plant) is currently $10/kg, while the cost in Europe is 9 euros/kg. The current exchange rate is 1 euro for US$1.33. Over each of the next three years, the dollar is expected to strengthen by 10 percent with a probability of 0.5 and weaken by 5 percent with a probability of 0.5. What should the chemical manufacturer do? Assume a discount factor of 10 percent. At what initial cost differential from building the two plants will the chemical manufacturer be indifferent between the two options?

Bibliography

Amram, Martha, and Nalin Kulatilaka. *Real Options*. Cambridge, MA: Harvard Business School Press, 1999.

Brealey, Richard A., and Stewart C. Myers. *Principles of Corporate Finance*. New York: McGraw-Hill, 1996.

Chopra, Sunil, and ManMohan S. Sodhi. "Managing Risk to Avoid Supply Chain Breakdown." *Sloan Management Review* (2004): 46(1): 53–61.

Horngren, Charles T., George Foster, and Srikant M. Datar. *Cost Accounting*. Upper Saddle River, NJ: Prentice Hall, 1997.

Johnson, Norman L., Samuel Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. New York: Wiley, 1994.

Luehrman, Timothy A. *Capital Projects as Real Options: An Introduction*. Harvard Business School Case 9–295–074, 1995.

Luehrman, Timothy A. "Investment Opportunities as Real Options: Getting Started on the Numbers." *Harvard Business Review* (July–August 1998): 51–67.

Luehrman, Timothy A. "Strategy as a Portfolio of Real Options." *Harvard Business Review* (September–October 1998): 89–99.

Ross, Sheldon M. *Introduction to Stochastic Dynamic Programming*. New York: Academic Press, 1983.

Stokey, Nancy L., Robert E. Lucas, Jr., and Edward C. Prescott. *Recursive Methods in Economic Dynamics*. Cambridge, MA: Harvard University Press, 1989.

Trigeorgis, Lenos. *Real Options*. Cambridge, MA: The MIT Press, 1996.

CASE STUDY

BIOPHARMA, INC.[1]

In 2005, Phillip (Phil) Landgraf faced several glaring problems in the financial performance of his company, BioPharma, Inc. The firm had experienced a steep decline in profits and very high costs at its plants in Germany and Japan. Landgraf, the company's president for worldwide operations, knew that demand for the company's products was stable across the globe. As a result, the surplus capacity in his global production network looked like a luxury he could no longer afford.

Any improvement in financial performance was dependent on having the most efficient network in place, because revenues were unlikely to grow. Cutting costs was thus a top priority for the coming year. To help design a more cost-effective network, Landgraf assigned a task force to recommend a course of action.

BACKGROUND

BioPharma, Inc., is a global manufacturer of bulk chemicals used in the pharmaceutical industry. The company holds patents on two chemicals that are called Highcal and Relax internally. These bulk chemicals are used internally by the company's pharmaceutical division, and are also sold to other drug manufacturers. There are distinctions in the precise chemical specifications to be met in different parts of the world. All plants, however, are currently set up to be able to produce both chemicals for any part of the world.

For 2005, sales of each product by region and the production and capacity at each plant are shown in Table 6-19. The plant capacity, measured in millions of kilograms of production, can be assigned to either chemical as long as the plant is capable of producing both. BioPharma has forecast that its sales for the two chemicals are likely to be stable for all parts of the world, except for Asia without Japan, where sales are expected to grow by 10 percent annually for each of the next five years before stabilizing.

The Japanese plant is a technology leader within the BioPharma network in terms of its ability to handle regulatory and environmental issues. Some developments in the Japanese plant had been transferred to other plants in the network. The German plant is a leader in terms of its production ability. The plant has routinely had the highest yields within the global network. The Brazilian, Indian, and Mexican plants have somewhat outdated technology and are in need of an update.

CURRENT PLANT COSTS AT BIOPHARMA

After considerable debate, the task force identified the cost structure at each plant in 2005 as shown in Table 6-20. Each plant incurs an annual fixed cost that is independent of the level of production in the plant. The fixed cost includes depreciation, utilities, and the salaries and fringe benefits of employees involved in general management, scheduling, expediting, accounting, maintenance, and so forth. Each plant that is capable of producing either Highcal or Relax also incurs a product-related fixed cost that is independent of the quantity of each chemical produced. The product-related fixed cost includes

TABLE 6-19 Sales by Region and Production/Capacity by Plant of Highcal and Relax in Million Kilograms

			Highcal		*Relax*	
Region	*Plant*	*Capacity*	*2005 Sales*	*2005 Production*	*2005 Sales*	*2005 Production*
Latin America	Brazil	18.0	7.0	11.0	7.0	7.0
Europe	Germany	45.0	15.0	15.0	12.0	0.0
Asia w/o Japan	India	18.0	5.0	10.0	3.0	8.0
Japan	Japan	10.0	7.0	2.0	8.0	0.0
Mexico	Mexico	30.0	3.0	12.0	3.0	18.0
U.S.	U.S.	22.0	18.0	5.0	17.0	17.0

[1]This case was inspired by *Applichem (A),* Harvard Business School Case 9–685–051, 1985.

TABLE 6-20 Fixed and Variable Production Costs at Each BioPharma Plant in 2005 (US$)

Plant	Plant Fixed Cost (million $)	Highcal Fixed Cost (million $)	Relax Fixed Cost (million $)	Highcal		Relax	
				Raw Material ($/kg)	Production cost ($/kg)	Raw Material ($/kg)	Production cost ($/kg)
Brazil	20.0	5.0	5.0	3.6	5.1	4.6	6.6
Germany	45.0	13.0	14.0	3.9	7.0	5.0	8.5
India	18.0	4.0	4.0	3.6	4.5	4.5	6.0
Japan	17.0	6.0	6.0	3.9	7.5	5.1	9.0
Mexico	30.0	6.0	6.0	3.6	5.0	4.6	6.5
U.S.	21.0	5.0	5.0	3.6	5.0	4.5	6.5

depreciation of equipment specific to a chemical and other fixed costs mentioned that are specific to a chemical. If a plant maintains the capability to produce a particular chemical, it incurs the corresponding product-related fixed cost even if the chemical is not produced at the plant.

The variable production cost of each chemical consists of two components: raw materials and production costs. The variable production cost is incurred in proportion to the quantity of chemical produced and includes direct labor and scrap. The plants themselves can handle varying levels of production. In fact, they can also be idled for the year, in which case they incur only the fixed cost, none of the variable cost.

BioPharma transports the chemicals in specialized containers by sea and in specialized trucks on land. The transportation costs between plants and markets are as shown in Table 6-21. Historical exchange rates are shown in Table 6-22 and the regional import duties in Table 6-23. Given regional trade alliances, import duties in reality vary based on the origin of the chemical. For simplicity's sake, however, the task force has assumed that the duties are driven only by the destination. Local production within each region is assumed to result in no import duty. Thus, production from Brazil, Germany, and India can be sent to Latin America, Europe, and the rest of Asia without Japan, respectively, without incurring any import duties. Duties apply only to the raw material, production,

TABLE 6-21 Transportation Costs from Plants to Markets (US$/kg)

From/To	Latin America	Europe	Asia w/o Japan	Japan	Mexico	U.S.
Brazil	0.20	0.45	0.50	0.50	0.40	0.45
Germany	0.45	0.20	0.35	0.40	0.30	0.30
India	0.50	0.35	0.20	0.30	0.50	0.45
Japan	0.50	0.40	0.30	0.10	0.45	0.45
Mexico	0.40	0.30	0.50	0.45	0.20	0.25
U.S.	0.45	0.30	0.45	0.45	0.25	0.20

TABLE 6-22 History of Exchange Rates in Currency/US$1 (at the Beginning of Each Year)

	Brazilian Real	Euro	Indian Rupee	Japanese Yen	Mexican Peso	U.S. Dollar
2005	2.70	0.74	43.47	103.11	11.21	1.00
2004	2.90	0.80	45.60	107.00	11.22	1.00
2003	3.50	0.96	48.00	119.25	10.38	1.00
2002	2.30	1.11	48.27	131.76	9.12	1.00
2001	1.95	1.06	46.75	114.73	9.72	1.00
2000	1.81	0.99	43.55	102.33	9.48	1.00

TABLE 6-23 Import Tariffs (Percent of Value of Product Imported, Including Transportation)

Latin America	*Europe*	*Asia w/o Japan*	*Japan*	*Mexico*	*U.S.*
30%	3%	27%	6%	35%	4%

and transportation cost component and not to the fixed cost component. Thus, a product entering Latin America with a raw material, production, and transportation cost of $10 incurs import duties of $3.

NETWORK OPTIONS UNDER CONSIDERATION

The task force is considering a variety of options for its analysis. One option is to keep the global network with its current structure and capabilities. Other options include shutting down some plants or limiting the capability of some plants to producing only one chemical. Closing down a plant eliminates all variable costs and saves 80 percent of the annual fixed costs (the remaining 20 percent accounts for costs that are incurred related to the plant shutdown). Similarly, if a plant is limited to producing only one chemical, the plant saves 80 percent of the fixed cost associated with that particular chemical. The two options being seriously considered are shutting the Japanese plant and limiting the German plant to a single chemical.

QUESTIONS

1. How should BioPharma have used its production network in 2005? Should any of the plants have been idled? What is the annual cost of your proposal, including import duties?
2. How should Phil structure his global production network? Assume that the past is a reasonable indicator of the future in terms of exchange rates.
3. Is there any plant for which it may be worth adding a million kilograms of additional capacity at a fixed cost of $3 million per year?
4. How are your recommendations affected by the reduction of duties?
5. The analysis has assumed that each plant has a 100 percent yield (percent output of acceptable quality). How would you modify your analysis to account for yield differences across plants?
6. What other factors should be accounted for when making your recommendations?

PART III

PLANNING DEMAND AND SUPPLY IN A SUPPLY CHAIN

CHAPTER 7
DEMAND FORECASTING IN A SUPPLY CHAIN

CHAPTER 8
AGGREGATE PLANNING IN A SUPPLY CHAIN

CHAPTER 9
PLANNING SUPPLY AND DEMAND IN A SUPPLY CHAIN: MANAGING PREDICTABLE VARIABILITY

The goal of the three chapters in Part III is to explain the significance of demand and supply planning in a supply chain, identify decisions that are part of the planning process, and discuss tools that supply chain managers can use for planning. Planning allows a supply chain manager to be proactive and manage demand and supply to ensure that profits are maximized.

Because most supply chain decisions are based on an estimate of future demand, Chapter 7 describes methodologies that can be used to forecast future demand based on historical demand data. Given a demand forecast, Chapter 8 describes the aggregate planning methodology that a supply chain manager can use to plan production, distribution, and allocation of resources for the near future (typically a quarter or a year) by making appropriate trade-offs among capacity, inventory, and backlogged orders across the entire supply chain. Chapter 9 then discusses how a supply chain manager can plan pricing and promotions to manage customer demand in coordination with production and distribution supply planning across the supply chain to maximize profits.

CHAPTER 7
DEMAND FORECASTING IN A SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of forecasting for both an enterprise and a supply chain.
2. Identify the components of a demand forecast.
3. Forecast demand in a supply chain given historical demand data using time-series methodologies.
4. Analyze demand forecasts to estimate forecast error.

Forecasts of future demand are essential for making supply chain decisions. In this chapter, we explain how historical demand information can be used to forecast future demand and how these forecasts affect the supply chain. We describe several methods to forecast demand and estimate a forecast's accuracy. We then discuss how these methods can be implemented using Microsoft Excel.

7.1 THE ROLE OF FORECASTING IN A SUPPLY CHAIN

Demand forecasts form the basis of all supply chain planning. Consider the push/pull view of the supply chain discussed in Chapter 1. All push processes in the supply chain are performed in anticipation of customer demand, whereas all pull processes are performed in response to customer demand. For push processes, a manager must plan the level of activity, be it production, transportation, or any other planned activity. For pull processes, a manager must plan the level of available capacity and inventory but not the actual amount to be executed. In both instances, the first step a manager must take is to forecast what customer demand will be.

For example, Dell orders PC components in anticipation of customer orders, whereas it performs assembly in response to customer orders. Dell uses a forecast of future demand to determine the quantity of components to have on hand (a push process) and to determine the capacity needed in its plants (for pull production). Farther up the supply chain, Intel also needs forecasts to determine its own production and inventory levels. Intel's suppliers also need forecasts for the same reason. When each stage in the supply chain makes its own separate forecast, these forecasts are often very different. The result is a mismatch between supply and demand. When all stages of a supply chain work together to produce a collaborative forecast, it tends to be much more accurate. The resulting forecast accuracy enables supply chains to be both more responsive and more efficient in serving their customers. Leaders in many supply chains, from PC manufacturers to packaged-goods retailers, have

improved their ability to match supply and demand by moving toward collaborative forecasting.

For example, consider the value of collaborative forecasting for Coca-Cola and its bottlers. Coca-Cola decides on the timing of various promotions based on the demand forecast over the coming quarter. Promotion decisions are then incorporated into an updated demand forecast. The updated forecast is essential for the bottlers to plan their capacity and production decisions. A bottler operating without an updated forecast based on the promotion is unlikely to have sufficient supply available for Coca-Cola, thus hurting supply chain profits.

Mature products with stable demand, such as milk or paper towels, are usually easiest to forecast. Forecasting and the accompanying managerial decisions are extremely difficult when either the supply of raw materials or the demand for the finished product is highly unpredictable. Fashion goods and many high-tech products are examples of items that are difficult to forecast. Good forecasting is very important in these cases because the time window for sales is narrow. If a firm has over- or underproduced, it has little chance to recover. For a product with stable demand, in contrast, the impact of a forecasting error is less significant.

Before we begin an in-depth discussion of the components of forecasts and forecasting methods in the supply chain, we briefly list characteristics of forecasts that a manager must understand to design and manage his or her supply chain effectively.

7.2 CHARACTERISTICS OF FORECASTS

Companies and supply chain managers should be aware of the following characteristics of forecasts.

1. Forecasts are always wrong and should thus include both the expected value of the forecast and a measure of forecast error. To understand the importance of forecast error, consider two car dealers. One of them expects sales to range between 100 and 1,900 units, whereas the other expects sales to range between 900 and 1,100 units. Even though both dealers anticipate average sales of 1,000, the sourcing policies for each dealer should be very different given the difference in forecast accuracy. Thus, the forecast error (or demand uncertainty) must be a key input into most supply chain decisions. Unfortunately, most firms do not maintain any estimate of forecast error.

2. Long-term forecasts are usually less accurate than short-term forecasts; that is, long-term forecasts have a larger standard deviation of error relative to the mean than short-term forecasts. Seven-Eleven Japan has exploited this key property to improve its performance. The company has instituted a replenishment process that enables it to respond to an order within hours. For example, if a store manager places an order by 10 A.M., the order is delivered by 7 P.M. the same day. Therefore, the manager only has to forecast what will sell that night less than 12 hours before the actual sale. The short lead time allows a manager to take into account current information, such as the weather, which could affect product sales. This forecast is likely to be more accurate than if the store manager had to forecast demand one week in advance.

3. Aggregate forecasts are usually more accurate than disaggregate forecasts, as they tend to have a smaller standard deviation of error relative to the mean. For example, it is easy to forecast the Gross Domestic Product (GDP) of the United States for a given year with less than a 2 percent error. However, it is much more difficult to forecast yearly revenue for a company with less than a 2 percent error, and it is even

harder to forecast revenue for a given product with the same degree of accuracy. The key difference among the three forecasts is the degree of aggregation. The GDP is an aggregation across many companies and the earnings of a company are an aggregation across several product lines. The greater the aggregation, the more accurate is the forecast.

4. In general, the farther up the supply chain a company is (or the farther it is from the consumer), the greater is the distortion of information it receives. One classic example of this is the bullwhip effect (see Chapter 17), in which order variation is amplified as orders move farther from the end customer. As a result, the farther up the supply chain an enterprise is, the larger is the forecast error. Collaborative forecasting based on sales to the end customer helps upstream enterprises reduce forecast error.

In the next section, we discuss the basic components of a forecast, explain the four classifications into which forecasting methods fall, and introduce the notion of forecast error.

7.3 COMPONENTS OF A FORECAST AND FORECASTING METHODS

Yogi Berra, the former New York Yankees catcher who is famous for his malapropisms, once said, "Predictions are usually difficult, especially about the future." One may be tempted to treat demand forecasting as magic or art and leave everything to chance. What a firm knows about its customers' past behavior, however, sheds light on their future behavior. Demand does not arise in a vacuum. Rather, customer demand is influenced by a variety of factors and can be predicted, at least with some probability, if a company can determine the relationship between these factors and future demand. To forecast demand, companies must first identify the factors that influence future demand and then ascertain the relationship between these factors and future demand.

Companies must balance objective and subjective factors when forecasting demand. Although we focus on quantitative forecasting methods in this chapter, companies must include human input when they make their final forecast. Seven-Eleven Japan illustrates this point.

Seven-Eleven Japan provides its store managers with a state-of-the-art decision support system that makes a demand forecast and provides a recommended order. The store manager, however, is responsible for making the final decision and placing the order, because he or she may have access to information about market conditions that are not available in historical demand data. This knowledge of market conditions is likely to improve the forecast. For example, if the store manager knows that the weather is likely to be rainy and cold the next day, he or she can reduce the size of an ice cream order to be placed with an upstream supplier, even if demand was high during the previous few days when the weather was hot. In this instance, a change in market conditions (the weather) would not have been predicted using historical demand data. A supply chain can experience substantial payoffs from improving its demand forecasting through qualitative human inputs.

A company must be knowledgeable about numerous factors that are related to the demand forecast. Some of these factors are listed next.

- Past demand
- Lead time of product
- Planned advertising or marketing efforts

- State of the economy
- Planned price discounts
- Actions that competitors have taken

A company must understand such factors before it can select an appropriate forecasting methodology. For example, historically a firm may have experienced low demand for chicken noodle soup in July and high demand in December and January. If the firm decides to discount the product in July, the situation is likely to change, with some of the future demand shifting to the month of July. The firm should make its forecast taking this factor into consideration.

Forecasting methods are classified according to the following four types.

1. ***Qualitative:*** Qualitative forecasting methods are primarily subjective and rely on human judgment. They are most appropriate when little historical data is available or when experts have market intelligence that may affect the forecast. Such methods may also be necessary to forecast demand several years into the future in a new industry.

2. ***Time series:*** Time-series forecasting methods use historical demand to make a forecast. They are based on the assumption that past demand history is a good indicator of future demand. These methods are most appropriate when the basic demand pattern does not vary significantly from one year to the next. These are the simplest methods to implement and can serve as a good starting point for a demand forecast.

3. ***Causal:*** Causal forecasting methods assume that the demand forecast is highly correlated with certain factors in the environment (the state of the economy, interest rates, etc.). Causal forecasting methods find this correlation between demand and environmental factors and use estimates of what environmental factors will be to forecast future demand. For example, product pricing is strongly correlated with demand. Companies can thus use causal methods to determine the impact of price promotions on demand.

4. ***Simulation:*** Simulation forecasting methods imitate the consumer choices that give rise to demand to arrive at a forecast. Using simulation, a firm can combine time-series and causal methods to answer such questions as: What will be the impact of a price promotion? What will be the impact of a competitor opening a store nearby? Airlines simulate customer buying behavior to forecast demand for higher-fare seats when there are no seats available at the lower fares.

A company may find it difficult to decide which method is most appropriate for forecasting. In fact, several studies have indicated that using multiple forecasting methods to create a combined forecast is more effective than using any one method alone.

In this chapter we deal primarily with time-series methods, which are most appropriate when future demand is related to historical demand, growth patterns, and any seasonal patterns. With any forecasting method, there is always a random element that cannot be explained by historical demand patterns. Therefore, any observed demand can be broken down into a systematic and a random component:

$$\text{Observed demand } (O) = \text{systematic component } (S) + \text{random component } (R)$$

The *systematic component* measures the expected value of demand and consists of what we will call *level,* the current deseasonalized demand; *trend,* the rate of growth or decline in demand for the next period; and *seasonality,* the predictable seasonal fluctuations in demand.

The *random component* is that part of the forecast that deviates from the systematic part. A company cannot (and should not) forecast the direction of the random

component. All a company can predict is the random component's size and variability, which provides a measure of forecast error. On average, a good forecasting method has an error whose size is comparable to the random component of demand. A manager should be skeptical of a forecasting method that claims to have no forecasting error on historical demand. In this case, the method has merged the historical random component with the systematic component. As a result, the forecasting method will likely perform poorly. The objective of forecasting is to filter out the random component (noise) and estimate the systematic component. The *forecast error* measures the difference between the forecast and actual demand.

7.4 BASIC APPROACH TO DEMAND FORECASTING

The following basic, six-step approach helps an organization perform effective forecasting.

1. Understand the objective of forecasting.
2. Integrate demand planning and forecasting throughout the supply chain.
3. Understand and identify customer segments.
4. Identify the major factors that influence the demand forecast.
5. Determine the appropriate forecasting technique.
6. Establish performance and error measures for the forecast.

UNDERSTAND THE OBJECTIVE OF FORECASTING

Every forecast supports decisions that are based on the forecast, so an important first step is to identify these decisions clearly. Examples of such decisions include how much of a particular product to make, how much to inventory, and how much to order. All parties affected by a supply chain decision should be aware of the link between the decision and the forecast. For example, Wal-Mart's plans to discount detergent during the month of July must be shared with the manufacturer, the transporter, and others involved in filling demand, as they all must make decisions that are affected by the forecast of demand. All parties should come up with a common forecast for the promotion and a shared plan of action based on the forecast. Failure to make these decisions jointly may result in either too much or too little product in various stages of the supply chain.

INTEGRATE DEMAND PLANNING AND FORECASTING THROUGHOUT THE SUPPLY CHAIN

A company should link its forecast to all planning activities throughout the supply chain. These include capacity planning, production planning, promotion planning, and purchasing, among others. This link should exist at both the information system and the human resources management level. As a variety of functions are affected by the outcomes of the planning process, it is important that all of them are integrated into the forecasting process. In one unfortunately common scenario, a retailer develops forecasts based on promotional activities, whereas a manufacturer, unaware of these promotions, develops a different forecast for its production planning based on historical orders. This leads to a mismatch between supply and demand, resulting in poor customer service.

To accomplish this integration, it is a good idea for a firm to have a cross-functional team, with members from each affected function responsible for forecasting demand—and an even better idea is to have members of different companies in the supply chain working together to create a forecast.

UNDERSTAND AND IDENTIFY CUSTOMER SEGMENTS

A firm must identify the customer segments the supply chain serves. Customers may be grouped by similarities in service requirements, demand volumes, order frequency, demand volatility, seasonality, and so forth. In general, companies may use different forecasting methods for different segments. A clear understanding of the customer segments facilitates an accurate and simplified approach to forecasting.

IDENTIFY MAJOR FACTORS THAT INFLUENCE THE DEMAND FORECAST

Next, a firm must identify demand, supply, and product-related phenomena that influence the demand forecast. On the demand side, a company must ascertain whether demand is growing, declining, or has a seasonal pattern. These estimates must be based on demad—not sales data. For example, a supermarket promoted a certain brand of cereal in July 2005. As a result, the demand for this cereal was high while the demand for other, comparable cereal brands was low in July. The supermarket should not use the sales data from 2005 to estimate that demand for this brand will be high in July 2006, because this will occur only if the same brand is promoted again in July 2006 and other brands respond as they did the previous year. When making the demand forecast, the supermarket must understand what the demand would have been in the absence of promotion activity and how demand is affected by promotions and competitor actions. A combination of these pieces of information will allow the supermarket to forecast demand for July 2006 given the promotion activity planned for that year.

On the supply side, a company must consider the available supply sources to decide on the accuracy of the forecast desired. If alternate supply sources with short lead times are available, a highly accurate forecast may not be especially important. However, if only a single supplier with a long lead time is available, an accurate forecast will have great value.

On the product side, a firm must know the number of variants of a product being sold and whether these variants substitute for or complement each other. If demand for a product influences or is influenced by demand for another product, the two forecasts are best made jointly. For example, when a firm introduces an improved version of an existing product, it is likely that the demand for the existing product will decline because new customers will buy the improved version. Although the decline in demand for the original product is not indicated by historical data, the historical demand is still useful in that it allows the firm to estimate the combined total demand for the two versions. Clearly, demand for the two products should be forecast jointly.

DETERMINE THE APPROPRIATE FORECASTING TECHNIQUE

In selecting an appropriate forecasting technique, a company should first understand the dimensions that are relevant to the forecast. These dimensions include geographic area, product groups, and customer groups. The company should understand the differences in demand along each dimension and will likely want different forecasts and techniques for each dimension. At this stage, a firm selects an appropriate forecasting method from among the four methods discussed earlier—qualitative, time-series, causal, or simulation. As mentioned earlier, using a combination of these methods is often most effective.

ESTABLISH PERFORMANCE AND ERROR MEASURES FOR THE FORECAST

Companies should establish clear performance measures to evaluate the accuracy and timeliness of the forecast. These measures should be highly correlated with the objectives

of the business decisions based on these forecasts. For example, consider a mail-order company that uses a forecast to place orders with its suppliers up the supply chain. Suppliers take two months to send in the orders. The mail-order company must ensure that the forecast is created at least two months before the start of the sales season because of the two-month lead time for replenishment. At the end of the sales season, the company must compare actual demand to forecasted demand to estimate the accuracy of the forecast. Then plans for decreasing future forecast errors or responding to the observed forecast errors can be put into place.

In the next section, we discuss techniques for static and adaptive time-series forecasting.

7.5 TIME-SERIES FORECASTING METHODS

The goal of any forecasting method is to predict the systematic component of demand and estimate the random component. In its most general form, the systematic component of demand data contains a level, a trend, and a seasonal factor. The equation for calculating the systematic component may take a variety of forms, as shown following.

- ***Multiplicative:*** Systematic component = level × trend × seasonal factor
- ***Additive:*** Systematic component = level + trend + seasonal factor
- ***Mixed:*** Systematic component = (level + trend) × seasonal factor

The specific form of the systematic component applicable to a given forecast depends on the nature of demand. Companies may develop both static and adaptive forecasting methods for each form. We now describe these static and adaptive forecasting methods.

STATIC METHODS

A static method assumes that the estimates of level, trend, and seasonality within the systematic component do not vary as new demand is observed. In this case, we estimate each of these parameters based on historical data and then use the same values for all future forecasts. In this section we discuss a static forecasting method for use when demand has a trend as well as a seasonal component. We assume that the systematic component of demand is mixed, that is,

$$\text{Systematic component} = (\text{level} + \text{trend}) \times \text{seasonal factor}$$

A similar approach can be applied for other forms as well. We begin with a few basic definitions:

L = estimate of level at $t = 0$ (the deseasonalized demand estimate during Period $t = 0$)
T = estimate of trend (increase or decrease in demand per period)
S_t = estimate of seasonal factor for Period t
D_t = actual demand observed in Period t
F_t = forecast of demand for Period t

In a static forecasting method, the forecast in Period t for demand in Period $t + l$ is given as

$$F_{t+l} = [L + (t + l)T]S_{t+l} \qquad \textbf{(7.1)}$$

We now describe one method for estimating the three parameters L, T, and S. As an example, consider the demand for rock salt used primarily to melt snow. This salt is

TABLE 7-1 Quarterly Demand for Tahoe Salt

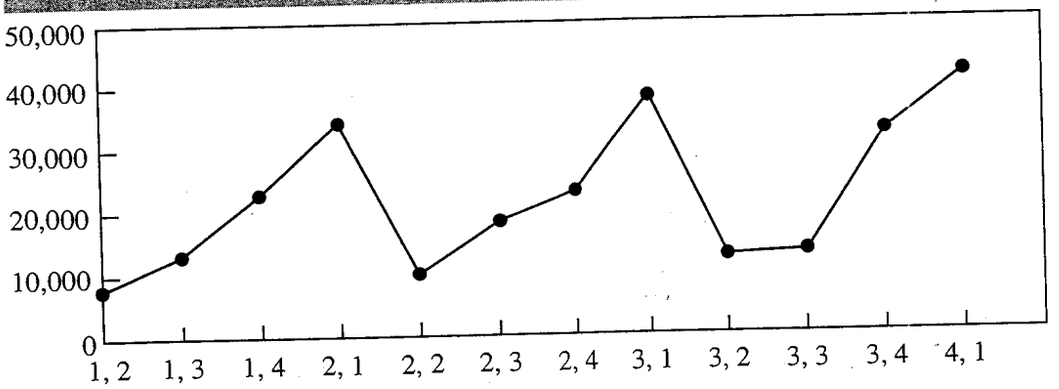
Year	*Quarter*	*Period, t*	*Demand, D_t*
1	2	1	8,000
1	3	2	13,000
1	4	3	23,000
2	1	4	34,000
2	2	5	10,000
2	3	6	18,000
2	4	7	23,000
3	1	8	38,000
3	2	9	12,000
3	3	10	13,000
3	4	11	32,000
4	1	12	41,000

produced by a firm called Tahoe Salt, which sells its salt through a variety of independent retailers around the Lake Tahoe area of the Sierra Nevada Mountains. In the past, Tahoe Salt has relied on estimates of demand from a sample of its retailers, but the company has noticed that these retailers always overestimate their purchases, leaving Tahoe (and even some retailers) stuck with excess inventory. After meeting with its retailers, Tahoe has decided to produce a collaborative forecast. Tahoe Salt wants to work with the retailers to create a more accurate forecast based on the actual retail sales of their salt. Quarterly retail demand data for the last three years is shown in Table 7-1 and charted in Figure 7-1.

In Figure 7-1, observe that demand for salt is seasonal, increasing from the second quarter of a given year to the first quarter of the following year. The second quarter of each year has the lowest demand. Each cycle lasts four quarters, and the demand pattern repeats every year. There is also a growth trend in the demand, with sales growing over the last three years. The company estimates that growth will continue in the coming year at historical rates. We now describe how each of the three parameters—level, trend, and seasonal factors—may be estimated. The following two steps are necessary to making this estimation:

1. Deseasonalize demand and run linear regression to estimate level and trend.
2. Estimate seasonal factors.

FIGURE 7-1 Quarterly Demand at Tahoe Salt



Estimating Level and Trend

The objective of this step is to estimate the level at Period 0 and the trend. We start by *deseasonalizing* the demand data. *Deseasonalized demand* represents the demand that would have been observed in the absence of seasonal fluctuations. The *periodicity* p is the number of periods after which the seasonal cycle repeats. For Tahoe Salt's demand, the pattern repeats every year. Given that we are measuring demand on a quarterly basis, the periodicity for the demand in Table 7-1 is $p = 4$.

To ensure that each season is given equal weight when deseasonalizing demand, we take the average of p consecutive periods of demand. The average of demand from Period $l + 1$ to Period $l + p$ provides deseasonalized demand for Period $l + (p + 1)/2$. If p is odd, this method provides deseasonalized demand for an existing period. If p is even, this method provides deseasonalized demand at a point between Period $l + (p/2)$ and $l + 1 + (p/2)$. By taking the average of deaseasonalized demand provided by Periods $l + 1$ to $l + p$ and $l + 2$ to $l + p + 1$, we obtain the deseasonalized demand for Period $l + 1 + (p/2)$. This procedure for obtaining the deseasonalized demand, $\overline{D}_t$, for Period t, is formulated as follows:

$$\overline{D}_t = \begin{cases} \left[D_{t-(p/2)} + D_{t+(p/2)} + \sum_{i=t+1-(p/2)}^{t-1+(p/2)} 2D_i \right] \Big/ 2p \text{ for } p \text{ even} \\ \sum_{i=t-(p/2)}^{t+(p/2)} D_i/p \text{ for } p \text{ odd} \end{cases} \tag{7.2}$$

In our example, $p = 4$ is even. For $t = 3$, we obtain the deseasonalized demand using Equation 7.2 as follows:

$$\overline{D}_3 = \left[D_{t-(p/2)} + D_{t+(p/2)} + \sum_{i=t+1-(p/2)}^{t-1+(p/2)} 2D_i \right] \Big/ 2p = \left[D_1 + D_5 + \sum_{i=2}^{4} 2D_i \right] \Big/ 8$$

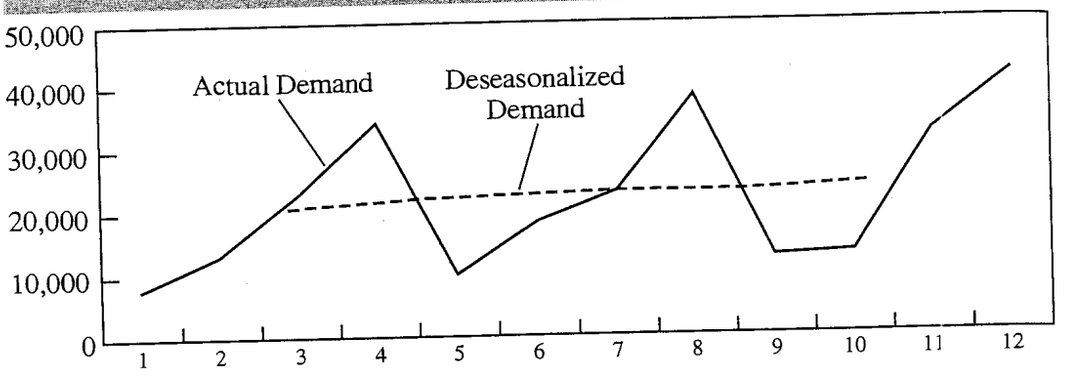
With this procedure we can obtain deseasonalized demand between Periods 3 and 10 as shown in Figure 7-2 and Figure 7-3.

FIGURE 7-2 Excel Workbook with Deseasonalized Demand for Tahoe Salt

	A	B	C
1	*Period t*	*Demand D_t*	*Deseasonalized Demand*
2	1	8,000	
3	2	13,000	
4	3	23,000	19,750
5	4	34,000	20,625
6	5	10,000	21,250
7	6	18,000	21,750
8	7	23,000	22,500
9	8	38,000	22,125
10	9	12,000	22,625
11	10	13,000	24,125
12	11	32,000	
13	12	41,000	

Cell	Cell Formula	Equation	Copied to
C4	=(B2+B6+2*SUM(B3:B5))/8	7.2	C5:C11

FIGURE 7-3 Deseasonalized Demand for Tahoe Salt



The following linear relationship exists between the deseasonalized demand, $\overline{D}_t$, and time t, based on the change in demand over time.

$$\overline{D}_t = L + Tt \tag{7.3}$$

Note that in Equation 7.3, $\overline{D}_t$ represents deseasonalized demand and not the actual demand in Period t, L represents the *level* or deseasonalized demand at Period 0, and T represents the rate of growth of deseasonalized demand or *trend*. We can estimate the values of L and T for the deseasonalized demand using linear regression with deseasonalized demand (in Figure 7-2) as the dependent variable and time as the independent variable. Such a regression can be run using Microsoft Excel (Tools | Data Analysis | Regression). This sequence of commands opens the Regression dialog box in Excel. For the Tahoe Salt workbook in Figure 7-2, in the resulting dialog box we enter

Input Y Range: C4:C11
Input X Range: A4:A11

and click the OK button. A new sheet containing the results of the regression opens up. This new sheet contains estimates for both the initial level L and the trend T. The initial level, L, is obtained as the *intercept coefficient* and the trend, T, is obtained as the X *variable coefficient* (or the slope) from the sheet containing the regression results. For the Tahoe Salt example, we obtain $L = 18{,}439$ and $T = 524$. For this example, deseasonalized demand $\overline{D}_t$ for any Period t is thus given by

$$\overline{D}_t = 18{,}439 + 524t \tag{7.4}$$

Note that it is not appropriate to run a linear regression between the original demand data and time to estimate level and trend because the original demand data are not linear and the resulting linear regression will not be accurate. The demand must be deseasonalized before we run the linear regression.

Estimating Seasonal Factors

We can now obtain deseasonalized demand for each period using Equation 7.4. The seasonal factor $\overline{S}_t$ for Period t is the ratio of actual demand D_t to deseasonalized demand $\overline{D}_t$ and is given as

$$\overline{S}_t = \frac{D_i}{\overline{D}_t} \tag{7.5}$$

For the Tahoe Salt example, the deseasonalized demand estimated using Equation 7.4 and the seasonal factors estimated using Equation 7.5 are shown in Figure 7-4.

FIGURE 7-4 Deseasonalized Demand and Seasonal Factors for Tahoe Salt

	A	B	C	D
1	*Period* t	*Demand* D_t	*Deseasonalized Demand (Eqn 7.4)* $\overline{D}_t$	*Seasonal Factor (Eqn 7.5)* $\overline{S}_t$
2	1	8,000	18,963	0.42
3	2	13,000	19,487	0.67
4	3	23,000	20,011	1.15
5	4	34,000	20,535	1.66
6	5	10,000	21,059	0.47
7	6	18,000	21,583	0.83
8	7	23,000	22,107	1.04
9	8	38,000	22,631	1.68
10	9	12,000	23,155	0.52
11	10	13,000	23,679	0.55
12	11	32,000	24,203	1.32
13	12	41,000	24,727	1.66

Cell	Cell Formula	Equation	Copied to
C2	=18439+A2*524	7.4	C3:C13
D2	=B2/C2	7.5	D3:D13

Given the periodicity, p, we obtain the seasonal factor for a given period by averaging seasonal factors that correspond to similar periods. For example, if we have a periodicity of $p = 4$, Periods 1, 5, and 9 have similar seasonal factors. The seasonal factor for these periods is obtained as the average of the three seasonal factors. Given r seasonal cycles in the data, for all periods of the form $pt + i$, $1 \leq i \leq p$ we obtain the seasonal factor as

$$S_i = \frac{\sum_{j=0}^{r-1} \overline{S}_{jp+i}}{r} \tag{7.6}$$

For the Tahoe Salt example, a total of 12 periods and a periodicity of $p = 4$ implies that there are $r = 3$ seasonal cycles in the data. We obtain seasonal factors using Equation 7.6 as

$$S_1 = (\overline{S}_1 + \overline{S}_5 + \overline{S}_9)/3 = (0.42 + 0.47 + 0.52)/3 = 0.47$$
$$S_2 = (\overline{S}_2 + \overline{S}_6 + \overline{S}_{10})/3 = (0.67 + 0.83 + 0.55)/3 = 0.68$$
$$S_3 = (\overline{S}_3 + \overline{S}_7 + \overline{S}_{11})/3 = (1.15 + 1.04 + 1.32)/3 = 1.17$$
$$S_4 = (\overline{S}_4 + \overline{S}_8 + \overline{S}_{12})/3 = (1.66 + 1.68 + 1.66)/3 = 1.67$$

At this stage, we have estimated the level, trend, and all seasonal factors. We can now obtain the forecast for the next four quarters using Equation 7.1. In the example, the forecast for the next four periods using the static forecasting method is given by

$$F_{13} = (L + 13T)S_{13} = (18{,}439 + 13 \times 524)0.47 = 11{,}868$$
$$F_{14} = (L + 14T)S_{14} = (18{,}439 + 14 \times 524)0.68 = 17{,}527$$
$$F_{15} = (L + 15T)S_{15} = (18{,}439 + 15 \times 524)1.17 = 30{,}770$$
$$F_{16} = (L + 16T)S_{16} = (18{,}439 + 16 \times 524)1.67 = 44{,}794$$

Tahoe Salt and its retailers now have a more accurate forecast of demand. Without the sharing of sell-through information between the retailers and the manufacturer, this supply chain would have a less accurate forecast and a variety of production and inventory inefficiencies would result.

ADAPTIVE FORECASTING

In adaptive forecasting, the estimates of level, trend, and seasonality are updated after each demand observation. We now discuss a basic framework and several methods that can be used for this type of forecast. The framework is provided in the most general setting, when the systematic component of demand data contains a level, a trend, and a seasonal factor. The framework we present is for the case in which the systematic component has the mixed form. It can, however, easily be modified for the other two cases. The framework can also be specialized for the case in which the systematic component contains no seasonality or trend. We assume that we have a set of historical data for n periods and that demand is seasonal with periodicity p. Given quarterly data, where the pattern repeats itself every year, we have a periodicity of $p = 4$.

We begin by defining a few terms:

L_t = estimate of level at the end of Period t
T_t = estimate of trend at the end of Period t
S_t = estimate of seasonal factor for Period t
F_t = forecast of demand for Period t (made in Period $t-1$ or earlier)
D_t = actual demand observed in Period t
E_t = forecast error in Period t

In adaptive methods, the forecast for Period $t + l$ in Period t is given as

$$F_{t+l} = (L_t + lT_t)S_{t+l} \tag{7.7}$$

The four steps in the adaptive forecasting framework are as follows.

1. ***Initialize:*** Compute initial estimates of the level (L_0), trend (T_0), and seasonal factors ($S_1, \ldots, S_p$) from the given data. This is done exactly as in the static forecasting method discussed earlier in the chapter.
2. ***Forecast:*** Given the estimates in Period t, forecast demand for Period $t + 1$ using Equation 7.7. Our first forecast is for Period 1 and is made with the estimates of level, trend, and seasonal factor at Period 0.
3. ***Estimate error:*** Record the actual demand D_{t+1} for Period $t + 1$ and compute the error E_{t+1} in the forecast for Period $t + 1$ as the difference between the forecast and the actual demand. The error for Period $t + 1$ is stated as

$$E_{t+1} = F_{t+1} - D_{t+1} \tag{7.8}$$

4. ***Modify estimates:*** Modify the estimates of level (L_{t+1}), trend (T_{t+1}), and seasonal factor (S_{t+p+1}), given the error E_{t+1} in the forecast. It is desirable that the modification be such that if the demand is lower than forecast, the estimates are revised downward, whereas if the demand is higher than forecast, the estimates are revised upward.

The revised estimates in Period $t + 1$ are then used to make a forecast for Period $t + 2$, and Steps 2, 3, and 4 are repeated until all historical data up to Period n have been covered. The estimates at Period n are then used to forecast future demand.

We now discuss various adaptive forecasting methods. The method that is most appropriate depends on the characteristic of demand and the composition of the systematic component of demand. In each case we assume the period under consideration to be t.

Moving Average

The moving-average method is used when demand has no observable trend or seasonality. In this case,

Systematic component of demand = level

In this method, the level in Period t is estimated as the average demand over the most recent N periods. This represents an N-period moving average and is evaluated as follows:

$$L_t = (D_t + D_{t-1} + \ldots + D_{t-N+1})/N \tag{7.9}$$

The current forecast for all future periods is the same and is based on the current estimate of level. The forecast is stated as

$$F_{t+1} = L_t \quad \text{and} \quad F_{t+n} = L_t \tag{7.10}$$

After observing the demand for Period $t + 1$, we revise the estimates as follows:

$$L_{t+1} = (D_{t+1} + D_t + \ldots + D_{t-N+2})/N, \quad F_{t+2} = L_{t+1}$$

To compute the new moving average, we simply add the latest observation and drop the oldest one. The revised moving average serves as the next forecast. The moving average corresponds to giving the last N periods of data equal weight when forecasting and ignoring all data older than this new moving average. As we increase N, the moving average becomes less responsive to the most recently observed demand. We illustrate the use of the moving average in Example 7-1.

Example 7-1 A supermarket has experienced weekly demand of milk of 120, 127, 114, and 122 gallons over the last four weeks. Forecast demand for Period 5 using a four-period moving average. What is the forecast error if demand in Period 5 turns out to be 125 gallons?

Analysis: We make the forecast for Period 5 at the end of Period 4. Thus, assume the current period to be $t = 4$. Our first objective is to estimate the level in Period 4. Using Equation 7.9, with $N = 4$, we obtain

$$L_4 = (D_4 + D_3 + D_2 + D_1)/4 = (120 + 127 + 114 + 122)/4 = 120.75$$

The forecast of demand for Period 5, using Equation 7.10, is expressed as

$$F_5 = L_4 = 120.75 \text{ gallons}$$

As demand in Period 5, D_5, is 125 gallons, we have a forecast error for Period 5 of

$$E_5 = F_5 - D_5 = 125 - 120.75 = 4.25$$

After observing demand in Period 5, the revised estimate of level for Period 5 is given by

$$L_5 = (D_5 + D_4 + D_3 + D_2)/4 = (127 + 114 + 122 + 125)/4 = 122$$

Simple Exponential Smoothing

The simple exponential smoothing method is appropriate when demand has no observable trend or seasonality. In this case,

$$\text{Systematic component of demand} = \text{level}$$

The initial estimate of level, L_0, is taken to be the average of all historical data because demand has been assumed to have no observable trend or seasonality. Given demand data for Periods 1 through n, we have the following:

$$L_0 = \frac{1}{n}\sum_{i=1}^{n} D_i \tag{7.11}$$

The current forecast for all future periods is equal to the current estimate of level and is given as

$$F_{t+1} = L_t \quad \text{and} \quad F_{t+n} = L_t \tag{7.12}$$

After observing the demand, D_{t+1}, for Period $t + 1$, we revise the estimate of the level as follows:

$$L_{t+1} = \alpha D_{t+1} + (1 - \alpha)L_t \tag{7.13}$$

where α is a smoothing constant for the level, $0 < \alpha < 1$. The revised value of the level is a weighted average of the observed value of the level (D_{t+1}) in Period $t + 1$ and the old estimate of the level (L_t) in Period t. Using Equation 7.13, we can express the level in a given period as a function of the current demand and the level in the previous period. We can thus rewrite Equation 7.13 as

$$L_{t+1} = \sum_{n=0}^{t-1} \alpha(1 - \alpha)^n D_{t+1-n} + (1 - \alpha)^t D_1$$

The current estimate of the level is a weighted average of all of the past observations of demand, with recent observations weighted higher than older observations. A higher value of α corresponds to a forecast that is more responsive to recent observations, whereas a lower value of α represents a more stable forecast that is less responsive to recent observations. We illustrate the use of exponential smoothing in Example 7-2.

Example 7-2 Consider the supermarket in Example 7-1, where weekly demand for milk has been 120, 127, 114, and 122 gallons over the last four weeks. Forecast demand for Period 1 using simple exponential smoothing with $\alpha = 0.1$.

Analysis: In this case we have demand data for $n = 4$ periods. Using Equation 7.11, the initial estimate of level is expressed by

$$L_0 = \sum_{i=1}^{4} D_i = 120.75$$

The forecast for Period 1 (using Equation 7.1) is thus given by

$$F_1 = L_0 = 120.75$$

The observed demand for Period 1 is $D_1 = 120$. The forecast error for Period 1 is given by

$$E_1 = F_1 - D_1 = 120.75 - 120 = 0.75$$

With $\alpha = 0.1$, the revised estimate of level for Period 1 using Equation 7.13 is given by

$$L_1 = \alpha D_1 + (1 - \alpha)L_0 = 0.1 \times 120 + 0.9 \times 120.75 = 120.68$$

Observe that the estimate of level for Period 1 is lower than for Period 0 because the demand in Period 1 is lower than the forecast for Period 1. Continuing in this manner, we obtain $F_3 = 121.31$, $F_4 = 120.58$, and $F_5 = 120.72$. Thus, the forecast for period 5 is 120.72.

Trend-Corrected Exponential Smoothing (Holt's Model)

The trend-corrected exponential smoothing (Holt's model) method is appropriate when demand is assumed to have a level and a trend in the systematic component but no seasonality. In this case, we have

$$\text{Systematic component of demand} = \text{level} + \text{trend}$$

We obtain an initial estimate of level and trend by running a linear regression between demand D_t and time Period t of the form

$$D_t = at + b$$

In this case, running a linear regression between demand and time periods is appropriate because we have assumed that demand has a trend but no seasonality. The underlying relationship between demand and time is thus linear. The constant b

measures the estimate of demand at Period $t = 0$ and is our estimate of the initial level L_0. The slope a measures the rate of change in demand per period and is our initial estimate of the trend T_0.

In Period t, given estimates of level L_t and trend T_t, the forecast for future periods is expressed as

$$F_{t+1} = L_t + T_t \quad \text{and} \quad F_{t+n} = L_t + nT_t \tag{7.14}$$

After observing demand for Period t, we revise the estimates for level and trend as follows:

$$L_{t+1} = \alpha D_{t+1} + (1 - \alpha)(L_t + T_t) \tag{7.15}$$

$$T_{t+1} = \beta(L_{t+1} - L_t) + (1 - \beta)T_t \tag{7.16}$$

where α is a smoothing constant for the level, $0 < \alpha < 1$, and β is a smoothing constant for the trend, $0 < \beta < 1$. Observe that in each of the two updates, the revised estimate (of level or trend) is a weighted average of the observed value and the old estimate. We illustrate the use of Holt's model in Example 7-3.

Example 7-3 An electronics manufacturer has seen demand for its latest MP3 player increase over the last six months. Observed demand (in thousands) has been 8,415, 8,732, 9,014, 9,808, 10,413, and 11,961. Forecast demand for Period 7 using trend-corrected exponential smoothing with $\alpha = 0.1$, $\beta = 0.2$.

Analysis: The first step is to obtain initial estimates of level and trend using linear regression. We first run a linear regression (using the Excel tool Regression Tools | Data Analysis | Regression) between demand and time periods. The estimate of initial level L_0 is obtained as the *intercept coefficient* and the trend T_0 is obtained as the *X variable coefficient* (or the slope). For the MP3 player data, we obtain

$$L_0 = 7{,}367 \quad \text{and} \quad T_0 = 673$$

The forecast for Period 1 (using Equation 7.14) is thus given by

$$F_1 = L_0 + T_0 = 7{,}367 + 673 = 8{,}040$$

The observed demand for Period 1 is $D_1 = 8{,}415$. The error for Period 1 is thus given by

$$E_1 = F_1 - D_1 = 8{,}040 - 8{,}415 = -375$$

With $\alpha = 0.1$, $\beta = 0.2$, the revised estimate of level and trend for Period 1 using Equations 7.15 and 7.16 is given by

$$L_1 = \alpha D_1 + (1 - \alpha)(L_0 + T_0) = 0.1 \times 8{,}415 + 0.9 \times 8{,}040 = 8{,}078$$
$$T_1 = \beta(L_1 - L_0) + (1 - \beta)T_0 = 0.2 \times (8{,}078 - 7{,}367) + 0.8 \times 673 = 681$$

Observe that the initial estimate for demand in Period 1 is too high. As a result, our updates have increased the estimate of level for Period 1 from 8,040 to 8,078 and the estimate of trend from 673 to 681. Using Equation 7.14, we thus obtain the following forecast for Period 2:

$$F_2 = L_1 + T_1 = 8{,}078 + 681 = 8{,}759$$

Continuing in this manner, we obtain $L_2 = 8{,}755$, $T_2 = 680$, $L_3 = 9{,}393$, $T_3 = 672$, $L_4 = 10{,}039$, $T_4 = 666$, $L_5 = 10{,}676$, $T_5 = 661$, $L_6 = 11{,}399$, $T_6 = 673$. This gives us a forecast for period 7 of

$$F_7 = L_6 + T_6 = 11{,}399 + 673 = 12{,}072$$

Trend- and Seasonality-Corrected Exponential Smoothing (Winter's Model)

This method is appropriate when the systematic component of demand has a level, a trend, and a seasonal factor. In this case we have

$$\text{Systematic component of demand} = (\text{level} + \text{trend}) \times \text{seasonal factor}$$

Assume periodicity of demand to be p. To begin, we need initial estimates of level (L_0), trend (T_0), and seasonal factors ($S_1, \ldots, S_p$). We obtain these estimates using the procedure for static forecasting described earlier in the chapter.

In Period t, given estimates of level, L_t, trend, T_t, and seasonal factors, $S_t, \ldots, S_{t+p-1}$, the forecast for future periods is given by

$$F_{t+1} = (L_t + T_t)S_{t+1} \quad \text{and} \quad F_{t+l} = (L_t + lT_t)S_{t+l} \tag{7.17}$$

On observing demand for Period $t + 1$ we revise the estimates for level, trend, and seasonal factors as follows:

$$L_{t+1} = \alpha(D_{t+1}/S_{t+1}) + (1 - \alpha)(L_t + T_t) \tag{7.18}$$

$$T_{t+1} = \beta(L_{t+1} - L_t) + (1 - \beta)T_t \tag{7.19}$$

$$S_{t+p+1} = \gamma(D_{t+1}/L_{t+1}) + (1 - \gamma)S_{t+1} \tag{7.20}$$

where α is a smoothing constant for the level, $0 < \alpha < 1$; β is a smoothing constant for the trend, $0 < \beta < 1$; and γ is a smoothing constant for the seasonal factor, $0 < \gamma < 1$. Observe that in each of the updates (level, trend, or seasonal factor), the revised estimate is a weighted average of the observed value and the old estimate. We illustrate the use of Winter's model in Example 7-4.

Example 7-4 Consider the Tahoe Salt demand data in Table 7-1. Forecast demand for Period 1 using trend- and seasonality-corrected exponential smoothing with $\alpha = 0.1$, $\beta = 0.2$, $\gamma = 0.1$.

Analysis: We obtain the initial estimates of level, trend, and seasonal factors exactly as in the static case. They are expressed as follows:

$L_0 = 18{,}439 \quad T_0 = 524 \quad S_1 = 0.47 \quad S_2 = 0.68 \quad S_3 = 1.17 \quad S_4 = 1.67$

The forecast for Period 1 (using Equation 7.17) is thus given by

$$F_1 = (L_0 + T_0)S_1 = (18{,}439 + 524)0.47 = 8{,}913$$

The observed demand for Period 1 is $D_1 = 8{,}000$. The forecast error for Period 1 is thus given by

$$E_1 = F_1 - D_1 = 8{,}913 - 8{,}000 = 913$$

With $\alpha = 0.1$, $\beta = 0.2$, $\gamma = 0.1$, the revised estimate of level and trend for Period 1 and seasonal factor for Period 5, using Equations 7.18, 7.19, and 7.20, is given by

$$\begin{aligned} L_1 &= \alpha(D_1/S_1) + (1 - \alpha)(L_0 + T_0) \\ &= 0.1 \times (8{,}000/0.47) + 0.9 \times (18{,}439 + 524) = 18{,}769 \\ T_1 &= \beta(L_1 - L_0) + (1 - \beta)T_0 = 0.2 \times (18{,}769 - 18{,}439) + 0.8 \times 524 = 485 \\ S_5 &= \gamma(D_1/L_1) + (1 - \gamma)S_1 = 0.1(8{,}000/18{,}769) + 0.9 \times 0.47 = 0.47 \end{aligned}$$

The forecast of demand for Period 2 (using Equation 7.17) is thus given by

$$F_2 = (L_1 + T_1)S_2 = (18{,}769 + 485)0.68 = 13{,}093$$

The forecasting methods we have discussed and the situations in which they are generally applicable are as follows:

Forecasting Method	*Applicability*
Moving average	No trend or seasonality
Simple exponential smoothing	No trend or seasonality
Holt's model	Trend but no seasonality
Winter's model	Trend and seasonality

If Tahoe Salt uses an adaptive forecasting method for the sell-through data obtained from its retailers, Winter's model is the best choice, because its demand experiences both a trend and seasonality.

If we do not know that Tahoe Salt experiences both trend and seasonality, how can we find out? Forecast error helps identify instances in which the forecasting method being used is inappropriate. In the next section, we describe how a manager can estimate and use forecast error.

7.6 MEASURES OF FORECAST ERROR

As mentioned earlier, every instance of demand has a random component. A good forecasting method should capture the systematic component of demand but not the random component. The random component manifests itself in the form of a forecast error. Forecast errors contain valuable information and must be analyzed carefully for two reasons:

1. Managers use error analysis to determine whether the current forecasting method is predicting the systematic component of demand accurately. For example, if a forecasting method consistently produces a positive error, the forecasting method is overestimating the systematic component and should be corrected.

2. All contingency plans must account for forecast error. For example, consider a mail-order company with two suppliers. The first is in the Far East and has a lead time of two months. The second is local and can fill orders with one week's notice. The local supplier is more expensive, whereas the Far East supplier costs less. The mail-order company wants to contract a certain amount of contingency capacity with the local supplier to be used if the demand exceeds the quantity the Far East supplier provides. The decision regarding the quantity of local capacity to contract is closely linked to the size of the forecast error.

As long as observed errors are within historical error estimates, firms can continue to use their current forecasting method. Finding an error that is well beyond historical estimates may indicate that the forecasting method in use is no longer appropriate. If all of a firm's forecasts tend to consistently over- or underestimate demand, this may be another signal that the firm should change its forecasting method.

As defined earlier, forecast error for Period t is given by E_t, where the following holds:

$$E_t = F_t - D_t$$

That is, the error in Period t is the difference between the forecast for Period t and the actual demand in Period t. It is important that a manager estimate the error of a forecast made at least as far in advance as the lead time required for the manager to take whatever action the forecast is to be used for. For example, if a forecast will be used to determine an order size and the supplier's lead time is six months, a manager should estimate the error for a forecast made six months before demand arises. In a situation with a six-month lead time, there is no point in estimating errors for a forecast made one month in advance.

One measure of forecast error is the *mean squared error* (MSE), where the following holds:

$$MSE_n = \frac{1}{n}\sum_{t=1}^{n} E_t^2 \qquad (7.21)$$

The MSE can be related to the variance of the forecast error. In effect, we estimate that the random component of demand has a mean of 0 and a variance of MSE.

Define the *absolute deviation* in Period t, A_t, to be the absolute value of the error in Period t; that is,

$$A_t = |E_t|$$

Define the *mean absolute deviation* (MAD) to be the average of the absolute deviation over all periods, as expressed by

$$MAD_n = \frac{1}{n}\sum_{t=1}^{n} A_t \tag{7.22}$$

The MAD can be used to estimate the standard deviation of the random component assuming that the random component is normally distributed. In this case the standard deviation of the random component is

$$\sigma = 1.25\, MAD \tag{7.23}$$

We then estimate that the mean of the random component is 0 and the standard deviation of the random component of demand is σ.

The *Mean Absolute Percentage Error* (MAPE) is the average absolute error as a percentage of demand and is given by

$$MAPE_n = \frac{\sum_{t=1}^{n} \left|\frac{E_t}{D_t}\right| 100}{n} \tag{7.24}$$

To determine whether a forecast method consistently over- or underestimates demand, we can use the sum of forecast errors to evaluate the *bias*, where the following holds:

$$Bias_n = \sum_{t=1}^{n} E_t \tag{7.25}$$

The bias will fluctuate around 0 if the error is truly random and not biased one way or the other. Ideally, if we plot all the errors, the slope of the best straight line passing through should be 0.

The *tracking signal* (TS) is the ratio of the bias and the MAD and is given as

$$TS_t = \frac{bias_t}{MAD_t} \tag{7.26}$$

If the TS at any period is outside the range ± 6, this is a signal that the forecast is biased and is either underforecasting ($TS < -6$) or overforecasting ($TS > +6$). In this case, a firm may decide to choose a new forecasting method. One instance in which a large negative TS will result is when demand has a growth trend and the manager is using a forecasting method such as moving average. Because trend is not included, the average of historical demand is always lower than future demand. The negative TS detects that the forecasting method consistently underestimates demand and alerts the manager.

7.7 FORECASTING DEMAND AT TAHOE SALT

Recall the Tahoe Salt example earlier in the chapter with the historical sell-through demand from its retailers shown in Table 7-1. The demand data are also shown in column B of Figure 7-5. Tahoe Salt is currently negotiating contracts with suppliers for the four quarters between the second quarter of year 4 and the first quarter of year 5. An important input into this negotiation is the forecast of demand that Tahoe Salt and its

FIGURE 7-5 Tahoe Salt Forecasts Using Four-Period Moving Average

	A	B	C	D	E	F	G	H	I	J	K
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Absolute Error A_t	Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	1	8,000									
3	2	13,000									
4	3	23,000									
5	4	34,000	19,500								
6	5	10,000	20,000	19,500	9,500	9,500	90,250,000	9,500	95	95	1.00
7	6	18,000	21,250	20,000	2,000	2,000	47,125,000	5,750	11	53	2.00
8	7	23,000	21,250	21,250	-1,750	1,750	32,437,500	4,417	8	38	2.21
9	8	38,000	22,250	21,250	-16,750	16,750	94,468,750	7,500	44	39	-0.93
10	9	12,000	22,750	22,250	10,250	10,250	96,587,500	8,050	85	49	0.40
11	10	13,000	21,500	22,750	9,750	9,750	96,333,333	8,333	75	53	1.56
12	11	32,000	23,750	21,500	-10,500	10,500	98,321,429	8,643	33	50	0.29
13	12	41,000	24,500	23,750	-17,250	17,250	123,226,563	9,719	42	49	-1.52

Cell	Cell Formula	Equation	Copied to
C6	=Average(B3:B6)	7.9	C7:C13
D6	=C5	7.10	D7:D13
E6	=D6-B6	7.8	E7:E13
F6	=Abs(E6)		F7:F13
G6	=Sumsq($E$6:E6)/(A6-4)	7.21	G7:G13
H6	=Sum($F$6:F6)/(A6-4)	7.22	H7:H13
I6	=100*(F6/B6)		I7:I13
J6	=Average($I$6:I6)	7.24	J7:J13
K6	=Sum($E$6:E6)/ H6	7.26	K7:K13

retailers are building collaboratively. They have assigned a team consisting of two sales managers from the retailers and the vice president of operations for Tahoe Salt to come up with this forecast. The forecasting team decides to apply each of the adaptive forecasting methods discussed in this chapter to the historical data. Their goal is to select the most appropriate forecasting method and then use it to forecast demand for the next four quarters. The team decides to select the forecasting method based on the errors that result when each method is used on the 12 quarters of historical demand data.

Demand in this case clearly has both a trend and seasonality in the systematic component. Thus the team initially expects Winter's model to produce the best forecast.

MOVING AVERAGE

The forecasting team initially decides to test a four-period moving average for the forecasting. All calculations are shown in Figure 7-5 and are as discussed in the section on the moving-average method earlier in this chapter. The team uses Equation 7.3 to estimate level and Equation 7.4 to forecast demand.

As indicated by column K in Figure 7-5, the TS is well within the ± 6 range, which indicates that the forecast using the four-period moving average does not contain any

significant bias. It does, however, have a fairly large MAD of 9,719, and a MAPE of 49 percent. From Figure 7-5, observe that

$$L_{12} = 24{,}500$$

Thus, using a four-period moving average, the forecast for Periods 13 through 16 (using Equation 7.10) is given by

$$F_{13} = F_{14} = F_{15} = F_{16} = L_{12} = 24{,}500$$

Given that the MAD is 9,719, the estimate of standard deviation of forecast error, using a four-period moving average, is $1.25 \times 9{,}719 = 12{,}148$. In this case, the standard deviation of forecast error is fairly large relative to the size of the forecast.

SIMPLE EXPONENTIAL SMOOTHING

The forecasting team next uses a simple exponential smoothing approach with $\alpha = 0.1$ to forecast demand. This method is also tested on the 12 quarters of historical data. Using Equation 7.11, the team estimates the initial level for Period 0 to be the average demand for Periods 1 through 12. The initial level is the average of the demand entries in cells B2 to B14 in Figure 7-6 and results in

$$L_0 = 22{,}083$$

The team then uses Equation 7.12 to forecast demand for the succeeding period. The estimate of level is updated each period using Equation 7.13. The results are shown in Figure 7-6.

As indicated by the TS, which ranges from –1.38 to 2.25, the forecast using simple exponential smoothing with $\alpha = 0.1$ does not indicate any significant bias. However, it has a fairly large MAD of 10,208, and a MAPE of 59 percent. From Figure 7-6, observe that

$$L_{12} = 23{,}490$$

Thus, the forecast for the next four quarters (using Equation 7.12) is given by

$$F_{13} = F_{14} = F_{15} = F_{16} = L_{12} = 23{,}490$$

In this case, MAD_{12} is 10,208 and $MAPE_{12}$ is 59 percent. Thus, the estimate of standard deviation of forecast error using simple exponential smoothing is $1.25 \times 10{,}208 = 12{,}761$. In this case, the standard deviation of forecast error is fairly large relative to the size of the forecast.

TREND-CORRECTED EXPONENTIAL SMOOTHING (HOLT'S MODEL)

The team next investigates the use of Holt's model. In this case the systematic component of demand is given by

$$\text{Systematic component of demand} = \text{level} + \text{trend}$$

The team applies the methodology discussed earlier. As a first step, they estimate the level at Period 0 and the initial trend. As described in Example 7-3, this estimate is obtained by running a linear regression between demand, D_t, and time, Period t. From the regression of the available data, the team obtains the following:

$$L_0 = 12{,}015 \quad \text{and} \quad T_0 = 1{,}549$$

The team now applies Holt's model with $\alpha = 0.1$ and $\beta = 0.2$ to obtain the forecasts for each of the 12 quarters for which demand data are available. They make the forecast using Equation 7.14, they update the level using Equation 7.15, and they update the trend using Equation 7.16. The results are shown in Figure 7-7.

FIGURE 7-6 Tahoe Salt Forecasts Using Simple Exponential Smoothing

	A	B	C	D	E	F	G	H	I	J	K
1	Period t	Demand D_t	Level L_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	0		22,083								
3	1	8,000	20,675	22,083	14,083	14,083	198,340,278	14,083	176	176	1
4	2	13,000	19,908	20,675	7,675	7,675	128,622,951	10,879	59	118	2
5	3	23,000	20,217	19,908	-3,093	3,093	88,936,486	8,284	13	83	2
6	4	34,000	21,595	20,217	-13,783	13,783	114,196,860	9,659	41	72	0.51
7	5	10,000	20,436	21,595	11,595	11,595	118,246,641	10,046	116	81	1.64
8	6	18,000	20,192	20,436	2,436	2,436	99,527,532	8,777	14	70	2.15
9	7	23,000	20,473	20,192	-2,808	2,808	86,435,714	7,925	12	62	2.03
10	8	38,000	22,226	20,473	-17,527	17,527	114,031,550	9,125	46	60	-0.16
11	9	12,000	21,203	22,226	10,226	10,226	112,979,315	9,247	85	62	0.95
12	10	13,000	20,383	21,203	8,203	8,203	108,410,265	9,143	63	63	1.86
13	11	32,000	21,544	20,383	-11,617	11,617	110,824,074	9,368	36	60	0.58
14	12	41,000	23,490	21,544	-19,456	19,456	133,132,065	10,208	47	59	-1.38

Cell	Cell Formula	Equation	Copied to
C3	=0.1*B3+(1-0.1)*C2	7.11	C4:C14
D3	=C2	7.12	D4:D14
E3	=D3-B3	7.8	E4:E14
F3	=Abs(E3)		F4:F14
G3	=Sumsq($E$3:E3)/A3	7.21	G4:G14
H3	=Sum($F$3:F3)/A3	7.22	H4:H14
I3	=100*(F3/B3)		I4:I14
J3	=Average($I$3:I3)	7.24	J4:J14
K3	=Sum($E$3:E3)/H3	7.26	K4:K14

As indicated by a TS that ranges from –1.90 to 2.00, trend-corrected exponential smoothing with $\alpha = 0.1$ and $\beta = 0.2$ does not seem to significantly over- or underforecast. However, the forecast has a fairly large MAD of 8,836, and a MAPE of 52 percent. From Figure 7-7, observe that

$$L_{12} = 30{,}443 \quad \text{and} \quad T_{12} = 1{,}541$$

Thus, using Holt's model (Equation 7.14), the forecast for the next four periods is given by the following:[1]

$$F_{13} = L_{12} + T_{12} = 30{,}443 + 1{,}541 = 31{,}984$$
$$F_{14} = L_{12} + 2T_{12} = 30{,}443 + 2 \times 1{,}541 = 33{,}525$$
$$F_{15} = L_{12} + 3T_{12} = 30{,}443 + 3 \times 1{,}541 = 35{,}066$$
$$F_{16} = L_{12} + 4T_{12} = 30{,}443 + 4 \times 1{,}541 = 36{,}607$$

[1]As a result of rounding, calculations done with only significant digits shown in the text may yield a different result. This is the case throughout the book.

FIGURE 7–7 Trend-Corrected Exponential Smoothing

	A	B	C	D	E	F	G	H	I	J	K	L
1	Period t	Demand D_t	Level L_t	Trend T_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2	0		12,015	1,549								
3	1	8,000	13,008	1,438	13,564	5,564	5,564	30,958,096	5,564	70	70	1
4	2	13,000	14,301	1,409	14,445	1,445	1,445	16,523,523	3,505	11	40	2
5	3	23,000	16,439	1,555	15,710	-7,290	7,290	28,732,318	4,767	32	37	0
6	4	34,000	19,594	1,875	17,993	-16,007	16,007	85,603,146	7,577	47	39.86	-2.15
7	5	10,000	20,322	1,645	21,469	11,469	11,469	94,788,701	8,355	115	54.83	-0.58
8	6	18,000	21,570	1,566	21,967	3,967	3,967	81,613,705	7,624	22	49.36	-0.11
9	7	23,000	23,123	1,563	23,137	137	137	69,957,267	6,554	1	42.39	-0.11
10	8	38,000	26,018	1,830	24,686	-13,314	13,314	83,369,836	7,399	35	41.48	-1.90
11	9	12,000	26,262	1,513	27,847	15,847	15,847	102,010,079	8,338	132	51.54	0.22
12	10	13,000	26,298	1,217	27,775	14,775	14,775	113,639,348	8,981	114	57.75	1.85
13	11	32,000	27,963	1,307	27,515	-4,485	4,485	105,137,395	8,573	14	53.73	1.41
14	12	41,000	30,443	1,541	29,270	-11,730	11,730	107,841,864	8,836	29	51.63	0.04

Cell	Cell Formula	Equation	Copied to
C3	=0.1*B3+(1-0.1)*(C2+D2)	7.15	C4:C14
D3	=0.2(C3-C2)+(1-0.2)D2	7.16	D4:D14
E3	=C2+D2	7.14	E4:E14
F3	=E3-B3	7.8	F4:F14
G3	=Abs(F3)		G4:G14
H3	=Sumsq($F$3:F3)/A3	7.21	H4:H14
I3	=Sum($F$3:F3)/A3	7.22	I4:I14
J3	=100*(G3/B3)		J4:J14
K3	=Average($J$3:J3)	7.24	K4:K14
L3	=Sum($G$3:G3)/I3	7.26	L4:L14

In this case, MAD = 8,836. Thus the estimate of standard deviation of forecast error using Holt's model with $\alpha = 0.1$ and $\beta = 0.2$ is $1.25 \times 8{,}836 = 11{,}045$. In this case, the standard deviation of forecast error relative to the size of the forecast is somewhat smaller than it was with the previous two methods. However, it is still fairly large.

TREND- AND SEASONALITY-CORRECTED EXPONENTIAL SMOOTHING (WINTER'S MODEL)

The team next investigates the use of Winter's model to make the forecast. As a first step, they estimate the level and trend for Period 0, and seasonal factors for Periods 1 through $p = 4$. To start, they deseasonalize the demand. Then, they estimate initial level and trend by running a regression between deseasonalized demand and time. This

FIGURE 7-8 Trend- and Seasonality-Corrected Exponential Smoothing

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	*Period* t	Demand D_t	Level L_t	Trend T_t	Seasonal Factor S_t	Forecast F_t	Error E_t	Absolute Error A_t	Mean Squared Error MSE_t	MAD_t	% Error	$MAPE_t$	TS_t
2			18,439	524									
3	1	8,000	18,866	514	0.47	8,913	913	913	832,857	913	11	11.41	1.00
4	2	13,000	19,367	513	0.68	13,179	179	179	432,367	546	1	6.39	2.00
5	3	23,000	19,869	512	1.17	23,260	260	260	310,720	450	1	4.64	3.00
6	4	34,000	20,380	512	1.67	34,036	36	36	233,364	347	0	3.50	4.00
7	5	10,000	20,921	515	0.47	9,723	-277	277	202,036	333	3	3.36	3.34
8	6	18,000	21,689	540	0.68	14,558	-3,442	3,442	2,143,255	851	19	5.98	-2.74
9	7	23,000	22,102	527	1.17	25,981	2,981	2,981	3,106,508	1,155	13	6.98	0.56
10	8	38,000	22,636	528	1.67	37,787	-213	213	2,723,856	1,037	1	6.18	0.42
11	9	12,000	23,291	541	0.47	10,810	-1,190	1,190	2,578,653	1,054	10	6.59	-0.72
12	10	13,000	23,577	515	0.69	16,544	3,544	3,544	3,576,894	1,303	27	8.66	2.14
13	11	32,000	24,271	533	1.16	27,849	-4,151	4,151	4,818,258	1,562	13	9.05	-0.87
14	12	41,000	24,791	532	1.67	41,442	442	442	4,432,987	1,469	1	8.39	-0.63
15	13				0.47	11,940							
16	14				0.68	17,579							
17	15				1.17	30,930							
18	16				1.67	44,928							

Cell	Cell Formula	Equation	Copied to
C3	=0.05*(B3/E3)+(1-0.05)*(C2+D2)	7.18	C4:C14
D3	=0.1*(C3-C2)+(1-0.1)*D2	7.19	D4:D14
E7	=0.1*(B3/C3)+(1-0.1)*E3	7.20	E4:E18
F3	=(C2+D2)*E3	7.17	F4:F18
G3	=F3-B3	7.8	G4:G14
H3	=Abs(G3)		H4:H14
I3	=Sumsq($G$3:G3)/A3	7.21	I4:I14
J3	=Sum($H$3:H3)/A3	7.22	J4:J14
K3	=100*(H3/B3)		K4:K14
L3	=Average($K$3:K3)	7.24	L4:L14
M3	=Sum($G$3:G3)/J3	7.26	M4:M14

information is used to estimate the seasonal factors. For the demand data in Figure 7-2, as discussed in Example 7-4, the team obtains the following:

$$L_0 = 18{,}439 \qquad T_0 = 524 \qquad S_1 = 0.47 \qquad S_2 = 0.68 \qquad S_3 = 1.17 \qquad S_4 = 1.67$$

They then apply Winter's model with $\alpha = 0.05$, $\beta = 0.1$, $\gamma = 0.1$ to obtain the forecasts. All calculations are shown in Figure 7-8. The team makes forecasts using Equation 7.17, they update the level using Equation 7.18, they update the trend using Equation 7.19, and they update seasonal factors using Equation 7.20.

In this case the MAD of 1,469 and MAPE of 8 percent are significantly lower than with any of the other methods. From Figure 7-8, observe that

$$L_{12} = 24{,}791 \qquad T_{12} = 532 \qquad S_{13} = 0.47 \qquad S_{14} = 0.68$$
$$S_{15} = 1.17 \qquad S_{16} = 1.67$$

TABLE 7-2 Error Estimates for Tahoe Salt Forecasting

Forecasting Method	*MAD*	*MAPE (%)*	TS *Range*
Four-period moving average	9,719	49	–1.52 to 2.21
Simple exponential smoothing	10,208	59	–1.38 to 2.25
Holt's model	8,836	52	–2.15 to 1.85
Winter's model	1,469	8	–2.74 to 4.00

Using Winter's model (Equation 7.17), the forecast for the next four periods is

$$F_{13} = (L_{12} + T_{12})S_{13} = (24{,}791 + 532) \times 0.47 = 11{,}940$$
$$F_{14} = (L_{12} + 2T_{12})S_{14} = (24{,}791 + 2 \times 532) \times 0.68 = 17{,}579$$
$$F_{15} = (L_{12} + 3T_{12})S_{15} = (24{,}791 + 3 \times 532) \times 1.17 = 30{,}930$$
$$F_{16} = (L_{12} + 4T_{12})S_{16} = (24{,}791 + 4 \times 532) \times 1.67 = 44{,}928$$

In this case, MAD = 1,469. Thus the estimate of standard deviation of forecast error using Winter's model with $\alpha = 0.05$, $\beta = 0.1$, and $\gamma = 0.1$ is $1.25 \times 1{,}469 = 1{,}836$. In this case, the standard deviation of forecast error relative to the demand forecast is much smaller than with the other methods.

The team compiles the error estimates for the four forecasting methods as shown in Table 7-2.

Based on the error information in Table 7-2, the forecasting team decides to use Winter's model. It is not surprising that Winter's model results in the most accurate forecast, because the demand data have both a growth trend as well as seasonality. Using Winter's model, the team forecasts the following demand for the coming four quarters:

Second Quarter, year 4: 11,940
Third Quarter, year 4: 17,579
Fourth Quarter, year 4: 30,930
First Quarter, year 5: 44,928

The standard deviation of forecast error is 1,836.

7.8 THE ROLE OF IT IN FORECASTING

There is a natural role for IT in forecasting, given the large amount of data involved, the frequency with which forecasting is performed, and the importance of getting the highest-quality results possible. The forecasting module within a supply chain IT system, often called the *demand planning module,* is a core supply chain software product. There are several important advantages to utilizing the capabilities of IT in forecasting.

Commercial demand planning modules come with a variety of forecasting algorithms, which can be quite advanced and are sometimes proprietary. These methodologies often give a more accurate forecast than what can be produced through the use of a general package such as Excel. Most demand planning applications make it fairly easy to test the various forecasting algorithms against historical data to determine the one that provides the best fit to the observed demand patterns. The availability of a variety of forecasting options is important because different forecasting algorithms provide different levels of quality depending on the actual demand patterns. The IT system can thus be used to best determine forecasting methods not just for the firm overall, but also by product categories and markets.

A good forecasting package provides forecasts across a wide range of products that are updated in real time by incorporating any new demand information. This helps firms respond quickly to changes in the marketplace and avoid the costs of a delayed reaction. Good demand planning modules link not only to customer orders but often directly to customer sales information as well, thus incorporating the most current data into the demand forecast. Much of the progress in areas such as collaborative planning is due to IT innovations that allow the exchange and incorporation of forecasts between enterprises.

Finally, as the name *demand planning* suggests, these modules facilitate the shaping of demand. Good demand planning modules contain tools to perform what-if analysis regarding the impact of potential changes in prices on demand. These tools help analyze the impact of promotions on demand and can be used to determine the extent and timing of promotions.

Keep in mind that none of these tools is foolproof. Forecasts are virtually always wrong. A good IT system should help track historical forecast errors so they can be incorporated into future decisions. A well-structured forecast, along with a measure of error, can significantly improve decision making. Even with all these sophisticated tools, sometimes it is better to rely on human intuition in forecasting. One of the pitfalls of these IT tools is relying on them too much, which eliminates the human element in forecasting. Use the forecasts and the value they deliver, but remember that they cannot assess some of the more qualitative aspects about future demand that you may be able to do on your own.

Forecasting modules are available from all the major supply chain software companies, including the ERP firms such as SAP and Oracle, as well as the best of breed supply chain players such as i2 Technologies and Manugistics. There are also a number of statistical analysis software firms, such as SAS, whose programs can be used for forecasting. Finally, some of the CRM-focused firms have elements of forecasting in their products, given their focus on customer facing processes.

Forecasting and IT have a long history. The forecasting module is one of three core products around which the entire supply chain software industry grew. The classic supply chain IT package has a forecasting module feeding forecasts to a planning module. The module sets schedules and inventory levels, which are then fed to an execution system that actually executes these plans. Thus, forecasting is a core part of IT in the supply chain.

7.9 RISK MANAGEMENT IN FORECASTING

The risks associated with forecast error must be considered when planning for the future. Errors in forecasting can cause significant misallocation of resources in inventory, facilities, transportation, sourcing, pricing, and even in information management. Forecast errors during network design may cause too many, too few, or the wrong type of facilities to be built. At the planning level, plans are determined from forecasts so the actual inventory, production, transportation, sourcing, and pricing plans that a company produces and follows depend on accurate forecasting. Even on an operational level, forecasting plays a role in the actual day-to-day activities that are executed within a company. As one of the initial processes in each of these phases that affects many other processes, forecasting contains a significant amount of inherent risk.

A wide range of factors can cause a forecast to be wrong, but a few occur so often that they deserve specific mention. Long lead times require forecasts to be

made further in advance, thus decreasing the reliability of the forecast. Seasonality also tends to increase forecast error. Forecast errors increase when product life cycles are short, because there are few historical data to build on when producing a forecast. Firms with a few customers often experience very lumpy demand that is harder to forecast than demand from many small customers, which tends to be smoother. Forecast quality suffers when it is based on orders placed by intermediaries in a supply chain rather than on end customer demand. This was particularly evident in the telecommunications sector in 2001, when manufacturer forecasts exceeded customer demand by a large amount. Without a view of end customer demand, a firm always has difficulty producing reliable forecasts.

Two strategies used to mitigate forecast risk are increasing the responsiveness of the supply chain and utilizing opportunities for pooling of demand. W.W. Grainger has worked with suppliers to decrease lead times from eight weeks to less than three weeks. Increased responsiveness allows the firm to reduce forecasting errors and thus decrease the associated risk. Pooling, which we discuss in Chapter 11, attempts to smooth out lumpy demand by bringing together multiple sources of demand. Thus, Amazon has a lower forecast error than Borders because it pools geographic demand into its warehouses.

Improved responsiveness and pooling often come at a cost. Increased speed may require capacity investment, whereas pooling tends to increase transportation cost. To achieve the right balance between risk mitigation and cost, it is important to tailor the mitigation strategies. For instance, when dealing with a commodity for which shortfalls can easily be made up for by spot market purchases, spending large amounts to increase the responsiveness of the supply chain is not warranted. In contrast, for a product with a short life cycle, investing in responsiveness may be worth the cost. Similarly, the benefit from pooling is likely to be large only when the underlying forecast error is high. An investment in pooling efforts may not be justified for products with small forecast errors.

7.10 FORECASTING IN PRACTICE

Collaborate in building forecasts. Collaboration with your supply chain partners can often create a much more accurate forecast. It takes an investment of time and effort to build the relationships with your partners to begin sharing information and creating collaborative forecasts. However, the supply chain benefits of collaboration are often an order of magnitude greater than the cost. The reality today, however, is that most forecasts do not even account for all the information available across the different functions of a firm. Progress needs to be made before all supply chain information is accounted for and utilized.

Share only the data that truly provide value. The value of data depends on where one sits in the supply chain. For instance, a retailer finds point-of-sale data to be quite valuable in measuring the performance of its stores. However, a manufacturer selling to a distributor who in turn sells to retailers does not need all the point-of-sale detail. The manufacturer finds aggregate demand data to be quite valuable, with marginally more value coming from detailed point-of-sale data. Keeping the data shared to what is truly required decreases investment in IT and improves the chances of successful collaboration.

Be sure to distinguish between demand and sales. Often, companies make the mistake of looking at historical sales and assuming that this is what the historical demand was. To

get true demand, adjustments need to be made for unmet demand due to stockouts, competitor actions, pricing, and promotions. Failure to do so results in forecasts that do not represent the current reality.

7.11 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of forecasting for both an enterprise and a supply chain.

   Forecasting is a key driver of virtually every design and planning decision made in both an enterprise and a supply chain. Enterprises have always forecasted demand and used it to make decisions. A relatively recent phenomenon, however, is to create collaborative forecasts for an entire supply chain and use this as the basis for decisions. Collaborative forecasting greatly increases the accuracy of forecasts and allows the supply chain to maximize its performance. Without collaboration, supply chain stages farther from demand will likely have poor forecasts that will lead to supply chain inefficiencies and a lack of responsiveness.
2. Identify the components of a demand forecast.

   Demand consists of a systematic and a random component. The systematic component measures the expected value of demand. The random component measures fluctuations in demand from the expected value. The systematic component consists of level, trend, and seasonality. Level measures the current deseasonalized demand. Trend measures the current rate of growth or decline in demand. Seasonality indicates predictable seasonal fluctuations in demand.
3. Forecast demand in a supply chain given historical data using time-series methodologies.

   Time-series methods for forecasting are categorized as *static* or *adaptive*. In static methods, the estimates of parameters and demand patterns are not updated as new demand is observed. Static methods include regression. In adaptive methods, the estimates are updated each time a new demand is observed. Adaptive methods include moving averages, simple exponential smoothing, Holt's model, and Winter's model. Moving averages and simple exponential smoothing are best used when demand displays no trend or seasonality. Holt's model is best when demand displays a trend but no seasonality. Winter's model is appropriate when demand displays both trend and seasonality.
4. Analyze demand forecasts to estimate forecast error.

   Forecast error measures the random component of demand. This measure is important because it reveals how inaccurate a forecast is likely to be and what contingencies a firm may have to plan for. The MAD and the MAPE are used to estimate the size of the forecast error. The bias and TS are used to estimate if the forecast consistently over- or underforecasts.

Discussion Questions

1. What role does forecasting play in the supply chain of a build-to-order manufacturer such as Dell?
2. How could Dell use collaborative forecasting with its suppliers to improve its supply chain?
3. What role does forecasting play in the supply chain of a mail order firm such as L.L.Bean?
4. What systematic and random components would you expect in demand for chocolates?
5. Why should a manager be suspicious if a forecaster claims to forecast historical demand without any forecast error?
6. Give examples of products that display seasonality of demand.
7. What is the problem if a manager uses last year's sales data instead of last year's demand to forecast demand for the coming year?
8. How do static and adaptive forecasting methods differ?

TABLE 7-3 Monthly Demand for ABC Corporation

Sales	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
January	2,000	3,000	2,000	5,000	5,000
February	3,000	4,000	5,000	4,000	2,000
March	3,000	3,000	5,000	4,000	3,000
April	3,000	5,000	3,000	2,000	2,000
May	4,000	5,000	4,000	5,000	7,000
June	6,000	8,000	6,000	7,000	6,000
July	7,000	3,000	7,000	10,000	8,000
August	6,000	8,000	10,000	14,000	10,000
September	10,000	12,000	15,000	16,000	20,000
October	12,000	12,000	15,000	16,000	20,000
November	14,000	16,000	18,000	20,000	22,000
December	8,000	10,000	8,000	12,000	8,000
Total	78,000	89,000	98,000	115,000	113,000

9. What information does the MAD and MAPE provide to a manager? How can the manager use this information?
10. What information do the bias and TS provide to a manager? How can the manager use this information?

Exercises

1. Consider monthly demand for the ABC Corporation as shown in Table 7-3. Forecast the monthly demand for year 6 using the static method for forecasting. Evaluate the bias, TS, MAD, MAPE, and MSE. Evaluate the quality of the forecast.
2. Weekly sales of Hot Pizza are as follows:

Week	*Demand ($)*	*Week*	*Demand ($)*	*Week*	*Demand ($)*
1	108	5	96	9	112
2	116	6	119	10	102
3	118	7	96	11	92
4	124	8	102	12	91

Estimate demand for the next four weeks using a four-week moving average as well as simple exponential smoothing with $\alpha = 0.1$. Evaluate the MAD, MAPE, MSE, bias, and TS in each case. Which of the two methods do you prefer? Why?

3. Quarterly sales of flowers at a wholesaler are as follows:

Year	*Quarter*	*Sales ('000 $)*	*Year*	*Quarter*	*Sales ('000 $)*
1	I	98	3	I	138
	II	106		II	130
	III	109		III	147
	IV	133		IV	141
2	I	130	4	I	144
	II	116		II	142
	III	133		III	165
	IV	116		IV	173

Forecast quarterly sales for year 5 using simple exponential smoothing with $\alpha = 0.1$ as well as Holt's model with $\alpha = 0.1$ and $\beta = 0.1$. Which of the two methods do you prefer? Why?

4. Consider monthly demand for the ABC Corporation as shown in Table 7-3. Forecast the monthly demand for year 6 using moving average, simple exponential smoothing, Holt's model, and Winter's model. In each case, evaluate the bias, TS, MAD, MAPE, and MSE. Which forecasting method do you prefer? Why?

Bibliography

Bernstein, Peter L., and Theodore H. Silbert. "Are Economic Forecasters Worth Listening To?" *Harvard Business Review* (September–October 1984.): 2–8.

Bowerman, Bruce L., and Richard T. O'Connell. *Forecasting and Time Series: An Applied Approach.* 3d ed. Belmont, CA: Duxbury, 1993.

Box, George E. P., and Gwilym M. Jenkins. *Time Series Analysis: Forecasting and Control.* Oakland, CA: Holden-Day, 1976.

Brown, Robert G. *Statistical Forecasting for Inventory Control.* New York: McGraw-Hill, 1959.

Chambers, John C., Satinder K. Mullick, and Donald D. Smith. "How to Choose the Right Forecasting Technique." *Harvard Business Review* (July–August 1971): 45–74.

Forecasting with Regression Analysis. Cambridge, MA: Harvard Business School Note #9–894–007, 1994.

Georgoff, David M., and Robert G. Murdick. "Manager's Guide to Forecasting." *Harvard Business Review* (January–February 1986): 2–9.

Gilliland, Michael. "Is Forecasting a Waste of Time?" *Supply Chain Management Review* (July–August 2002): 16–23.

Makridakis, Spyros, and Steven C. Wheelwright. *Forecasting Methods for Management.* New York: Wiley, 1989.

Yurkiewicz, Jack. "Forecasting 2000." *ORMS Today* (February 2000): 58–65.

CASE STUDY

SPECIALTY PACKAGING CORPORATION, PART A

Julie Williams had a lot on her mind when she left the conference room at Specialty Packaging Corporation (SPC). Her divisional manager had informed her that she would be assigned to a team consisting of SPC's marketing vice president and staff members from their key customers. The goal of this team was to improve supply chain performance, as SPC had been unable to meet demand effectively over the previous several years. This often left SPC's customers scrambling to meet new client demands. Julie had little contact with SPC's customers and wondered how she would add value to this process. She was told by her division manager that the team's first task was to establish a collaborative forecast using data from both SPC and its customers. This forecast would serve as the basis for improving the firm's performance, as managers could use this more accurate forecast for their production planning. Improved forecasts would allow SPC to improve delivery performance.

SPC

SPC turns polystyrene resin into recyclable/disposable containers for the food industry. Polystyrene is purchased as a commodity in the form of resin pellets. The resin is unloaded from bulk rail containers or overland trailers into storage silos. Making the food containers is a two-step process. First,

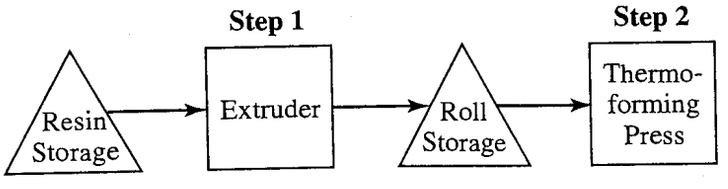
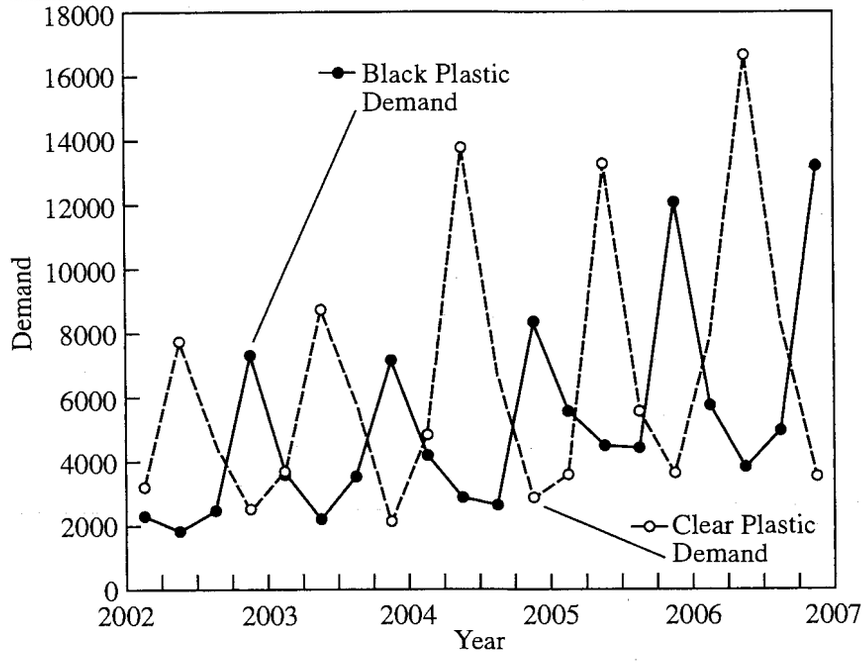


FIGURE 7-9 Manufacturing Process at SPC

TABLE 7-4 Quarterly Historical Demand for Clear and Black Plastic Containers

Year	*Quarter*	*Black Plastic Demand ('000 lb)*	*Clear Plastic Demand ('000 lb)*
2002	I	2,250	3,200
	II	1,737	7,658
	III	2,412	4,420
	IV	7,269	2,384
2003	I	3,514	3,654
	II	2,143	8,680
	III	3,459	5,695
	IV	7,056	1,953
2004	I	4,120	4,742
	II	2,766	13,673
	III	2,556	6,640
	IV	8,253	2,737
2005	I	5,491	3,486
	II	4,382	13,186
	III	4,315	5,448
	IV	12,035	3,485
2006	I	5,648	7,728
	II	3,696	16,591
	III	4,843	8,236
	IV	13,097	3,316

FIGURE 7-10 Plot of Quarterly Demand for Clear and Black Plastic Containers



resin is conveyed to an extruder, which converts it into polystyrene sheet wound into rolls. The plastic comes in two forms—clear and black. The rolls are either used immediately to make containers or are put into storage. Second, the rolls are loaded onto thermoforming presses, which form the sheet into containers and trim the containers from the sheet. The two manufacturing steps are shown in Figure 7-9.

Over the past five years, the plastic packaging business has grown steadily. Demand for containers made from clear plastic comes from grocery stores, bakeries, and restaurants. Caterers and grocery stores use the black plastic trays as packaging and serving trays. Demand for clear plastic containers peaks in the summer months, whereas demand for black plastic containers peaks in the fall. Capacity on the extruders is not sufficient to cover demand for sheets during the peak seasons. As a result, the plant is forced to build inventory of each type of sheet in anticipation of future demand. Table 7-4 and Figure 7-10 display historical quarterly demand for each of the two types of containers (clear and black). The team modified SPC's sales data by accounting for lost sales to obtain true demand data. Without the customers involved in this team, SPC would never have known this information, as the company did not keep track of lost orders.

FORECASTING

As a first step in the team's decision making, they want to forecast quarterly demand for each of the two types of containers for the years 2007 to 2009. Based on historical trends, demand is expected to continue to grow until 2009, after which it is expected to plateau. Julie must select the appropriate forecasting method and estimate the likely forecast error. Which method should she choose?

CHAPTER 8
AGGREGATE PLANNING IN A SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Identify the decisions that are best solved by aggregate planning.
2. Understand the importance of aggregate planning as a supply chain activity.
3. Describe the information needed to produce an aggregate plan.
4. Explain the basic trade-offs to consider when creating an aggregate plan.
5. Formulate and solve basic aggregate planning problems using Microsoft Excel.

In this chapter, we discuss how the aggregate planning methodology is used to make decisions about production, outsourcing, inventory, and backlogs in a supply chain. We identify the information required to produce an aggregate plan and outline the basic trade-offs that must be made to create an optimal aggregate plan. We also describe how to formulate and solve an aggregate planning problem using Microsoft Excel.

8.1 THE ROLE OF AGGREGATE PLANNING IN A SUPPLY CHAIN

Imagine a world in which manufacturing, transportation, warehousing, and even information capacity are all limitless and free. Imagine lead times of zero, allowing goods to be produced and delivered instantaneously. In this world, there would be no need to plan in anticipation of demand, because whenever a customer demands a product, the demand would be instantly satisfied. In this world, aggregate planning plays no role.

In the real world, however, capacity has a cost, and lead times are often long. Therefore, companies must make decisions regarding capacity levels, production levels, outsourcing, and promotions well before demand is known. A company must anticipate demand and determine, in advance of that demand, how to meet it. Should a company invest in a plant with large capacity that is able to produce enough to satisfy demand even in the busiest months? Or should a company build a smaller plant but incur the costs of holding inventory built during slow periods in anticipation of demand in later months? These are the types of questions that aggregate planning helps companies answer.

Aggregate planning is a process by which a company determines ideal levels of capacity, production, subcontracting, inventory, stockouts, and even pricing over a specified time horizon. The goal of aggregate planning is to satisfy demand while maximizing profit. Aggregate planning, as the name suggests, solves problems involving aggregate decisions rather than stock-keeping unit (SKU)–level decisions. For example, aggregate planning determines the total production level in a plant for a given month, but it does so

without determining the quantity of each individual SKU that will be produced. This level of detail makes aggregate planning a useful tool for thinking about decisions with an intermediate time frame of between roughly 3 and 18 months. In this time frame, it is too early to determine production levels by SKU, but it is also generally too late to arrange for additional capacity. Therefore, aggregate planning answers the question, "How should a firm best utilize the facilities that it currently has?"

Traditionally, much of aggregate planning is focused within an enterprise and may not always be seen as a part of supply chain management. Aggregate planning, however, is an important supply chain issue. To be effective, it requires inputs from throughout the supply chain, and its results have a tremendous impact on supply chain performance. As we saw in the previous chapter on forecasting, collaborative forecasts are created by multiple supply chain enterprises and are an important input for aggregate planning. Good forecasts require collaboration with downstream supply chain partners. In addition, many constraints in aggregate planning come from supply chain partners outside the enterprise. These constraints are key inputs to aggregate planning, mainly from upstream partners in the supply chain. Without these inputs from both up and down the supply chain, aggregate planning cannot realize its full potential to create value. The output from aggregate planning is also of value to both upstream and downstream partners. Production plans for a firm define demand for suppliers and establish supply constraints for customers. This chapter is meant to create a foundation for using aggregate planning both solely within an enterprise as well as across the entire supply chain. The supply chain implications of aggregate planning will become even more clear in Chapter 9 once the foundations of aggregate planning are in place.

As an example, consider how a premium paper supply chain uses aggregate planning to maximize profit. Many types of paper mills face seasonal demand that ripples up from customers to printers to distributors and finally to the manufacturers. Many types of premium paper have demand peaks in the spring, when annual reports are printed, and in the fall, when new-car brochures are released. Building a mill with capacity to meet demand in the spring and fall on an as-needed basis is too costly, because of the high cost of mill capacity. On the other side of the supply chain, premium papers often require special additives and coatings that may be in short supply. The paper manufacturer must deal with these constraints and maximize profit around them. To deal with these potential problems, mills use aggregate planning to determine production levels and inventory levels that they should build up in the slower months for sale in the spring and fall when demand is greater than the mill's capacity. By taking into account the inputs from throughout the supply chain, aggregate planning allows the mill and the supply chain to maximize profit.

The aggregate planner's main objective is to identify the following operational parameters over the specified time horizon:

Production Rate: the number of units to be completed per unit time (such as per week or per month)
Workforce: the number of workers/units of capacity needed for production
Overtime: the amount of overtime production planned
Machine Capacity Level: the number of units of machine capacity needed for production
Subcontracting: the subcontracted capacity required over the planning horizon
Backlog: demand not satisfied in the period in which it arises but carried over to future periods
Inventory on Hand: the planned inventory carried over the various periods in the planning horizon

The aggregate plan serves as a broad blueprint for operations and establishes the parameters within which short-term production and distribution decisions are made. The aggregate plan allows the supply chain to alter capacity allocations and change supply contracts. As mentioned in earlier chapters, the entire supply chain should be coordinated with the planning process. If a manufacturer has planned an increase in production over a given time period, the supplier, transporter, and warehouser must be aware of this plan and incorporate the increase into their own plans. Ideally, all stages of the supply chain should work together on an aggregate plan that optimizes supply chain performance. If each stage develops its own aggregate plan independently, it is extremely unlikely that all the plans will mesh in a coordinated manner. This lack of coordination results in shortages or oversupply in the supply chain. Therefore, it is important to perform aggregate plans over a wide scope of the supply chain.

In the next section, we formally define the aggregate planning problem. We specify the information required for aggregate planning and discuss the decision outcomes that aggregate planning can provide.

8.2 THE AGGREGATE PLANNING PROBLEM

The objective of the aggregate plan is to satisfy demand in a way that maximizes profit for the firm. We can state the aggregate planning problem formally as follows:

Given the demand forecast for each period in the planning horizon, determine the production level, inventory level, and capacity level (internal and outsourced) for each period that maximizes the firm's profit over the planning horizon.

To create an aggregate plan, a company must specify the planning horizon for the plan. A *planning horizon* is the time period over which the aggregate plan is to produce a solution—usually between 3 and 18 months. A company must also specify the duration of each period within the planning horizon (e.g., weeks, months, or quarters). In general, aggregate planning takes place over months or quarters. Next, a company specifies key information required to produce an aggregate plan and to make the decisions for which the aggregate plan will develop recommendations. This information and the recommendations are specified for a generic aggregate planning problem in this section. The model we propose in the next section is flexible enough to accommodate situation-specific requirements.

An aggregate planner requires the following information:

- Demand forecast F_t for each Period t in a planning horizon that extends over T periods
- Production costs
  - Labor costs, regular time ($/hour), and overtime costs ($/hour)
  - Cost of subcontracting production ($/unit or $/hour)
  - Cost of changing capacity; specifically, cost of hiring/laying off workforce ($/worker) and cost of adding or reducing machine capacity ($/machine)
- Labor/machine hours required per unit
- Inventory holding cost ($/unit/period)
- Stockout or backlog cost ($/unit/period)
- Constraints
  - Limits on overtime
  - Limits on layoffs

- Limits on capital available
- Limits on stockouts and backlogs
- Constraints from suppliers to the enterprise

Using this information, a company makes the following determinations through aggregate planning:

Production Quantity from Regular time, Overtime, and Subcontracted Time: used to determine number of workers and supplier purchase levels
Inventory Held: used to determine the warehouse space and working capital required
Backlog/Stockout Quantity: used to determine customer service levels
Workforce Hired/Laid Off: used to determine any labor issues likely to be encountered
Machine Capacity Increase/Decrease: used to determine if new production equipment should be purchased or idled

The quality of an aggregate plan has a significant impact on the profitability of a firm. A poor aggregate plan can result in lost sales and lost profits if the available inventory and capacity are unable to meet demand. A poor aggregate plan may also result in a large amount of excess inventory and capacity, thereby raising costs. Therefore, aggregate planning is a very important tool in helping a supply chain maximize profitability.

8.3 AGGREGATE PLANNING STRATEGIES

The aggregate planner must make trade-offs among capacity, inventory, and backlog costs. An aggregate plan that increases one of these costs typically results in reduction of the other two. In this sense, the costs represent a trade-off—to lower inventory cost, a planner must increase capacity cost or delay delivery to the customer. Thus the planner trades inventory cost for capacity or backlog cost. Arriving at the most profitable combination of trade-offs is the goal of aggregate planning. Given that demand varies over time, the relative level of the three costs leads to one of them being the key lever the planner uses to maximize profits. If the cost of varying capacity is low, a company may not need to build inventory or carry backlogs. If the cost of varying capacity is high, a company may compensate by building some inventory and carrying some backlogs from peak demand periods to off-peak demand periods.

In general, a company attempts to use a combination of the three costs to best meet demand. Therefore, the fundamental trade-offs available to a planner are among

- Capacity (regular time, overtime, subcontracted)
- Inventory
- Backlog/lost sales because of delay

There are essentially three distinct aggregate planning strategies for achieving balance between these costs. These strategies involve trade-offs among capital investment, workforce size, work hours, inventory, and backlogs/lost sales. Most strategies that a planner actually uses are a combination of these three and are referred to as *tailored strategies*. The three strategies are as follows.

1. ***Chase strategy—using capacity as the lever:*** With this strategy, the production rate is synchronized with the demand rate by varying machine capacity or hiring and laying

off employees as the demand rate varies. In practice, achieving this synchronization can be very problematic because of the difficulty of varying capacity and workforce on short notice. This strategy can be expensive to implement if the cost of varying machine or labor capacity over time is high. It can also have a significant negative impact on the morale of the workforce. The chase strategy results in low levels of inventory in the supply chain and high levels of change in capacity and workforce. It should be used when the cost of carrying inventory is very high and costs to change levels of machine and labor capacity are low.

2. ***Time flexibility from workforce or capacity strategy—using utilization as the lever:*** This strategy may be used if there is excess machine capacity (i.e., if machines are not used 24 hours a day, seven days a week). In this case the workforce (capacity) is kept stable but the number of hours worked is varied over time in an effort to synchronize production with demand. A planner can use variable amounts of overtime or a flexible schedule to achieve this synchronization. Although this strategy does require that the workforce be flexible, it avoids some of the problems associated with the chase strategy, most notably, changing the size of the workforce. This strategy results in low levels of inventory but with lower average machine utilization. It should be used when inventory carrying costs are relatively high and machine capacity is relatively inexpensive.

3. ***Level strategy—using inventory as the lever:*** With this strategy, a stable machine capacity and workforce are maintained with a constant output rate. Shortages and surpluses result in inventory levels fluctuating over time. In this case, production is not synchronized with demand. Either inventories are built up in anticipation of future demand or backlogs are carried over from high- to low-demand periods. Employees benefit from stable working conditions. A drawback associated with this strategy is that large inventories may accumulate and customer orders may be delayed. This strategy keeps capacity and costs of changing capacity relatively low. It should be used when inventory carrying and backlog costs are relatively low.

In the next section, we discuss a methodology that is commonly used for aggregate planning.

8.4 AGGREGATE PLANNING USING LINEAR PROGRAMMING

As we discussed earlier, the goal of aggregate planning is to maximize profit while meeting demand. Every company, in its effort to meet customer demand, faces certain constraints, such as the capacity of its facilities or a supplier's ability to deliver a component. A highly effective tool for a company to use when it tries to maximize profits while being subjected to a series of constraints is linear programming. *Linear programming* finds the solution that creates the highest profit while satisfying the constraints that the company faces.

We illustrate linear programming through the discussion of Red Tomato Tools, a small manufacturer of gardening equipment with manufacturing facilities in Mexico. Red Tomato's products are sold through retailers in the United States. Red Tomato's operations consist of the assembly of purchased parts into a multipurpose gardening tool. Because of the limited equipment and space required for its assembly operations, Red Tomato's capacity is determined mainly by the size of its workforce.

For this example, we use a six-month time period because this is a long enough time horizon to illustrate many of the main points of aggregate planning.

TABLE 8-1 Demand Forecast at Red Tomato Tools

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200

RED TOMATO TOOLS

The demand for Red Tomato's gardening tools from consumers is highly seasonal, peaking in the spring as people plant their gardens. This seasonal demand ripples up the supply chain from the retailer to Red Tomato, the manufacturer. Red Tomato has decided to use aggregate planning to overcome the obstacle of seasonal demand and maximize profits. The options Red Tomato has for handling the seasonality are adding workers during the peak season, subcontracting out some of the work, building up inventory during the slow months, or building up a backlog of orders that will be delivered late to customers. To determine how to best use these options through an aggregate plan, Red Tomato's vice president of supply chain starts with the first task—building a demand forecast. Although Red Tomato could attempt to forecast this demand itself, a much more accurate forecast comes from a collaborative process used by both Red Tomato and its retailers to produce the forecast shown in Table 8-1.

Red Tomato sells each tool to the retailers for $40. The company has a starting inventory in January of 1,000 tools. At the beginning of January the company has a workforce of 80 employees. The plant has a total of 20 working days in each month, and each employee earns $4 per hour regular time. Each employee works eight hours per day on straight time and the rest on overtime. As discussed previously, the capacity of the production operation is determined primarily by the total labor hours worked. Therefore, machine capacity does not limit the capacity of the production operation. Because of labor rules, no employee works more than 10 hours of overtime per month. The various costs are shown in Table 8-2.

Currently, Red Tomato has no limits on subcontracting, inventories, and stockouts/backlog. All stockouts are backlogged and supplied from the following months' production. Inventory costs are incurred on the ending inventory in the month. The

TABLE 8-2 Costs for Red Tomato

Item	*Cost*
Material cost	$10/unit
Inventory holding cost	$2/unit/month
Marginal cost of stockout/backlog	$5/unit/month
Hiring and training costs	$300/worker
Layoff cost	$500/worker
Labor hours required	4/unit
Regular time cost	$4/hour
Overtime cost	$6/hour
Cost of subcontracting	$30/unit

supply chain manager's goal is to obtain the optimal aggregate plan that allows Red Tomato to end June with at least 500 units (i.e., no stockouts at the end of June and at least 500 units in inventory).

The optimal aggregate plan is one that results in the highest profit over the six-month planning horizon. For now, given Red Tomato's desire for a very high level of customer service, assume all demand is to be met, although it can be met late. Therefore, the revenues earned over the planning horizon are fixed. As a result, minimizing cost over the planning horizon is the same as maximizing profit. In many instances, a company has the option of not meeting certain demand, or price itself may be a variable that a company has to determine based on the aggregate plan. In such a scenario, minimizing cost is not equivalent to maximizing profits.

DECISION VARIABLES

The first step in constructing an aggregate planning model is to identify the set of decision variables whose values are to be determined as part of the aggregate plan. For Red Tomato, the following decision variables are defined for the aggregate planning model:

W_t = workforce size for Month t, $t = 1, \ldots, 6$
H_t = number of employees hired at the beginning of Month t, $t = 1, \ldots, 6$
L_t = number of employees laid off at the beginning of Month t, $t = 1, \ldots, 6$
P_t = number of units produced in Month t, $t = 1, \ldots, 6$
I_t = inventory at the end of Month t, $t = 1, \ldots, 6$
S_t = number of units stocked out/backlogged at the end of Month t, $t = 1, \ldots, 6$
C_t = number of units subcontracted for Month t, $t = 1, \ldots, 6$
O_t = number of overtime hours worked in Month t, $t = 1, \ldots, 6$

The next step in constructing an aggregate planning model is to define the objective function.

OBJECTIVE FUNCTION

Denote the demand in Period t by D_t. The values of D_t are as specified by the demand forecast in Table 8-1. The objective function is to minimize the total cost (equivalent to maximizing total profit as all demand is to be satisfied) incurred during the planning horizon. The cost incurred has the following components:

- Regular-time labor cost
- Overtime labor cost
- Cost of hiring and layoffs
- Cost of holding inventory
- Cost of stocking out
- Cost of subcontracting
- Material cost

These costs are evaluated as follows:

1. ***Regular-time labor cost.*** Recall that workers are paid a regular-time wage of \$640 (\$4/hour × 8 hours/day × 20 days/month) per month. Because W_t is the number of workers in Period t, the regular-time labor cost over the planning horizon is given by

$$\text{Regular-time labor cost} = \sum_{t=1}^{6} 640 W_t$$

2. ***Overtime labor cost.*** As overtime labor cost is \$6 per hour (see Table 8-2) and O_t represents the number of overtime hours worked in Period t, the overtime cost over the planning horizon is

$$\text{Overtime labor cost} = \sum_{t=1}^{6} 6O_t$$

3. ***Cost of hiring and layoffs.*** The cost of hiring a worker is \$300 and the cost of laying off a worker is \$500 (see Table 8-2). H_t and L_t represent the number hired and the number laid off, respectively, in Period t. Thus the cost of hiring and layoff is given by

$$\text{Cost of hiring and layoff} = \sum_{t=1}^{6} 300H_t + \sum_{t=1}^{6} 500L_t$$

4. ***Cost of inventory and stockout.*** The cost of carrying inventory is \$2 per unit per month, and the cost of stocking out is \$5 per unit per month (see Table 8-2). I_t and S_t represent the units in inventory and the units stocked out, respectively, in Period t. Thus, the cost of holding inventory and stocking out is

$$\text{Cost of holding inventory and stocking out} = \sum_{t=1}^{6} 2I_t + \sum_{t=1}^{6} 5S_t$$

5. ***Cost of materials and subcontracting.*** The material cost is \$10 per unit and the subcontracting cost is \$30/unit (see Table 8-2). P_t represents the quantity produced and C_t represents the quantity subcontracted in Period t. Thus, the material and subcontracting cost is

$$\text{Cost of materials and subcontracting} = \sum_{t=1}^{6} 10P_t + \sum_{t=1}^{6} 30C_t$$

The total cost incurred during the planning horizon is the sum of all the aforementioned costs and is given by

$$\sum_{t=1}^{6} 640W_t + \sum_{t=1}^{6} 6O_t + \sum_{t=1}^{6} 300H_t + \sum_{t=1}^{6} 500L_t + \sum_{t=1}^{6} 2I_t + \sum_{t=1}^{6} 5S_t + \sum_{t=1}^{6} 10P_t + \sum_{t=1}^{6} 30C_t \quad \textbf{(8.1)}$$

Red Tomato's objective is to find an aggregate plan that minimizes the total cost (see Equation 8.1) incurred during the planning horizon.

The values of the decision variables in the objective function cannot be set arbitrarily. They are subject to a variety of constraints. The next step in setting up the aggregate planning model is to define clearly the constraints linking the decision variables.

CONSTRAINTS

Red Tomato's vice president must now specify the constraints that the decision variables must not violate. They are as follows:

1. ***Workforce, hiring, and layoff constraints.*** The workforce size W_t in Period t is obtained by adding the number hired H_t in Period t to the workforce size W_{t-1} in Period $t-1$, and subtracting the number laid off L_t in Period t as follows:

$$W_t = W_{t-1} + H_t - L_t \qquad \text{for} \qquad t = 1, \ldots, 6 \quad \textbf{(8.2)}$$

The starting workforce size is given by $W_0 = 80$.

2. ***Capacity constraints.*** In each period, the amount produced cannot exceed the available capacity. This set of constraints limits the total production by the total internally available capacity (which is determined based on the available labor hours, regular or overtime). Subcontracted production is not included in this constraint because the constraint is limited to production within the plant. As each worker can produce 40 units per month on regular time (four hours per unit as specified in Table 8-2) and one unit for every four hours of overtime, we have the following:

$$P_t \leq 40W_t + \frac{O_t}{4} \qquad \text{for} \qquad t = 1, \ldots, 6 \tag{8.3}$$

3. ***Inventory balance constraints.*** The third set of constraints balances inventory at the end of each period. Net demand for Period t is obtained as the sum of the current demand D_t and the previous backlog S_{t-1}. This demand is either filled from current production (in-house production P_t or subcontracted production C_t) and previous inventory I_{t-1} (in which case some inventory I_t may be left over) or part of it is backlogged S_t. This relationship is captured by the following equation:

$$I_{t-1} + P_t + C_t = D_t + S_{t-1} + I_t - S_t \qquad \text{for} \qquad t = 1, \ldots, 6 \tag{8.4}$$

The starting inventory is given by $I_0 = 1{,}000$, the ending inventory must be at least 500 units (i.e., $I_6 \geq 500$), and initially there are no backlogs (i.e., $S_0 = 0$).

4. ***Overtime limit constraints.*** The fourth set of constraints requires that no employee work more than 10 hours of overtime each month. This requirement limits the total amount of overtime hours available as follows:

$$O_t \leq 10W_t \qquad \text{for} \qquad t = 1, \ldots, 6 \tag{8.5}$$

In addition, each variable must be nonnegative and there must be no backlog at the end of Period 6 (i.e., $S_6 = 0$).

When implementing the model in Microsoft Excel, which we discuss later, it is easiest if all the constraints are written so that the right-hand side for each constraint is 0. The overtime limit constraint (Equation 8.5) in this form is written as

$$O_t - 10W_t \leq 0 \qquad \text{for} \qquad t = 1, \ldots, 6$$

Observe that one can easily add constraints that limit the amount purchased from subcontractors each month or the maximum number of employees to be hired or laid off. Any other constraints limiting backlogs or inventories can also be accommodated. Ideally, the number of employees should be an integer variable. We can obtain a good approximation, however, by allowing the number of employees to take on fractional values. This change significantly reduces the time necessary solve the problem. Such a linear program can be solved using the tool Solver in Excel.

If we assume the average inventory in Period t to be the average of the starting and ending inventories, that is, $(I_{t-1} + I_t)/2$, the average inventory over the planning horizon is given by

$$\text{Average inventory} = \frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T}$$

The average time that units spend in inventory over the planning horizon is obtained using Little's law (average flow time = average inventory/throughput). The

TABLE 8-3 Aggregate Plan for Red Tomato

Period, t	*No. Hired, H_t*	*No. Laid Off, L_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	1,983	0	0	2,583
2	0	0	65	0	1,567	0	0	2,583
3	0	0	65	0	950	0	0	2,583
4	0	0	65	0	0	267	0	2,583
5	0	0	65	0	117	0	0	2,583
6	0	0	65	0	500	0	0	2,583

average time in inventory is given as

$$\text{Average time in inventory} = \left[\frac{(I_0 + I_T)/2 + \left(\sum_{t=1}^{T-1} I_t\right)}{T}\right] \Bigg/ \left[\frac{\left(\sum_{t=1}^{T} D_t\right)}{T}\right] \quad \textbf{(8.6)}$$

By optimizing the objective function (minimizing cost in Equation 8.1) subject to the listed constraints (Equations 8.2 to 8.5), the vice president obtains the aggregate plan shown in Table 8-3. (Later in the chapter we discuss how to perform this optimization using Excel.)

For this aggregate plan we have the following:

$$\text{Total cost over planning horizon} = \$422{,}275$$

Red Tomato lays off a total of 15 employees at the beginning of January. After that, the company maintains the workforce and production level. They do not use the subcontractor during the entire planning horizon. They carry a backlog only from April to May. In all other months, they plan no stockouts. In fact, Red Tomato carries inventory in all other periods. We describe this inventory as seasonal inventory because it is carried in anticipation of a future increase in demand. Given the sale price of $40 per unit and total sales of 16,000 units, revenue over the planning horizon is given by

$$\text{Revenue over planning horizon} = 40 \times 16{,}000 = \$640{,}000$$

The average seasonal inventory during the planning horizon is given by

$$\text{Average seasonal inventory} = \frac{(I_0 + I_6) \Big/ \left(2 + \sum_{t=1}^{5} I_t\right)}{T} = \frac{5{,}367}{6} = 895$$

The average flow time for this aggregate plan over the planning horizon (using Equation 8.6) is given by

$$\text{Average flow time} = \frac{895}{2{,}667} = 0.34 = 0.34 \text{ months}$$

If the seasonal fluctuation of demand grows, synchronization of supply and demand becomes more difficult, resulting in an increase in either inventory or backlogs as well

TABLE 8-4 Demand Forecast with Higher Seasonal Fluctuation

Month	*Demand Forecast*
January	1,000
February	3,000
March	3,800
April	4,800
May	2,000
June	1,400

as an increase in the total cost to the supply chain. This is illustrated in Example 8-1, in which the demand forecast is more variable.

Example 8-1 All the data are exactly the same as in our previous discussion of Red Tomato, except for the demand forecast. Assume that the same overall demand (16,000 units) is distributed over the six months in such a way that the seasonal fluctuation of demand is higher, as shown in Table 8-4. Obtain the optimal aggregate plan in this case.

Analysis: In this case the optimal aggregate plan (using the same costs as those used before) is shown in Table 8-5.

Observe that monthly production remains the same but both inventories and stock-outs (backlogs) go up compared to the aggregate plan in Table 8-3 for the demand profile in Table 8-1. The cost of meeting the new demand profile in Table 8-4 is higher at $432,858 (compared to $422,275 for the previous demand profile in Table 8-1).

The seasonal inventory during the planning horizon is given by

$$\text{Seasonal inventory} = \frac{[(I_0 + I_T)/2] + \sum_{t=1}^{T-1} I_t}{T} = \frac{6{,}450}{6} = 1{,}075$$

The average flow time for this aggregate plan over the planning horizon (using Equation 8.6) is given by

$$\text{Average flow time} = \frac{1{,}075}{2{,}667} = 0.40 \text{ months}$$

From Example 8-1, we can see that the increase in demand variability at the retailer has an impact up the supply chain in terms of the manufacturer's production schedule as well as the amount of storage space required for inventory.

Using the Red Tomato example, we also see that the optimal trade-off changes as the costs change. This is illustrated in Example 8-2, in which we show that, as holding

TABLE 8-5 Optimal Aggregate Plan for Demand in Table 8-4

Period, t	*No. Hired, H_t*	*No. Laid Off, L_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	2,583	0	0	2,583
2	0	0	65	0	2,167	0	0	2,583
3	0	0	65	0	950	0	0	2,583
4	0	0	65	0	0	1,267	0	2,583
5	0	0	65	0	0	683	0	2,583
6	0	0	65	0	500	0	0	2,583

TABLE 8-6 Optimal Aggregate Plan for Holding Cost of $6/Unit/Month

Period, t	*No. Hired, H_t*	*No. Laid Off, O_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80	0	1,000	0	0	
1	0	23	57	0	1,667	0	0	2,267
2	0	0	57	0	933	0	0	2,267
3	0	0	57	0	0	0	0	2,267
4	0	0	57	0	0	67	1,467	2,267
5	0	0	57	0	0	0	0	2,267
6	0	0	57	0	500	0	433	2,267

costs increase, it is better to carry less inventory and resort to excess capacity, backlogs, or subcontracting.

Example 8-2 Assume that demand at Red Tomato is as shown in Table 8-1, and all other data are the same except that holding cost per unit increases from $2 per unit per month to $6 per unit per month. Evaluate the total cost corresponding to the aggregate plan in Table 8-3. Suggest an optimal aggregate plan for the new cost structure.

Analysis: If the holding cost increases from $2 per unit per month to $6 per unit per month, the cost corresponding to the aggregate plan in Table 8-3 increases from $422,275 to $442,742. Taking this new cost into account and determining a new optimal aggregate plan yields the plan shown in Table 8-6.

As expected, the inventory carried is reduced (because inventory holding cost has been raised) compared to the aggregate plan in Table 8-3. The aggregate plan compensates by increasing the amount subcontracted. The total cost of the aggregate plan in Table 8-6 is $441,200, compared to $442,742 (for the aggregate plan in Table 8-3) if the holding cost is $6 per unit per month.

The seasonal inventory during the planning horizon is given by

$$\text{Seasonal inventory} = \frac{[(I_0 + I_T)/2] + \sum_{t=1}^{T-1} I_t}{T} = \frac{3{,}350}{6} = 558$$

The average flow time for this aggregate plan over the planning horizon (using Equation 8.6) is given by

$$\text{Average flow time} = \frac{558}{2{,}667} = 0.21 \text{ months}$$

From Example 8-2, observe that increasing the cost of one variable not only increases the total cost but also shifts the optimal balance away from that variable. An increase in holding cost at the manufacturer leads to an increase in production outsourced to the subcontractor.

FORECAST ERROR IN AGGREGATE PLANS

The aggregate planning methodology we have discussed in this chapter does not take into account any forecast error. However, we know that all forecasts have errors. To improve the quality of these aggregate plans, forecast errors must be taken into account. Forecasting errors are dealt with using either *safety inventory,* defined as inventory held to satisfy demand that is higher than forecasted (discussed thoroughly in Chapter 11), or *safety capacity,* defined as capacity used to satisfy demand that is higher than forecasted. A company can create a buffer for forecast

error using safety inventory and safety capacity in a variety of ways, some of which are listed next.

- Use overtime as a form of safety capacity.
- Carry extra workforce permanently as a form of safety capacity.
- Use subcontractors as a form of safety capacity.
- Build and carry extra inventories as a form of safety inventory.
- Purchase capacity or product from an open or spot market as a form of safety capacity.

The actions a company takes depend on the relative cost of the choices. Of course, if in practice a company can vary the capacity on short notice by hiring extra people, this is always an option. The problem with this option relates to the cost (monetary as well as morale) of letting them go later.

In the next section, we explain how to implement the linear programming methodology for aggregate planning using Microsoft Excel.

8.5 AGGREGATE PLANNING IN EXCEL

Next we discuss how to generate the aggregate plan for Red Tomato in Table 8-3 using Excel. To access Excel's linear programming capabilities, use Solver (Tools | Solver). To begin, we need to create a table, which we illustrate with Figure 8-1, containing the following decision variables:

W_t = workforce size for Month t, $t = 1, \ldots, 6$
H_t = number of employees hired at the beginning of Month t, $t = 1, \ldots, 6$
L_t = number of employees laid off at the beginning of Month t, $t = 1, \ldots, 6$
P_t = number of units produced in Month t, $t = 1, \ldots, 6$
I_t = inventory at the end of Month t, $t = 1, \ldots, 6$
S_t = number of units stocked out at the end of Month t, $t = 1, \ldots, 6$
C_t = number of units subcontracted for Month t, $t = 1, \ldots, 6$
O_t = number of overtime hours worked in Month t, $t = 1, \ldots, 6$

The first step is to build a table containing each decision variable. Figure 8-1 illustrates what this table should look like. The decision variables are contained in cells B5 to I10, with each cell corresponding to a decision variable. For example, cell D7 corresponds to the workforce size in Period 3. Begin by setting all the decision variables to 0 as shown in Figure 8-1.

FIGURE 8-1 Spreadsheet Area for Decision Variables

	A	B	C	D	E	F	G	H	I	J
1	*Aggregate Plan Decision Variables*									
2		Ht	Lt	Wt	Ot	It	St	Ct	Pt	
3	*Period*	*# Hired*	*# Laid off*	*# Workforce*	*Overtime*	*Inventory*	*Stockout*	*Subcontract*	*Production*	*Demand*
4	0	0	0	80	0	1,000	0	0		
5	1	0	0	0	0	0	0	0	0	1,600
6	2	0	0	0	0	0	0	0	0	3,000
7	3	0	0	0	0	0	0	0	0	3,200
8	4	0	0	0	0	0	0	0	0	3,800
9	5	0	0	0	0	0	0	0	0	2,200
10	6	0	0	0	0	0	0	0	0	2,200

FIGURE 8-2 Spreadsheet Area for Constraints

	M	N	O	P
1	Constraints			
2				
3	Workforce	Production	Inventory	Over time
4				
5	0	0	0	646
6	0	0	0	646
7	0	0	0	646
8	0	0	0	646
9	0	0	0	646
10	0	0	0	646

Cell	Cell Formula	Equation	Copied to
M5	=D5 - D4 - B5 + C5	8.2	M6:M10
N5	=40*D5 + E5/4 -I5	8.3	N6:N10
O5	=F4-G4+I5+H5-J5-F5+G5	8.4	O6:O10
P5	=-E5 + 10*D5	8.5	P6:P10

Also note that column J contains the actual demand. The demand information is included because it is required to calculate the aggregate plan.

The second step is to construct a table for the constraints in Equations 8.2 to 8.5. The constraint table may be constructed as shown in Figure 8-2.

Column M contains workforce constraints (Equation 8.2), column N contains capacity constraints (Equation 8.3), column O contains inventory balance constraints (Equation 8.4), and column P contains overtime constraints (Equation 8.5). These constraints are applied to each of the six periods.

Each constraint will eventually be written in solver as

$$\text{Cell value } \{\leq,\ =, \text{ or } \geq\}\ 0$$

In our case we have constraints

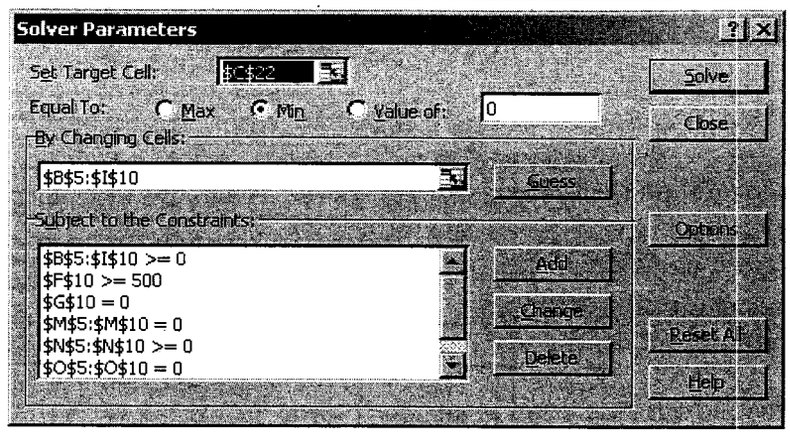
$$M5 = 0, N5 \geq 0, O5 = 0, P5 \geq 0$$

The third step is to create a cell containing the objective function, which is how each solution is judged. This cell need not contain the entire formula but can be written as a formula using cells with intermediate cost calculations. For the Red Tomato example, all cost calculations are shown in Figure 8-3. Cell B15, for instance, contains the hiring costs incurred in Period 1. The formula in cell B15 is the product of cell B5 and the cell

FIGURE 8-3 Spreadsheet Area for Cost Calculations

	A	B	C	D	E	F	G	H	I
12	Aggregate Plan Costs								
13									
14	Period	Hiring	Lay off	Regular time	Over time	Inventory	Stockout	Subcontract	Material
15	1	0	0	0	0	0	0	0	0
16	2	0	0	0	0	0	0	0	0
17	3	0	0	0	0	0	0	0	0
18	4	0	0	0	0	0	0	0	0
19	5	0	0	0	0	0	0	0	0
20	6	0	0	0	0	0	0	0	0
21									
22	Total Cost =		$ -						

FIGURE 8-4 Solver Parameters Dialog Box



containing the hiring cost per worker, which is obtained from Table 8-2. Other cells are filled similarly. Cell C22 contains the sum of cells B15 to I20, representing the total cost.

The fourth step is to use Tools | Solver to invoke Solver. Within the Solver parameters dialog box, enter the following information to represent the linear programming model:

Set Target Cell: C22
Equal to: Select *Min*
By Changing Cells: B5:I10
Subject to the constraints:
B5:I10 $\geq$ 0 {All decision variables are nonnegative}
F10 $\geq$ 500 {Inventory at end of Period 6 is at least 500}
G10 = 0 {Stockout at end of Period 6 equals 0}
M5:M10 = 0 $\{W_t - W_{t-1} - H_t + L_t = 0 \text{ for } t = 1, \ldots, 6\}$
N5:N10 $\geq$ 0 $\{40W_t + O_t/4 - P_t \geq 0 \text{ for } t = 1, \ldots, 6\}$
O5:O10 = 0 $\{I_{t-1} - S_{t-1} + P_t + C_t - D_t - I_t + S_t = 0 \text{ for } t = 1, \ldots, 6\}$
P5:P10 $\geq$ 0 $\{10W_t - O_t \geq 0 \text{ for } t = 1, \ldots, 6\}$

The Solver parameters dialog box is shown in Figure 8-4. Within the Solver parameters dialog box, click on Options and then select Assume Linear Model (this will speed up the solution time significantly). Selecting this option allows Solver to recognize a linear programming problem and use faster algorithms that do not work for nonlinear problems. Return to the Solver parameters dialog box and click on Solve. The optimal solution should be returned. If Solver does not return the optimal solution, solve the problem again after saving the solution that Solver has returned. (In some cases, multiple repetitions of this step may be required because of some flaws in the version of Solver that comes with Excel. Add-ins are available at relatively low cost that do not have any of these issues.) The optimal solution turns out to be the one shown in Table 8-3.

8.6 THE ROLE OF IT IN AGGREGATE PLANNING

Aggregate planning is arguably the supply chain area in which information technology has been used the most. The earliest IT supply chain products were aggregate planning modules, often called factory, production, or manufacturing planning. Some of the early modules focused only on obtaining a feasible production plan subject to constraints arising from demand and available capacity. Later modules provided tools that

chose an optimal solution from among the feasible production plans, based on objectives such as increased output or lowered cost.

These classic solutions generally formulated the aggregate planning problem as a linear program (LP) to get a production schedule of products to be made in each period of time. Today, some planning modules incorporate nonlinear optimization to account for the fact that not all constraints or reasonable objective functions are linear functions. However, given the large amount of data considered in producing aggregate plans, which can render nonlinear problems computationally prohibitive, and the ability to create linear approximations of nonlinear functions, linear programming is often the best way to solve these problems.

Supply chain planning modules today often combine both production planning and inventory planning. The supply chain planning module uses the output of the forecasting module as a constraint in setting up the production schedule and inventory levels. These production schedules and inventory levels are used by the execution system for the actual production of the goods and the setting of inventory levels throughout the supply chain. Given the complexity of the problem, aggregate planning modules can add significant value even for small companies.

There are a number of dimensions along which IT can add value in the aggregate planning realm:

- The ability to handle large problems
- The ability to handle complex problems (through either nonlinear optimization or linear approximations)
- The ability to interact with other core IT systems such as inventory management and sourcing

Because aggregate planning problems are so complex, there is often no other way to arrive at a feasible solution than through IT.

Major software players in this area include the ERP software firms (SAP and Oracle) and the best-of-breed players (such as i2 Technologies and Manugistics). Some firms also specialize their planning software by industry verticals. For example, the production planning problems for an oil company are structured differently than those for an aircraft manufacturer. These differences allow IT firms to enhance the value of their product by focusing on particular industries.

8.7 IMPLEMENTING AGGREGATE PLANNING IN PRACTICE

1. ***Think beyond the enterprise to the entire supply chain.*** Most aggregate planning today takes only the enterprise as its breadth of scope. However, many factors outside the enterprise throughout the supply chain can affect the optimal aggregate plan dramatically. Therefore, avoid the trap of thinking only about your enterprise when planning. Work with downstream partners to produce forecasts, with upstream partners to determine constraints, and with any other supply chain entities that can improve the quality of the inputs into the aggregate plan. The plan is only as good as the quality of the inputs. So using the supply chain to increase the quality of the inputs will greatly improve the quality of the aggregate plan. Also make sure to communicate the aggregate plan to all supply chain partners who will be affected by it.

2. ***Make plans flexible, because forecasts are always wrong.*** Aggregate plans are based on forecasts of future demand. Given that these forecasts are always wrong to some degree, the aggregate plan needs to have some flexibility built into it if it is to be useful. By building flexibility into the plan, when future demand changes, or other changes occur such as increases in costs, the plan can adjust appropriately to handle the new situation.

How do we create this flexibility? In addition to the suggestions earlier in the chapter, we recommend that a manager perform sensitivity analysis on the inputs into an aggregate plan. For example, if the plan recommends expanding expensive capacity while facing uncertain demand, examine the outcome of a new aggregate plan when demand is higher and when it is lower than expected. If this examination reveals a small savings from expanding capacity when demand is high but a large increase in cost when demand is lower than expected, deciding to postpone the capacity investment decision is a potentially attractive option. Using sensitivity analysis on the inputs into the aggregate plan enables a planner to choose the best solution for the range of possibilities that could occur.

3. ***Rerun the aggregate plan as new data emerge.*** As we have mentioned, aggregate plans provide a map for the next 3 to 18 months. This does not mean that a firm should run aggregate plans only once every 3 to 18 months. As inputs such as demand forecasts change, managers should use the latest values of these inputs and rerun the aggregate plan. By using the latest inputs, the plan will avoid suboptimization based on old data and will produce a better solution.

4. ***Use aggregate planning as capacity utilization increases.*** Surprisingly, many companies do not create aggregate plans and instead rely solely on orders from their distributors or warehouses to determine their production schedules. These orders are driven either by actual demand or through inventory management algorithms. If a company has no trouble meeting demand efficiently this way, then the lack of aggregate planning may not harm the company significantly. However, when utilization becomes high and capacity is an issue, relying on orders to set the production schedule can lead to capacity problems. When utilization is high, the likelihood of producing for all the orders as they arrive is very low. Planning needs to be done to best utilize the capacity to meet the forecasted demand. Therefore, as capacity utilization increases, it becomes more important to perform aggregate planning.

8.8 SUMMARY OF LEARNING OBJECTIVES

1. Identify the decisions that are best solved by aggregate planning.

   Aggregate planning is best used to determine capacity, production, and inventory decisions for each period of time over a range of three to 18 months. It is most important to perform aggregate planning when capacity is limited and lead times are long.

2. Understand the importance of aggregate planning as a supply chain activity.

   Aggregate planning has a significant impact on supply chain performance and must be viewed as an activity that involves all supply chain partners. An aggregate plan prepared by an enterprise in isolation is not very useful because it does not take into account all requirements of the customer stage and constraints from the supplier stage. Localized aggregate planning cannot do a good job of matching supply and demand. Good aggregate planning is done in collaboration with both customers and suppliers because accurate input is required from both stages. The quality of these inputs, in terms of both the demand forecast to be met and the constraints to be dealt with, determines the quality of the aggregate plan. The results of the aggregate plan must also be shared across the supply chain because they influence activities at both customers and suppliers. For suppliers, the aggregate plan determines anticipated orders; whereas for customers, the aggregate plan determines planned supply.

3. Describe the information needed to produce an aggregate plan.

   To create an aggregate plan, a planner needs a demand forecast, cost and production information, and any supply constraints. The demand forecast consists of an estimate of demand for each period of time in the planning horizon. The production and cost data

consist of capacity levels and costs to raise and lower them, production costs, costs to store the product, costs of stocking out the product, and any restrictions that limit these factors. Supply constraints determine limits on outsourcing, overtime, or materials.

4. Explain the basic trade-offs to consider when creating an aggregate plan.

   The basic trade-offs involve balancing the cost of capacity, the cost of inventory, and the cost of stockouts to maximize profitability. Increasing any one of the three allows the planner to lower the other two.

5. Formulate and solve aggregate planning problems using Microsoft Excel.

   Aggregate planning problems can be solved in Excel by setting up cells for the objective function and the constraints and using the solver to produce the solution.

Discussion Questions

1. What are some industries in which aggregate planning would be particularly important?
2. What are the characteristics of these industries that make them good candidates for aggregate planning?
3. What are the main differences between the aggregate planning strategies?
4. What types of industries or situations are best suited to the chase strategy? The flexibility strategy? The level strategy?
5. What are the major cost categories needed as inputs for aggregate planning?
6. How does the availability of subcontracting affect the aggregate planning problem?
7. If a company currently employs the chase strategy and the cost of training increases dramatically, how might this change the company's aggregate planning strategy?
8. How can aggregate planning be used in an environment of high demand uncertainty?

Exercises

1. Skycell, a major European cell phone manufacturer, is making production plans for the coming year. Skycell has worked with its customers (the service providers) to come up with forecasts of monthly requirements (in thousands of phones) as shown in Table 8-7.

   Manufacturing is primarily an assembly operation, and capacity is governed by the number of people on the production line. The plant operates for 20 days a month, eight hours each day. One person can assemble a phone every 10 minutes. Workers are paid 20 euros per hour and a 50 percent premium for overtime. The plant currently employs 1,250 workers. Component cost for each cell phone totals 20 euros. Given the rapid decline in component and finished-product prices, carrying inventory from one month to the next incurs a cost of 3 euros per phone per month. Skycell currently has a no-layoff policy in place. Overtime is limited to a maximum of 20 hours per month per employee. Assume that Skycell has a starting inventory of 50,000 units and wants to end the year with the same level of inventory.

   (a) Assuming no backlogs, no subcontracting, and no new hires, what is the optimum production schedule? What is the annual cost of this schedule?

TABLE 8-7 Monthly Demand for Cell Phones, in Thousands

Month	*Demand*	*Month*	*Demand*
January	1,000	July	1,600
February	1,100	August	900
March	1,000	September	1,100
April	1,200	October	800
May	1,500	November	1,400
June	1,600	December	1,700

(b) Is there any value for management to negotiate an increase of allowed overtime per employee per month from 20 hours to 40?
(c) Reconsider parts (a) and (b) if Skycell starts with only 1,200 employees. Reconsider parts (a) and (b) if Skycell starts with 1,300 employees. What happens to the value of additional overtime as the workforce size decreases?
(d) Consider part (a) for the case in which Skycell aims for a level production schedule such that the quantity produced each month does not exceed the average demand over the next 12 months (1,241,667) by 50,000 units. Monthly production including overtime is no more than 1,291,667. What would be the cost of a level production schedule? What is the value of overtime flexibility?

2. Reconsider the Skycell data in Exercise 1. Assume that the plant has 1,250 employees and a no-layoff policy. Overtime is limited to 20 hours per employee per month. A third party has offered to produce cell phones as needed at a cost of $26 per unit (this includes component costs of $20 per unit).
(a) What is the average per unit of in-house production (including inventory holding and overtime cost) if the third party is not used?
(b) How should Skycell use the third party? How does your answer change if the third party offers a price of $25 per unit?
(c) Should Skycell use the third party if the per unit cost is $28?
(d) Why does Skycell use the third party even when the per-unit cost of the third party is higher than the average per-unit cost (including inventory holding and overtime) for in-house production?

3. Reconsider the Skycell data in Exercise 1. Assume that the plant has 1,250 employees and a no-layoff policy. Overtime is limited to at most 20 hours per employee per month. Also assume no subcontracting option. Skycell has a team of 50 people who are willing to work as seasonal employees. The cost of bringing them on is 800 euros per employee, and the layoff cost is 1,200 euros per employee.
(a) What is the optimal production, hiring, and layoff schedule?
(b) How does the optimal schedule change if the seasonal pool grows from 50 to 100?
(c) Relative to having 1,250 permanent employees and 50 seasonal, will Skycell gain significantly if it carries only 1,100 permanent employees but has 200 seasonal employees?
(d) Consider the case in which Skycell has 1,250 permanent employees and 50 seasonal employees. What would you say about Skycell's no-layoff policy for its permanent employees? Assume permanent employees can be hired or laid off at the same cost as the seasonal employees.

4. FlexMan, an electronics contract manufacturer, uses its Topeka, Kansas, facility to produce two product categories: routers and switches. Consultation with customers has indicated a demand forecast for each category over the next 12 months (in thousands of units) to be as shown in Table 8-8.

Manufacturing is primarily an assembly operation, and capacity is governed by the number of people on the production line. The plant operates 20 days a month, eight hours each day. Production of a router takes 20 minutes and production of a switch requires 10 minutes of worker time. Each worker is paid $10 per hour with a 50 percent premium for any overtime. The plant currently has 6,300 employees. Overtime is limited to 20 hours per employee per month. The plant currently maintains 100,000 routers and 50,000 switches in inventory. The cost of holding a router in inventory is $2 per month and the cost of holding a switch in inventory is $1 per month. The holding cost arises because products are paid for by the customer at existing market rates when purchased. Thus, if FlexMan produces early and holds in inventory, the company recovers less given the rapidly dropping component prices.
(a) Assuming no backlogs, no subcontracting, no layoffs, and no new hires, what is the optimum production schedule for FlexMan? What is the annual cost of this

TABLE 8-8 Demand Forecast for FlexMan

Month	*Router Demand*	*Switch Demand*	*Month*	*Router Demand*	*Switch Demand*
January	1,800	1,600	July	1,200	700
February	1,600	1,400	August	1,400	800
March	2,600	1,500	September	2,500	1,400
April	2,500	2,000	October	2,800	1,700
May	800	1,500	November	1,000	800
June	1,800	900	December	1,000	900

schedule? What inventories does the optimal production schedule build? Does this seem reasonable?

(b) Is there any value for management to negotiate an increase of allowed overtime per employee per month from 20 hours to 40? What variables are affected by this change?

(c) Reconsider parts (a) and (b) if FlexMan starts with only 5,900 employees. Reconsider parts (a) and (b) if FlexMan starts with 6,700 employees. What happens to the value of additional overtime as the workforce size decreases?

5. Reconsider the FlexMan data from Exercise 4. The firm is considering the option of changing workforce size with demand. The cost of hiring a new employee is $700 and the cost of a layoff is $1,000. It takes an employee two months to reach full production capacity. During those two months, a new employee provides only 50 percent productivity. Anticipating a similar demand pattern next year, FlexMan aims to end the year with 6,300 employees.

   (a) What is the optimal production, hiring, and layoff schedule? What is the cost of such a schedule?

   (b) If FlexMan could improve its training so that new employees achieve full productivity right away, how much improvement in annual cost would the company see? How is the hiring and layoff policy during the year affected by this change?

6. FlexMan has identified a third party that is willing to produce routers and switches as needed. The third party will charge $6 per router and $4 per switch. Assume all other data as in Exercise 4 except that hiring and layoffs are allowed as in Exercise 5.

   (a) How should FlexMan use the third party if new employees provide only 50 percent productivity for the first two months?

   (b) How should FlexMan use the third party if new employees are able to achieve full productivity right away?

   (c) Why does the use of the third party change with the productivity of new employees?

7. Return to the FlexMan data in Exercise 4. The company has signed a service-level agreement with its customers and committed to carry safety inventory from one month to the next that equals at least 15 percent of the following month's demand. Thus, FlexMan is committed to carrying over at least $0.15 \times 1{,}800{,}000 = 270{,}000$ routers and $0.15 \times 1{,}600{,}000 = 240{,}000$ in inventory from December to January.

   (a) Assuming no backlogs, no subcontracting, no layoffs, and no new hires, what is the optimum production schedule for FlexMan? What is the annual cost of this schedule?

   (b) How much does the service contract mandating minimum inventories increase costs for FlexMan?

   (c) What would be the increase in cost if FlexMan agreed to a 15 percent minimum for switches but only a 5 percent minimum for routers? What would be the increase in cost if FlexMan agreed to a only a 5 percent minimum for switches but a 15 percent minimum for routers? Which of the two is better for FlexMan?

CASE STUDY

SPECIALTY PACKAGING CORPORATION, PART B

Julie Williams, facility production planning manager at Specialty Packaging Corporation, left the meeting with the collaborative forecast team with forecasts and error estimates for the next three years. She now needed to determine how to meet this demand. Because SPC sometimes outsourced warehousing to its supply chain partners, one decision Julie had to make was whether to use public or private warehousing. She also had to decide how much warehouse space to lease or build if she chose to use private warehousing.

SPC

From the discussion of this case in Chapter 7, recall that SPC processes polystyrene resin into recyclable/disposable containers for the food industry. Polystyrene is purchased as a commodity in the form of resin pellets. The resin is unloaded from bulk rail containers or overland trailers into storage silos. Making the food containers is a two-step process. In the first step, resin is conveyed to an extruder, which turns pellets into a polystyrene sheet that is wound into rolls. The plastic comes in two forms—clear and black. The rolls are then either used immediately to make containers or are put into storage. In the second step, the rolls are loaded onto thermoforming presses, which form the sheet into container cavities and trim the cavities from the sheet. These manufacturing steps are shown in Figure 7-1. SPC currently operates for 63 working days each quarter. Each work day consists of eight hours of regular time and any scheduled overtime.

DEMAND FORECAST FOR NEXT THREE YEARS

The collaborative forecasting team used the historical demand data provided in Table 7-4 supplemented with stockout data to develop a forecast for quarterly demand for both clear and black plastic containers. The demand forecast between 2007 and 2009 is shown in Table 8-9.

EXTRUDERS

The extrusion process is capital intensive, as is the investment in the facilities required to support it. The plant currently has 14 extruders. Each extruder has a rated processing capacity of 3,000 pounds per hour. A changeover is required whenever the extruder switches between clear and black sheets. SPC estimates that there is a 5 percent capacity loss due to changeovers. The effective processing capacity of an extruder is thus 2,850 pounds per hour. Each extruder requires six workers. SPC pays each worker $15 per hour including benefits. Overtime is paid at 150 percent of regular-time salary. Workers are limited to 60 overtime hours per quarter.

Extruders are fairly expensive, and the addition of an extruder requires the hiring of six additional people. Each new extruder incurs a fixed cost of $80,000 per quarter. Any new personnel hired need to be trained. Training cost per person is $3,000. As a result, SPC has decided not to purchase any new extruders over the current planning horizon. During any quarter, available extruders may be idled if they are not to be used. The only savings here is the salary of associated workers. Laying off each worker, however, costs $2,500. If idled extruders are brought online, SPC incurs a training cost of $3,000 per worker.

THERMOFORMING PRESSES

The plant currently has 25 thermoforming presses. Each thermoforming press requires one operator and can produce containers at the rate of 2,000 pounds per hour. SPC pays each operator $15 per hour including benefits. Overtime is paid at 150 percent of regular-time salary. Workers are limited to 60 hours of overtime per quarter. Presses may be idled for the quarter if they are not to be used. Laying off a thermoforming operator costs $2,500, and training a newly hired operator costs $3,000.

SUBCONTRACTING

SPC has the option of subcontracting the production of plastic sheets to one of its supply chain partners; sufficient capacity is always available on the open market. SPC spends $60 per 1,000 pounds of plastic sheet produced by a subcontractor.

MATERIALS MANAGEMENT PRACTICES

Resin purchased is stored in silos. As there is no shortage of resin in the market, it can easily be purchased at $10 per 1,000 pounds when needed. As a result, SPC's practice has been to purchase resin on a quarterly basis to match the planned production.

As the extruders produce rolls of plastic sheet, the amount required at the thermoforming presses is passed forward, with the rest driven via shuttle trailer to one of two public warehouses. Transportation is again required to bring the sheets back from the warehouse when they

TABLE 8-9 Demand Forecast for Clear and Black Plastic Containers

Year	*Quarter*	*Black Plastic Forecast ('000 lb)*	*Clear Plastic Forecast ('000 lb)*
2007	I	6,650	7,462
	II	4,576	18,250
	III	6,293	8,894
	IV	13,777	4,064
2008	I	7,509	8,349
	II	5,149	20,355
	III	7,056	9,891
	IV	15,399	4,507
2009	I	8,367	9,235
	II	5,721	22,461
	III	7,819	10,889
	IV	17,021	4,950
		MAD = 608	MAD = 786

are needed to feed the thermoforming presses. SPC's total transportation cost is $2 per 1,000 pounds of plastic sheet. Each quarter, SPC follows a policy of first using sheets in storage for thermoforming and only then using the newly produced sheets. Any sheets left over at the end of the quarter are put back into storage. This policy is followed to ensure that sheets do not deteriorate because of time in storage.

PUBLIC WAREHOUSING

Public warehousing charges customers for both material handling and storage. The SPC plant contracts with local warehouses to store material on a per-thousand-pound basis. Material handling charges are from $4 to $6 per 1,000 pounds unloaded at the warehouse. Storage charges are from $10 to $12 per 1,000 pounds in storage at the end of each quarter. The SPC plant negotiates annually with local warehouses to establish rates for each cost element.

PRIVATE WAREHOUSING

Operating a private warehouse requires capitalized investment either to construct a facility or to lease an existing facility. Lease rates in any location are determined by the economics associated with building costs in that location and the option value of a lease versus a long-term capital commitment. Leases are typically in force for three years, but the time span can be shorter depending on a given company's negotiating strengths. Several viable leasing options exist for the SPC plant, all more favorable than the option of building a new facility. Lease rates average $4 per square foot per quarter in each location. On average, one square foot is required per 1,000 pounds in storage.

Private warehousing also results in operating costs, both variable and fixed. Private warehousing is available from a third-party logistics provider who has agreed to charge SPC a variable operating cost of $4 per 1,000 pounds of plastic sheet stored per quarter. To obtain this rate, SPC must sign a lease for the full three years. As a result, SPC will pay for the space each quarter even if it is not used for storage. SPC must take this cost into account when making its decision.

SPC must consider several variables in determining the amount of warehouse space it requires. Usable warehousing space is the fraction of a warehouse that can actually be used to store inventory. Considerations are made for aisle space, shipping and receiving dock space, administrative office space, and ceiling height. Storage density is another consideration. SPC must also take into account velocity and times of materials movement because the staffing level required and storage configurations are dependent on both. For example, if materials must be retrieved readily, the warehouse layout must include a greater ratio of aisle and staging space to actual storage space.

THE ACTIONS AND DECISIONS

Julie and her group must take two actions. The first, given a three-year forecast as shown in Table 8-7, is to come up with an aggregate production plan. The second is to choose from the following three options:

1. Continue with the strategy of storing materials off-site in public warehousing.

2. Lease and run a private warehouse to handle off-site inventory.
3. Use a combination of both public and private warehousing.

In the case of private warehousing, Julie must make a decision regarding the square footage to be leased. This decision will apply over the period 2007 to 2009. Clearly, this decision must be made in conjunction with the preparation of an aggregate plan over the three-year period. Ideally, the two decisions should be made jointly, as each will affect the other.

What factors do you think influence the actions and decisions? For example, do you think that the price the subcontractor charges has any relationship to the amount of private warehousing space to be leased?

Julie also has to decide how to handle any potential error in the demand forecast. How do you recommend she handle these errors?

CHAPTER 9

PLANNING SUPPLY AND DEMAND IN A SUPPLY CHAIN: MANAGING PREDICTABLE VARIABILITY



Learning Objectives

After reading this chapter, you will be able to:

1. Manage supply to improve synchronization in a supply chain in the face of predictable variability.
2. Manage demand to improve synchronization in a supply chain in the face of predictable variability.
3. Use aggregate planning to maximize profitability when faced with predictable variability in a supply chain.

In Chapter 8, we discussed how companies manage supply by using aggregate planning to make optimal trade-offs in a way that maximizes profits. In this chapter, we build on the knowledge we gained from Chapter 8 and continue to expand our scope beyond the enterprise to the supply chain as we deal with predictable variability of demand. We also discuss how demand may be managed to counter predictable variability through the use of price and promotion. By managing supply and demand, managers can maximize overall profitability of a supply chain.

9.1 RESPONDING TO PREDICTABLE VARIABILITY IN THE SUPPLY CHAIN

In Chapter 8, we discussed how companies use aggregate planning to plan supply to maximize profits. For products with stable demand, devising an aggregate plan is relatively simple. In such cases, a firm arranges for sufficient capacity to match the expected demand and then produces an amount to match that demand. Products can be produced close to the time when they will be sold. Therefore, the supply chain carries little inventory.

Demand for many products, however, changes frequently from period to period, often because of a predictable influence. These influences include seasonal factors that affect products (e.g., lawn mowers and ski jackets), as well as nonseasonal factors (e.g., promotions or product adoption rates) that may cause large, predictable increases and declines in sales.

Predictable variability is change in demand that can be forecasted. Products that undergo this type of change in demand create numerous problems in the supply chain, ranging from high levels of stockouts during peak demand periods to high levels of excess inventory during periods of low demand. These problems increase the costs and

decrease the responsiveness of the supply chain. Supply and demand management has significant impact when applied to predictably variable products.

Faced with predictable variability, a company's goal is to respond in a manner that maximizes profitability. A firm must choose between two broad options to handle predictable variability:

1. Manage supply using capacity, inventory, subcontracting, and backlogs.
2. Manage demand using short-term price discounts and trade promotions.

The use of these tools enables the supply chain to increase profitability, because supply and demand are matched in a more coordinated fashion.

To illustrate some of the issues involved, let us consider the garden equipment manufacturer discussed in Chapter 8, Red Tomato Tools. Demand for garden tools is seasonal, with sales concentrated in the spring. Red Tomato must plan how it will meet the demand to maximize profit. One way requires Red Tomato to carry enough manufacturing capacity to meet demand from production in any period. The advantage of this approach is that Red Tomato incurs very low inventory costs because no inventory is carried from period to period. The disadvantage, however, is that much of the expensive capacity is unused during most months, when demand is lower.

Another approach to meeting demand is to build up inventory during the off-season to keep production stable year round. The advantage of this approach lies in the fact Red Tomato can get by with a lower-capacity, less expensive factory. High inventory carrying costs, however, make this alternative expensive. A third approach is for Red Tomato to work with its retail partners in the supply chain to offer a price promotion before the spring months, during periods of low demand. This promotion shifts some of the spring demand forward into a slow period, thereby spreading demand more evenly throughout the year and reducing the seasonal surge. Such a demand pattern is less expensive to supply. Red Tomato needs to decide which alternative maximizes its profitability.

Often companies divide the task of supply and demand management into different functions. Marketing typically manages demand, while Operations manages supply. At a higher level, supply chains suffer from this phenomenon as well, with retailers managing demand independently and manufacturers managing supply independently. Lack of coordination hurts supply chain profits when supply and demand management decisions are made independently. Therefore, supply chain partners must work together across enterprises to coordinate these decisions and maximize profitability. We illustrate the value of this coordination through further discussion of Red Tomato.

First, we focus on actions that a supply chain can take to improve profitability by managing supply.

9.2 MANAGING SUPPLY

A firm can vary supply of product by controlling a combination of the following two factors:

1. Production capacity
2. Inventory

The objective is to maximize profit, which, for our discussion, is the difference between revenue generated from sales and the total cost associated with material, capacity, and inventory. In general, companies use a combination of varying capacity and inventory to manage supply. In the following, we list some specific approaches to managing capacity and inventory with the goal of maximizing profits.

MANAGING CAPACITY

In managing capacity to meet predictable variability, firms use a combination of the following approaches.

- ***Time flexibility from workforce:*** In this approach, a firm uses flexible work hours by the workforce to manage capacity to better meet demand. In many instances, plants do not operate continually and are left idle during portions of the day or week. Therefore, spare plant capacity exists in the form of hours when the plant is not operational. For example, many plants do not run three shifts, so the existing workforce could work overtime during peak periods to produce more to meet demand. The overtime is varied to match the fluctuation in demand. This system allows production from the plant to match demand from customers more closely. If demand fluctuates by day of the week or week of the month and the workforce is willing to be flexible, a firm may schedule the workforce so that the available capacity matches demand better. In such settings, use of a part-time workforce may further increase capacity flexibility by enabling the firm to put more people to work during peak periods. Telemarketing centers and banks use part-time workers extensively to match supply and demand better.
- ***Use of seasonal workforce:*** In this approach, a firm uses a temporary workforce during the peak season to increase capacity to match demand. The tourism industry often uses seasonal workers. A base of full-time employees exists, and more are hired only for the peak season. Toyota regularly uses seasonal workforce in Japan to match supply and demand better. This approach, however, may be hard to sustain if the labor market is tight.
- ***Use of subcontracting:*** In this approach, a firm subcontracts peak production so that internal production remains level and can be done cheaply. With the subcontractor handling the peaks, the company is able to build a relatively inflexible but low-cost facility in which production rates are kept relatively constant (other than variations from the use of overtime). Peaks are subcontracted out to facilities that are more flexible. A key here is the availability of relatively flexible subcontractor capacity. The subcontractor can often provide flexibility at a lower cost by pooling the fluctuations in demand across different manufacturers. Thus the flexible subcontractor capacity must have both volume (fluctuating demand from a manufacturer) as well as variety flexibility (demand from several manufacturers) to be sustainable. For example, most power companies do not have the capacity to supply their customers with all the electricity demanded on peak days. They instead rely on being able to purchase power from suppliers and subcontractors who have excess electricity. This allows the power companies to maintain a level supply and, consequently, a lower cost.
- ***Use of dual facilities—specialized and flexible:*** In this approach, a firm builds both specialized and flexible facilities. Specialized facilities produce a relatively stable output of products over time in a very efficient manner. Flexible facilities produce a widely varying volume and variety of products but at a higher unit cost. For instance, a PC components manufacturer might have specialized facilities for each type of circuit board as well as a flexible facility that can manufacture all types of circuit boards. Each specialized facility can produce at a relatively steady rate, with fluctuations being absorbed by the flexible facility.
- ***Designing product flexibility into the production processes:*** In this approach, a firm has flexible production lines whose production rate can easily be varied. Production is then changed to match demand. Hino Trucks in Japan has several production lines for different product families. The production lines are designed so that changing the number of workers on a line can vary the production rate. As long as variation of demand across different product lines is complementary (i.e., when one goes up, the other tends

to go down), the capacity on each line can be varied by moving the workforce from one line to another. Of course, this requires that the workforce be multiskilled and adapt easily to being moved from line to line. Production flexibility can also be achieved if the production machinery is flexible and can be changed easily from producing one product to producing another. This approach is effective only if the overall demand across all the products is relatively constant. Several firms that produce products with seasonal demand try to exploit this approach by carrying a portfolio of products that have peak demand seasons distributed over the year. A classic example is that of a lawn mower manufacturer that also manufactures snow blowers to maintain a steady demand on its factory throughout the year. In the services field, an example comes from strategy consulting firms, which often offer a balanced product portfolio, with growth strategies emphasized when economic times are good and cost-cutting projects emphasized when times are bad.

MANAGING INVENTORY

When managing inventory to meet predictable variability, firms use a combination of the following approaches.

- ***Using common components across multiple products:*** In this approach, a firm designs common components to be used in multiple products. The total demand of these components is relatively stable, even though each product displays predictable variability. For example, the use of a common engine for both lawn mowers and snow blowers allows for engine demand to be relatively stable even though lawn mower and snow blower demand fluctuates over the year. Therefore, the part of the supply chain that produces components can easily synchronize supply with demand, and a relatively low inventory of parts has to be built up. Similarly, in a consulting firm, many of the same consultants produce growth strategies when they are in demand and produce cost-reduction strategies when these are in demand.
- ***Build inventory of high-demand or predictable-demand products:*** When most of the products a firm produces have the same peak demand season, the previous approach is not feasible. In such an environment, it is best for the firm to build products that have more predictable demand during the off-season, because there is less to be learned about their demand by waiting. Production of more uncertain items should take place closer to the selling season, when demand is more predictable. As an example, consider a manufacturer of winter jackets that produces jackets both for retail sale and for the Boston Police and Fire Departments. Demand for the Boston Police and Fire jackets is more predictable, and these jackets can be made in the off-season and stocked up until winter. The retail jacket's demand, however, will likely be better known closer to the time when it is sold, because fashion trends can change quickly. Therefore, the manufacturer should produce the retail jackets close to the peak season, when demand is easier to predict. This strategy helps the supply chain synchronize supply and demand better.

Next we consider actions a supply chain can take to improve profitability by managing demand.

9.3 MANAGING DEMAND

Supply chains can influence demand by using pricing and other forms of promotion. Promotion decisions are often made by retailers without taking into account the impact on the rest of the supply chain. In this section, our goal is to show how supply

chain members can collaborate on pricing and aggregate planning (both demand and supply management) decisions to maximize supply chain profitability.

Let us return to Red Tomato Tools, the garden equipment manufacturer. Green Thumb Gardens is a large retail chain that has signed an exclusive contract to sell all products made by Red Tomato Tools. Demand for garden tools peaks in the spring months of March and April as gardeners prepare to begin planting. In planning, the goal of both firms should be to maximize supply chain profits because this outcome leaves them more money to share. For profit maximization to take place, Red Tomato and Green Thumb need to devise a way to collaborate and, just as important, determine a way to split the supply chain profits. Determining how these profits will be allocated to different members of the supply chain is key to successful collaboration.

Red Tomato and Green Thumb are exploring how the timing of retail promotions affects profitability. Are they in a better position if they offer the price promotion during the peak period of demand or during a low-demand period? Green Thumb's vice president of sales favors a promotion during the peak period because this increases revenue by the largest amount. In contrast, Red Tomato's vice president of manufacturing is against such a move because it increases manufacturing costs. She favors a promotion during the low-demand season because it levels demand and lowers production costs.

Red Tomato and Green Thumb must start by considering the demand forecast shown in Table 9-1 and the resulting optimal aggregate plan (this is the same as discussed in Chapter 8).

Each tool has a retail price of $40. Red Tomato ships assembled tools to Green Thumb, where all inventory is held. Green Thumb has a starting inventory in January of 1,000 tools. At the beginning of January, Red Tomato has a workforce of 80 employees at its manufacturing facility in Mexico. There are a total of 20 working days in each month, and Red Tomato workers earn the equivalent of $4 per hour. Each employee works eight hours on normal time and the rest on overtime. Because the Red Tomato operation consists mostly of hand assembly, the capacity of the production operation is determined primarily by the total labor hours worked (i.e., it is not limited by machine capacity). No employee works more than 10 hours of overtime per month. The various costs are shown in Table 9-2.

There are no limits on subcontracting, inventories, and stockouts. All stockouts are backlogged and supplied from the following month's production. Inventory costs are incurred on the ending inventory in each month. The companies' goal is to obtain the optimal aggregate plan that leaves at least 500 units of inventory at the end of June (i.e., no stockouts at the end of June and at least 500 units in inventory).

The optimal aggregate plan for Red Tomato and Green Thumb is shown in Table 9-3.

TABLE 9-1 Demand for Red Tomato Tools

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	3,800
May	2,200
June	2,200

TABLE 9-2 Costs for Red Tomato and Green Thumb

Item	*Cost*
Material cost	$10/unit
Inventory holding cost	$2/unit/month
Marginal cost of a stockout	$5/unit/month
Hiring and training costs	$300/worker
Layoff cost	$500/worker
Labor hours required	4/unit
Regular-time cost	$4/hour
Overtime cost	$6/hour
Cost of subcontracting	$30/unit

For this aggregate plan, the supply chain obtains the following costs and revenues:

$$\text{Total cost over planning horizon} = \$422{,}275$$

Given the sale price of $40/unit and total sales of 16,000 units, revenue over the planning horizon is given by

$$\text{Revenue over planning horizon} = 40 \times 16{,}000 = \$640{,}000$$
$$\text{Profit over the planning horizon} = \$217{,}725$$

The average seasonal inventory during the planning horizon is given by

$$\text{Average seasonal inventory} = \frac{[(I_0 + I_6)/2] + \sum_{t=1}^{5} I_t}{T} = \frac{5{,}367}{6} = 895$$

The average flow time for this aggregate plan over the planning horizon is

$$\text{Average flow time} \frac{\text{average inventory}}{\text{average sales}} = \frac{895}{2{,}667} = 0.34 \text{ months}$$

These results all pertain to the situation in which there is no promotion. Now the companies want to explore if and when to offer a promotion. Four key factors influence the timing of a trade promotion:

- Impact of the promotion on demand
- Product margins

TABLE 9-3 Aggregate Plan for Red Tomato and Green Thumb

Period, t	*No. Hired, H_t*	*No. Laid Off, L_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	1,983	0	0	2,583
2	0	0	65	0	1,567	0	0	2,583
3	0	0	65	0	950	0	0	2,583
4	0	0	65	0	0	267	0	2,583
5	0	0	65	0	117	0	0	2,583
6	0	0	65	0	500	0	0	2,583

- Cost of holding inventory
- Cost of changing the level of capacity

Management at both companies wants to identify whether each factor favors offering a promotion during the high- or low-demand periods. They start by considering the impact of promotion on demand. When a promotion is offered during a period, that period's demand tends to go up. This increase in demand results from a combination of the following three factors:

1. ***Market growth:*** An increase in consumption of the product either from new or existing customers. For example, when Toyota offers a price promotion on the Camry, it may attract buyers who were considering the purchase of a lower-end model. Thus, the promotion increases the size of the overall family sedan market as well as increasing Toyota's sales.

2. ***Stealing share:*** Customers substitute the firm's product for a competitor's product. When Toyota offers a Camry promotion, buyers who might have purchased a Honda Accord may now purchase a Camry. Thus, the promotion increases Toyota's sales while keeping the overall size of the family sedan market the same.

3. ***Forward buying:*** Customers move up future purchases (as discussed in Chapter 10) to the present. A promotion may attract buyers who would have purchased a Camry a few months down the road. The promotion does not increase Toyota's sales in the long run and also leaves the family sedan market the same size.

The first two factors increase the overall demand for Toyota, whereas the third simply shifts future demand to the present. It is important to understand the relative impact from the three factors as a result of a promotion before making a decision regarding the optimal timing of the promotion. In general, as the fraction of increased demand coming from forward buying grows, offering the promotion during the peak demand period becomes less attractive. Offering a promotion during a peak period that has significant forward buying creates even more variable demand than before the promotion. Product that was once demanded in the slow period is now demanded in the peak period, making this demand pattern even more costly to serve.

Green Thumb estimates that discounting a Red Tomato tool from $40 to $39 (a $1 discount) results in the period demand increasing by 10 percent because of increased consumption or substitution. Further, 20 percent of each of the two following months' demand is moved forward. Management would like to determine whether it is more effective to offer the discount in January or April.

The team first considers the impact of offering the discount in January. If the discount is offered in January, the demand forecast is as shown in Table 9-4. The optimal

TABLE 9-4 Demand When Discounting Price in January to $39

Month	*Demand Forecast*
January	3,000
February	2,400
March	2,560
April	3,800
May	2,200
June	2,200

TABLE 9-5 Optimal Aggregate Plan for Demand in Table 9-4

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stockout, S_t	Subcontract, C_t	Total Production, P_t
0	0	0	80	0	1,000	0	0	
1	0	15	65	0	610	0	0	2,610
2	0	0	65	0	820	0	0	2,610
3	0	0	65	0	870	0	0	2,610
4	0	0	65	0	0	320	0	2,610
5	0	0	65	0	90	0	0	2,610
6	0	0	65	0	500	0	0	2,610

TABLE 9-6 Demand Profile on Discounting Price in April to $39

Month	Demand Forecast
January	1,600
February	3,000
March	3,200
April	5,060
May	1,760
June	1,760

aggregate plan is shown in Table 9-5. With a discount in January the supply chain obtains:

Total cost over planning horizon = $421,915
Revenue over planning horizon = $643,400
Profit over planning horizon = $221,485

Now they consider the impact of offering the discount in April. If Green Thumb offers the discount in April, the demand forecast is as shown in Table 9-6. The optimal aggregate plan is shown in Table 9-7. With a discount in April we have:

Total cost over planning horizon = $438,857
Revenue over planning horizon = $650,140
Profit over planning horizon = $211,283

TABLE 9-7 Optimal Aggregate Plan for Demand in Table 9-6

Period, t	No. Hired, H_t	No. Laid Off, L_t	Workforce Size, W_t	Overtime, O_t	Inventory, I_t	Stockout, S_t	Subcontract, C_t	Total Production, P_t
0	0	0	80		1,000	0	0	
1	0	14	66	0	2,047	0	0	2,647
2	0	0	66	0	1,693	0	0	2,647
3	0	0	66	0	1,140	0	0	2,647
4	0	0	66	0	0	1,273	0	2,647
5	0	0	66	0	0	387	0	2,647
6	0	0	66	0	500	0	0	2,647

TABLE 9-8 Demand Profile from Discounting Price in January to $39 with Large Increase in Demand

Month	*Demand Forecast*
January	4,440
February	2,400
March	2,560
April	3,800
May	2,200
June	2,200

Observe that the demand fluctuation has increased relative to the profile in Table 9-1 because the discount was offered in the highest-demand month. The optimal aggregate plan for this demand pattern is shown in Table 9-7.

Observe that a price promotion in January results in a higher supply chain profit, whereas a promotion in April results in a lower supply chain profit, compared to not running a promotion. As a result, Red Tomato and Green Thumb decide to offer the discount in the off-peak month of January. Even though revenues are higher when the discount is offered in April, the increase in operating costs makes it a less profitable option. A promotion in January allows Red Tomato and Green Thumb to increase the profit they can share.

Note that this analysis is possible only because the retailer and manufacturer have collaborated during the planning phase. This conclusion supports our earlier statement that it is not appropriate for a supply chain to leave pricing decisions solely in the domain of retailers and aggregate planning solely in the domain of manufacturers, with each having their own forecasts. It is crucial that forecasts, pricing, and aggregate planning be coordinated in a supply chain.

The importance of collaboration is further supported by the fact that the optimal action is different if most of the demand increase comes from market growth or stealing market share rather than forward buying. Reconsider the situation in which discounting a unit from $40 to $39 results in the period demand increasing by 100 percent because of increased consumption or substitution. Further, 20 percent of each of the two following months' demand is moved forward. The supply chain team wants to determine whether it is preferable to offer the discount in January or April.

Offering the discount in January results in the demand forecast shown in Table 9-8. The optimal aggregate plan in this case is shown in Table 9-9.

TABLE 9-9 Optimal Aggregate Plan for Demand in Table 9-8

Period, t	*No. Hired, H_t*	*No. Laid Off, L_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80		1,000	0	0	
1	0	0	80	0	0	240	0	3,200
2	0	11	69	0	140	0	0	2,780
3	0	0	69	0	360	0	0	2,780
4	0	0	69	0	0	660	0	2,780
5	0	0	69	0	0	80	0	2,780
6	0	0	69	0	500	0	0	2,780

TABLE 9-10 Demand Profile on Discounting Price in April to $39 with Large Increase in Demand

Month	*Demand Forecast*
January	1,600
February	3,000
March	3,200
April	8,480
May	1,760
June	1,760

With a discount in January the team obtains:

Total cost over planning horizon = $456,750
Revenue over planning horizon = $699,560
Profit over planning horizon = $242,810

If the discount is offered in April, the demand forecast is as shown in Table 9-10. The optimal aggregate plan in this case is shown in Table 9-11.
With a discount in April the team obtains:

Total cost over planning horizon = $536,200
Revenue over planning horizon = $783,520
Profit over planning horizon = $247,320

When forward buying is a small part of the increase in demand from discounting, the supply chain is better off offering the discount in the peak-demand month of April.

Exactly as discussed earlier, the optimal aggregate plan and profitability can also be determined for the case in which the unit price is $31 and the discounted price is $30. The results of the various instances are summarized in Table 9-12.

From the results in Table 9-12, we can draw the following conclusions regarding the impact of promotions.

1. As seen in Table 9-12, average inventory increases if a promotion is run during the peak period and decreases if the promotion is run during the off-peak period.

2. Promoting during a peak-demand month may decrease overall profitability if a significant fraction of the demand increase results from a forward buy. In Table 9-12,

TABLE 9-11 Optimal Aggregate Plan for Demand in Table 9-10

Period, t	*No. Hired, H_t*	*No. Laid Off, L_t*	*Workforce Size, W_t*	*Overtime, O_t*	*Inventory, I_t*	*Stockout, S_t*	*Subcontract, C_t*	*Total Production, P_t*
0	0	0	80		1,000	0	0	
1	0	0	80	0	2,600	0	0	3,200
2	0	0	80	0	2,800	0	0	3,200
3	0	0	80	0	2,800	0	0	3,200
4	0	0	80	0	0	2,380	100	3,200
5	0	0	80	0	0	940	0	3,200
6	0	0	80	0	500	0	0	3,200

TABLE 9-12 Supply Chain Performance Under Different Scenarios

Regular Price	*Promotion Price*	*Promotion Period*	*Percent Increase in Demand*	*Percent Forward Buy*	*Profit*	*Average Inventory*
$40	$40	NA	NA	NA	$217,725	895
$40	$39	January	10%	20%	$221,485	523
$40	$39	April	10%	20%	$211,283	938
$40	$39	January	100%	20%	$242,810	208
$40	$39	April	100%	20%	$247,320	1,492
$31	$31	NA	NA	NA	$73,725	895
$31	$30	January	100%	20%	$84,410	208
$31	$30	April	100%	20%	$69,120	1,492

observe that running a promotion in April decreases profitability when forward buying is 20 percent and the demand increase from increased consumption and substitution is 10 percent.

3. As forward buying becomes a smaller fraction of the demand increase from a promotion, it is more profitable to promote during the peak period. From Table 9-12, for a sale price of $40, it is optimal to promote in the off-peak month of January, when forward buying is 20 percent and increased consumption is 10 percent. When forward buying is 20 percent and increased consumption is 100 percent, however, it is optimal to promote in the peak month of April.

4. As the product margin declines, promoting during the peak-demand period becomes less profitable. In Table 9-12, observe that for a unit price of $40 it is optimal to promote in the peak month of April when forward buying is 20 percent and increased consumption is 100 percent. In contrast, if the unit price is $31, it is optimal to promote in the off-peak month of January.

Other factors such as holding cost and the cost of changing capacity also affect the optimal timing of promotions. The various factors and their impacts are summarized in Table 9-13.

A key point from the Red Tomato supply chain examples we have considered in this chapter is that when a firm is faced with seasonal demand, it should use a combination of pricing (to manage demand) and production and inventory (to manage supply) to improve profitability. The precise use of each lever varies with the situation. This makes it crucial that enterprises in a supply chain coordinate both their forecasting and planning efforts. Only then are profits maximized.

TABLE 9-13 Summary of Impact on Promotion Timing

Factor	*Impact on Timing of Promotion*
High forward buying	Favors promotion during low-demand periods
High ability to steal market share	Favors promotion during peak-demand periods
High ability to increase overall market	Favors promotion during peak-demand periods
High margin	Favors promotion during peak-demand periods
Low margin	Favors promotion during low-demand periods
High holding costs	Favors promotion during low-demand periods
High costs of changing capacity	Favors promotion during low-demand periods

9.4 IMPLEMENTING SOLUTIONS TO PREDICTABLE VARIABILITY IN PRACTICE

1. ***Coordinate planning across enterprises in the supply chain.*** For a supply chain to manage predictable variability successfully, the entire chain must work toward the one goal of maximizing profitability. Every member of a supply chain may agree with this in principal. In reality, however, it is very difficult for an entire supply chain to agree on how to maximize profitability. Firms have even had trouble getting different functions within an enterprise to plan collaboratively. Incentives play a large role in this. Within a company, marketing often has incentives based on revenue, whereas operations has incentives based on cost. Within a supply chain, different enterprises are judged by their own profitability, not necessarily by the overall supply chain's profitability. From the examples considered earlier, it is clear that without a focus on getting companies to work together, a supply chain will return suboptimal profits. Collaboration should occur through the formation of joint teams. Incentives of the members of a supply chain must be aligned. High-level support within an organization is needed because this coordination often requires groups to act against their traditional operating procedures. Although this collaboration is difficult, the payoffs are significant.

2. ***Take predictable variability into account when making strategic decisions.*** Predictable variability has a tremendous impact on the operations of a company. A firm must always take this impact into account when making strategic decisions. However, predictable variability is not always taken into account when strategic plans are made, such as what type of products to offer, whether or not to build new facilities, and what sort of pricing structure a company should have. As indicated in this chapter, the level of profitability is greatly affected by predictable variability and, therefore, the success or failure of strategic decisions can be determined by it.

3. ***Preempt, do not just react to, predictable variability.*** Companies often have a tendency to focus on how they can react effectively to predictable variability. This responsibility often falls on operations, which tries to manage supply to deal best with predictable variability. As discussed in this chapter, the management of supply as well as demand provides the best response to predictable variability. Actions such as pricing and promotion that manage demand are preemptive and often in the domain of marketing. It is important for marketing and operations to coordinate their efforts and plan for predictable variability together well before the peak demand is observed. This coordination allows a firm to preempt predictable variability and come up with a response that maximizes profits.

9.5 SUMMARY OF LEARNING OBJECTIVES

1. Manage supply to improve synchronization in a supply chain in the face of predictable variability.

   To manage supply with the goal of maximizing profit, companies must manage their capacity through the use of workforce flexibility, subcontracting, dual facilities, and product flexibility. Companies must also manage supply through the use of inventory by emphasizing common parts and building and holding products with predictable demand ahead of time. These methodologies, combined with aggregate planning, enable a company to manage supply effectively.

2. Manage demand to improve synchronization in a supply chain in the face of predictable variability.

   To manage demand with the goal of maximizing profit, companies must use pricing and promotion decisions. The timing of promotions can have a tremendous impact on demand. Therefore, using pricing to shape demand can help synchronize the supply chain.
3. Use aggregate planning to maximize profitability when faced with predictable variability in a supply chain.

   To handle predictable variability in a profit-maximizing manner, supply chains must coordinate the management of both supply and demand. This requires coordinated planning across all stages of the supply chain to select aggregate plans that maximize supply chain profit.

Discussion Questions

1. What are some obstacles to creating a flexible workforce? What are the benefits?
2. Discuss why subcontractors can often offer products and services to a company more cheaply than if the company produced them themselves.
3. In what industries would you tend to see dual facility types (some facilities focusing on only one type of product and others able to produce a wide variety)? In what industries would this be relatively rare? Why?
4. Discuss how you would set up a collaboration mechanism for the enterprises in a supply chain.
5. What are some product lines that use common parts across many products? What are the advantages of doing this?
6. Discuss how a company can get marketing and operations to work together with the common goal of coordinating supply and demand to maximize profitability.
7. How can a firm use pricing to change demand patterns?
8. Why would a firm want to offer pricing promotions in its peak-demand periods?
9. Why would a firm want to offer pricing promotions during its low-demand periods?

Exercises

1. Lavare, located in the Chicago suburbs, is a major manufacturer of stainless steel sinks. Lavare is in the middle of the demand and supply planning exercise for the coming year. Anticipated monthly demand from distributors over the 12 months is shown in Table 9-14.

   Capacity at Lavare is governed by the number of machine operators it hires. The firm works 20 days a month, with a regular operating shift of eight hours per day. Any time beyond that is considered overtime. Regular-time pay is $15 per employee and overtime is $22 per hour. Overtime is limited to 20 hours per month per employee. The plant currently has 250 employees. Each sink requires two hours of labor input. It costs $3 to carry a sink in inventory for a month. Material cost per sink is $40. Sinks are sold to distributors at a price of $125 each. We assume that no stockouts are allowed.

TABLE 9-14 Anticipated Monthly Demand at Lavare

Month	*Demand*	*Month*	*Demand*
January	10,000	July	30,000
February	11,000	August	29,000
March	15,000	September	21,000
April	18,000	October	18,000
May	25,000	November	14,000
June	26,000	December	11,000

Market research has indicated that a promotion dropping prices by 1 percent in a given month will increase sales in that month by 20 percent and bring forward 10 percent demand from each of the following two months. Thus a 1 percent drop in price in March increases sales in March by 3,000 (= 0.2 × 15,000) and shifts 1,800 (= 0.1 × 18,000) units in demand from April and 2,500 (= 0.1 × 25,000) units from May forward to March.

(a) What is the optimal production plan for the year if we assume no promotions? What is the annual profit from this plan? What is the cost of this plan?

(b) Is it better to promote in April or July? How much increase in profit can be achieved as a result?

(c) If sinks are sold for $250 instead of $125, does the decision about the timing of the promotion change? Why?

2. Consider the data for Lavare in Exercise 1. We now assume that Lavare can change the size of the workforce by laying off or hiring employees. Hiring a new employee incurs a cost of $1,000, while laying off an employee incurs a layoff cost of $2,000.

(a) What is the optimal production plan for the year if we assume no promotions? What is the annual profit with this plan? What is the cost of this plan?

(b) Is it better to promote in April or July? How much increase in profit can be achieved as a result?

(c) If the holding cost for sinks increases from $3 per month to $5 per month, does the decision of the timing of promotion change? Why?

3. Return to the data for Lavare in Exercise 1. Now assume that a third party has offered to produce sinks at $74 per unit. How does this change affect the optimal production plan without a promotion? How does this change affect the optimal timing of a promotion? Explain the changes.

4. Jumbo manufactures bicycles for all ages. The demand forecast for the coming year is as shown in Table 9-15.

Capacity at Jumbo is limited by the number of employees it hires. Employees are paid $10 per hour for regular time and $15 per hour for overtime. Each bicycle requires two hours of work from one employee. The plant works 20 days a month and eight hours a day of regular time. Overtime is restricted to a maximum of 20 hours per employee per month. Jumbo currently has 250 employees and prefers not to change that number.

Each bicycle uses $35 of material. Carrying a bicycle in inventory from one month to the next costs $4. Jumbo starts with 4,000 bicycles in inventory and wants to end the year with 4,000 bicycles in inventory. Bicycles are currently sold to retailers for $80 each. The market is shared between Jumbo and its competitor, Shrimpy.

Jumbo is in the process of making its production planning and promotion decisions. Jumbo wants to consider only plans without any stockouts. One option is to drop the sale price by $3 (from $80 to $77) for one month in the year. The outcome of this action by Jumbo is influenced by the action taken by Shrimpy. If neither firm promotes, the forecast demand for Jumbo is as shown in Table 9-15. If Jumbo promotes in a given month but Shrimpy does

TABLE 9-15 Anticipated Monthly Demand at Jumbo

Month	*Demand*	*Month*	*Demand*
January	12,000	July	24,000
February	11,000	August	20,000
March	14,000	September	15,000
April	20,000	October	10,000
May	25,000	November	11,000
June	27,000	December	10,000

not, Jumbo sees consumption (this does not include forward buying) in that month increase by 40 percent and forward buying of 10 percent from each of the two following months. If Shrimpy promotes in a given month but Jumbo does not, Jumbo sees consumption in the month drop by 40 percent with no change in other months. If both promote in a given month, neither sees an increase in consumption but both see forward buying of 15 percent from each of the two following months. The debate within Jumbo is whether to promote, and if so, whether to do it in April or June. For the following questions, assume that Shrimpy and Jumbo have similar demand.

(a) What is the optimal production plan for Jumbo assuming no promotion by either Jumbo or Shrimpy? What are the annual profits for Jumbo?

(b) What are the profits for Jumbo if Shrimpy promotes in April but Jumbo does not promote throughout the year (they follow everyday low pricing)? What are the profits for Jumbo if it promotes in April but Shrimpy does not promote throughout the year? Comment on the benefit from promoting versus the loss from not promoting if the competitor does.

(c) What are the optimal production plan and profits if both promote in April? Both promote in June? Jumbo promotes in April but Shrimpy in June? Jumbo promotes in June but Shrimpy in April?

(d) What is the best decision for Jumbo if it can coordinate its decision with Shrimpy?

(e) What is the best decision for Jumbo if it wants to maximize its minimum profits no matter what Shrimpy does?

5. We now reconsider the issue of competitors and promotions in the context of a commodity product such as detergent, for which demand is relatively stable during the year. Q&H is a major detergent manufacturer with a demand forecast for the coming year as shown in Table 9-16 (in tons).

Capacity at Q&H is governed by the number of hours the line runs. The line requires a team of 100 employees. Employees are paid $10 per hour for regular time and $15 per hour for overtime. Each ton of detergent requires one hour of operation of the line. The plant works 20 days a month, two shifts a day, and eight hours a shift of regular time. Overtime is restricted to a maximum of 20 hours per employee per month.

Each ton of detergent uses $1,000 of material. Carrying a ton of detergent in inventory from one month to the next costs $100. Q&H starts with 150 tons in inventory and wants to end with the same level. During intermediate months Q&H wants at least 100 tons of inventory. Detergent is currently sold to retailers for $2,600 per ton. The detergent market is shared between Q&H and its competitor, Unilock.

Q&H is in the process of making its production planning and promotion decisions. Q&H wants to consider only plans without any stockouts. One option is to drop the sale price by $260 per ton (from $2,600 to $2,340) for one month in the year. The outcome of this action by Q&H is influenced by the action taken by Unilock. If neither firm promotes, the forecast demand for Q&H is as shown in Table 9-15. If Q&H promotes in a given month but

TABLE 9-16 Anticipated Monthly Demand at Q&H

Month	*Demand*	*Month*	*Demand*
January	280	July	291
February	301	August	277
March	277	September	304
April	302	October	291
May	285	November	302
June	278	December	297

Unilock does not, Q&H sees consumption (does not include forward buying) in that month increase by 50 percent and forward buying of 20 percent from each of the two following months. If Unilock promotes in a given month but Q&H does not, Q&H sees consumption in the month drop by 50 percent. If both promote in a given month, neither sees an increase in consumption but both see forward buying of 25 percent from each of the two following months. The debate within Q&H is whether to promote, and if so whether to do it in April or June. For the following questions, assume that demand for Unilock is like that of Q&H.

(a) What is the optimal production plan for Q&H assuming no promotion by either Q&H or Unilock? What are the annual profits for Q&H?

(b) What are the profits for Q&H if Unilock promotes in April but Q&H does not promote throughout the year (they use everyday low pricing)? What are the profits for Q&H if it promotes in April but Unilock does not promote throughout the year? Comment on the benefit from promoting versus the loss from not promoting if the competitor does.

(c) What are the optimal production plan and profits if both firms promote in April? Both promote in June? Q&H promotes in April but Unilock in June? Q&H promotes in June but Unilock in April?

(d) What is the best decision for Q&H if it can coordinate its decision with Unilock?

(e) What is the best decision for Q&H if it wants to maximize its minimum profits no matter what Unilock does?

6. Return to the data for Exercise 5. Assume that Q&H has a third party willing to manufacture detergent as needed for $2,300 per ton. Repeat the analysis for all questions (a) through (e).

Bibliography

Geary, Steve, Paul Childerhouse, and Denis Towill. "Uncertainty and the Seamless Supply Chain." *Supply Chain Management Review* (July–August 2002): 52–61.

Martin, André J. "Capacity Planning: The Antidote to Supply Chain Constraints." *Supply Chain Management Review* (November–December 2001): 62–67.

Sodhi, Mohan. "Getting the Most from Planning Technologies." *Supply Chain Management Review, Special Global Supplement* (Winter 2000): 19–23.

CASE STUDY

MINTENDO GAME GIRL

It is late June, and Sandra, head of operations at Mintendo, and Bill, head of sales of We "R" Toys, are about to get together to discuss production and marketing plans for the next six months. Mintendo is the manufacturer of the popular Game Girl hand-held electronic game that is sold exclusively through We "R" Toys retail stores. The second half of the year is critical to Game Girl's success, because a majority of its sales occur during the holiday shopping period.

Sandra is worried about the impact that the upcoming holiday surge in demand will have on her production line. Costs to subcontract assembly of the Game Girls are expected to increase, and she has been trying to keep costs down given that her bonus depends on the level of production costs.

Bill is worried about competing toy stores gaining share during the Christmas buying season. He has seen many companies lose their share by failing to keep prices in line with the performance of their products. He would like to maximize the Game Girl market share.

Both Sandra and Bill's teams produce a joint forecast of demand over the next six months, as shown in Table 9-17.

We "R" Toys sells Game Girls for $50 apiece. At the end of June, the company has an inventory of 50,000 Game Girls. Capacity of the production facility is set purely by the number of workers assembling the Game Girls. At the end of June, the company has a workforce of 300 employees, each of whom works eight hours of nonovertime at $15/hour for 20 days each month. Work rules require that no employee work more than 40 hours of overtime per month. The various costs are shown in Table 9-18.

Sandra, concerned about controlling costs during the periods of surging demand over the holidays, proposes to Bill that the price be lowered by $5 for the month of September. This would likely increase September's demand by 50 percent due to new customers being attracted to Game Girl. Additionally, 30 percent of each of the following two months of demand would occur in September as forward buys. She believes strongly that this leveling of demand will help the company.

Bill counters with the idea of offering the same promotion in November, during the heart of the buying season. In this case, the promotion increases November's demand by 50 percent due to new customers being attracted to Game Girl. Additionally, 30 percent of December's demand would occur in November as forward buying. Bill wants to increase revenue and sees no better way to do this than to offer a promotion during the peak season.

TABLE 9-17 Demand for Game Girls

Month	*Demand Forecast*
July	100,000
August	110,000
September	130,000
October	180,000
November	250,000
December	300,000

TABLE 9-18 Costs for Mintendo/We "R" Toys

Item	*Cost*
Material cost	$12/unit
Inventory holding cost	$4/unit/month
Marginal cost of a stockout	$10/unit/month
Hiring and training costs	$3,000/worker
Layoff cost	$5,000/worker
Labor hours required	0.25/unit
Regular-time cost	$15/hour
Overtime cost	$22.50/hour
Cost of subcontracting	$18/unit

QUESTIONS

1. Which option delivers the maximum profit for the supply chain: Sandra's plan, Bill's plan, or no promotion plan at all?
2. How does the answer change if a discount of $10 must be given to reach the same level of impact that the $5 discount received?
3. Suppose Sandra's fears about increasing outsourcing costs come to fruition and the cost rises to $22/unit for subcontracting. Does this change the decision when the discount is $5?

PART IV

PLANNING AND MANAGING INVENTORIES IN A SUPPLY CHAIN

CHAPTER 10
MANAGING ECONOMIES OF SCALE IN A SUPPLY CHAIN: CYCLE INVENTORY

CHAPTER 11
MANAGING UNCERTAINTY IN A SUPPLY CHAIN: SAFETY INVENTORY

CHAPTER 12
DETERMINING THE OPTIMAL LEVEL OF PRODUCT AVAILABILITY

The goal of the three chapters in Part IV is to describe the role that inventory plays in a supply chain and discuss actions that managers can take to decrease inventories without increasing cost or hurting the level of product availability.

Chapter 10 discusses factors that affect the level of cycle inventory within a supply chain. Several managerial actions that allow a supply chain manager to decrease the level of cycle inventory without increasing costs are described. Chapter 11 focuses on the buildup of safety inventory to counter supply or demand uncertainty. Factors influencing the level of safety inventory are discussed. Based on these factors, a variety of managerial levers are explained that can be used to reduce the amount of safety inventory required without hurting the level of product availability. Chapter 12 discusses factors that influence the appropriate level of product availability within a supply chain. Several managerial levers that can be used to increase overall profitability in the supply chain, such as quick response and postponement, are described.

CHAPTER 10
MANAGING ECONOMIES OF SCALE IN A SUPPLY CHAIN: CYCLE INVENTORY



Learning Objectives

After reading this chapter, you will be able to:

1. Balance the appropriate costs to choose the optimal amount of cycle inventory in a supply chain.
2. Understand the impact of quantity discounts on lot size and cycle inventory.
3. Devise appropriate discounting schemes for a supply chain.
4. Understand the impact of trade promotions on lot size and cycle inventory.
5. Identify managerial levers that reduce lot size and cycle inventory in a supply chain without increasing cost.

Cycle inventory exists because producing or purchasing in large lots allows a stage of the supply chain to exploit economies of scale and thus lower cost. The presence of fixed costs associated with ordering and transportation, quantity discounts in product pricing, and short-term discounts or trade promotions encourages different stages of a supply chain to exploit economies of scale and order in large lots. In this chapter, we study how each of these factors affects the lot size and cycle inventories within a supply chain. Our goal is to identify managerial levers that reduce cycle inventory in a supply chain without raising cost.

10.1 THE ROLE OF CYCLE INVENTORY IN A SUPPLY CHAIN

A *lot* or *batch size* is the quantity that a stage of a supply chain either produces or purchases at a time. Consider, for example, a computer store that sells an average of four printers a day. The store manager, however, orders 80 printers from the manufacturer each time he places an order. The lot or batch size in this case is 80 printers. Given daily sales of four printers, it takes an average of 20 days before the store sells the entire lot and purchases a replenishment lot. The computer store holds an inventory of printers because the manager purchases a lot size larger than the store's daily sales. *Cycle inventory* is the average inventory in a supply chain due to either production or purchases in lot sizes that are larger than those demanded by the customer.

In the rest of this chapter we use the following notation:

Q: Quantity in a lot or batch size
D: Demand per unit time

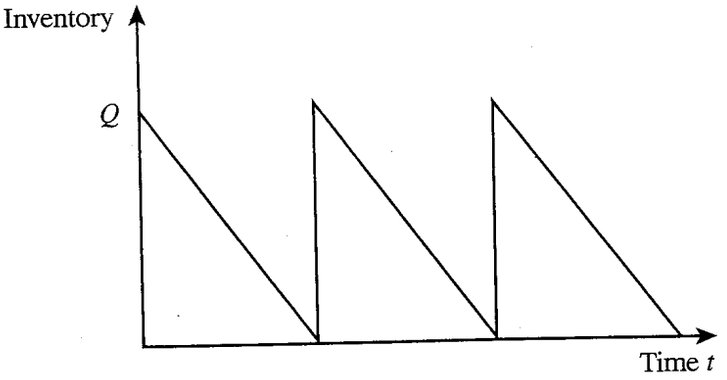


FIGURE 10-1
Inventory Profile of Jeans at Jean-Mart

In this chapter, we ignore the impact of demand variability and assume that demand is stable. In Chapter 11, we introduce demand variability and its impact on safety inventory.

Let us consider the cycle inventory of jeans at Jean-Mart, a department store. The demand for jeans is relatively stable at $D = 100$ pairs of jeans per day. The store manager at Jean-Mart currently purchases in lots of $Q = 1{,}000$ pairs. The *inventory profile* of jeans at Jean-Mart is a plot depicting the level of inventory over time, as shown in Figure 10-1.

Because purchases are in lots of $Q = 1{,}000$ units, whereas demand is only $D = 100$ units per day, it takes 10 days for an entire lot to be sold. Over these 10 days, the inventory of jeans at Jean-Mart declines steadily from 1,000 units (when the lot arrives) to 0 (when the last pair is sold). This sequence of a lot arriving and demand depleting inventory until another lot arrives repeats itself every 10 days, as shown in the inventory profile in Figure 10-1.

When demand is steady, cycle inventory and lot size are related as follows:

$$\text{Cycle inventory} = \frac{\text{lot size}}{2} = \frac{Q}{2} \tag{10.1}$$

For a lot size of 1,000 units, Jean-Mart carries a cycle inventory of $Q/2 = 500$ pairs of jeans. From Equation 10.1, we see that cycle inventory is proportional to the lot size. A supply chain in which stages produce or purchase in larger lots has more cycle inventory than a supply chain in which stages purchase in smaller lots. For example, if a competing department store with the same demand purchases in lot sizes of 200 pairs of jeans, it will carry a cycle inventory of only 100 pairs of jeans.

Lot sizes and cycle inventory also influence the flow time of material within the supply chain. Recall from Little's law (Equation 3.1) that

$$\text{Average flow time} = \frac{\text{average inventory}}{\text{average flow rate}}$$

For any supply chain, average flow rate equals demand. We thus have

$$\text{Average flow time resulting from cycle inventory} = \frac{\text{cycle inventory}}{\text{demand}} = \frac{Q}{2D}$$

For lot sizes of 1,000 pairs of jeans and daily demand of 100 pairs of jeans, we obtain

$$\text{Average flow time resulting from cycle inventory} = \frac{Q}{2D} = \frac{1{,}000}{200} = 5 \text{ days}$$

Cycle inventory at the Jean-Mart store thus adds five days to the average amount of time that jeans spend in the supply chain. The larger the cycle inventory, the longer is the lag time between when a product is produced and when it is sold. A lower level of cycle inventory is always desirable, because long time lags leave a firm vulnerable to demand changes in the marketplace. A lower cycle inventory also decreases a firm's working capital requirement. Toyota, for example, keeps a cycle inventory of only a few hours of production between the factory and most suppliers. As a result, Toyota is never left with unneeded parts and its working capital requirements are less than those of its competitors. Toyota also allocates very little space in the factory to inventory.

Before we suggest actions that a manager can take to reduce cycle inventory, it is important to understand why stages of a supply chain produce or purchase in large lots and how lot size reduction affects supply chain performance.

Cycle inventory is held to take advantage of economies of scale and reduce cost within a supply chain. To understand how the supply chain achieves these economies of scale, we first identify supply chain costs that are influenced by lot size.

The *average price paid per unit purchased* is a key cost in the lot sizing decision. A buyer may increase the lot size if this action results in a reduction in the price paid per unit purchased. For example, if the jeans manufacturer charges $20 per pair for orders under 500 pairs of jeans and $18 per pair for larger orders, the store manager at Jean-Mart gets the lower price by ordering in lots of at least 500 pairs of jeans. The price paid per unit is referred to as the *material cost* and is denoted by C. It is measured in $/unit. In many practical situations, material cost displays economies of scale and increasing lot size decreases material cost.

The *fixed ordering cost* includes all costs that do not vary with the size of the order but are incurred each time an order is placed. For example, there may be a fixed administrative cost to place an order, a trucking cost to transport the order, and a labor cost to receive the order. Jean-Mart, for example, incurs a cost of $400 for the truck regardless of the number of pairs of jeans shipped. If the truck can hold up to 2,000 pairs of jeans, a lot size of 100 pairs results in a transportation cost of $4/pair, whereas a lot size of 1,000 pairs results in a transportation cost of $0.40/pair. Given the fixed transportation cost per batch, the store manager can reduce transportation cost per unit by increasing the lot size. The fixed ordering cost per lot or batch is denoted by S (commonly thought of as a setup cost) and is measured in $/lot. The ordering cost also displays economies of scale, and increasing the lot size decreases the fixed ordering cost per unit purchased.

Holding cost is the cost of carrying one unit in inventory for a specified period of time, usually one year. It is a combination of the cost of capital, the cost of physically storing the inventory, and the cost that results from the product becoming obsolete. The holding cost is denoted by H and is measured in $/unit/year. It may also be obtained as a fraction, h, of the unit cost of the product. Given a unit cost of C, the holding cost H is given by

$$H = hC \tag{10.2}$$

The total holding cost increases with an increase in lot size and cycle inventory.

To summarize, the costs that must be considered in any lot sizing decision are

- Average price per unit purchased, $\$C$/unit
- Fixed ordering cost incurred per lot, $\$S$/lot
- Holding cost incurred per unit per year, $\$H$/unit/year $= hC$

Later in the chapter, we discuss how the various costs may be estimated in practice. However, for the purposes of this discussion, we assume they are already known.

The primary role of cycle inventory is to allow different stages in a supply chain to purchase product in lot sizes that minimize the sum of the material, ordering, and holding costs. If a manager considers the holding cost alone, he or she will reduce the lot size and cycle inventory. Economies of scale in purchasing and ordering, however, motivate a manager to increase the lot size and cycle inventory. A manager must make the trade-off that minimizes total cost when making lot sizing decisions.

Ideally, cycle inventory decisions should be made considering the total cost across the entire supply chain. In practice, however, it is generally the case that each stage makes its cycle inventory decisions independently. As we discuss later in the chapter, this practice increases the level of cycle inventory as well as the total cost in the supply chain.

KEY POINT Cycle inventory exists in a supply chain because different stages exploit economies of scale to lower total cost. The costs considered include material cost, fixed ordering cost, and holding cost.

Any stage of the supply chain exploits economies of scale in its replenishment decisions in the following three typical situations:

1. A fixed cost is incurred each time an order is placed or produced.
2. The supplier offers price discounts based on the quantity purchased per lot.
3. The supplier offers short-term price discounts or holds trade promotions.

In the next three sections, we review how purchasing managers can take advantage of these situations.

10.2 ECONOMIES OF SCALE TO EXPLOIT FIXED COSTS

To better understand the trade-offs discussed in this section, consider a situation that often arises in daily life—the purchase of groceries and other household products. These may be purchased at a nearby convenience store or at a Sam's Club (a large warehouse club selling consumer goods), which is generally located much farther away. The fixed cost of going shopping is the time it takes to go to either location. This fixed cost is much lower for the nearby convenience store. Prices, however, are higher at the local convenience store. Taking the fixed cost into account, we tend to tailor our lot size decision accordingly. When we need only a small quantity, we go to the nearby convenience store because the benefit of a low fixed cost outweighs the cost of the convenience store's higher prices. When we are buying a large quantity, however, we go to Sam's Club, where the lower prices over the larger quantity purchased more than make up for the increase in fixed cost.

In this section we focus on the situation in which a fixed cost associated with placing, receiving, and transporting an order is incurred each time the order is placed. A purchasing manager wants to minimize the total cost of satisfying demand and must therefore make the appropriate cost trade-offs when making the lot sizing decision. We start by considering the lot sizing decision for a single product.

LOT SIZING FOR A SINGLE PRODUCT (ECONOMIC ORDER QUANTITY)

As Best Buy sells its current inventory of HP computers, the purchasing manager places a replenishment order for a new lot of Q computers. Including the cost of transportation, Best Buy incurs a fixed cost of $\$S$ per order. The purchasing manager must

decide on the number of computers to order from HP in a lot. For this decision, we assume the following inputs:

D = Annual demand of the product
S = Fixed cost incurred per order
C = Cost per unit
h = Holding cost per year as a fraction of product cost

Assume that HP does not offer any discounts and each unit costs $\$C$ no matter how large an order is. The holding cost is thus given by $H = hC$ (using Equation 10.2).

The purchasing manager makes the lot sizing decision to minimize the total cost the store incurs. He must consider three costs when deciding on the lot size:

- Annual material cost
- Annual order cost
- Annual holding cost

Because purchase price is independent of lot size, we have

$$\text{Annual material cost} = CD$$

The number of orders must suffice to meet the annual demand D. Given a lot size of Q, we thus have

$$\text{Number of orders per year} = \frac{D}{Q} \tag{10.3}$$

Because an order cost of S is incurred for each order placed, we infer that

$$\text{Annual order cost} = \left(\frac{D}{Q}\right)S \tag{10.4}$$

Given a lot size of Q, we have an average inventory of $Q/2$. The annual holding cost is thus the cost of holding $Q/2$ units in inventory for one year and is given as

$$\text{Annual holding cost} = \left(\frac{Q}{2}\right)H = \left(\frac{Q}{2}\right)hC$$

The total annual cost, TC, is the sum of all three costs and is given as

$$\text{Total annual cost, } TC = CD + \left(\frac{D}{Q}\right)S + \left(\frac{Q}{2}\right)hC$$

Figure 10-2 shows the variation in different costs as the lot size is changed. Observe that the annual holding cost increases with an increase in lot size. In contrast, the annual order cost declines with an increase in lot size. The material cost is independent of lot size because we have assumed the price to be fixed. The total annual cost thus first declines and then increases with an increase in lot size.

From the perspective of the manager at Best Buy, the optimal lot size is one that minimizes the total cost to Best Buy. It is obtained by taking the first derivative of the total cost with respect to Q and setting it equal to 0 (see Appendix 10A). The optimal lot size is referred to as the *economic order quantity* (EOQ). It is denoted by Q^* and is given by the following equation:

$$\text{Optimal lot size, } Q^* = \sqrt{\frac{2DS}{hC}} \tag{10.5}$$

Note that for this formula, it is important to use the same time units for the holding cost h and the demand D. With each lot or batch of size Q^*, the cycle inventory in

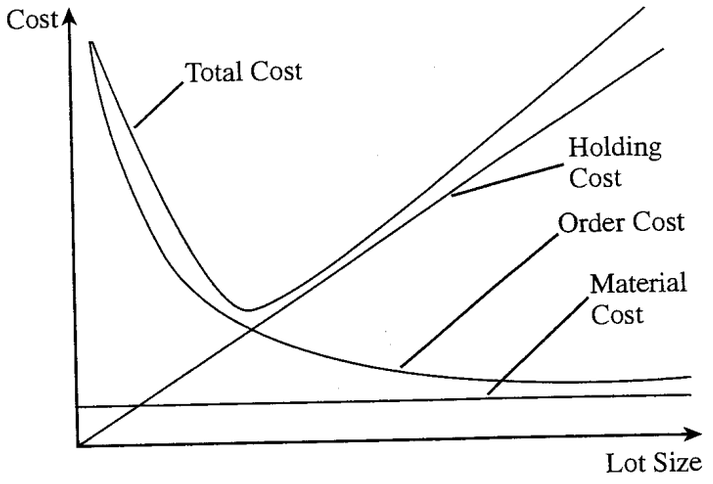


FIGURE 10-2 Effect of Lot Size on Costs at Best Buy

the system is given by $Q^*/2$. The flow time spent by each unit in the system is given by $Q^*/(2D)$. As the optimal lot size increases, so does the cycle inventory and the flow time. The optimal ordering frequency is given by n^*, where

$$n^* = \frac{D}{Q^*} = \sqrt{\frac{DhC}{2S}} \tag{10.6}$$

In Example 10-1, we illustrate the EOQ formula and the procedure to make lot sizing decisions.

Example 10-1: **Economic Order Quantity**

Demand for the Deskpro computer at Best Buy is 1,000 units per month. Best Buy incurs a fixed order placement, transportation, and receiving cost of $4,000 each time an order is placed. Each computer costs Best Buy $500 and the retailer has a holding cost of 20 percent. Evaluate the number of computers that the store manager should order in each replenishment lot.

Analysis: In this case, the store manager has the following inputs:

Annual demand, $D = 1{,}000 \times 12 = 12{,}000$ units
Order cost per lot, $S = \$4{,}000$
Unit cost per computer, $C = \$500$
Holding cost per year as a fraction of inventory value, $h = 0.2$

Using the EOQ formula (Equation 10.5), the optimal lot size is

$$\text{Optimal order size} = Q^* = \sqrt{\frac{2 \times 12{,}000 \times 4{,}000}{0.2 \times 500}} = 980$$

To minimize the total cost at Best Buy, the store manager orders a lot size of 980 computers for each replenishment order. The cycle inventory is the average resulting inventory and (using Equation 10.1) is given by

$$\text{Cycle inventory} = \frac{Q^*}{2} = \frac{980}{2} = 490$$

For a lot size of $Q^* = 980$, the store manager evaluates

$$\text{Number of orders per year} = \frac{D}{Q^*} = \frac{12{,}000}{980} = 12.24$$

$$\text{Annual ordering and holding cost} = \frac{D}{Q^*}S + \left(\frac{Q^*}{2}\right)hC = \$97{,}980$$

$$\text{Average flow time} = \frac{Q^*}{2D} = \frac{490}{12{,}000} = 0.041 \text{ year} = 0.49 \text{ month}$$

Each computer thus spends 0.49 month, on average, at Best Buy before it is sold because it was purchased in a batch of 980.

A few key insights can be gained from Example 10.1. Using a lot size of 1,100 (instead of 980) increases annual costs to \$98,636 (from \$97,980). Even though the order size is more than 10 percent larger than the optimal order size Q^*, total cost increases by only 0.6 percent. This issue can be relevant in practice. For example, Best Buy may find that the economic order quantity for computer diskettes is 6.5 cases. The manufacturer may be reluctant to ship half a case and may want to charge extra for this service. Our discussion illustrates that Best Buy is perhaps better off with lot sizes of six or seven cases, because this change has a very small impact on their inventory-related costs but can save on any fee that the manufacturer charges for shipping half a case.

KEY POINT Total ordering and holding costs are relatively stable around the economic order quantity. A firm is often better served by ordering a convenient lot size close to the economic order quantity rather than the precise EOQ.

If demand at Best Buy increases to 4,000 computers a month (demand has increased by a factor of 4), the EOQ formula shows that the optimal lot size doubles and the number of orders placed per year also doubles. In contrast, average flow time decreases by a factor of 2. In other words, as demand increases, cycle inventory measured in terms of days (or months) of demand should reduce if the lot sizing decision is made optimally. This observation can be stated as follows:

KEY POINT If demand increases by a factor of k, the optimal lot size increases by a factor of $\sqrt{k}$. The number of orders placed per year should also increase by a factor of $\sqrt{k}$. Flow time attributed to cycle inventory should decrease by a factor of $\sqrt{k}$.

Let us return to the situation where monthly demand for the Deskpro model is 1,000 computers. Now assume that the manager would like to reduce the lot size to $Q = 200$ units to reduce flow time. If this lot size is decreased without any other change, we have

$$\text{Annual inventory-related costs} = \left(\frac{D}{Q}\right)S + \left(\frac{Q}{2}\right)hC = \$250{,}000$$

This is significantly higher than the total cost of \$97,980 that Best Buy incurred when ordering in lots of 980 units as in Example 10-1. Thus, there are clear financial reasons why the store manager would be unwilling to reduce the lot size to 200. To make it feasible to reduce the lot size, the manager should work to reduce the fixed order cost. For example, if the fixed cost associated with each lot is reduced to \$1,000 (from the current value of \$4,000), the optimal lot size reduces to 490 (from the current value of 980). We illustrate the relationship between desired lot size and order cost in Example 10-2.

Example 10-2: **Relationship Between Desired Lot Size and Order Cost**

The store manager at Best Buy would like to reduce the optimal lot size from 980 to 200. For this lot size reduction to be optimal, the store manager wants to evaluate how much the order cost per lot should be reduced.

Analysis: In this case we have

Desired lot size, $Q^* = 200$
Annual demand, $D = 1{,}000 \times 12 = 12{,}000$ units
Unit cost per computer, $C = \$500$
Holding cost per year as a fraction of inventory value, $h = 0.2$

Using the EOQ formula (Equation 10.5), the desired order cost is

$$S = \frac{hC(Q^*)^2}{2D} = \frac{0.2 \times 500 \times 200^2}{2 \times 12{,}000} = 166.7$$

Thus, the store manager at Best Buy would have to reduce the order cost per lot from $4,000 to $166.7 for a lot size of 200 to be optimal.

The observation in Example 10-2 may be stated as follows:

KEY POINT To reduce the optimal lot size by a factor of k, the fixed order cost S must be reduced by a factor of k^2.

AGGREGATING MULTIPLE PRODUCTS IN A SINGLE ORDER

To reduce the lot size effectively, the store manager must understand the source of the fixed cost. As pointed out earlier, one major source of fixed costs is transportation. In several companies the array of products sold is divided into families or groups, with each group managed independently by a separate product manager. This results in separate orders and deliveries for each product family, thus increasing the overall cycle inventory. Aggregating orders and deliveries across product families is an effective mechanism to lower cycle inventories.

Consider the data from Example 10-1. Assume that the demand for each of the four models is 1,000 units per month. In this case, if each product manager orders separately, she would order a lot size of 980 units. Across the four models, the total cycle inventory would thus be 1960 units.

Now consider the case where the store manager at Best Buy realizes that all four shipments originate from the same source. She asks the product managers to coordinate their purchasing to ensure that all four products arrive on the same truck. In this case the optimal combined lot size across all four models turns out to be 1,960 units. This is equivalent to 490 units for each model. As a result of aggregating orders and spreading the fixed transportation cost across multiple products originating from the same supplier, it becomes financially optimal for the store manager at Best Buy to reduce the lot size for each individual product. This action significantly reduces the cycle inventory as well as cost to Best Buy.

Another way to achieve this result is to have a single delivery coming from multiple suppliers (allowing fixed transportation cost to be spread across multiple suppliers) or have a single truck delivering to multiple retailers (allowing fixed transportation cost to be spread across multiple retailers). This observation can be stated as follows:

KEY POINT Aggregating replenishment across products, retailers, or suppliers in a single order allows for a reduction in lot size for individual products because fixed ordering and transportation costs are now spread across multiple products, retailers, or suppliers.

Wal-Mart and other retailers have facilitated aggregation across multiple supply and delivery points without storing intermediate inventories through the use of cross-docking. Each supplier sends full truckloads to the distribution center (DC), containing an aggregate delivery destined for multiple retail stores. At the DC, each inbound truck is unloaded, product is cross-docked, and outbound trucks are loaded. Each outbound truck now contains product aggregated from several suppliers for one retail store.

When considering fixed costs, one cannot ignore the receiving or loading costs. As more products are included in a single order, the product variety on a truck increases. The receiving warehouse now has to update inventory records for more items per truck. In addition, the task of putting inventory into storage now becomes more expensive because each distinct item must be stocked in a separate location. Thus, when attempting to reduce lot sizes, it is important to focus on reducing these costs. *Advanced shipping notices* (ASN) are files sent electronically by the supplier to the customer that contain precise records of the contents of the truck. These electronic notices facilitate updating of inventory records as well as the decision regarding storage locations, helping to reduce the fixed cost of receiving. RFID technology is also likely to help reduce the variety related fixed costs associated with receiving. The reduced fixed cost of receiving makes it optimal to reduce the lot size ordered, thus reducing cycle inventory. We next analyze how optimal lot sizes may be determined in such a setting.

LOT SIZING WITH MULTIPLE PRODUCTS OR CUSTOMERS

In general, the ordering, transportation, and receiving cost of an order grows with the variety of products or pickup points. For example, it is cheaper for Wal-Mart to receive a truck containing a single product than it is to receive a truck containing many different products, because the inventory update and restocking effort is much less for a single product. A portion of the fixed cost of an order can be related to transportation (this depends only on the load and is independent of product variety on the truck). A portion of the fixed cost is related to loading and receiving (this cost increases with variety on the truck). We now discuss how optimal lot sizes may be determined in such a setting.

Our objective is to arrive at lot sizes and an ordering policy that minimize the total cost. We assume the following inputs:

D_i: Annual demand for product i
S: Order cost incurred each time an order is placed, independent of the variety of products included in the order
s_i: Additional order cost incurred if product i is included in the order

In the case of Best Buy and multiple models, the store manager may consider three approaches to the lot sizing decision:

1. Each product manager orders his model independently.
2. The product managers jointly order every product in each lot.
3. Product managers order jointly but not every order contains every product; that is, each lot contains a selected subset of the products.

The first approach does not use any aggregation and results in high cost. The second approach aggregates all products in each order. The weakness of the second approach is that low-demand products are aggregated with high-demand products in every order. This complete aggregation results in high costs if the product-specific order cost for the low-demand products is large. In such a situation it may be better to order the low-demand products less frequently than the high-demand products. This practice results in a reduction of the product-specific order cost associated with the low-demand product. As a result, the third approach is likely to yield the lowest cost. However, it is more complex to coordinate.

We consider the example of Best Buy purchasing computers and illustrate the effect of each of the three approaches on supply chain costs.

Lots are Ordered and Delivered Independently for Each Product

In this approach, each product is ordered independently of the others. This scenario is equivalent to applying the EOQ formula to each product when evaluating lot sizes, as illustrated in Example 10-3.

Example 10-3: **Multiple Products with Lots Ordered and Delivered Independently**

Best Buy sells three models of computers, the Litepro, the Medpro, and the Heavypro. Annual demands for the three products are D_L = 12,000 for the Litepro, D_M = 1,200 units for the Medpro, and D_H = 120 units for the Heavypro. Each model costs Best Buy $500. A fixed transportation cost of $4,000 is incurred each time an order is delivered. For each model ordered and delivered on the same truck, an additional fixed cost of $1,000 is incurred for receiving and storage. Best Buy incurs a holding cost of 20 percent. Evaluate the lot sizes that the Best Buy manager should order if lots for each product are ordered and delivered independently. Also evaluate the annual cost of such a policy.

Analysis: In this example we have the following information:

Demand, D_L = 12,000/year, D_M = 1,200/year, D_H = 120/year
Common order cost, S = $4,000
Product-specific order cost, s_L = $1,000, s_M = $1,000, s_H = $1,000
Holding cost, h = 0.2
Unit cost, C_L = $500, C_M = $500, C_H = $500

Because each model is ordered and delivered independently, a separate truck delivers each model. Thus, a fixed ordering cost of $5,000 ($4,000 + $1,000) is incurred for each product delivery. The optimal ordering policies and resulting costs for the three products (when the three products are ordered independently) are evaluated using the EOQ formula (Equation 10.5) and are shown in Table 10-1.

The Litepro model is ordered 11 times a year, the Medpro model is ordered 3.5 times a year, and the Heavypro model is ordered 1.1 times each year. The annual ordering and holding cost Best Buy incurs if the three models are ordered independently turns out to be $155,140.

Independent ordering ignores the opportunity to aggregate orders. Thus, the product managers at Best Buy could potentially lower costs by combining orders on a single truck. We next consider the scenario in which all three products are ordered and delivered each time an order is placed.

Lots are Ordered and Delivered Jointly for All Three Models

Here all three models are included each time an order is placed. In this case the combined fixed order cost per order is given by

$$S^* = S + s_L + s_M + s_H$$

TABLE 10-1 Lot Sizes and Costs for Independent Ordering

	Litepro	*Medpro*	*Heavypro*
Demand per year	12,000	1,200	120
Fixed cost/order	$5,000	$5,000	$5,000
Optimal order size	1,095	346	110
Cycle inventory	548	173	55
Annual holding cost	$54,772	$17,321	$5,477
Order frequency	11.0/year	3.5/year	1.1/year
Annual ordering cost	$54,772	$17,321	$5,477
Average flow time	2.4 weeks	7.5 weeks	23.7 weeks
Annual cost	$109,544	$34,642	$10,954

Note: While these figures are correct, some may differ from calculations due to rounding.

The next step is to identify the optimal ordering frequency. Let n be the number of orders placed per year. We then have

$$\text{Annual order cost} = S^*n$$

$$\text{Annual holding cost} = \frac{D_L h C_L}{2n} + \frac{D_M h C_M}{2n} + \frac{D_H h C_H}{2n}$$

The total annual cost is thus given by

$$\text{Total annual cost} = \frac{D_L h C_L}{2n} + \frac{D_M h C_M}{2n} + \frac{D_H h C_H}{2n} + S^*n$$

The optimal order frequency minimizes the total annual cost and is obtained by taking the first derivative of the total cost with respect to n and setting it equal to 0. This results in the optimal order frequency n^*, where

$$n^* = \sqrt{\frac{D_L h C_L + D_M h C_M + D_H h C_H}{2S^*}} \tag{10.7}$$

Equation 10.7 can be generalized to the case where there are k items consolidated on a single order as follows:

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i h C_i}{2S^*}} \tag{10.8}$$

Truck capacity can also be included in this setting by comparing the total load for the optimal n^* with truck capacity. If the optimal load exceeds truck capacity, n^* is increased until the load equals truck capacity. By applying Equation 10.8 for different values of k, we can also find the optimal number of items or suppliers to be aggregated in a single delivery.

In Example 10-4 we consider the case in which the product managers at Best Buy order all three models each time they place an order.

Example 10-4: **Products Ordered and Delivered Jointly**

Consider the Best Buy data in Example 10-3. The three product managers have decided to aggregate and order all three models each time they place an order. Evaluate the optimal lot size for each model.

Analysis: Because all three models are included in each order, the combined order cost is

$$S^* = S + s_A + s_B + s_C = \$7{,}000 \text{ per order}$$

The optimal order frequency is obtained using Equation 10.7 and is given by

$$n^* = \sqrt{\frac{12{,}000 \times 100 + 1{,}200 \times 100 + 120 \times 100}{2 \times 7{,}000}} = 9.75$$

Thus, if each model is to be included in every order and delivery, the product managers at Best Buy should place 9.75 orders each year. In this case the ordering policies and costs are as shown in Table 10-2.

Because 9.75 orders are placed each year and each order costs a total of \$7,000, we have

$$\text{Annual order cost} = 9.75 \times 7{,}000 = \$68{,}250$$

The annual ordering and holding cost, across the three sizes, of the aforementioned policy is given by

$$\text{Annual ordering and holding cost} = \$61{,}512 + \$6{,}151 + \$615 + \$68{,}250 = \$136{,}528$$

Observe that the product managers at Best Buy lower the annual cost from \$155,140 to \$136,528 by ordering all products jointly. This represents a decrease of about 13 percent.

TABLE 10-2 Lot Sizes and Costs for Joint Ordering at Best Buy

	Litepro	*Medpro*	*Heavypro*
Demand per year (D)	12,000	1,200	120
Order frequency (n^*)	9.75/year	9.75/year	9.75/year
Optimal order size (D/n^*)	1,230	123	12.3
Cycle inventory	615	61.5	6.15
Annual holding cost	$61,512	$6,151	$615
Average flow time	2.67 weeks	2.67 weeks	2.67 weeks

In Example 10.5, we consider optimal aggregation of orders or deliveries in the presence of capacity constraints.

Example 10-5: **Aggregation with Capacity Constraint**

W.W. Grainger sources from hundreds of suppliers and is considering the aggregation of inbound shipments to lower costs. Truckload shipping costs $500 per truck along with $100 per pickup. Average annual demand from each supplier is 10,000 units. Each unit costs $50 and Grainger incurs a holding cost of 20 percent. What is the optimal order frequency and order size if Grainger decides to aggregate four suppliers per truck? What is the optimal order size and frequency if each truck has a capacity of 2,500 units?

Analysis: In this case, W.W. Grainger has the following inputs:

Demand per product, $D_i = 10{,}000$
Holding cost, $h = 0.2$
Unit cost per product, $C_i = \$50$
Common order cost, $S = \$500$
Supplier-specific order cost, $s_i = \$100$

The combined order cost from four suppliers is given by

$$S^* = S + s_1 + s_2 + s_3 + s_4 = \$900 \text{ per order}$$

From Equation 10.8, the optimal order frequency is

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i h C_i}{2S^*}} = \sqrt{\frac{4 \times 10{,}000 \times 0.2 \times 50}{2 \times 900}} = 14.91$$

It is thus optimal for Grainger to order 14.91 times per year. The annual ordering cost per supplier is

$$\text{Annual order cost} = 14.91 \times \frac{900}{4} = \$3{,}354$$

The quantity ordered from each supplier is $Q = 10{,}000/14.91 = 671$ units per order. The annual holding cost per supplier is

$$\text{Annual holding cost per supplier} = \frac{hC_iQ}{2} = 0.2 \times 50 \times \frac{671}{2} = \$3{,}355$$

This policy, however, requires a total capacity per truck of $4 \times 671 = 2{,}684$ units. Given a truck capacity of 2,500 units, the order frequency must be increased to ensure that the order quantity from each supplier is $2{,}500/4 = 625$. Thus, W.W. Grainger should increase the order frequency to $10{,}000/625 = 16$. This action will increase the annual order cost per supplier to $3,600 and decrease the annual holding cost per supplier to $3,125.

The main advantage of ordering all products jointly is that it is easy to administer and implement. The disadvantage is that it is not selective enough in combining the particular models that should be ordered together. If product-specific order costs are high, joint ordering of all products is very expensive. In our example, product-specific order costs of $1,000 are incurred for all three models with each order. Total costs can

be reduced if low-demand models are ordered less frequently. Next we consider a policy under which the product managers do not necessarily order all models each time an order is placed but still coordinate their orders.

Lots are Ordered and Delivered Jointly for a Selected Subset of the Products

We now discuss a procedure that is more selective in combining products to be ordered jointly. The procedure we discuss here does not necessarily provide the optimal solution. It does, however, yield an ordering policy whose cost is close to optimal.

The first step is to identify the product that is to be ordered most frequently. For each successive product we then identify orders in which it is included. In general, it is not optimal for a particular product to be included at regular intervals (i.e., it should be included in every second or third order). In our procedure, however, we make the assumption that each product is included in the order at regular intervals. Once we have identified the most frequently ordered model, for each successive product i we identify the frequency m_i, where model i is ordered every m_i deliveries.

We first describe the procedure in general and then apply it to the specific example. Assume that the products are indexed by i, where i varies from 1 to n (assuming a total of n products). Each product i has an annual demand D_i, a unit cost C_i, and a product-specific order cost s_i. The common order cost is S.

Step 1: As a first step, identify the most frequently ordered product assuming each product is ordered independently. In this case a fixed cost of $S + s_i$ is allocated to each product. For each product i (using Equation 10.6), evaluate the ordering frequency:

$$\overline{n_i} = \sqrt{\frac{hC_iD_i}{2(S + s_i)}}$$

This is the frequency at which product i would be ordered if it were the only product being ordered (in which case a fixed cost of $S + s_i$ would be incurred per order). Let $\overline{n}$ be the frequency of the most frequently ordered product; that is, $\overline{n}$ is the maximum among all $\overline{n_i}$. The most frequently ordered product is included each time an order is placed.

Step 2: Identify the frequency with which other products are included with the most frequently ordered product; that is, calculate the order frequency for each product as a multiple of the order frequency of the most frequently ordered product. The most frequently ordered product is ordered each time and all of the fixed cost S is thus allocated to it. For each of the other products i, we thus have only the product-specific fixed cost component s_i. The order frequency for all other products is thus calculated using only the product-specific fixed cost in Equation 10.6. For each product i (other than the most frequently ordered product), evaluate the ordering frequency:

$$\overline{\overline{n_i}} = \sqrt{\frac{hC_iD_i}{2s_i}}$$

Evaluate the frequency of product i relative to the most frequently ordered product to be $\overline{m_i}$, where

$$\overline{m_i} = \overline{n}/\overline{\overline{n_i}}$$

In general, $\overline{m_i}$ will contain a fractional component. For each product i (other than the most frequently ordered product), define the frequency m_i with which it is included with the most frequently ordered product, where

$$m_i = \lceil \overline{m_i} \rceil$$

In this case $\lceil\ \rceil$ is the operation that rounds a fraction up to the closest integer.

Step 3: Having decided the ordering frequency of each product, recalculate the ordering frequency of the most frequently ordered product to be n, where

$$n = \sqrt{\frac{\sum hC_i m_i D_i}{2\left(S + \sum s_i/m_i\right)}} \tag{10.9}$$

The initial calculation of $\overline{n_i}$ is not valid because the fixed cost allocated to each order was $S + s_i$, where i is the most frequently ordered product. Equation 10.9 reflects the fact that product i is ordered with frequency m_i.

Step 4: For each product, evaluate an order frequency of $n_i = n/m_i$ and the total cost of such an ordering policy.

The procedure described above results in *tailored aggregation*, with higher-demand products ordered more frequently and lower-demand products ordered less frequently. Example 10-6 considers tailored aggregation for the Best Buy ordering decision in Example 10-3.

Example 10-6: **Lot Sizes Ordered and Delivered Jointly for a Selected Subset That Varies by Order**

Consider the Best Buy data in Example 10-3. Product managers have decided to order jointly, but to be selective about which models they include in each order. Evaluate the ordering policy and costs using the procedure discussed previously.

Analysis: Recall that $S = \$4{,}000$, $s_L = \$1{,}000$, $s_M = \$1{,}000$, $s_H = \$1{,}000$. Applying Step 1, we obtain

$$\overline{n_L} = \sqrt{\frac{hC_L D_L}{2(S + s_L)}} = 11.0, \overline{n_M} = 3.5, \text{ and } \overline{n_H} = 1.1$$

Clearly Litepro is the most frequently ordered model. Thus we set $\bar{n} = 11.0$.

We now apply Step 2 to evaluate the frequency with which Medpro and Heavypro are included with Litepro in the order. We first obtain

$$\overline{\overline{n_M}} = \sqrt{\frac{hC_M D_M}{2s_M}} = 7.7 \quad \text{and} \quad \overline{\overline{n_H}} = 2.4$$

Next we evaluate

$$\overline{m_M} = \frac{\bar{n}}{\overline{\overline{n_M}}} = \frac{11.0}{7.7} = 1.4 \quad \text{and} \quad \overline{m_H} = 4.5$$

Next we evaluate

$$m_M = \lceil 1.4 \rceil = 2 \quad \text{and} \quad m_H = \lceil 4.5 \rceil = 5$$

Thus, Medpro is included in every other order and Heavypro is included in every fifth order (Litepro, the most frequently ordered model, is included in every order.) Now that we have decided on the ordering frequency of each model, apply Step 3 (Equation 10.9) to recalculate the ordering frequency of the most frequently ordered model as

$$n = 11.47$$

Thus the Litepro is ordered 11.47 times per year. Next, we apply Step 4 to obtain an ordering frequency for each product:

$$n_L = 11.47/\text{year}, n_M = 5.74/\text{year}, \text{and } n_H = 11.47/5 = 2.29/\text{year}$$

The ordering policies and resulting costs for the three products are shown in Table 10-3.

The annual holding cost of this policy is $65,383.5. The annual order cost is given by

$$ns + n_L s_L + n_M s_M + n_H s_H = \$65{,}383.5$$

TABLE 10-3 Lot Sizes and Costs for Ordering Policy Using Heuristic

	Litepro	*Medpro*	*Heavypro*
Demand per year (D)	12,000	1,200	120
Order frequency (n)	11.47/year	5.74/year	2.29/year
Order size (D/n)	1,046	209	52
Cycle inventory	523	104.5	26
Annual holding cost	$52,307	$10,461	$2,615
Average flow time	2.27 weeks	4.53 weeks	11.35 weeks

The total annual cost is thus equal to $130,767. Tailored aggregation results in a cost reduction of $5,761 (about 4 percent) compared to the joint ordering of all models. The cost reduction results because each model-specific fixed cost of $1,000 is not incurred with every order.

From the Best Buy examples, it follows that aggregation can provide significant cost savings and reduction in cycle inventory in the supply chain. Simple aggregation of all products into each order is quite effective if product-specific order costs are low. Tailored aggregation, however, provides an even lower cost because it exploits the difference between low- and high-volume products and adjusts their ordering frequency accordingly. In general, complete aggregation should be used when product-specific order costs are small and tailored aggregation should be used when product-specific order costs are large.

We have looked at fixed ordering costs and their impact on the inventory and costs in a supply chain. What is most significant from this discussion is that the key to reducing lot sizes is to focus on the reduction of fixed costs associated with each lot ordered. These costs and the processes causing them must be well understood so appropriate action may be taken.

KEY POINT A key to reducing cycle inventory is the reduction of lot size. A key to reducing lot size without increasing costs is to reduce the fixed cost associated with each lot. This may be achieved by reducing the fixed cost itself or by aggregating lots across multiple products, customers, or suppliers. When aggregating across multiple products, customers, or suppliers, tailored aggregation is best, especially if product-specific order costs are large.

Next we consider lot sizes when material cost displays economies of scale.

10.3 ECONOMIES OF SCALE TO EXPLOIT QUANTITY DISCOUNTS

There are many instances where the pricing schedule displays economies of scale, with prices decreasing as lot size increases. This form of pricing is very common in business-to-business transactions. A discount is *lot size based* if the pricing schedule offers discounts based on the quantity ordered in a single lot. A discount is *volume based* if the discount is based on the total quantity purchased over a given period, regardless of the number of lots purchased over that period. Two commonly used lot size–based discount schemes are

- All unit quantity discounts
- Marginal unit quantity discount or multiblock tariffs

In this section we investigate the impact of such quantity discounts on the supply chain. We must answer the following two basic questions in this context:

1. Given a pricing schedule with quantity discounts, what is the optimal purchasing decision for a buyer seeking to maximize profits? How does this decision affect the supply chain in terms of lot sizes, cycle inventories, and flow times?
2. Under what conditions should a supplier offer quantity discounts? What are appropriate pricing schedules that a supplier, seeking to maximize profits, should offer?

We start by studying the optimal response of a retailer (the buyer) when faced with either of the two lot size–based discount schemes offered by a manufacturer (the supplier). The retailer's objective is to select lot sizes to minimize the total annual material, order, and holding cost. Next we evaluate the optimal lot size in the case of all unit quantity discounts.

ALL UNIT QUANTITY DISCOUNTS

In all unit quantity discounts, the pricing schedule contains specified break points q_0, $q_1, \ldots, q_r$, where $q_0 = 0$. If an order placed is at least as large as q_i but smaller than q_{i+1}, each unit is obtained at a cost of C_i. In general, the unit cost decreases as the quantity ordered increases; that is, $C_0 \geq C_1 \geq \cdots \geq C_r$. The retailer's objective is to decide on lot sizes to maximize profits or, equivalently, to minimize the sum of material, order, and holding costs.

For all unit discounts, the average unit cost varies with the quantity ordered, as shown in Figure 10-3. Observe that under this discount scheme, ordering $q_1 + 1$ units may be less expensive (in terms of material cost) than ordering $q_1 - 1$ units.

The solution procedure evaluates the optimal lot size for each price C_i (this forces a lot size between q_i and q_{i+1}) and then settles on the lot size that minimizes the overall cost. For each value of $i, 0 \leq i \leq r$, evaluate the following:

$$Q_i = \sqrt{\frac{2DS}{hC_i}} \tag{10.10}$$

There are three possible cases for Q_i:

1. $q_i \leq Q_i < q_{i+1}$
2. $Q_i < q_i$
3. $Q_i \geq q_{i+1}$

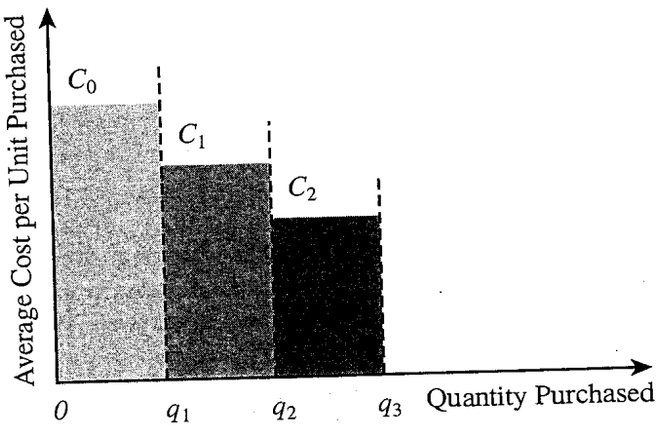


FIGURE 10-3 Average Unit Cost with All Unit Quantity Discounts

Case 3 can be ignored for Q_i because it is considered for Q_{i+1}. Thus, we need to consider only the first two cases.

Case 1

If $q_i \leq Q_i < q_{i+1}$, then a lot size of Q_i units will result in the discounted price of C_i per unit. In this case the total annual cost of ordering Q_i (this includes order cost, holding cost, and material cost) is given as follows:

$$\text{Total annual cost, } TC_i = \left(\frac{D}{Q_i}\right)S + \frac{Q_i}{2}hC_i + DC_i \tag{10.11}$$

Case 2

If $Q_i < q_i$, then a lot size of Q_i does not result in a discount. Raising the lot size to q_i units results in the discounted price of C_i per unit. Ordering more than q_i units raises the order and holding costs without reducing the material cost. In this case it is thus optimal to order a lot size of q_i units to get a unit price C_i. The annual cost is given by

$$\text{Total annual cost, } TC_i = \left(\frac{D}{q_i}\right)S + \frac{q_i}{2}hC_i + DC_i \tag{10.12}$$

For each price C_i we apply the appropriate case and evaluate the total cost TC_i and the corresponding lot size. The solution is to order the lot size that minimizes the total annual cost across all prices in the schedule. Goyal (1995) has shown that the above procedure can be further shortened by identifying a cutoff price C^* above which the optimal solution cannot occur. Recall that C_r is the lowest unit cost above the threshold quantity q_r. The cutoff is obtained as follows:

$$C^* = \frac{1}{D}\left(DC_r + \frac{DS}{q_r} + \frac{h}{2}q_rC_r - \sqrt{2hDSC_r}\right)$$

In Example 10-7, we evaluate the optimal lot size given an all unit quantity discount.

Example 10-7: **All Unit Quantity Discount**

Drugs Online (DO) is an online retailer of prescription drugs and health supplements. Vitamins represent a significant percentage of its sales. Demand for vitamins is 10,000 bottles per month. DO incurs a fixed order placement, transportation, and receiving cost of $100 each time an order for vitamins is placed with the manufacturer. DO incurs a holding cost of 20 percent. The price charged by the manufacturer follows the all unit discount pricing schedule is shown following. Evaluate the number of bottles that the DO manager should order in each lot.

Order Quantity	*Unit Price*
0–5,000	$3.00
5,000–10,000	$2.96
10,000 or more	$2.92

Analysis: In this case, the manager has the following inputs:

$q_0 = 0, q_1 = 5{,}000, q_2 = 10{,}000$
$C_0 = \$3.00, C_1 = \$2.96, C_2 = \$2.92$
$D = 120{,}000$/year, $S = \$100$/lot, $h = 0.2$

For $i = 0$, evaluate Q_0 (using Equation 10.10) as

$$Q_0 = \sqrt{\frac{2DS}{hC_0}} = 6{,}324$$

Given that $6,324 > q_1 = 5,000$, we move on to the case $i = 1$. For $i = 1$, using Equation 10.10 we obtain $Q_1 = 6,367$ units. Because $5,000 < 6,367 < 10,000$, we set the lot size at $Q_1 = 6,367$ units and evaluate the cost of ordering 6,637 units using Equation 10.11 as follows:

$$TC_1 = \left(\frac{D}{Q_1}\right)S + \left(\frac{Q_1}{2}\right)hC_1 + DC_1 = \$358,969$$

For $i = 2$, using Equation 10.10, we obtain $Q_2 = 6,410$ units. Because $6,410 < q_2 = 10,000$, we set the lot size at $q_2 = 10,000$ units and evaluate the cost of ordering 10,000 units using Equation 10.12 as

$$TC_2 = \left(\frac{D}{q_2}\right)S + \left(\frac{q_2}{2}\right)hC_2 + DC_2 = \$354,520$$

Observe that the lowest total cost is for $i = 2$. Thus, it is optimal for DO to order $q_2 = 10,000$ bottles per lot and obtain the discount price of $2.92 per bottle.

If the manufacturer in Example 10-7 sold all bottles for $3, it would be optimal for DO to order in lots of 6,324 bottles. The quantity discount is an incentive for DO to order in larger lots of 10,000 bottles, raising both the cycle inventory and the flow time. The impact of the discount is further magnified if DO works hard to reduce its fixed ordering cost to $S = \$4$. The optimal lot size in the absence of a discount is 1,265 bottles. In the presence of the all unit quantity discount, the optimal lot size is still 10,000 bottles. In this case, the presence of quantity discounts leads to an eightfold increase in average inventory as well as flow time at DO.

Pricing schedules with all unit quantity discounts encourage retailers to order in larger lots to take advantage of price discounts. This adds to the average inventory and flow time in a supply chain. This increase in inventory raises a question about the value that all unit quantity discounts offer in a supply chain. Before we consider this question, we discuss marginal unit quantity discounts.

MARGINAL UNIT QUANTITY DISCOUNT

Marginal unit quantity discounts are also referred to as *multiblock tariffs*. In this case, the pricing schedule contains specified break points $q_0, q_1, \ldots, q_r$. It is not the *average cost* of a unit but the *marginal cost* of a unit that decreases at a breakpoint (in contrast to the all unit discount scheme). If an order of size q is placed, the first $q_1 - q_0$ units are priced at C_0, the next $q_2 - q_1$ are priced at C_1, and so on. The marginal cost per unit varies with the quantity purchased, as shown in Figure 10-4.

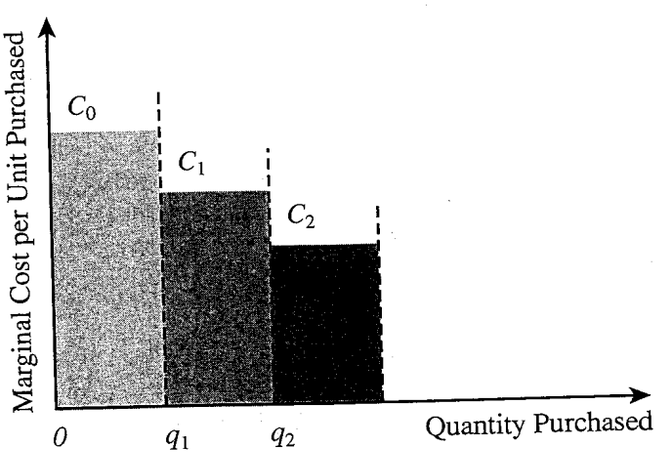


FIGURE 10-4 Marginal Unit Cost with Marginal Unit Quantity Discount

Faced with such a pricing schedule, the retailer's objective is to decide on a lot size that maximizes profits or, equivalently, minimizes material, order, and holding costs.

The solution procedure evaluates the optimal lot size for each marginal price C_i (this forces a lot size between q_i and q_{i+1}) and then settles on the lot size that minimizes the overall cost.

For each value of $i, 0 \le i \le r$, let V_i be the cost of ordering q_i units. Define $V_0 = 0$ and V_i for $0 \le i \le r$ as follows:

$$V_i = C_0(q_1 - q_0) + C_1(q_2 - q_1) + \cdots + C_{i-1}(q_i - q_{i-1}) \qquad \textbf{(10.13)}$$

For each value of i, $0 \le i \le r - 1$, consider an order of size Q in the range q_i to q_{i+1} units; that is, $q_{i+1} \ge Q \ge q_i$. The material cost of each order of size Q is given by $V_i + (Q - q_i)C_i$. The various costs associated with such an order are as follows:

$$\text{Annual order cost} = \left(\frac{D}{Q}\right)S$$

$$\text{Annual holding cost} = [V_i + (Q - q_i)C_i]h/2$$

$$\text{Annual material cost} = \frac{D}{Q}[V_i + (Q - q_i)C_i]$$

The total annual cost is the sum of the three costs and is given by

$$\text{Total annual cost} = \left(\frac{D}{Q}\right)S + [V_i + (Q - q_i)C_i]h/2 + \frac{D}{Q}[V_i + (Q - q_i)C_i]$$

The optimal lot size for this price range is obtained by taking the first derivative of the total cost with respect to the lot size and setting it equal to 0. This results in an optimal lot size for this price range of

$$\text{Optimal lot size for price, } C_i, \text{ is } Q_i = \sqrt{\frac{2D(S + V_i - q_iC_i)}{hC_i}} \qquad \textbf{(10.14)}$$

Observe that the optimal lot size is obtained using a formula very much like the EOQ formula (Equation 10.5), except that the presence of the quantity discount has the effect of raising the fixed cost per order by $V_i - q_iC_i$ (from S to $S + V_i - q_iC_i$). There are three possible cases for Q_i:

1. $q_i \le Q_i \le q_{i+1}$
2. $Q_i < q_i$
3. $Q_i > q_{i+1}$

Case 1

If $q_i \le Q_i \le q_{i+1}$, then a lot size of Q_i will result in the discounted price in this range. In this case the optimal lot size in this price range is to order Q_i units. The total annual cost of this policy is given by

$$TC_i = \left(\frac{D}{Q_i}\right)S + [V_i + (Q_i - q_i)C_i]h/2 + \frac{D}{Q_i}[V_i + (Q_i - q_i)C_i]$$

Cases 2 and 3

If $Q_i < q_i$ or $Q_i > q_{i+1}$, the lot size in this range is either q_i or q_{i+1}, depending on which has the lower total cost. Evaluate the total annual cost:

$$TC_i = \text{Min}\left[\left(\frac{D}{q_i}\right)S + \frac{V_ih}{2} + \frac{D}{q_i}V_i, \frac{D}{q_{i+1}}S + \frac{V_{i+1}h}{2} + \frac{D}{q_{i+1}}V_{i+1}\right]$$

The lot size for this range then corresponds to the break point giving the minimum total cost. Observe that for each range the optimal lot size is the quantity defined by Equation 10.14 if it is feasible or one of the break points if it is not feasible.

For each i we evaluate the optimal lot size and total cost. The solution is to set the lot size to be the one that minimizes the total annual cost across all ranges i.

In Example 10-8, we evaluate the optimal lot size given a marginal unit quantity discount.

Example 10-8: **Marginal Unit Quantity Discount**

Let us return to DO from Example 10-7. Assume that the manufacturer uses the following marginal unit discount pricing schedule:

Order Quantity	*Marginal Unit Price*
0–5,000	$3.00
5,000–10,000	$2.96
Over 10,000	$2.92

This implies that if an order is placed for 7,000 bottles, the first 5,000 are at a unit cost of $3.00, with the remaining 2,000 at a unit cost of $2.96. Evaluate the number of bottles that DO should order in each lot.

Analysis: In this case we have

$$q_0 = 0, q_1 = 5{,}000, q_2 = 10{,}000$$
$$C_0 = \$3.00, C_1 = \$2.96, C_2 = \$2.92$$
$$V_0 = 0; V_1 = 3(5{,}000 - 0) = \$15{,}000$$
$$V_2 = 3(5{,}000 - 0) + 2.96(10{,}000 - 5{,}000) = \$29{,}800$$
$$D = 120{,}000/\text{year}, S = \$100/\text{lot}, h = 0.2$$

For $i = 0$, evaluate Q_0 (using Equation 10.14) as follows:

$$Q_0 = \sqrt{\frac{2D(S + V_0 - q_0C_0)}{hC_0}} = 6{,}324$$

Because $6{,}324 > q_1 = 5{,}000$, we evaluate the cost of ordering lots of $q_1 = 5{,}000$ (we do not consider lots of 0). The total annual cost of ordering 5,000 bottles per lot is as follows (set $Q = 5{,}000$ and $i = 1$):

$$TC_0 = \left(\frac{D}{Q}\right)S + [V_i + (Q - q_i)C_i]h/2 + \frac{D}{Q}[V_i + (Q - q_i)C_i] = \$363{,}900$$

For $i = 1$, evaluate Q_1 using Equation 10.14 as follows:

$$Q_1 = \sqrt{\frac{2D(S + V_1 - q_1C_1)}{hC_1}} = 11{,}028$$

Because $11{,}028 > q_2 = 10{,}000$, we evaluate the cost of ordering lots of $q_2 = 10{,}000$ (the cost of ordering lots of 5,000 has already been evaluated). The total annual cost of ordering 10,000 bottles per lot is as follows (set $Q = 10{,}000$ and $i = 2$):

$$TC_1 = \left(\frac{D}{Q}\right)S + [V_i + (Q - q_i)C_i]h/2 + \frac{D}{Q}[V_i + (Q - q_i)C_i] = \$361{,}780$$

Because $\$361{,}780 < \$363{,}900$, it is less expensive to order in lots of 10,000 than in lots of 5,000. If the lot size is to be 10,000 units or less, we are better off ordering 10,000 units per lot. Now we investigate the cost of ordering in lots larger than 10,000 units; that is, $i = 2$. For $i = 2$, evaluate Q_2 using Equation 10.14 as follows:

$$Q_2 = \sqrt{\frac{2D(S + V_2 - q_2C_2)}{hC_2}} = 16{,}961$$

The total annual cost of ordering 16,961 bottles per lot is as follows (set $Q = 16{,}961$ and $i = 2$):

$$TC_2 = \left(\frac{D}{Q}\right)S + [V_i + (Q - q_i)C_i]h/2 + \frac{D}{Q}[V_i + (Q - q_i)C_i] = \$360{,}365$$

DO minimizes its total cost by ordering in lots of 16,961 bottles. This is much larger than the optimal lot size of 6,324 in the case where the manufacturer does not offer any discount.

If the fixed cost of ordering is \$4, the optimal lot size for DO is 15,755 with the discount compared to a lot size of 1,265 without the discount. This discussion demonstrates that there can be significant order sizes and thus cycle inventory in the absence of any formal fixed ordering costs as long as quantity discounts are offered. Thus, quantity discounts lead to a significant buildup of cycle inventory in a supply chain. In many supply chains, quantity discounts contribute more to cycle inventory than fixed ordering costs. This forces us once again to question the value of quantity discounts in a supply chain.

WHY QUANTITY DISCOUNTS?

In this section we develop arguments supporting the presence of quantity discounts in a supply chain. Quantity discounts are valuable in a supply chain for the following two reasons:

1. Improved coordination to increase total supply chain profits
2. Extraction of surplus through price discrimination

Coordination to Increase Total Supply Chain Profits

A supply chain is *coordinated* if the decisions the retailer and supplier make maximize total supply chain profits. In reality, each stage in a supply chain may have a separate owner and thus attempt to maximize that stage's own profits. The result of this independent decision making can be a lack of coordination in a supply chain because actions that maximize retailer profits may not maximize supply chain profits. In this section we discuss how a manufacturer may use appropriate quantity discounts to ensure that total supply chain profits are maximized even if the retailer is acting to maximize its own profits.

Quantity discounts for commodity products. Economists have argued that for commodity products such as milk, a competitive market exists and costs are driven down to the products' marginal cost. In this case, the market sets the price and the firm's objective is to lower costs. Consider, for example, the online retailer DO, discussed earlier. It can be argued that it sells a commodity product. When placing orders with the manufacturer, DO makes its lot sizing decisions based on costs it faces.

Demand for vitamins is 10,000 bottles per month. DO incurs a fixed order placement, transportation, and receiving cost of \$100 each time it places an order for vitamins with the manufacturer. DO incurs a holding cost of 20 percent. The manufacturer charges \$3 for each bottle of vitamins purchased. Using the EOQ formula (Equation 10.5), DO evaluates its optimal lot size to be $Q = 6{,}324$ bottles. As a result, the annual ordering and holding costs incurred by DO are \$3,795.

Each time DO places an order, the manufacturer has to process, pack, and ship the order. The manufacturer has a line packing bottles at a steady rate that matches demand. The manufacturer incurs a fixed order filling cost of \$250, production cost of \$2 per bottle, and a holding cost of 20 percent. Given that DO orders in lot sizes

of 6,324 bottles, the annual ordering and holding cost for the manufacturer are as follows:

$$\text{Annual order cost at manufacturer} = (120{,}000/6{,}324) \times 250 = \$4{,}744$$
$$\text{Annual holding cost at manufacturer} = (6{,}324/2) \times 2 \times 0.2 = \$1{,}265$$
$$\text{Total order and holding cost at manufacturer} = \$6{,}009$$

The manufacturer thus incurs an annual cost of $6,009 as a result of DO ordering in lots of 6,324. The total cost, across the supply chain, as a result of DO ordering in lots of 6,324 is thus $6,009 + $3,795 = $9,804.

If DO can be convinced to order in lots of 9,165 units, the total cost in the supply chain decreases to $9,165. There is thus an opportunity for the supply chain to save $638. Observe that ordering in lots of 9,165 bottles raises the cost for DO by $238 per year to $4,059 (even though it reduces overall supply chain costs). The manufacturer's costs, in contrast, go down by $902 to $5,106 per year. The manufacturer must offer DO a suitable incentive for DO to raise its lot size.

A lot size–based quantity discount is an appropriate incentive in this case. If the manufacturer were to price vitamins so that each bottle cost $3 for all orders with lot sizes under 9,165 and $2.9978 for all orders in lots of 9,165 or more, DO has an incentive to order in lots of 9,165 bottles. The quantity discount reduces the material cost for DO by just enough to offset the increase in ordering and holding cost. The manufacturer returns $264 to DO as material cost reduction (in the form of a quantity discount) to make it optimal for DO to order in lots of 9,165 bottles. The manufacturer's and the total supply chain's profits increase by $638 in this case. In practice, the manufacturer may have to share some of the $638 increase with DO. The precise division of the increase in supply chain profits depends on the relative bargaining power of different stages in the supply chain.

Observe that offering a lot size–based discount in this case decreases total supply chain cost. It does, however, increase the lot size the retailer purchases and thus increases cycle inventory in the supply chain.

KEY POINT For commodity products for which price is set by the market, manufacturers with large fixed costs per lot can use lot size–based quantity discounts to maximize total supply chain profits. Lot size–based discounts, however, increase cycle inventory in the supply chain.

Our discussion on coordination for commodity products highlights the important link between the lot size–based quantity discount offered and the order costs incurred by the manufacturer. As the manufacturer works on lowering order or setup cost, the discount it offers to retailers should change. For a low enough setup or order cost, the manufacturer gains very little from using a lot size–based quantity discount. In the example of DO discussed earlier, if the manufacturer lowers its fixed cost per order from $250 to $100, the total supply chain costs are close to the minimum without quantity discounts even if DO is trying to minimize its cost. Thus, if its fixed order costs are lowered to $100, it makes sense for the manufacturer to eliminate all quantity discounts. In most companies, however, marketing and sales design quantity discounts while operations works on reducing setup or order cost. As a result, changes in pricing do not always occur in response to setup cost reduction in manufacturing. It is very important that the two functions coordinate these activities.

Quantity discounts for products for which the firm has market power. Now consider the scenario in which the manufacturer has invented a new vitamin pill, vitaherb, which is derived from herbal ingredients and has other properties highly valued in the market. Few competitors have a similar product, so it can be argued that the price at which DO sells vitaherb influences demand. Assume that the annual demand faced by DO is given by the demand curve $360{,}000 - 60{,}000p$, where p is the price at which DO sells vitaherb. The manufacturer incurs a production cost of $C_S = \$2$ per bottle of vitaherb sold. The manufacturer must decide on the price to charge DO, and DO in turn must decide on the price to charge the customer. When the two make their decisions independently, it is optimal for DO to charge a price of $p = \$5$ per bottle and for the manufacturer to charge DO a price of $C_R = \$4$ per bottle. The total market demand in this case is for $360{,}000 - 60{,}000p = 60{,}000$ bottles of vitaherb. The profit at DO as a result of this policy is given by

$$Prof_R = p(360{,}000 - 60{,}000p) - (360{,}000 - 60{,}000p)C_R = \$60{,}000$$

The profit at the manufacturer is given by

$$Prof_M = C_R(180{,}000 - 30{,}000C_R) - C_S(180{,}000 - 30{,}000C_R) = \$120{,}000$$

If the two stages coordinate pricing and DO prices at $p = \$4$, market demand is 120,000 bottles. The total supply chain profit if the two stages coordinate is $120{,}000 \times (\$4 - \$2) = \$240{,}000$. As a result of each stage settings its price independently, the supply chain thus loses \$60,000 in profit. This phenomenon is referred to as *double marginalization.* Double marginalization leads to a loss in profit because the supply chain margin is divided between two stages but each stage makes its decision considering only its local margin.

KEY POINT The supply chain profit is lower if each stage of the supply chain makes its pricing decisions independently, with the objective of maximizing its own profit. A coordinated solution results in higher profit.

There are two pricing schemes that the manufacturer may use to achieve the coordinated solution and maximize supply chain profits even though DO acts in a way that maximizes its own profit.

1. ***Two-part tariff:*** In this case the manufacturer charges its entire profit as an up-front franchise fee and then sells to the retailer at cost. It is then optimal for the retailer to price as though the two stages are coordinated. In the case of DO, recall that total supply chain profit when the two stages coordinate is \$240,000 with DO charging the customer \$4 per bottle of vitaherb. The profit made by DO when the two stages do not coordinate is \$60,000. One option available to the manufacturer is to construct a two-part tariff by which DO is charged an up-front fee of \$180,000 and material cost of $C_R = \$2$ per bottle. DO maximizes its profit if it prices the vitamins at $p = \$4$ per bottle. It has annual sales of $360{,}000 - 60{,}000p = 120{,}000$ and profits of \$60,000. The manufacturer makes a profit of \$180,000 given its material cost of \$2 per bottle.

2. ***Volume-based quantity discount:*** Observe that the two-part tariff is really a volume-based quantity discount. The average material cost for DO declines as it increases the quantity it purchases per year. This observation can be made explicit by designing a volume-based discount scheme that also achieves coordination. The objective here is to price in such a way that the retailer buys the total volume sold when the two stages coordinate pricing. In the case of DO, recall that 120,000 bottles are sold per year when the

supply chain is coordinated. The manufacturer must offer DO a volume discount to encourage DO to purchase this quantity. The manufacturer thus offers a price of $C_R = \$4$ per bottle if the quantity DO purchases per year is less than 120,000. If the total volume in the year is 120,000 or higher, DO has to pay only $C_R = \$3.50$. It is then optimal for DO to order 120,000 units and price them at $p = \$4$ per bottle to the customers. The total profit earned by DO is $(360{,}000 - 60{,}000 \times p) \times (p - C_R) = \$60{,}000$. The total profit earned by the manufacturer is $120{,}000 \times (C_R - \$2) = \$180{,}000$. The total supply chain profit is $240,000.

KEY POINT For products for which the firm has market power, two-part tariffs or volume-based quantity discounts can be used to achieve coordination in the supply chain and maximize supply chain profits.

At this stage, we have seen that even in the absence of inventory-related costs, quantity discounts play a role in supply chain coordination and improved supply chain profits. The discount schemes that are optimal, however, are volume based and not lot size based. In our analysis, we do not assume any inventory-related costs, so one may argue that in the presence of inventory costs, lot size–based discounts may be optimal. It can be shown, however, that even in the presence of inventory costs (order and holding), a two-part tariff or volume-based discount, with the manufacturer passing on some of the fixed cost to the retailer, optimally coordinates the supply chain and maximizes profits given the assumption that customer demand decreases when the retailer increases price.

KEY POINT For products for which a firm has market power, lot size–based discounts are not optimal for the supply chain even in the presence of inventory costs. In such a setting, either a two-part tariff or a volume-based discount, with the supplier passing on some of its fixed cost to the retailer, is needed for the supply chain to be coordinated and maximize profits.

A key distinction between lot size–based and volume discounts is that lot size discounts are based on the quantity purchased per lot, not the rate of purchase. Volume discounts, in contrast, are based on the rate of purchase or volume purchased on average per specified time period (say, a month, quarter, or year). Lot size–based discounts tend to raise the cycle inventory in the supply chain by encouraging retailers to increase the size of each lot. Volume-based discounts, in contrast, are compatible with small lots that reduce cycle inventory. Lot size–based discounts make sense only when the manufacturer incurs very high fixed cost per order. In all other instances it is better to have volume-based discounts.

One can make the point that even with volume-based discounts, retailers will tend to increase the size of the lot toward the end of the evaluation period. For example, the manufacturer offers DO a 2 percent discount if the number of bottles of vitaherb purchased over a quarter exceeds 40,000. This policy will not affect the lot sizes DO orders early during the quarter and DO will order in small lots to match the quantity ordered with demand. Consider a situation, however, in which DO has sold only 30,000 bottles with a week left before the end of the quarter. To get the quantity discount, DO may order 10,000 bottles over the last week even though it expects to sell only 3,000. In this case, cycle inventory in the supply chain goes up in spite of the fact

that there is no lot size–based quantity discount. The situation in which orders peak toward the end of a financial horizon is referred to as the *hockey stick phenomenon* because demand increases dramatically toward the end of a period, similar to the way a hockey stick bends upward toward the end of the stick. It has been observed in many industries. One possible solution to this phenomenon is to base the volume discounts on a rolling horizon. For example, each week the manufacturer may offer DO the volume discount based on sales over the last 12 weeks. Such a rolling horizon dampens the hockey stick phenomenon by making each week the last week in some 12-week horizon.

Thus far, we have only discussed the scenario in which the supply chain has a single retailer. One may ask whether our insights are robust and also apply if the supply chain has multiple retailers, each with different demand curves, all supplied by a single manufacturer. As one would expect, the form of the discount scheme to be offered becomes more complicated in these settings (typically, instead of having only one break point at which the volume-based discount is offered, there are multiple breakpoints). The basic form of the optimal pricing scheme, however, does not change. The optimal discount continues to be volume based, with the average price charged to the retailers decreasing as the rate of purchase (volume purchased per unit time) increases.

Price Discrimination to Maximize Supplier Profits

Price discrimination is the practice whereby a firm charges differential prices to maximize profits. An example of price discrimination is airlines: Passengers traveling on the same plane often pay different prices for their seats.

As discussed in Chapter 15, setting a fixed price for all units does not maximize profits for the manufacturer. In principle, the manufacturer can obtain the entire area under the demand curve above its marginal cost by pricing each unit differently based on customers' marginal evaluation at each quantity. Quantity discounts are one mechanism for price discrimination because customers pay different prices based on the quantity purchased.

KEY POINT Price discrimination to maximize profits at the manufacturer may also be a reason to offer quantity discounts within a supply chain.

Next we discuss trade promotions and their impact on lot sizes and cycle inventory in the supply chain.

10.4 SHORT-TERM DISCOUNTING: TRADE PROMOTIONS

Manufacturers use *trade promotions* to offer a discounted price and a time period over which the discount is effective. For example, a manufacturer of canned soup may offer a price discount of 10 percent for the shipping period December 15 to January 25. For all purchases within the specified time horizon, retailers get a 10 percent discount. In some cases, the manufacturer may require specific actions from the retailer, such as displays, advertising, promotion, and so on, to qualify for the trade promotion. Trade promotions are quite common in the consumer packaged-goods industry, with manufacturers promoting different products at different times of the year.

The goal of trade promotions is to influence retailers to act in a way that helps the manufacturer achieve its objectives. A few of the key goals (from the manufacturer's perspective) of a trade promotion are as follows[1]:

1. Induce retailers to use price discounts, displays, or advertising to spur sales.
2. Shift inventory from the manufacturer to the retailer and the customer.
3. Defend a brand against competition.

Although these may be the manufacturer's objectives, it is not clear that they are always achieved as the result of a trade promotion. Our goal in this section is to investigate the impact of a trade promotion on the behavior of the retailer and the performance of the entire supply chain. The key to understanding this impact is to focus on how a retailer reacts to a trade promotion that a manufacturer offers. In response to a trade promotion, the retailer has the following options:

1. Pass through some or all of the promotion to customers to spur sales.
2. Pass through very little of the promotion to customers but purchase in greater quantity during the promotion period to exploit the temporary reduction in price.

The first action lowers the price of the product for the end customer, leading to increased purchases and thus increased sales for the entire supply chain. The second action does not increase purchases by the customer but increases the amount of inventory held at the retailer. As a result, the cycle inventory and flow time within the supply chain increase.

A *forward buy* occurs when a retailer purchases in the promotional period for sales in future periods. A forward buy helps reduce the retailer's future cost of goods for product sold after the promotion ends. Although a forward buy is often the retailer's appropriate response to a price promotion, it usually increases demand variability with a resulting increase in inventory and flow times within the supply chain, and it can decrease supply chain profits.

Our objective in this section is to understand a retailer's optimal response when faced with a trade promotion. We identify the factors affecting the forward buy and quantify the size of a forward buy by the retailer. We also identify factors that influence the amount of the promotion that a retailer passes on to the customer.

We first illustrate the impact of a trade promotion on forward buying behavior of the retailer. Consider a Cub Foods supermarket selling chicken noodle soup manufactured by the Campbell Soup Company. Customer demand for chicken noodle soup is D cans per year. The price Campbell charges is $\$C$ per can. Cub Foods incurs a holding cost of h (per dollar of inventory held for a year). Using the EOQ formula (Equation 10.5), Cub Foods normally orders in the following lot sizes:

$$Q^* = \sqrt{\frac{2DS}{hC}}$$

Campbell announces that it is offering a discount of $\$d$ per can for the coming four-week period. Cub Foods must decide how much to order at the discounted price compared to the lot size of Q^* that it normally orders. Let Q^d be the lot size ordered at the discounted price.

The costs the retailer must consider when making this decision are material cost, holding cost, and order cost. Increasing the lot size Q^d lowers the material cost for Cub Foods because they purchase more cans (for sale now and in the future) at the discounted price. Increasing the lot size Q^d increases the holding cost because inventories

[1]See Blattberg and Neslin (1990) for more details.

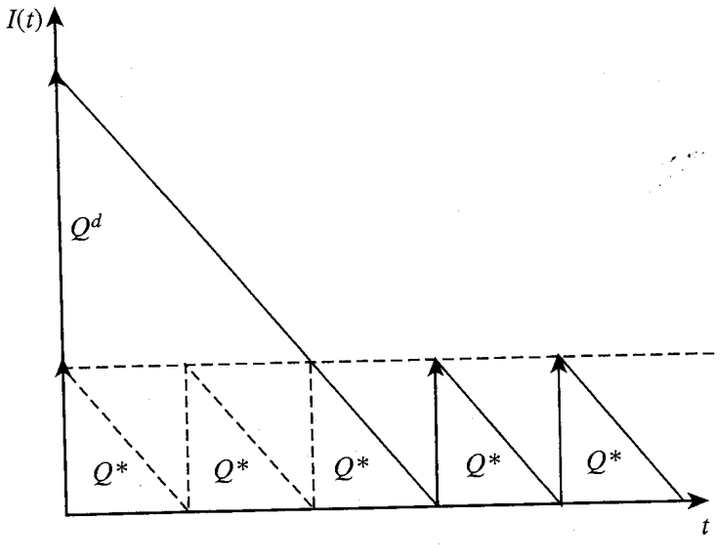


FIGURE 10-5
Inventory Profile for Forward Buying

increase. Increasing the lot size Q^d lowers the order cost for Cub Foods because some orders that would otherwise have been placed are now not necessary. Cub Food's goal is to make the trade-off that minimizes the total cost.

The inventory pattern when a lot size of Q^d is followed by lot sizes of Q^* is shown in Figure 10-5. The objective is to identify Q^d that minimizes the total cost (material cost + ordering cost + holding cost) over the time interval during which the quantity Q^d (ordered during the promotion period) is consumed.

The precise analysis in this case is complex, so we present a result that holds under some restrictions.[2] The first key assumption is that the discount is offered once, with no future discounts. The second key assumption is that the retailer takes no action (such as passing on part of the trade promotion) to influence customer demand. The customer demand thus remains unchanged. The third key assumption is that we analyze a period over which the demand is an integer multiple of Q^*. With these assumptions, the optimal order quantity at the discounted price is given by

$$Q^d = \frac{dD}{(C-d)h} + \frac{CQ^*}{C-d} \qquad \textbf{(10.15)}$$

In practice, retailers are often aware of the timing of the next promotion. If the demand until the next anticipated trade promotion is Q_1, it is optimal for the retailer to order $min\{Q^d, Q_1\}$. Observe that the quantity Q^d ordered as a result of the promotion is larger than the regular order quantity Q^*. The forward buy in this case is given by

$$\text{Forward buy} = Q^d - Q^*$$

Even for relatively small discounts, the order size increases by a large quantity, as illustrated in Example 10-9.

Example 10-9: Impact of Trade Promotions on Lot Sizes

DO is a retailer that sells vitaherb, a popular vitamin diet supplement. Demand for vitaherb is 120,000 bottles per year. The manufacturer currently charges \$3 for each bottle and DO incurs a holding cost of 20 percent. DO currently orders in lots of $Q^* = 6{,}324$ bottles. The manufacturer has offered a discount of \$0.15 for all bottles purchased by retailers over the coming month. How many bottles of vitaherb should DO order given the promotion?

[2] See Silver, Pyke, and Petersen (1998) for a more detailed discussion.

Analysis: In the absence of any promotion, DO orders in lot sizes of $Q^* = 6{,}324$ bottles. Given a monthly demand of 10,000 bottles, DO normally orders every 0.6324 months. In the absence of the trade promotion we have the following:

$$\text{Cycle inventory at DO} = Q^*/2 = 6{,}324/2 = 3{,}162 \text{ bottles}$$
$$\text{Average flow time} = Q^*/2R = 6{,}324/(2R) = 0.3162 \text{ months}$$

The optimal lot size during the promotion is obtained using Equation 10.15 and is given by

$$Q^d = \frac{dR}{(C-d)h} + \frac{CQ^*}{C-d} = \frac{0.15 \times 120{,}000}{(3.00 - 0.15) \times 0.20} + \frac{3 \times 6{,}324}{3.00 - 0.15} = 38{,}236$$

During the promotion, DO should place an order for a lot size of 38,236. In other words, DO places an order for 3.8236 months' worth of demand. In the presence of the trade promotion we have

$$\text{Cycle inventory at DO} = Q^d/2 = 38{,}236/2 = 19{,}118 \text{ bottles}$$
$$\text{Average flow time} = Q^*/2R = 38{,}236/(2R) = 1.9118 \text{ months}$$

In this case, the forward buy is given by

$$\text{Forward buy} = Q^d - Q^* = 38{,}236 - 6{,}324 = 31{,}912 \text{ bottles}$$

As a result of this forward buy, DO will not place any order for the next 3.8236 months (without a forward buy, DO would have placed 31,912/6,324 = 5.05 orders for 6,324 bottles each during this period). Observe that a 5 percent discount causes the lot size to increase by more than 500 percent.

As the example illustrates, forward buying as a result of trade promotions leads to a significant increase in the quantity ordered by the retailer. The large order is then followed by a period of low orders to compensate for the inventory built up at the retailer. The fluctuation in orders as a result of trade promotions is one of the major contributors to the bullwhip effect discussed in Chapter 17. The retailer can justify the forward buying during a trade promotion because it decreases its total cost. In contrast, the manufacturer can justify this action only if it has either inadvertently built up a lot of excess inventory or the forward buy allows the manufacturer to smooth demand by shifting it from peak- to low-demand periods. In practice, manufacturers often build up inventory in anticipation of planned promotions. During the trade promotion this inventory shifts to the retailer, primarily as a forward buy. If the forward buy during trade promotions is a significant fraction of total sales, manufacturers end up reducing the revenues they earn from sales because most of the product is sold at a discount. The increase in inventory and the decrease in revenues often lead to a reduction in manufacturer as well as total supply chain profits as a result of trade promotions.[3]

KEY POINT Trade promotions lead to a significant increase in lot size and cycle inventory because of forward buying by the retailer. This generally results in reduced supply chain profits unless the trade promotion reduces demand fluctuations.

Now let us consider the extent to which the retailer may find it optimal to pass through some of the discount to the end customer to spur sales. As Example 10-10 shows, it is not optimal for the retailer to pass through the entire discount to the customer. In other words, it is optimal for the retailer to capture part of the promotion and pass through only part of it to the customer.

[3]See Blattberg and Neslin (1990) for more details.

Example 10-10 Assume that DO faces a demand curve for vitaherb of 300,000 − 60,000p. The normal price charged by the manufacturer to the retailer is C_R = \$3 per bottle. Ignoring all inventory-related costs, evaluate the optimal response of DO to a discount of \$0.15 per unit.

Analysis: The profits for DO, the retailer, are given as follows:

$$Prof_R = (300{,}000 - 60{,}000p)p - (300{,}000 - 60{,}000p)C_R$$

The retailer prices to maximize profits and the optimal retail price is obtained by setting the first derivative of retailer profits with respect to p to 0. This implies that

$$300{,}000 - 120{,}000p + 60{,}000C_R = 0$$

or

$$p = (300{,}000 + 60{,}000C_R)/120{,}000 \qquad \textbf{(10.16)}$$

Substituting C_R = \$3 into Equation 10.16, we obtain a retail price of p = \$4. As a result the customer demand at the retailer in the absence of the promotion is

$$D_R = 300{,}000 - 60{,}000p = 60{,}000$$

During the promotion the manufacturer offers a discount of \$0.15, resulting in a price to the retailer of C_R = \$2.85. Substituting into Equation 10.16, the optimal price set by DO is

$$p = (300{,}000 + 60{,}000 \times 2.85)/120{,}000 = \$3.925$$

Observe that the retailer's optimal response is to pass through only \$0.075 of the \$0.15 discount to the customer. The retailer does not pass through the entire discount. At the discounted price, DO experiences a demand of

$$D_R = 300{,}000 - 60{,}000p = 64{,}500$$

This represents an increase of 7.5 percent in demand. In this case it is optimal for DO to pass on half the trade promotion discount to the customers. This action results in a 7.5 percent increase in customer demand.

From Examples 10-9 and 10-10, observe that the increase in customer demand resulting from a trade promotion (7.5 percent of demand in Example 10-10) is insignificant relative to the increased purchase by the retailer due to forward buying (500 percent from Example 10-9). The impact of the increase in customer demand may be further dampened by customer behavior. For many products, such as detergent and toothpaste, most of the increase in customer purchases is a forward buy by the customer; customers are unlikely to start brushing their teeth more frequently simply because they have purchased a lot of toothpaste. For such products, a trade promotion does not truly increase demand.

KEY POINT Faced with a short-term discount, it is optimal for retailers to pass through only a fraction of the discount to the customer, keeping the rest for themselves. Simultaneously, it is optimal for retailers to increase the purchase lot size and forward buy for future periods. Thus, trade promotions often lead to an increase of cycle inventory in a supply chain without a significant increase in customer demand.

Manufacturers have always struggled with the fact that retailers pass along only a small fraction of a trade discount to the customer. Almost a quarter of all distributor inventories in the dry-grocery supply chain in 1990 could be attributed to forward buying.[4]

[4] See Kurt Salmon Associates (1993).

Our previous discussion supports the claim that trade promotions generally increase cycle inventory in a supply chain and hurt performance. This realization has led many firms, including the world's largest retailer, Wal-Mart, and several manufacturers such as Proctor & Gamble, to adopt "Every Day Low Pricing" (EDLP). Here the price is fixed over time and no short-term discounts are offered. This eliminates any incentive for forward buying. As a result, all stages of the supply chain purchase in quantities that match demand.

In general, the discount passed through by the retailer to the consumer is influenced by the retailer deal elasticity, which is the increase in retail sales per unit discount in price. The higher the deal elasticity, the more of the discount the retailer is likely to pass through to the consumer. Thus, trade promotions by the manufacturer may make sense for products with a high deal elasticity that ensures high pass-through by the retailer, and high holding costs that ensure low forward buying. Blattberg and Neslin (1990) identify paper goods as products with high deal elasticity and holding cost. They also identify trade promotions as being more effective with strong brands relative to weak brands.

Trade promotions may also make sense as a competitive response. In a category such as cola, some customers are loyal to their brand while others switch depending on the brand being offered at the lowest price. Consider a situation in which one of the competitors, say Pepsi, offers retailers a trade promotion. Retailers increase their purchases of Pepsi and pass through some of the discount to the customer. Price-sensitive customers increase their purchase of Pepsi. If a competitor such as Coca-Cola does not respond, it loses some market share in the form of price-sensitive customers. A case can be made that a trade promotion is justified in such a setting as a competitive response. Observe that with both competitors offering trade promotions, there is no real increase in demand for either unless customer consumption grows. Inventory in the supply chain, however, does increase for both brands. This is then a situation in which trade promotions are a competitive necessity but they increase supply chain inventory, leading to reduced profits for all competitors.

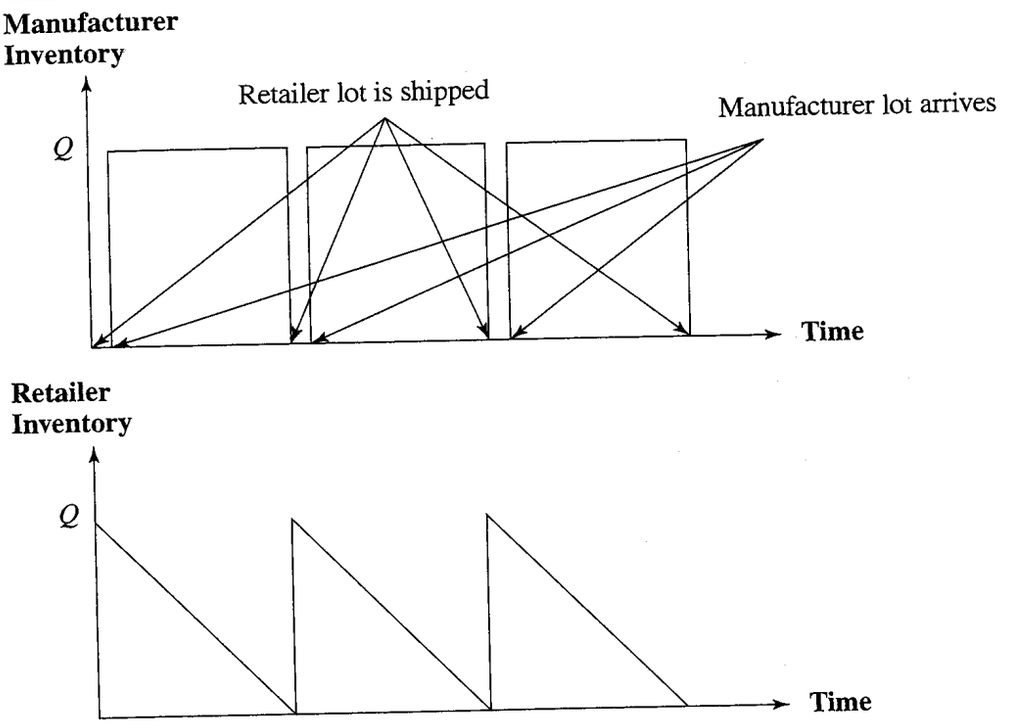
Trade promotions should be designed so that retailers limit their forward buying and pass along more of the discount to end customers. The manufacturer's objective is to increase market share and sales without allowing the retailer to forward buy significant amounts. This outcome can be achieved by offering discounts to the retailer that are based on actual sales to customers rather than the amount purchased by the retailer. The discount price thus applies to items sold to customers (*sell-through*) during the promotion, not the quantity purchased by the retailer (*sell-in*). This eliminates all incentive for forward buying.

Given the information technology in place, many manufacturers today offer scanner-based promotions by which the retailer receives credit for the promotion discount for every unit sold. Another option is to limit the allocation to a retailer based on past sales. This is also an effort to limit the amount that the retailer can forward buy. It is unlikely, however, that retailers will accept such schemes for weak brands.

10.5 MANAGING MULTIECHELON CYCLE INVENTORY

A *multiechelon* supply chain has multiple stages and possibly many players at each stage. The lack of coordination in lot sizing decisions across the supply chain results in high costs and more cycle inventory than required. The goal in a multiechelon system is to decrease total costs by coordinating orders across the supply chain.

FIGURE 10-6 Inventory Profile at Retailer and Manufacturer with No Synchronization



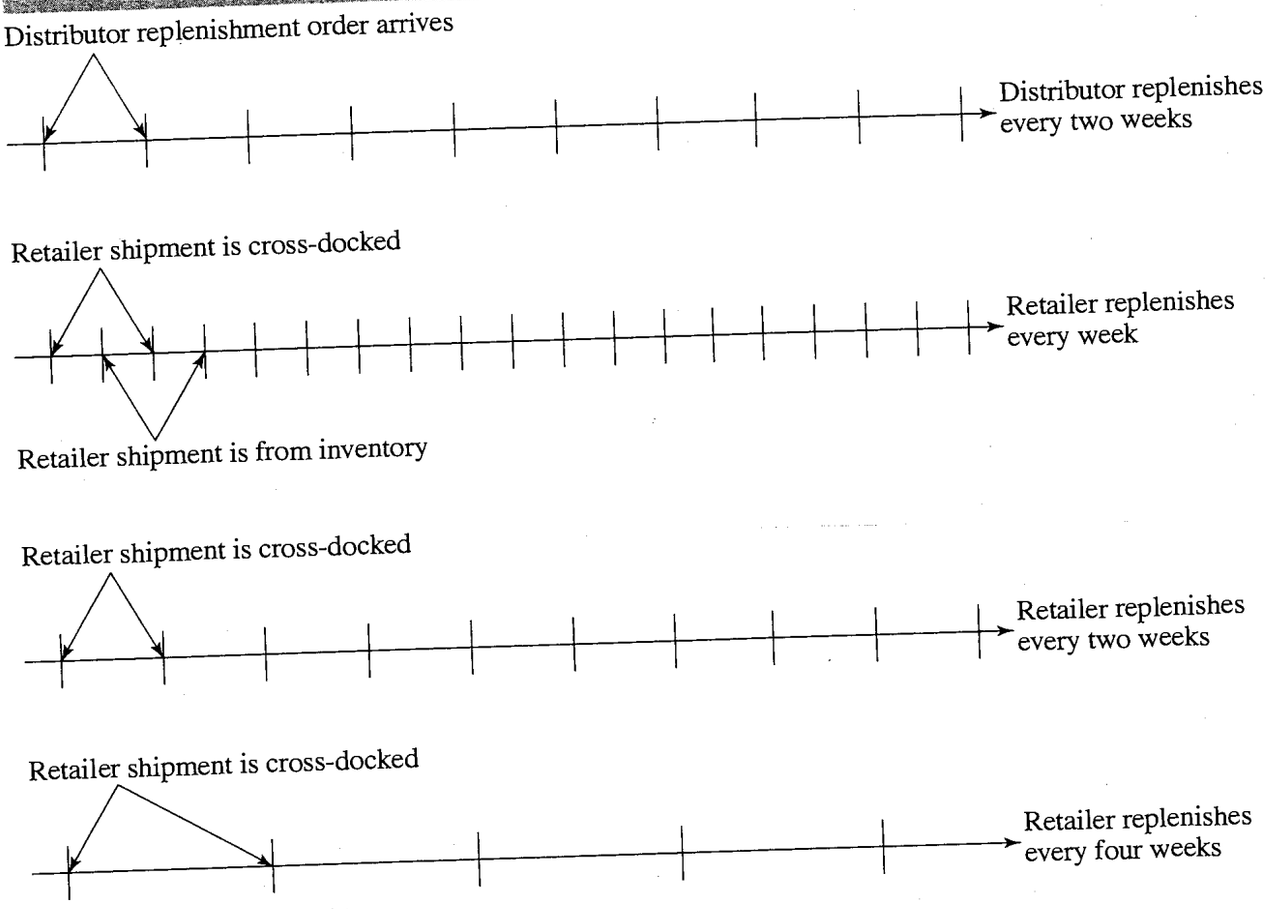
Consider a simple multiechelon system with one manufacturer supplying one retailer. Assume that production is instantaneous, so the manufacturer can produce a lot when needed. If the two stages are not synchronized, the manufacturer may produce a new lot of size Q right after shipping a lot of size Q to the retailer. Inventory at the two stages is as shown in Figure 10-6. In this case the retailer carries an average inventory of $Q/2$ and the manufacturer carries an average inventory of about Q.

Overall supply chain inventory can be lowered if the manufacturer synchronizes its production to be ready just in time to be shipped to the retailer. In this case, the manufacturer carries no inventory and the retailer carries an average inventory of $Q/2$. In this case, synchronization of production and replenishment allows the supply chain to lower total cycle inventory from about $3Q/2$ to $Q/2$.

For a simple multiechelon supply chain with only one player at each stage, ordering policies in which the lot size at each stage is an integer multiple of the lot size at its immediate customer have been shown to be quite close to optimal. When lot sizes are integer multiples, coordination of ordering across stages allows for a portion of the delivery to a stage to be cross-docked on to the next stage. The extent of cross-docking depends on the ratio of the fixed cost of ordering S and the holding cost H at each stage. The closer this ratio is between two stages, the higher is the optimal percentage of cross-docked product.

If one party (distributor) in a supply chain supplies multiple parties (retailers) at the next stage of the supply chain, it is important to distinguish retailers with high demand from those with low demand. In this setting, Roundy (1985) has shown that a near-optimal policy results if retailers are grouped such that all retailers in one group order together and, for any retailer, either the ordering frequency is an integer multiple of the ordering frequency at the distributor or the ordering frequency at the distributor

FIGURE 10-7 Illustration of an Integer Replenishment Policy



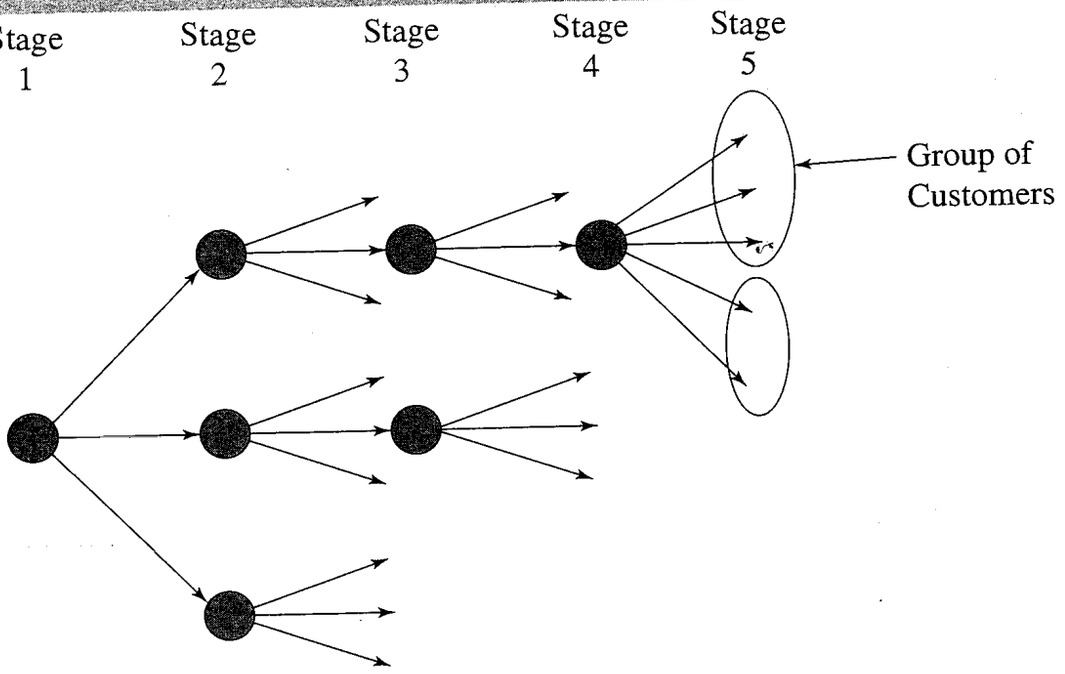
is an integer multiple of the frequency at the retailer. An integer replenishment policy has every player ordering periodically, with the length of the reorder interval for each player an integer multiple of some base period. An example of such a policy is shown in Figure 10-7. Under this policy, the distributor places a replenishment order every two weeks. Some retailers place replenishment orders every week and others place replenishment orders every two or four weeks. Observe that for retailers ordering more frequently than the distributor, the retailers' ordering frequency is an integer multiple of the distributor's frequency. For retailers ordering less frequently than the distributor, the distributor's ordering frequency is an integer multiple of the retailers' frequency.

If an integer replenishment policy is synchronized across the two stages, the distributor can cross-dock part of its supply on to the next stage. All shipments to retailers ordering no more frequently than the distributor (every two or four weeks) are cross-docked as shown in Figure 10-8. For retailers ordering more frequently (every week) than the distributor, half the orders are cross-docked, with the other half shipped from inventory as shown in Figure 10-8.

Integer replenishment policies for the supply chain shown in Figure 10-8 can be summarized as follows:

- Divide all parties within a stage into groups such that all parties within a group order from the same supplier and have the same reorder interval.

FIGURE 10-8 A Multiechelon Distribution Supply Chain



- Set reorder intervals across stages such that the receipt of a replenishment order at any stage is synchronized with the shipment of a replenishment order to at least one of its customers. The synchronized portion can be cross-docked.
- For customers with a longer reorder interval than the supplier, make the customer's reorder interval an integer multiple of the supplier's interval and synchronize replenishment at the two stages to facilitate cross-docking. In other words, a supplier should cross-dock all orders from customers who reorder less frequently than the supplier himself.
- For customers with a shorter reorder interval than the supplier, make the supplier's reorder interval an integer multiple of the customer's interval and synchronize replenishment at the two stages to facilitate cross-docking. In other words, a supplier should cross-dock one out of every k shipments to a customer who orders more frequently than itself, where k is an integer.
- The relative frequency of reordering depends on the setup cost, holding cost, and demand at different parties.

KEY POINT Integer replenishment policies can be synchronized in multiechelon supply chains to keep cycle inventory and order costs low. Under such policies, the reorder interval at any stage is an integer multiple of a base reorder interval. Synchronized integer replenishment policies facilitate a high level of cross-docking across the supply chain.

Whereas the integer policies discussed above synchronize replenishment within the supply chain and decrease cycle inventories, they increase safety inventories as discussed in Chapter 11, because of the lack of flexibility with the timing of a reorder. Thus, these polices make the most sense for supply chains in which cycle inventories are large and demand is relatively predictable.

10.6 ESTIMATING CYCLE INVENTORY–RELATED COSTS IN PRACTICE

When setting cycle inventory levels in practice, a common hurdle is estimating the ordering and holding costs. Given the robustness of cycle inventory models, it is better to get a good approximation quickly rather than spend a lot of time trying to estimate costs exactly.

Our goal is to identify incremental costs that change with the lot sizing decision. We can ignore costs that are unchanged with a change in lot size. For example, if a factory is running at 50 percent of capacity and all labor is full-time and not earning overtime, it can be argued that the incremental setup cost for labor is zero. Reducing the lot size in this case will not have any impact on setup cost until either labor is fully utilized (and earning overtime) or machines are fully utilized (with a resulting loss in production capacity).

INVENTORY HOLDING COST

Holding cost is estimated as a percentage of the cost of a product and is the sum of the following major components.

- ***Cost of capital:*** This is the dominant component of holding cost for products that do not become obsolete quickly. The appropriate approach is to evaluate the *weighted-average cost of capital* (*WACC*),[5] which takes into account the required return on the firm's equity and the cost of its debt. These are weighted by the amount of equity and debt financing that the firm has. The formula for the *WACC* is

$$WACC = \frac{E}{D+E}(R_f + \beta \times MRP) + \frac{D}{D+E}R_b(1-t)$$

where

E = amount of equity
D = amount of debt
R_f = risk-free rate of return (which is usually in the mid-single digits)
β = the firm's beta
MRP = market risk premium (which is around the high single digits)
R_b = rate at which the firm can borrow money (related to its debt rating)
t = tax rate

The *WACC* is adjusted for use in a pretax setting as follows:

$$\text{Pretax } WACC = \text{after-tax } WACC/(1-t)$$

The pretax *WACC* is appropriate for a firm that can increase its business using funds released by reducing inventories because inventory calculations are done pretax. Most of these numbers can be found in a company's annual report and in any equity research report on the company. The borrowing rate comes from tables listing the rates charged for bonds from firms with the same credit ratings. The risk-free rate is the return on U.S. Treasuries, and the market risk premium is the return of the market above the risk-free rate. If access to a company's financial structure is not available, a good approximation can be made by using numbers from public companies in the same industry and of similar size.

[5]See Brealey and Myers (2000).

- ***Obsolescence (or spoilage) cost:*** The obsolescence cost estimates the rate at which the value of the stored product drops because its market value or quality falls. This cost can range dramatically, from rates of many thousands percent to virtually zero, depending on the type of product. Perishable products have high obsolescence rates. Even nonperishables can have high obsolescence rates if they have short life cycles. A product with a life cycle of six months has an effective obsolescence cost of 200 percent. At the other end of the spectrum are products such as crude oil that take a long time to become obsolete or spoil. For such products a very low obsolescence rate may be applied.
- ***Handling cost:*** Handling cost should include only incremental receiving and storage costs that vary with the quantity of product received. Quantity-independent handling costs that vary with the number of orders should be included in the order cost. The quantity-dependent handling cost often does not change if quantity varies within a range. If the quantity is within this range (e.g., the range of inventory a crew of four people can unload per period of time), incremental handling cost added to the holding cost is zero. If the quantity handled requires more people, an incremental handling cost is added to the holding cost.
- ***Occupancy cost:*** The occupancy cost reflects the incremental change in space cost due to changing cycle inventory. If the firm is being charged based on the actual number of units held in storage, we have the direct occupancy cost. Firms often lease or purchase a fixed amount of space. As long as a marginal change in cycle inventory does not change the space requirements, the incremental occupancy cost is zero. Occupancy costs often take the form of a step function, with a sudden increase in cost when capacity is fully utilized and new space must be acquired.
- ***Miscellaneous costs:*** The final component of holding cost deals with a number of other relatively small costs. These costs include theft, security, damage, tax, and additional insurance charges that are incurred. Once again, it is important to estimate the incremental change in these costs on changing cycle inventory.

ORDER COST

The order cost includes all incremental costs associated with placing or receiving an extra order that are incurred regardless of the size of the order. Components of order cost include:

- ***Buyer time:*** Buyer time is the incremental time of the buyer placing the extra order. This cost should be included only if the buyer is utilized fully. The incremental cost of getting an idle buyer to place an order is zero and does not add to the order cost. Electronic ordering can significantly reduce the buyer time to place an order.
- ***Transportation costs:*** A fixed transportation cost is often incurred regardless of the size of the order. For instance, if a truck is sent to deliver every order, it costs the same amount to send a half-empty truck as it does a full truck. Less-than-truckload pricing also includes a fixed component that is independent of the quantity shipped and a variable component that increases with the quantity shipped. The fixed component should be included in the order cost.
- ***Receiving costs:*** Some receiving costs are incurred regardless of the size of the order. These include any administration work such as purchase order matching and any effort associated with updating inventory records. Receiving costs that are quantity dependent should not be included here.
- ***Other costs:*** Each situation can have costs unique to it that should be considered if they are incurred for each order regardless of the quantity of that order.

The order cost is estimated as the sum of all its component costs. It is important that the order cost include only the incremental change in real cost for an additional order. The order cost is often a step function that is zero when the resource is not fully utilized, but takes on a large value when the resource is fully utilized. At that point the order cost is the cost of the additional resource required.

10.7 SUMMARY OF LEARNING OBJECTIVES

1. Balance the appropriate costs to choose the optimal amount of cycle inventory in a supply chain.

   Cycle inventory generally equals half the lot size. Therefore, as the lot size grows, so does the cycle inventory. In deciding on the optimal amount of cycle inventory, the supply chain goal is to minimize the total cost—the order cost, holding cost, and material cost. As cycle inventory increases, so does the holding cost. However, the order cost and, in some instances, the material cost decrease with an increase in lot size and cycle inventory. The EOQ balances the three costs to obtain the optimal lot size. The higher the order and transportation cost, the higher the lot size and cycle inventory.
2. Understand the impact of quantity discounts on lot size and cycle inventory.

   Lot size–based quantity discounts increase the lot size and cycle inventory within the supply chain because they encourage buyers to purchase in larger quantities to take advantage of the decrease in price.
3. Devise appropriate discounting schemes for a supply chain.

   Quantity discounts are justified to increase total supply chain profits. Volume-based discounts are more effective than lot size–based discounts in increasing supply chain profits without increasing lot size and cycle inventory.
4. Understand the impact of trade promotions on lot size and cycle inventory.

   Trade promotions increase inventory and total supply chain costs through forward buying, which shifts future demand to the present and creates a spike in demand followed by a dip. The increased variability raises inventories and costs.
5. Identify managerial levers that reduce lot size and cycle inventory in a supply chain without increasing cost.

The key managerial levers for reducing lot size and thus cycle inventory in the supply chain without increasing cost are the following:

- Reduce fixed ordering and transportation costs incurred per order.
- Implement volume-based discounting schemes rather than individual lot size–based discounting schemes.
- Eliminate or reduce trade promotions and encourage EDLP. Base trade promotions on sell-through rather than sell-in to the retailer.

Discussion Questions

1. Consider a supermarket deciding on the size of its replenishment order from Proctor & Gamble. What costs should it take into account when making this decision?
2. Discuss how various costs for the supermarket change as it decreases the lot size ordered from Proctor & Gamble.
3. As demand at the supermarket chain grows, how would you expect the cycle inventory measured in days of inventory to change? Explain.
4. The manager at the supermarket wants to decrease the lot size without increasing the costs he incurs. What actions can he take to achieve this objective?

5. When are quantity discounts justified in a supply chain?
6. What is the difference between lot size–based and volume-based quantity discounts?
7. Why do manufacturers such as Kraft and Sara Lee offer trade promotions? What impact do trade promotions have on the supply chain? How should trade promotions be structured to maximize their impact while minimizing the additional cost they impose on the supply chain?
8. Why is it appropriate to include only the incremental cost when estimating the holding and order cost for a firm?

Exercises

1. Harley Davidson has its engine assembly plant in Milwaukee and its motorcycle assembly plant in Pennsylvania. Engines are transported between the two plants using trucks, with each trip costing $1,000. The motorcycle plant assembles and sells 300 motorcycles each day. Each engine costs $500, and Harley incurs a holding cost of 20 percent per year. How many engines should Harley load onto each truck? What is the cycle inventory of engines at Harley?
2. As part of its initiative to implement just-in-time (JIT) manufacturing at the motorcycle assembly plant, Harley has reduced the number of engines loaded on each truck to 100. If each truck trip still costs $1,000, how does this decision impact annual inventory costs at Harley? What should the cost of each truck be if a load of 100 engines is to be optimal for Harley?
3. Harley purchases components from three suppliers. Components purchased from Supplier A are priced at $5 each and used at the rate of 20,000 units per month. Components purchased from Supplier B are priced at $4 each and are used at the rate of 2,500 units per month. Components purchased from Supplier C are priced at $5 each and used at the rate of 900 units per month. Currently Harley purchases a separate truckload from each supplier. As part of its JIT drive, Harley has decided to aggregate purchases from the three suppliers. The trucking company charges a fixed cost of $400 for the truck with an additional charge of $100 for each stop. Thus, if Harley asks for a pickup from only one supplier, the trucking company charges $500; from two suppliers it charges $600; and from three suppliers it charges $700. Suggest a replenishment strategy for Harley that minimizes annual cost. Compare the cost of your strategy with Harley's current strategy of ordering separately from each supplier. What is the cycle inventory of each component at Harley?
4. Prefab, a furniture manufacturer, uses 20,000 square feet of plywood per month. Their trucking company charges Prefab $400 per shipment, independent of the quantity purchased. The manufacturer offers an all unit quantity discount with a price of $1 per square foot for orders under 20,000 square feet, $0.98 per square foot for orders between 20,000 square feet and 40,000 square feet, and $0.96 per square foot for orders larger than 40,000 square feet. Prefab incurs a holding cost of 20 percent. What is the optimal lot size for Prefab? What is the annual cost of such a policy? What is the cycle inventory of plywood at Prefab? How does it compare with the cycle inventory if the manufacturer does not offer a quantity discount but sells all plywood at $0.96 per square foot?
5. Reconsider Exercise 4 about Prefab. However, the manufacturer now offers a marginal unit quantity discount for the plywood. The first 20,000 square feet of any order is sold at $1 per square foot, the next 20,000 square feet is sold at $0.98 per square foot, and any quantity over 40,000 square feet is sold for $0.96 per square foot. What is the optimal lot size for Prefab given this pricing structure? How much cycle inventory of plywood will Prefab carry given the ordering policy?
6. The Dominick's supermarket chain sells Nut Flakes, a popular cereal manufactured by the Tastee cereal company. Demand for Nut Flakes is 1,000 boxes per week. Dominick's has a holding cost of 25 percent and incurs a fixed trucking cost of $200 for each replenishment

order it places with Tastee. Given that Tastee normally charges $2 per box of Nut Flakes, how much should Dominick's order in each replenishment lot? Tastee runs a trade promotion, lowering the price of Nut Flakes to $1.80 for a month. How much should Dominick's order be, given the short-term price reduction?

7. Flanger is an industrial distributor that sources from hundreds of suppliers. The two modes of transportation available for inbound shipping are LTL (less than truckload) and TL (truckload). LTL shipping costs $1 per unit, whereas TL shipping cost $400 per truck. Each truck can carry up to 1,000 units. Flanger wants a rule assigning products to shipping mode (TL or LTL) based on annual demand. Each units costs $50 and Flanger uses a holding cost of 20 percent. Flanger incurs a fixed cost of $100 for each order placed with a supplier.
   (a) Determine a threshold for annual demand above which TL is preferred and below which LTL is preferred.
   (b) How does the threshold change [relative to part (a)] if unit cost is $100 (instead of $50) with all other data unchanged? Which mode becomes preferable as unit cost grows?
   (c) How does the threshold change [relative to part (a)] if the LTL cost comes down to $0.8 per unit (instead of $1 per unit)?
8. SuperPart, an auto parts distributor, has a large warehouse in the Chicago region and is deciding on a policy for the use of TL or LTL transportation for inbound shipping. LTL shipping costs $1 per unit. TL shipping costs $800 per truck plus $100 per pickup. Thus, a truck used to pick up from three suppliers costs $800 + 3 \times 100 = \$1{,}100$. A truck can carry up to 2,000 units. SuperPart incurs a fixed cost of $100 for each order placed with a supplier. Thus, an order with three distinct suppliers incurs an ordering cost of $300. Each units costs $50 and SuperPart uses a holding cost of 20 percent. Assume that product from each supplier has an annual demand of 3,000 units.
   (a) What is the optimal order size and annual cost if LTL shipping is used? What is the time between orders?
   (b) What is the optimal order size and annual cost if TL shipping is used with a separate truck for each supplier? What is the time between orders?
   (c) What is the optimal order size and annual cost per product if TL shipping is used but two suppliers are grouped together per truck?
   (d) What is the optimal number of suppliers that should be grouped together? What is the optimal order size and annual cost per product in this case? What is the time between orders?
   (e) What is the shipping policy you recommend if each product has an annual demand of 3,000? What is the shipping policy you recommend for products with an annual demand of 1,500? What is the shipping policy you recommend for products with an annual demand of 18,000?
9. PlasFib is a manufacturer of synthetic fibers used for making furniture upholstery. PlasFib manufactures fiber in 50 different colors on one line. When changing over from one color to the next, part of the line has to be cleaned, leading to a loss of material. Each changeover costs $200 in lost material and changeover labor. Assume that each changeover requires the line to shut down for 0.5 hour. When it is running, the line produces fiber at the rate of 100 pounds per hour.

   The fibers sold by PlasFib are divided into three categories. There are 5 fast-moving colors that average sales of 30,000 pounds per color per year. There are 10 medium-moving colors that average sales of 12,000 pounds per color per year. The remaining are slow-moving products and average sales of 2,400 pounds per year each. Each pound of fiber costs $5 and PlasFib has a holding cost of 20 percent.
   (a) What is the batch size that PlasFib should produce for each fast-/ medium-/ slow-moving color? How many days of demand does this translate into?

(b) What is the annual setup and holding cost of the policies you suggested in part (a)?
(c) How many hours of plant operation will the above schedule require in a year (include a half-hour of setup per batch)?

10. TopOil, a refiner in Indiana, serves three customers near Nashville, Tennessee, and maintains consignment inventory (owned by TopOil) at each location. Currently, TopOil uses TL transportation to deliver separately to each customer. Each truck costs $800 plus $250 per stop. Thus, delivering to each customer separately costs $1,050 per truck. TopOil is considering aggregating deliveries to Nashville on a single truck. Demand at the large customer is 60 tons a year, demand at the medium customer is 24 tons per year, and demand at the small customer is 8 tons per year. Product cost for TopOil is $10,000 per ton and they use a holding cost of 25 percent. Truck capacity is 12 tons.
    (a) What is the annual transportation and holding cost if TopOil ships a full truckload each time a customer is running out of stock? How many days of inventory is carried at each customer under this policy?
    (b) What is the optimal delivery policy to each customer if TopOil ships separately to each of them? What is the annual transportation and holding cost? How many days of inventory is carried at each customer under this policy?
    (c) What is the optimal delivery policy to each customer if TopOil aggregates shipments to each of the three customers on every truck that goes to Nashville? What is the annual transportation and holding cost? How many days of inventory are carried at each customer under this policy?
    (d) Can you come up with a tailored policy that has lower costs than the policies in (b) or (c)? What are the costs and inventories for your suggested policy?
11. Crunchy, a cereal manufacturer, has dedicated a plant for one major retail chain. Sales at the retail chain average about 20,000 boxes a month and production at the plant keeps pace with this average demand. Each box of cereal costs Crunchy $3 and is sold to the retailer at a wholesale price of $5. Both Crunchy and the retailer use a holding cost of 20 percent. For each order placed, the retailer incurs an ordering cost of $200 per order placed. Crunchy incurs the cost of transportation and loading that totals $1,000 per order shipped.
    (a) Given that it is trying to minimize its ordering and holding cost, what lot size will the retailer ask for in each order? What is the annual ordering and holding cost for the retailer as a result of this policy? What is the annual ordering and holding cost for Crunchy as a result of this policy? What is the total inventory cost across both parties as a result of this policy?
    (b) What lot size minimizes the inventory costs (ordering, delivery, and holding) across both Crunchy and the retailer? How much reduction in cost relative to (a) results from this policy?
    (c) Design an all unit quantity discount that results in the retailer ordering the quantity in (b).
    (d) How much of the $1,000 delivery cost should Crunchy pass along to the retailer for each lot to get the retailer to order the quantity in (b)?
12. The Orange company has introduced a new music device called the J-Pod. The J-Pod is sold through Good Buy, a major electronics retailer. Good Buy has estimated that demand for the J-Pod will depend on the final retail price p according to the demand curve

$$\text{Demand } D = 2{,}000{,}000 - 2{,}000p$$

The production cost for Orange is $100 per J-Pod.
    (a) What wholesale price should Orange charge for the J-Pod? At this wholesale price, what retail price should Good Buy set? What are the profits for Orange and Good Buy at equilibrium?

(b) If Orange decides to discount the wholesale price by $40, how much of a discount should Good Buy offer to customers if it wants to maximize its own profits? What fraction of the discount offered by Orange does Good Buy pass along to the customer?

13. The Orange company prices J-Pods at $550 per unit. Good Buy sells the J-Pods at $775. Annual demand at this retail price turns out to be 450,000 units. Good Buy incurs, ordering, receiving, and transportation costs of $10,000 for each lot of J-Pods ordered. The holding cost used by the retailer is 20 percent.
    (a) What is the optimal lot size that Good Buy should order?
    (b) The Orange company has discounted J-Pods by $40 for the short term (about the next two weeks). Good Buy has decided not to change the retail price but may change the lot size ordered with Orange. How should Good Buy adjust its lot size given this discount? How much does the lot size increase because of the discount?

Bibliography

Blattberg, Robert C., and Scott A. Neslin. *Sales Promotion: Concepts, Methods, and Strategies*. Upper Saddle River, NJ: Prentice Hall, 1990.

Brealey, Richard A., and Stewart C. Myers. *Principles of Corporate Finance*. Boston: Irwin McGraw-Hill. 2000.

Buzzell, Robert, John Quelch, and Walter Salmon. "The Costly Bargain of Trade Promotions." *Harvard Business Review* (March–April 1990): 141–9.

Crowther, John F. "Rationale for Quantity Discounts." *Harvard Business Review*, (March–April 1964): 121–7.

Dolan, Robert J. "Quantity Discounts: Managerial Issues and Research Opportunities." *Marketing Science* (1987) 6: 1–24.

Federgruen, Awi, and Yu-Sheng Zheng. "Optimal Power-of-Two Replenishment Strategies in Capacitated General Production/Distribution Networks." *Management Science* (1993) 39: 710–27.

Goyal, Suresh K. "A Simple Procedure for Price Break Models." *Production Planning & Control* (1995). 6: 584–5.

Kurt Salmon Associates, Inc. *Efficient Consumer Response*. Washington, DC: Food Marketing Institute, 1993.

Lee, Hau L., and Corey Billington. "Managing Supply Chain Inventories: Pitfalls and Opportunities." *Sloan Management Review* (Spring 1992): 65–73.

Maxwell, William L., and John A. Muckstadt. "Establishing Consistent and Realistic Reorder Intervals in Production-Distribution Systems." *Operations Research* (1985) 33: 1316–41.

Roundy, Robin. "98%-Effective Integer-Ratio Lot-Sizing for One-Warehouse Multi-Retailer Systems." *Management Science* (1985) 31: 1416–29.

Roundy, Robin. "A 98%-Effective Lot-Sizing Rule for a Multi-Product, Multi-Stage Production Inventory System." *Mathematics of Operations Research* (1986) 11: 699–727.

Silver, Edward A., David Pyke, and Rein Petersen. *Inventory Management and Production Planning and Scheduling*. New York: Wiley, 1998.

Zipkin, Paul H. *Foundations of Inventory Management*. Boston: Irwin McGraw-Hill, 2000.

CASE STUDY

DELIVERY STRATEGY AT MOONCHEM

John Kresge, Vice President of Supply Chain, was very concerned as he left the meeting at MoonChem, a manufacturer of specialty chemicals. The year-end meeting evaluated financial performance and discussed the fact that the firm was achieving only two inventory turns a year. A more careful look revealed that over half the inventory MoonChem owned was in consignment with its customers. This was very surprising, given that only 20 percent of its customers carried consignment inventory. John was responsible for inventory as well as transportation costs. He decided to take a careful look at the management of consignment inventory and come up with an appropriate plan.

MOONCHEM OPERATIONS

MoonChem, a manufacturer of specialty chemicals, had eight manufacturing plants and 40 distribution centers. The plants manufactured the base chemicals and the distribution centers mixed them to produce hundreds of end products that fit customer specifications. In the specialty chemicals market, MoonChem decided to differentiate itself in the Midwest region by providing consignment inventory to its customers. The company wanted to take this strategy national if it proved effective. MoonChem kept the chemicals required by each customer in the Midwest region on consignment at the customers' sites. Customers used the chemicals as needed, and MoonChem managed replenishment to ensure availability. In most instances, consumption of chemicals by customers was very stable. MoonChem owned the consignment inventories and was paid for the chemicals as they were used.

DISTRIBUTION AT MOONCHEM

MoonChem used Golden trucking, a full-truckload carrier, for all its shipments. Each truck had a capacity of 40,000 pounds, and Golden charged a fixed rate given the origin and destination, regardless of the quantity shipped on the truck. MoonChem sent full truckloads to each customer to replenish their consignment inventory.

THE ILLINOIS PILOT STUDY

John decided to take a careful look at his distribution operations. He focused on the state of Illinois, which was supplied from the Chicago distribution center. He broke up the state of Illinois into a collection of Zip Codes that were contiguous, as shown in Figure 10-9. He restricted attention within the Peoria region, which was classified as Zip Code 615. A careful study of the Peoria region revealed two large customers, six medium-sized customers, and 12 small customers. The annual consumption at each type of customer was as shown in Table 10-4. Golden charged $400 for each shipment from Chicago to Peoria, and MoonChem's policy was to send a full truckload to each customer as needed.

John checked with Golden to find out what it would take to include shipments for multiple customers on a single load. Golden informed him that they would continue to charge $350 per truck and would then add $50 for each drop-off that Golden was responsible for. Thus, if Golden carried a truck that had to make one delivery, the total charge would be $400. However, if a truck had to make four deliveries, the total charge would be $550.

Each pound of chemical in consignment cost MoonChem $1, and MoonChem had a holding cost of 25 percent. John wanted to analyze different options for distribution available in the Peoria region to decide on the optimal distribution policy. The detailed study of the Peoria region would provide the blueprint for the distribution strategy that MoonChem planned to roll out nationally.

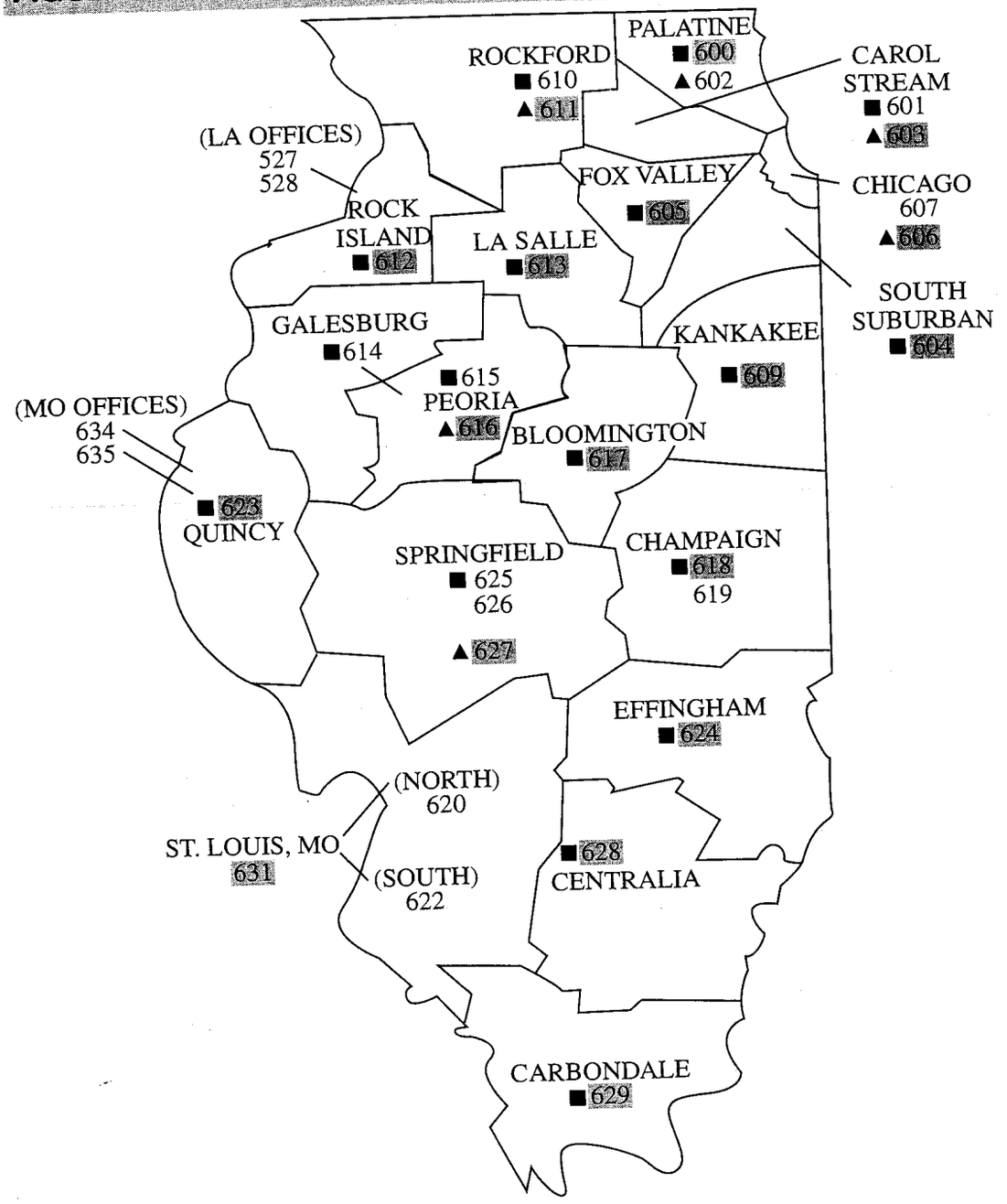
QUESTIONS

1. What is the annual cost of MoonChem's strategy of sending full truckloads to each customer in the Peoria region to replenish consignment inventory?
2. Consider different delivery options and evaluate the cost of each. What delivery option do you recommend for MoonChem?
3. How does your recommendation impact consignment inventory for MoonChem?

TABLE 10-4 Customer Profile for MoonChem in Peoria Region

Customer Type	*Number of Customers*	*Consumption (Pounds per Month)*
Small	12	1,000
Medium	6	5,000
Large	2	12,000

FIGURE 10-9 Illinois Zip Code Map



APPENDIX 10A

ECONOMIC ORDER QUANTITY

Objective: Derive the economic order quantity (EOQ) formula.

Analysis: Given an annual demand D, order cost S, unit cost C, and holding cost h, our goal is to estimate the lot size Q that minimizes the total annual cost. For a lot size of Q, the total annual cost is given by

Total annual cost, $TC = (D/Q)S + (Q/2)hC + CD$

To minimize the total cost we take the first derivative with respect to the lot size Q and set it to zero. Taking the first derivative with respect to Q, we have

$$\frac{d(TC)}{dQ} = -\frac{DS}{Q^2} + \frac{hC}{2}$$

Setting the first derivative to be zero, the EOQ is given by

$$Q^2 = \frac{2DS}{hC} \quad \text{or} \quad Q = \sqrt{\frac{2DS}{hC}}$$

CHAPTER 11
MANAGING UNCERTAINTY IN A SUPPLY CHAIN: SAFETY INVENTORY



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of safety inventory in a supply chain.
2. Identify factors that influence the required level of safety inventory.
3. Describe different measures of product availability.
4. Utilize managerial levers available to lower safety inventory and improve product availability.

In this chapter, we discuss how safety inventory can help a supply chain improve product availability in the presence of supply and demand variability. We discuss various measures of product availability and how managers can set safety inventory levels to provide the desired product availability. We also explore what managers can do to reduce the amount of safety inventory required while maintaining or even improving product availability.

11.1 THE ROLE OF SAFETY INVENTORY IN A SUPPLY CHAIN

Safety inventory is inventory carried to satisfy demand that exceeds the amount forecasted for a given period. Safety inventory is carried because demand is uncertain and a product shortage may result if actual demand exceeds the forecast demand. Consider, for example, Bloomingdale's, a high-end department store. Bloomingdale's sells purses purchased from Gucci, an Italian manufacturer. Given the high transportation cost from Italy, the store manager at Bloomingdale's orders in lots of 600 purses. Demand for purses at Bloomingdale's averages 100 a week. Gucci takes three weeks to deliver the purses to Bloomingdale's in response to an order. If there is no demand uncertainty and exactly 100 purses are sold each week, the store manager at Bloomingdale's can place an order when the store has exactly 300 purses remaining. In the absence of demand uncertainty, such a policy ensures that the new lot arrives just as the last purse is being sold at the store.

However, given demand fluctuations and forecast errors, actual demand over the three weeks may be higher or lower than the 300 purses forecasted. If the actual demand at Bloomingdale's is higher than 300, some customers will be unable to purchase purses, resulting in a potential loss of margin for Bloomingdale's. The store manager thus decides to place an order with Gucci when the store still has 400 purses. This policy improves product availability for the customer because the store now runs out

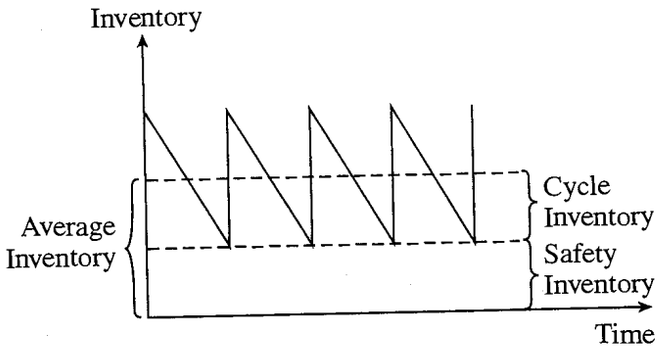


FIGURE 11-1 Inventory Profile with Safety Inventory

of purses only if the demand over the three weeks exceeds 400. Given an average weekly demand of 100 purses, the store will have an average of 100 purses remaining when the replenishment lot arrives. Safety inventory is the average inventory remaining when the replenishment lot arrives. Thus, Bloomingdale's carries a safety inventory of 100 purses.

Given a lot size of $Q = 600$ purses, the cycle inventory, the focus of the previous chapter, is $Q/2 = 300$ purses. The inventory profile at Bloomingdale's in the presence of safety inventory is shown in Figure 11-1. As Figure 11-1 illustrates, the average inventory at Bloomingdale's is the sum of the cycle and safety inventories.

This example illustrates a trade-off that a supply chain manager must consider when planning safety inventory. On one hand, raising the level of safety inventory increases product availability and thus the margin captured from customer purchases. On the other hand, raising the level of safety inventory increases inventory holding costs. This issue is particularly significant in industries in which product life cycles are short and demand is very volatile. Carrying excessive inventory can help counter demand volatility but can really hurt if new products come on the market and demand for the product in inventory dries up. The inventory on hand then becomes worthless.

In today's business environment, it has become easier for customers to search across stores for product availability. When shopping for books online, if Amazon.com is out of a title, a customer can easily check to see if BarnesandNoble.com has the title available. The increased ease of searching puts pressure on firms to improve product availability. Simultaneously, product variety has grown with increased customization. As a result, markets have become increasingly heterogeneous and demand for individual products is very unstable and difficult to forecast. Both the increased variety and the greater pressure for availability push firms to raise the level of safety inventory they hold. Given the product variety and high demand uncertainty in most high-tech supply chains, a significant fraction of the inventory carried is safety inventory.

As product variety has grown, however, product life cycles have shrunk. Thus, it is more likely that a product that is "hot" today will be obsolete tomorrow, which increases the cost to firms of carrying too much inventory. Thus, a key to the success of any supply chain is to figure out ways to decrease the level of safety inventory carried without hurting the level of product availability.

The importance of reduced safety inventories is emphasized by the experience of Dell and Compaq in the early part of 1998, when prices dropped. Compaq carried 100 days of inventory compared to Dell, which carried only 10 days of inventory. Declining prices hurt Compaq much more, given the extra inventory that it carried. In fact, this situation resulted in Compaq not making any profits in the first quarter of 1998.

A key to Dell's success has been its ability to provide a high level of product availability to customers while carrying very low levels of safety inventory in its supply

chain. This fact has also played a very important role in the success of Wal-Mart and Seven-Eleven Japan.

For any supply chain, there are two key questions to consider when planning safety inventory:

1. What is the appropriate level of safety inventory to carry?
2. What actions can be taken to improve product availability while reducing safety inventory?

The remainder of this chapter focuses on answering these questions. Next we consider factors that influence the appropriate level of safety inventory.

11.2 DETERMINING APPROPRIATE LEVEL OF SAFETY INVENTORY

The appropriate level of safety inventory is determined by the following two factors:

- The uncertainty of both demand and supply
- The desired level of product availability

As the uncertainty of supply or demand grows, the required level of safety inventories increases. Consider the sale of Palm personal digital assistants (PDAs) at B&M Office Supplies. When a new Palm model is introduced, demand is highly uncertain. B&M thus carries a much higher level of safety inventory relative to demand. As the market's reaction to the new model becomes clearer, uncertainty is reduced and demand is easier to predict. At that point, B&M can carry a lower level of safety inventory relative to demand.

As the desired level of product availability increases, the required level of safety inventory also increases. If B&M targets a higher level of product availability for the new Palm model, it must carry a higher level of safety inventory for that model.

Next we discuss some measures of demand uncertainty.

MEASURING DEMAND UNCERTAINTY

As discussed in Chapter 7, demand has a systematic as well as a random component. The goal of forecasting is to predict the systematic component and estimate the random component. The random component is usually estimated as the standard deviation of forecast error. We assume the following inputs for demand:

D: Average demand per period
σ_D: Standard deviation of demand (forecast error) per period

For now, we assume that weekly demand for the Palm at B&M is normally distributed, with a mean of D and a standard deviation of σ_D.

Lead time is the gap between when an order is placed and when it is received. In our discussion, we denote the lead time by L. In the B&M example, L is the time between when B&M orders Palms and when they are delivered. In this case, B&M is exposed to the uncertainty of demand during the lead time. Whether B&M is able to satisfy all demand from inventory depends on the demand for Palms experienced during the lead time and the inventory B&M has when a replenishment order is placed. Thus, B&M must estimate the uncertainty of demand during the lead time, not just a single period. We now evaluate the distribution of demand over k periods, given the distribution of demand during each period.

Assume that demand for each period i, $i = 1, \ldots, L$ is normally distributed with a mean D_i and standard deviation σ_i. Let ρ_{ij} be the correlation coefficient of demand between periods i and j. In this case, the total demand during L periods is normally distributed with a mean of P and a standard deviation of Ω, where the following is true:

$$P = D_L = \sum_{i=1}^{L} D_i \qquad \Omega = \sqrt{\sum_{i=1}^{k} \sigma_i^2 + 2\sum_{i>j} \rho_{ij}\sigma_i\sigma_j} \tag{11.1}$$

Demand in two periods is *perfectly positively correlated* if $\rho_{ij} = 1$. Demand in two periods is *perfectly negatively correlated* if $\rho_{ij} = -1$. Demand in two periods is *independent* if $\rho_{ij} = 0$. Assume that demand during each of L periods is independent and normally distributed with a mean of D and a standard deviation of σ_D. From Equation 11.1 we find that total demand during the L periods is normally distributed with a mean D_L and a standard deviation of σ_L, where the following is true:

$$D_L = LD \qquad \sigma_L = \sqrt{L}\sigma_D \tag{11.2}$$

Another important measure of uncertainty is the *coefficient of variation* (cv), which is the ratio of the standard deviation to the mean. Given demand with a mean of μ and a standard deviation of σ, we have

$$cv = \sigma/\mu$$

The coefficient of variation measures the size of the uncertainty relative to demand. It captures the fact that a product with mean demand of 100 and a standard deviation of 100 has greater demand uncertainty than a product with mean demand of 1,000 and a standard deviation of 100. Considering the standard deviation alone cannot capture this difference.

Next we discuss some measures of product availability.

MEASURING PRODUCT AVAILABILITY

Product availability reflects a firm's ability to fill a customer order out of available inventory. A *stockout* results if a customer order arrives when product is not available. There are several ways to measure product availability. Some of the important measures are as listed next.

1. ***Product fill rate (fr)*** is the fraction of product demand that is satisfied from product in inventory. Fill rate should be measured over specified amounts of demand rather than time. Thus, it is more appropriate to measure fill rate over every million units of demand rather than every month. Fill rate is equivalent to the probability that product demand is supplied from available inventory. Assume that B&M provides Palms to 90 percent of its customers from inventory, with the remaining 10 percent lost to a neighboring competitor because of a lack of available inventory. In this case B&M achieves a fill rate of 90 percent.

2. ***Order fill rate*** is the fraction of orders that are filled from available inventory. Order fill rate should also be measured over a specified number of orders rather than time. In a multiproduct scenario, an order is filled from inventory only if all products in the order can be supplied from the available inventory. In the case of B&M, a customer may order a Palm along with a calculator. The order is filled from inventory only if both the Palm and the calculator are available through the store. Order fill rates tend to be lower than product fill rates because all products must be in stock for an order to be filled.

3. ***Cycle service level (CSL)*** is the fraction of *replenishment cycles* that end with all the customer demand being met. A replenishment cycle is the interval between two

successive replenishment deliveries. The CSL is equal to the probability of not having a stockout in a replenishment cycle. CSL should be measured over a specified number of replenishment cycles. If B&M orders replenishment lots of 600 Palms, the interval between the arrival of two successive replenishment lots is a replenishment cycle. If the manager at B&M manages inventory such that the store does not run out of inventory in 6 out of 10 replenishment cycles, the store achieves a CSL of 60 percent. Observe that a CSL of 60 percent typically results in a much higher fill rate. In the 60 percent of cycles in which B&M does not run out of inventory, all customer demand is satisfied from available inventory. In the 40 percent of cycles in which a stockout does occur, most of the customer demand is satisfied from inventory. Only the small fraction toward the end of the cycle that arrives after B&M is out of inventory is lost. As a result, the fill rate is much higher than 60 percent.

The distinction between product fill rate and order fill rate is usually not significant in a single-product situation. When a firm is selling multiple products, however, this difference may be significant. For example, if most orders include 10 or more different products that are to be shipped, an out-of-stock situation of one product results in the order not being filled from stock. The firm in this case may have a poor order fill rate even though it has good product fill rates. Tracking order fill rates is important when customers place a high value on the entire order being filled simultaneously.

Next we describe two replenishment policies that are often used in practice.

REPLENISHMENT POLICIES

A replenishment policy consists of decisions regarding when to reorder and how much to reorder. These decisions determine the cycle and safety inventories along with the *fr* and the CSL. Replenishment policies may take any of several forms. We restrict attention to two types:

1. ***Continuous review:*** Inventory is continuously tracked and an order for a lot size Q is placed when the inventory declines to the reorder point (ROP). As an example, consider the store manager at B&M who continuously tracks the inventory of Palms. He orders 600 Palms when the inventory drops below 400. In this case, the size of the order does not change from one order to the next. The time between orders may fluctuate given variable demand.
2. ***Periodic review:*** Inventory status is checked at regular periodic intervals and an order is placed to raise the inventory level to a specified threshold. As an example, consider the purchase of film at B&M. The store manager does not track film inventory continuously. Every Saturday, employees check film inventory and the manager orders enough so that the available inventory and the size of the order total equals 1,000 films. In this case the time between orders is fixed. The size of each order, however, can fluctuate given variable demand.

These inventory policies are not comprehensive but suffice to illustrate the key managerial issues concerning safety inventories.

EVALUATING CYCLE SERVICE LEVEL AND FILL RATE GIVEN A REPLENISHMENT POLICY

We now discuss procedures for evaluating the CSL and *fr* given a replenishment policy. In this section, we restrict our attention to the continuous review policy, which is discussed in detail in Section 11.5. The replenishment policy consists of a lot size Q ordered when the inventory on hand declines to the ROP. Assume that weekly demand

is normally distributed, with mean D and standard deviation σ_D. Assume replenishment lead time of L weeks.

Evaluating Safety Inventory Given a Replenishment Policy

In the case of B&M, safety inventory corresponds to the average number of Palms on hand when a replenishment order arrives. Given the lead time of L weeks and a mean weekly demand of D, using Equation 11.2, we have

$$\text{Expected demand during lead time} = DL$$

Given that the store manager places a replenishment order when ROP Palms are on hand, we have

$$\text{Safety inventory, } ss = ROP - DL \tag{11.3}$$

This is because, on average, DL Palms will sell over the period between when the order is placed and when the lot arrives. The average inventory when the replenishment lot arrives will thus be $ROP - DL$.

Example 11-1: **Evaluating safety inventory given an inventory policy**
Assume that weekly demand for Palms at B&M Computer World is normally distributed, with a mean of 2,500 and a standard deviation of 500. The manufacturer takes two weeks to fill an order placed by the B&M manager. The store manager currently orders 10,000 Palms when the inventory on hand drops to 6,000. Evaluate the safety inventory carried by B&M and the average inventory carried by B&M. Also evaluate the average time spent by a Palm at B&M.

Analysis: Under this replenishment policy, we have

Average demand per week, $D = 2{,}500$
Standard deviation of weekly demand, $\sigma_D = 500$
Average lead time for replenishment, $L = 2$ weeks
Reorder point, $ROP = 6{,}000$
Average lot size, $Q = 10{,}000$

Using Equation 11.3, we thus have

$$\text{Safety inventory, } ss = ROP - DL = 6{,}000 - 5{,}000 = 1{,}000$$

B&M thus carries a safety inventory of 1,000 Palms. From Chapter 10, recall that

$$\text{Cycle inventory} = Q/2 = 10{,}000/2 = 5{,}000$$

We thus have

$$\text{Average inventory} = \text{cycle inventory} + \text{safety inventory} = 5{,}000 + 1{,}000 = 6{,}000$$

B&M thus carries an average of 6,000 Palms in inventory. Using Little's law (Equation 3.1), we have

$$\text{Average flow time} = \text{average inventory/throughput} = 6{,}000/2{,}500 = 2.4 \text{ weeks}$$

Each Palm thus spends an average of 2.4 weeks at B&M.

Next we discuss how to evaluate the CSL given a replenishment policy.

Evaluating Cycle Service Level Given a Replenishment Policy

Given a replenishment policy, our goal is to evaluate CSL, the probability of not stocking out in a replenishment cycle. We return to B&M's continuous review replenishment policy of ordering Q units when the inventory on hand drops to the ROP. The lead time is L weeks and weekly demand is normally distributed, with a mean of D and a standard deviation of σ_D. Observe that a stockout occurs in a cycle if demand during the lead time is larger than the ROP. Thus, we have

$$CSL = \text{Prob}(\text{demand during lead time of } L \text{ weeks} \leq ROP)$$

To evaluate this probability, we need to obtain the distribution of demand during the lead time. From Equation 11.2, we know that demand during lead time is normally distributed, with a mean of D_L and a standard deviation of σ_L. Using the notation for the normal distribution from Appendix 11A, the CSL is

$$CSL = F(ROP, D_L, \sigma_L) \tag{11.4}$$

We now illustrate this evaluation in Example 11-2.

Example 11-2: **Evaluating cycle service level given a replenishment policy**
Weekly demand for Palms at B&M is normally distributed, with a mean of 2,500 and a standard deviation of 500. The replenishment lead time is two weeks. Assume that the demand is independent from one week to the next. Evaluate the CSL resulting from a policy of ordering 10,000 Palms when there are 6,000 Palms in inventory.

Analysis: In this case we have

$Q = 10{,}000, ROP = 6{,}000, L = 2$ weeks
$D = 2{,}500$/week, $\sigma_D = 500$

Observe that B&M runs the risk of stocking out during the two weeks between when an order is placed and when the replenishment arrives. Thus, whether a stockout occurs or not depends on the demand during the lead time of two weeks.

Because demand across time is independent, we use Equation 11.2 to obtain demand during the lead time to be normally distributed with a mean of D_L and a standard deviation of σ_L, where

$$D_L = DL = 2 \times 2{,}500 = 5{,}000 \qquad \sigma_L = \sqrt{L}\sigma_D = \sqrt{2} \times 500 = 707$$

Using Equation 11.4, the CSL is evaluated as

$$CSL = \text{probability of not stocking out in a cycle} = F(ROP, D_L, \sigma_L) = F(6{,}000, 5{,}000, 707)$$

Using Equation 11.19 in Appendix 11B, the CSL is evaluated using the Excel function *NORMDIST* as

$$\begin{aligned} CSL &= F(ROP, D_L, \sigma_L) = NORMDIST(ROP, D_L, \sigma_L, 1) \\ &= NORMDIST(6{,}000, 5{,}000, 707, 1) = 0.92 \end{aligned}$$

A CSL of 0.92 implies that in 92 percent of the replenishment cycles, B&M supplies all demand from available inventory. In the remaining 8 percent of the cycles, stockouts occur and some demand is not satisfied because of the lack of inventory.

Next we discuss the evaluation of the fill rate given a replenishment policy.

Evaluating Fill Rate Given a Replenishment Policy

Recall that fill rate measures the proportion of customer demand that is satisfied from available inventory. Fill rate is generally a more relevant measure than cycle service level because it allows the retailer to estimate the fraction of demand that is turned into sales. The two measures are very closely related, as raising the cycle service level also raises the fill rate for a firm. Our discussion focuses on evaluating fill rate for a continuous review policy under which Q units are ordered when the quantity on hand drops to the ROP.

To evaluate the fill rate it is important to understand the process by which a stockout occurs during a replenishment cycle. A stockout occurs if the demand during the lead time exceeds the ROP. We thus need to evaluate the average amount of demand in excess of the ROP in each replenishment cycle.

The *expected shortage per replenishment cycle* (ESC) is the average units of demand that are not satisfied from inventory in stock per replenishment cycle. Given a lot size of Q (which is also the average demand in a replenishment cycle), the fraction of demand lost is thus ESC/Q. The product fill rate fr is thus given by

$$fr = 1 - ESC/Q = (Q - ESC)/Q \tag{11.5}$$

A shortage occurs in a replenishment cycle only if the demand during the lead time exceeds the ROP. Let $f(x)$ be the density function of the demand distribution during the lead time. The ESC is given by

$$ESC = \int_{x=ROP}^{\infty} (x - ROP) f(x)\, dx \tag{11.6}$$

In the case where demand during the lead time is normally distributed with mean D_L and standard deviation σ_L, given a safety inventory ss, Equation 11.6 can be simplified to

$$ESC = -ss\left[1 - F_s\left(\frac{ss}{\sigma_L}\right)\right] + \sigma_L f_s\left(\frac{ss}{\sigma_L}\right) \tag{11.7}$$

where F_s is the standard normal cumulative distribution function and f_s is the standard normal density function. A detailed description of the normal distribution is given in Appendix 11A. Details of the simplification in Equation 11.7 are described in Appendix 11C. Using Excel functions (Equations 11.22 and 11.23) discussed in Appendix 11B, ESC may be evaluated (using Equation 11.7) as

$$\begin{aligned} ESC = {} & -ss[1 - NORMDIST(ss/\sigma_L, 0, 1, 1)] \\ & + \sigma_L\, NORMDIST(ss/\sigma_L, 0, 1, 0) \end{aligned} \tag{11.8}$$

Given the ESC, we can use Equation 11.5 to evaluate the fill rate fr. Next we illustrate this evaluation in Example 11-3.

Example 11-3: **Evaluating fill rate given a replenishment policy**
From Example 11-2, recall that weekly demand for Palms at B&M is normally distributed, with a mean of 2,500 and a standard deviation of 500. The replenishment lead time is two weeks. Assume that the demand is independent from one week to the next. Evaluate the fill rate resulting from the policy of ordering 10,000 Palms when there are 6,000 Palms in inventory.

Analysis: From the analysis of Example 11-2, we have

Lot size, $Q = 10{,}000$
Average demand during lead time, $D_L = 5{,}000$
Standard deviation of demand during lead time, $\sigma_L = 707$

Using Equation 11.3, we obtain

$$\text{Safety inventory, } ss = ROP - DL = 6{,}000 - 5{,}000 = 1{,}000$$

From Equation 11.8, we thus have

$$\begin{aligned} ESC = {} & -1{,}000[1 - NORMDIST(1{,}000/707, 0, 1, 1)] \\ & + 707\, NORMDIST(1{,}000/707, 0, 1, 0) = 25 \end{aligned}$$

Thus, on average, in each replenishment cycle, 25 Palms are demanded by customers but not available in inventory. Using Equation 11.5, we thus obtain the following fill rate:

$$fr = (Q - ESC)/Q = (10{,}000 - 25)/10{,}000 = 0.9975$$

In other words, 99.75 percent of the demand is filled from inventory in stock. This is much higher than the CSL of 92 percent that resulted in Example 11-2 for the same replenishment policy.

All the calculations for Example 11-3 may be done easily in Excel, as shown in Figure 11-2.

A few key observations should be made. First, observe that the fill rate (0.9975) in Example 11-3 is significantly higher than the CSL (0.92) in Example 11-2 for the same replenishment policy. Next, by rerunning the examples with a different lot size, we can observe the impact of lot size changes on the service level. Increasing the lot size of

	A	B	C	D	E
1	*Inputs*				
2	Q	R	σ_R	L	ss
3	10,000	2,500	500	2	1,000
4	*Distribution of demand during lead time*				
5	R_L	σ_L			
6	5,000	707			
7	*Cycle Service Level and Fill Rate*				
8	CSL	ESC	fr		
9	0.92	25.13	0.9975		

Cell	Cell Formula	Equation
A6	=B3*D3	11.2
B6	=SQRT(D3)*C3	11.2
A9	=NORMDIST(A6+E3, A6, B6, 1)	11.4
B9	=-E3*(1-NORMDIST(E3/B6, 0, 1, 1)) + B6*NORMDIST(E3/B6, 0, 1, 0)	11.8
C9	=(A3-B9)/A3	11.5

FIGURE 11-2 Excel Solution of Example 11-3

Palms from 10,000 to 20,000 has no impact on the CSL (which stays at 0.92). The fill rate, however, now increases to 0.9987. This is because an increase in lot size results in fewer replenishment cycles. In the case of B&M, an increase in lot size from 10,000 to 20,000 results in replenishment occurring once every eight weeks instead of once every four weeks. With a 92 percent CSL, a lot size of 10,000 results in, on average, one cycle with a stockout per year. With a lot size of 20,000, we have, on average, one stockout every two years. Thus, the fill rate is higher.

KEY POINT Both fill rate and cycle service level increase as the safety inventory is increased. For the same safety inventory, an increase in lot size increases the fill rate but not the cycle service level.

We now discuss how the appropriate level of safety inventory may be obtained given a desired CSL or fill rate.

EVALUATING SAFETY INVENTORY GIVEN DESIRED CYCLE SERVICE LEVEL OR FILL RATE

In many practical settings, firms have a desired level of product availability and want to design replenishment polices that achieve this level. For example, Wal-Mart has a desired level of product availability for each product sold in a store. The store manager must design a replenishment policy with the appropriate level of safety inventory to meet this goal. The desired level of product availability may be determined by trading off the cost of holding inventory with the cost of a stockout. This trade-off is discussed in detail in Chapter 12. In other instances, the desired level of product availability (in terms of CSL or fill rate) is stated explicitly in contracts, and management must design replenishment policies that achieve the desired target.

Evaluating Required Safety Inventory Given Desired Cycle Service Level

Our goal is to obtain the appropriate level of safety inventory given the desired CSL. We assume that a continuous review replenishment policy is followed. Consider the

store manager at Wal-Mart responsible for designing replenishment policies for all products in the store. He has targeted a CSL for the basic box of Lego building blocks. Given a lead time of L, the store manager wants to identify a suitable ROP and safety inventory that achieves the desired service level. Assume that demand for Lego at Wal-Mart is normally distributed and independent from one week to the next. We assume the following inputs:

Desired cycle service level = CSL
Mean demand during lead time = D_L
Standard deviation of demand during lead time = σ_L

From Equation 11.3, recall that $ROP = D_L + ss$. The store manager needs to identify safety inventory ss such that the following is true:

$$\text{Probability(demand during lead time} \leq D_L + ss) = CSL$$

Given that demand is normally distributed, (using Equation 11.4), the store manager must identify safety inventory ss such that the following is true:

$$F(D_L + ss, D_L, \sigma_L) = CSL$$

Given the definition of the inverse normal in Appendix 11A, we obtain

$$D_L + ss = F^{-1}(CSL, D_L, \sigma_L) \quad \text{or} \quad ss = F^{-1}(CSL, D_L, \sigma_L) - D_L$$

Using the definition of the standard normal distribution and its inverse from Appendix 11A, it can also be shown that the following is true:

$$ss = F_S^{-1}(CSL) \times \sigma_L \tag{11.9}$$

In Example 11-4 we illustrate the evaluation of safety inventory given a desired CSL.

Example 11-4: **Evaluating safety inventory given a desired cycle service level**
Weekly demand for Lego at a Wal-Mart store is normally distributed, with a mean of 2,500 boxes and a standard deviation of 500. The replenishment lead time is two weeks. Assuming a continuous-review replenishment policy, evaluate the safety inventory that the store should carry to achieve a CSL of 90 percent.

Analysis: In this case we have

Q = 10,000, CSL = 0.9, L = 2 weeks
D = 2,500/week, σ_D = 500

Because demand across time is independent, we use Equation 11.2 to find demand during the lead time to be normally distributed with a mean of D_L and a standard deviation of σ_L, where

$$D_L = DL = 2 \times 2{,}500 = 5{,}000 \qquad \sigma_L = \sqrt{L}\sigma_D = \sqrt{2} \times 500 = 707$$

Using Equations 11.9 and 11.24 in Appendix 11B, we obtain

$$ss = F_s^{-1}(CSL) \times \sigma_L = NORMSINV(CSL) \times \sigma_L = NORMSINV(0.90) \times 707 = 906$$

Thus, the required safety inventory to achieve a CSL of 90 percent is 906 boxes.

Evaluating Required Safety Inventory Given Desired Fill Rate

We now evaluate the required safety inventory given a desired fill rate fr and the fact that a continuous review replenishment policy is followed. Consider the store manager at Wal-Mart targeting a fill rate fr for Lego building blocks. The current replenishment lot size is Q. The first step is to obtain the ESC using Equation 11.5. The expected shortage per replenishment cycle is

$$ESC = (1 - fr)Q$$

The next step is to obtain a safety inventory *ss* that solves Equation 11.7 (and its Excel equivalent, Equation 11.8) given the ESC evaluated earlier. It is not possible to give a formula that provides the answer. The appropriate safety inventory that solves Equation 11.8 can be obtained easily using Excel and trying different values of *ss*. In Excel the safety inventory may also be obtained directly using the tool *GOALSEEK*, as illustrated in Example 11-5.

Example 11-5: **Evaluating safety inventory given desired fill rate**
Weekly demand for Legos at a Wal-Mart store is normally distributed, with a mean of 2,500 boxes and a standard deviation of 500. The replenishment lead time is two weeks. The store manager currently orders replenishment lots of 10,000 boxes from Lego. Assuming a continuous-review replenishment policy, evaluate the safety inventory the store should carry to achieve a fill rate of 97.5 percent.

Analysis: In this case we have

Desired fill rate, $fr = 0.975$
Lot size, $Q = 10{,}000$ boxes
Standard deviation of demand during lead time, $\sigma_L = 707$

From Equation 11.5, we thus obtain an ESC as

$$ESC = (1 - fr)Q = (1 - 0.975)10{,}000 = 250$$

Now we need to solve Equation 11.7 for the safety inventory *ss*, where

$$ESC = 250 = -ss\left[1 - F_s\left(\frac{ss}{\sigma_L}\right)\right] + \sigma_L f_s\left(\frac{ss}{\sigma_L}\right) = -ss\left[1 - F_s\left(\frac{ss}{707}\right)\right] + 707\, f_s\left(\frac{ss}{707}\right)$$

Using Equation 11.8, this equation may be restated with Excel functions as follows:

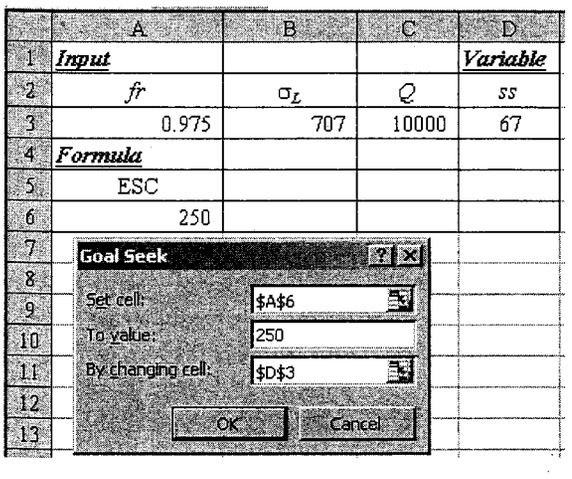
$$250 = -ss[1 - NORMSDIST(ss/707)] + 707NORMDIST(ss/707) \qquad \textbf{(11.10)}$$

Equation 11.10 may be solved in Excel by trying different values of *ss* until the equation is satisfied. A more elegant approach for solving Equation 11.10 is to use the Excel tool *GOALSEEK* as follows.

First set up the spreadsheet as shown in Figure 11-3, where cell D3 can have any value for the safety inventory *ss*.

Invoke *GOALSEEK* using Tools | Goal Seek. In the *GOALSEEK* dialog box, enter the data as shown in Figure 11-3 and click the OK button. In this case, cell D3 is changed until the value of the formula in cell A6 equals 250.

FIGURE 11-3 Spreadsheet to Solve for *ss* Using *GOALSEEK*



Cell	Cell Formula	Equation
A6	-D3*(1-NORMSDIST(D3/B3)) + B3*NORMDIST(D3/B3, 0, 1, 0)	11.10

TABLE 11-1 Required Safety Inventory for Different Values of Fill Rate

Fill Rate	*Safety Inventory*
97.5%	67
98.0%	183
98.5%	321
99.0%	499
99.5%	767

Using *GOALSEEK*, we obtain a safety inventory of $ss = 67$ boxes as shown in Figure 11-3. Thus, the store manager at Wal-Mart should target a safety inventory of 67 boxes to achieve the desired fill rate of 97.5 percent.

Next we identify the factors that affect the required level of safety inventory.

IMPACT OF DESIRED PRODUCT AVAILABILITY AND UNCERTAINTY ON SAFETY INVENTORY

The two key factors that affect the required level of safety inventory are the desired level of product availability and uncertainty. We now discuss the impact that each factor has on the safety inventory.

As the desired product availability goes up, the required safety inventory also increases because the supply chain must now be able to accommodate uncommonly high demand or uncommonly low supply. For the Wal-Mart situation in Example 11-5, we evaluate the required safety inventory for varying levels of fill rate as shown in Table 11-1.

Observe that raising the fill rate from 97.5 percent to 98.0 percent requires an additional 116 units of safety inventory, whereas raising the fill rate from 99.0 percent to 99.5 percent requires an additional 268 units of safety inventory. Thus, the marginal increase in safety inventory grows as product availability rises. This phenomenon highlights the importance of selecting suitable product availability levels. It is very important for a supply chain manager to be aware of the products that require a high level of availability and hold high safety inventories only for those products. It is not appropriate to select a very high level of product availability and require it arbitrarily for all products.

KEY POINT The required safety inventory grows rapidly with an increase in the desired product availability.

From Equation 11.9, we see that the required safety inventory ss is also influenced by the standard deviation of demand during the lead time, σ_L. The standard deviation of demand during the lead time is influenced by the duration of the lead time L as well as the standard deviation of periodic demand σ_D, as shown in Equation 11.2. The relationship between safety inventory and σ_D is linear in that a 10 percent increase in σ_D results in a 10 percent increase in safety inventory. Safety inventory also increases with an increase in lead time L. The safety inventory, however, is proportional to the square root of the lead time (if demand is independent over time) and thus grows more slowly than the lead time itself.

KEY POINT The required safety inventory increases with an increase in the lead time and the standard deviation of periodic demand.

A goal of any supply chain manager is to reduce the level of safety inventory required in a way that does not adversely affect product availability. The aforementioned discussion highlights two key managerial levers that may be used to achieve this goal.

1. ***Reduce the supplier lead time L:*** If lead time decreases by a factor of k, the required safety inventory decreases by a factor of $\sqrt{k}$. The only caveat here is that reducing the supplier lead time requires significant effort from the supplier, whereas reduction in safety inventory occurs at the retailer. Thus it is important for the retailer to share some of the resulting benefits as discussed in Chapter 14. Wal-Mart, Seven-Eleven Japan, and many other retailers apply tremendous pressure on their suppliers to reduce the replenishment lead time. Manufacturers such as Dell also require suppliers to reduce their lead times. In each case, the benefit has manifested itself in the form of reduced safety inventory.

2. ***Reduce the underlying uncertainty of demand (represented by σ_D):*** If σ_D is reduced by a factor of k, the required safety inventory also decreases by a factor of k. A reduction in σ_D may be achieved by better market intelligence and the use of more sophisticated forecasting methods. Seven-Eleven Japan provides its store managers with detailed data about prior demand along with weather and other factors that may influence demand. This market intelligence allows the store managers to make better forecasts, reducing uncertainty. In most supply chains, however, the key to reducing the underlying forecast uncertainty is to link all forecasts throughout the supply chain to customer demand data. A lot of the demand uncertainty exists only because each stage of the supply chain plans and forecasts independently. This distorts demand throughout the supply chain, increasing uncertainty. Improved coordination, as discussed in Chapter 17, can often reduce the demand uncertainty significantly. Both Dell and Seven-Eleven Japan share demand information with their suppliers, reducing uncertainty and thus safety inventory within the supply chain.

11.3 IMPACT OF SUPPLY UNCERTAINTY ON SAFETY INVENTORY

In our discussion to this point, we have focused on situations with demand uncertainty in the form of a forecast error. In many practical situations, supply uncertainty also plays a significant role. Consider the case of the Dell assembly plant in Austin, Texas. Dell assembles computers to customer order. When it is planning its level of component inventory, Dell clearly has to take demand uncertainty into account. Suppliers, however, may not be able to deliver the components required on time, for a variety of reasons. Dell must also account for this supply uncertainty when planning its safety inventories.

In our previous discussion we considered the replenishment lead time to be fixed. In this section we consider the case in which the lead time is uncertain and identify the impact of lead time uncertainty on safety inventories. Assume that the customer demand per period for Dell computers and the replenishment lead time from the component supplier are normally distributed. We are provided the following inputs:

D: Average demand per period
σ_D: Standard deviation of demand per period
L: Average lead time for replenishment
s_L: Standard deviation of lead time

We consider the safety inventory requirements given that Dell follows a continuous review policy to manage component inventory. Dell experiences a stockout of components if demand during the lead time exceeds the ROP; that is, the quantity on hand when Dell places a replenishment order. Thus we need to identify the distribution of customer demand during the lead time. Given that both lead time and periodic demand are uncertain, demand during the lead time is normally distributed with a mean of D_L and a standard deviation σ_L, where

$$D_L = DL \qquad \sigma_L = \sqrt{L\sigma_D^2 + D^2 s_L^2} \tag{11.11}$$

Given the distribution of demand during the lead time in Equation 11.11 and a desired CSL, Dell can obtain the required safety inventory using Equation 11.9. If product availability is specified as a fill rate, Dell can obtain the required safety inventory using the procedure outlined in Example 11-5. In Example 11-6, we illustrate the impact of lead time uncertainty on the required level of safety inventory at Dell.

Example 11-6: **Impact of lead time uncertainty on safety inventory**
Daily demand for PCs at Dell is normally distributed, with a mean of 2,500 and a standard deviation of 500. A key component in PC assembly is the hard drive. The hard drive supplier takes an average of $L = 7$ days to replenish inventory at Dell. Dell is targeting a CSL of 90 percent (providing a fill rate close to 100 percent) for its hard drive inventory. Evaluate the safety inventory of hard drives that Dell must carry if the standard deviation of the lead time is seven days. Dell is working with the supplier to reduce the standard deviation to zero. Evaluate the reduction in safety inventory that Dell can expect as a result of this initiative.

Analysis: In this case we have

Average demand per period, $D = 2{,}500$
Standard deviation of demand per period, $\sigma_D = 500$
Average lead time for replenishment, $L = 7$ days
Standard deviation of lead time, $s_L = 7$ days

We first evaluate the distribution of demand during the lead time. Using Equation 11.11, we have

$$\text{Mean demand during lead time, } D_L = DL = 2{,}500 \times 7 = 17{,}500$$

$$\text{Standard deviation of demand during lead time } \sigma_L = \sqrt{L\sigma_D^2 + D^2 s_L^2}$$
$$= \sqrt{7 \times 500^2 + 2{,}500^2 \times 7^2} = 17{,}550$$

The required safety inventory is obtained using Equations 11.9 and 11.24 as follows:

$$ss = F_S^{-1}(CSL) \times \sigma_L = NORMSINV(CSL) \times \sigma_L = NORMSINV(0.90) \times 17{,}550$$
$$= 22{,}491 \text{ hard drives}$$

If the standard deviation of lead time is seven days, Dell must carry a safety inventory of 22,491 drives. Observe that this is equivalent to about nine days of demand for hard drives.

In Table 11-2 we provide the required safety inventory as Dell works with the supplier to reduce standard deviation of lead time down to zero. From Table 11-2, observe that the reduction in lead time uncertainty allows Dell to reduce its safety inventory of hard drives by a significant amount. As the standard deviation of lead time declines from seven days to zero, the amount of safety inventory declines from about nine days of demand to less than a day of demand.

The preceding example emphasizes the impact of lead time variability on safety inventory requirements (and thus material flow time) and the large potential benefits from reducing lead time variability or improving on-time deliveries. Often, safety inventory calculations in practice do not include any measure of supply uncertainty, resulting in levels that may be lower than required. This hurts product availability.

TABLE 11-2 Required Safety Inventory as a Function of Lead Time Uncertainty

σ_R	σ_L	*ss (units)*	*ss (days)*
6	15,058	19,298	7.72
5	12,570	16,109	6.44
4	10,087	12,927	5.17
3	7,616	9,760	3.90
2	5,172	6,628	2.65
1	2,828	3,625	1.45
0	1,323	1,695	0.68

KEY POINT A reduction in supply uncertainty can help dramatically reduce safety inventory required without hurting product availability.

In practice, variability of supply lead time is caused by practices at both the supplier as well as the party receiving the order. Suppliers sometimes have poor planning tools that do not allow them to schedule production in a way that can be executed. Today, most supply chain planning software suites have good production planning tools that allow suppliers to promise lead times that can be met. This helps reduce lead-time variability. In other instances, the behavior of the party placing the order often increases lead-time variability. In one instance, a distributor placed orders to all suppliers on the same day of the week. As a result, all deliveries arrived on the same day of the week. The surge in deliveries made it impossible for all of them to be recorded into inventory on the day they arrived. This led to a perception that supply lead times were long and variable. Just by leveling out the orders over the week, the lead time and the lead-time variability were significantly reduced, allowing the distributor to reduce its safety inventory.

Next we discuss how aggregation can help reduce the amount of safety inventory in the supply chain.

11.4 IMPACT OF AGGREGATION ON SAFETY INVENTORY

In practice, supply chains have varying degrees of inventory aggregation. For example, HP sells computers through retail stores such as Best Buy with inventory distributed all over the country. Dell, in contrast, has a few centralized facilities from which all customer orders are shipped. Borders and Barnes & Noble sell books and music from retail stores with inventory geographically distributed across the country. Amazon.com, in contrast, ships all its books and music from a few facilities. Seven-Eleven Japan has many small convenience stores densely distributed across Japan. In contrast, supermarkets tend to be much larger, with fewer outlets that are not as densely distributed.

Our goal is to understand how aggregation in each of the aforementioned cases affects forecast accuracy and safety inventories. Consider k regions, with demand in each region normally distributed with the following characteristics:

D_i: Mean weekly demand in region $i, i = 1, \ldots, k$
σ_i: Standard deviation of weekly demand in region $i, i = 1, \ldots, k$
ρ_{ij}: Correlation of weekly demand for regions $i, j, 1 \leq i \neq j \leq k$

There are two ways to serve demand in the k regions. One is to have local inventories in each region and the other is to aggregate all inventories into one centralized facility. Our goal is to compare safety inventories in the two cases. With a replenishment lead time of L and a desired cycle service level CSL, the total safety inventory in the decentralized case is (using Equation 11.9).

$$\text{Total safety inventory in decentralized option} = \sum_{i=1}^{k} F_S^{-1}(CSL) \times \sqrt{L} \times \sigma_i \quad \textbf{(11.12)}$$

If all inventories are aggregated in a central location, we need to evaluate the distribution of aggregated demand. The aggregate demand is normally distributed, with a mean of D^C, standard deviation of σ_D^C, and a variance of $\text{var}(D^C)$ as follows:

$$D^C = \sum_{i=1}^{k} D_i \qquad \text{var}(D^C) = \sum_{i=1}^{k} \sigma_i^2 + 2\sum_{i>j} \rho_{ij}\sigma_i\sigma_j \qquad \sigma_D^C = \sqrt{\text{var}(D^C)} \quad \textbf{(11.13)}$$

If all k regions have demand that is independent ($\rho_{ij} = 0$) and identically distributed, with mean D and standard deviation σ, Equation 11.13 can be simplified as

$$D^C = kD \qquad \sigma_D^C = \sqrt{k}\sigma \quad \textbf{(11.14)}$$

The required safety inventory at the centralized location is given as

$$\text{Required safety inventory on aggregation} = F_S^{-1}(CSL) \times \sqrt{L} \times \sigma_D^C \quad \textbf{(11.15)}$$

The holding-cost savings on aggregation per unit sold are obtained by dividing the savings in holding cost by the total demand kD. If H is the holding cost per unit, using Equations 11.13 and 11.15 the savings per units are

$$\text{Holding-cost savings on aggregation per unit sold} = \frac{F_S^{-1}(CSL) \times \sqrt{L} \times H}{D^C} \times \left(\sum_{i=1}^{k} \sigma_i - \sigma_D^C\right) \quad \textbf{(11.16)}$$

From Equation 11.13 it follows that the difference $(\Sigma_{i=1}^{k}\sigma_i - \sigma_D^C)$ is influenced by the correlation coefficients ρ_{ij}. This difference is large when the correlation coefficients are close to -1 (negative correlation) and shrinks as they approach $+1$ (positive correlation). Inventory savings on aggregation are always positive as long as the correlation coefficients are less than 1. From Equation 11.16, we thus draw the following conclusions regarding the value of aggregation.

- The safety inventory savings on aggregation increase with the desired cycle service level CSL.
- The safety inventory savings on aggregation increase with the replenishment lead time L.
- The safety inventory savings on aggregation increase with the holding cost H.
- The safety inventory savings on aggregation decrease as the correlation coefficients increase.

In Example 11-7 we illustrate the inventory savings on aggregation and the impact of the correlation coefficient on these savings.

Example 11-7: **Impact of correlation on value of aggregation**
A BMW dealership has four retail outlets serving the entire Chicago area (disaggregate option). Weekly demand at each outlet is normally distributed, with a mean of $D = 25$ cars and a standard deviation of $\sigma_D = 5$. The lead time for replenishment from the manufacturer is $L = 2$ weeks. Each outlet covers a separate geographic area, and the correlation of demand across any pair of areas is ρ. The dealership is considering the possibility of

TABLE 11-3 Safety Inventory in the Disaggregate and Aggregate Options

ρ	*Disaggregate Safety Inventory*	*Aggregate Safety Inventory*
0	36.24	18.12
0.2	36.24	22.92
0.4	36.24	26.88
0.6	36.24	30.32
0.8	36.24	33.41
1.0	36.24	36.24

replacing the four outlets with a single large outlet (aggregate option). Assume that the demand in the central outlet is the sum of the demand across all four areas. The dealership is targeting a CSL of 0.90. Compare the level of safety inventory needed in the two options as the correlation coefficient ρ varies between 0 and 1.

Analysis: We provide a detailed analysis for the case when demand in each area is independent (i.e., $\rho = 0$). For each retail outlet we have

Standard deviation of weekly demand, $\sigma_D = 5$.
Replenishment lead time, $L = 2$ weeks

Using Equation 11.12 with $\rho_{ij} = 0$, the required safety inventory in the decentralized option for $CSL = 0.90$ is

$$\text{Total required safety inventory, } ss = k \times F_s^{-1}(CSL) \times \sqrt{L} \times \sigma_D$$
$$= 4 \times F_s^{-1}(0.9) \times \sqrt{2} \times 5 = 36.24 \text{ cars}$$

Now consider the aggregate option. Because demand in all four areas is independent, $\rho = 0$. Using Equation 11.14, the standard deviation of aggregate weekly demand is

$$\text{Standard deviation of weekly demand at central outlet, } \sigma_D^C = \sqrt{4} \times 5 = 10$$

For a CSL of 0.90, safety inventory required for the aggregate option (using Equation 11.15) is given as

$$ss = F_s^{-1}(0.90) \times \sqrt{L} \times \sigma_D^C = NORMSINV(0.90) \times \sqrt{2} \times 10 = 18.12$$

Using Equations 11.12–11.15, the required level of safety inventory for the disaggregate as well as the aggregate option can be obtained for different values of ρ as shown in Table 11-3. Observe that the safety inventory for the disaggregate option is higher than for the aggregate option except when all demands are perfectly positively correlated. The benefit of aggregation decreases as demand in different areas is more positively correlated.

Example 11-7 and the previous discussion demonstrate that aggregation reduces demand uncertainty and thus the required safety inventory as long as the demand being aggregated is not perfectly positively correlated. Demand for most products does not show perfect positive correlation across different geographic regions. Products such as heating oil are likely to have demand that is positively correlated across nearby regions. In contrast, products such as milk and sugar are likely to have demand that is much more independent across regions. If demand in different geographic regions is about the same size and independent, aggregation reduces safety inventory by the square root of the number of areas aggregated. In other words, if the number of independent stocking locations decreases by a factor of n, the average safety inventory is expected to decrease by a factor of $\sqrt{n}$. This principle is referred to as the *square-root law*. The square-root law is illustrated in Figure 11-4.

Most e-commerce firms exploit the benefits of aggregation in terms of reduced inventories. The best-known example in this regard is Amazon.com, which has

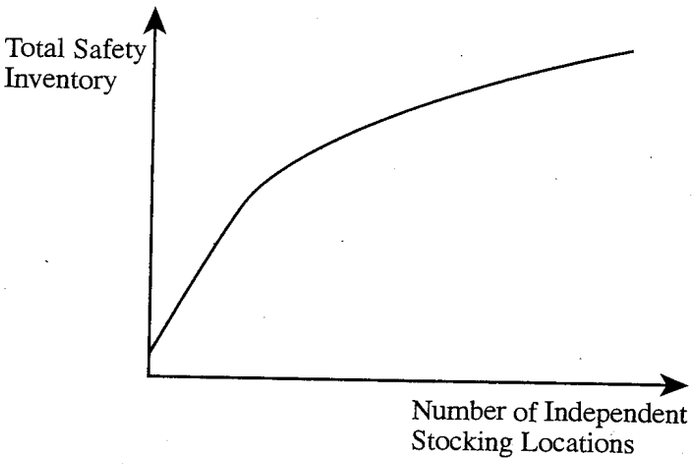


FIGURE 11-4
Square-Root Law

aggregated its inventories of books and music in a few locations. As a result, it has lower levels of book and music inventories than bookstore chains such as Borders and Barnes & Noble, which must keep inventory in every retail store.

There are, however, situations where physical aggregation of inventories in one location may not be optimal. There are two major disadvantages of aggregating all inventories in one location:

1. Increase in response time to customer order
2. Increase in transportation cost to customer

Both disadvantages result because the average distance between the inventory and the customer increases with aggregation. With this situation, either the customer has to travel more to reach the product or the product has to be shipped over longer distances to reach the customer. For example, a retail chain such as The Gap has the option of building many small retail outlets or a few large ones. The Gap tends to have many smaller outlets distributed evenly in a region because this strategy reduces the distance that customers travel to reach a store. If The Gap had one large centralized outlet, the average distance that customers need to travel would increase and thus the response time would increase. A desire to decrease customer response time is thus the impetus for the firm to have multiple outlets. Another example is McMaster-Carr, a distributor of MRO supplies. McMaster-Carr uses UPS for shipping product to customers. Because shipping charges are based on distance, having one centralized warehouse increases the average shipping cost as well as the response time to the customer. Thus, McMaster-Carr has six warehouses that allow it to provide next-day delivery to a large fraction of the United States. Next-day delivery by UPS would not be feasible at a reasonable cost if McMaster-Carr had only one warehouse. Even Amazon.com, which started with one warehouse in Seattle, has added more warehouses in other parts of the United States in an effort to improve response time and reduce transportation cost to the customer.

These examples highlight instances in which physical aggregation of inventory at one location may not be optimal. However, there are clear benefits to aggregating safety inventory. We now discuss various methods by which a supply chain can extract the benefits of aggregation without having to physically centralize all inventories in one location.

INFORMATION CENTRALIZATION

McMaster-Carr uses *information centralization* to virtually aggregate all its inventories despite having six stocking locations. The company has set up an information system

that allows access to current inventory records from each warehouse. Consider, for example, a customer in Chicago ordering a motor and a pump. When the customer order arrives, McMaster-Carr makes an initial check to see if the Chicago warehouse can fill the entire order. If so, the order is shipped from there to minimize response time and transportation cost.

If the Chicago warehouse has motors but is out of pumps, McMaster-Carr obtains the pump from the closest warehouse that has the pump in inventory. The pump is shipped from the warehouse to Chicago, where it is merged with the motor into a single shipment and sent to the customer. Thus, inventory at all locations is available to all orders, no matter where they originate. Information centralization allows McMaster-Carr to reduce the level of inventories required while providing a high level of product availability by virtually aggregating inventories.

The benefit of information centralization derives from the fact that most orders are filled from the warehouse closest to the customer, keeping transportation costs low. In case of a stockout, other warehouses fill the order, improving product availability. As a result, McMaster-Carr can improve product availability without increasing its safety inventory while keeping shipping costs relatively low.

Retailers such as the Gap also use information centralization very effectively. If a store does not have the size or color that a customer wants, store employees can use their information system to inform the customer of the closest store with the product in inventory. Customers can then either go to this store or have the product delivered to their house. The Gap thus uses information centralization to virtually aggregate inventory across all retail stores even though the inventory is physically separated. This allows the Gap to reduce the amount of safety inventory it carries while providing a high level of product availability.

Wal-Mart has an information system in place that allows store managers to search other stores for an excess of items that may be hot sellers at their stores. Wal-Mart provides transportation that allows store managers to exchange products so they arrive at stores where they are in high demand. In this case, Wal-Mart uses information centralization with a responsive transportation system to reduce the amount of safety inventory carried while providing a high level of product availability.

SPECIALIZATION

Most supply chains provide a variety of products to customers. When inventory is carried at multiple locations, a key decision for a supply chain manager is whether all products should be stocked at every location. Clearly, a product that does not sell in a geographic region should not be carried in inventory by the warehouse or retail store located there. For example, it does not make sense for a Sears retail store in southern Florida to carry a wide variety of snow boots in inventory.

Another important factor that must be considered when making stocking decisions is the reduction in safety inventory that results from aggregation. If aggregation reduces the required safety inventory for a product by a large amount, it is better to carry the product in one central location. If aggregation reduces the required safety inventory for a product by a small amount, it may be best to carry the product in multiple decentralized locations to reduce response time and transportation cost.

The reduction in safety inventory due to aggregation is strongly influenced by the demand's coefficient of variation. For a product with a very low coefficient of variation, disaggregate demand can be forecast with accuracy. As a result, the benefit from aggregation is minimal. For a product with a high coefficient of variation of demand, disaggregate demand is very difficult to forecast. In this case, aggregation improves

forecast accuracy significantly, providing great benefits. We illustrate this idea in Example 11-8.

Example 11-8: **Impact of coefficient of variation on value of aggregation**
Assume that W.W. Grainger, a supplier of MRO products, has 1,600 stores distributed throughout the United States. Consider two products—large electric motors and industrial cleaners. Large electric motors are high-value items with low demand, whereas the industrial cleaner is a low-value item with high demand. Each motor costs $500 and each can of cleaner costs $30. Weekly demand for motors at each store is normally distributed, with a mean of 20 and a standard deviation of 40. Weekly demand for cleaner at each store is normally distributed, with a mean of 1,000 and a standard deviation of 100. Demand experienced by each store is independent, and supply lead time for both motors and cleaner is four weeks. W.W. Grainger has a holding cost of 25 percent. For each of the two products, evaluate the reduction in safety inventories that will result if they are removed from retail stores and carried only in a centralized DC. Assume a desired CSL of 0.95.

Analysis: The evaluation of safety inventories and the value of aggregation for each of the two products is shown in Table 11-4. All calculations use the approach discussed earlier and illustrated in Example 11-7. As Table 11-4 shows, the benefit from centralizing motors is much larger than the benefit from centralizing cleaner. From this analysis, W.W. Grainger should stock cleaner at the stores and motors in the DC. Given that cleaner is a high-demand item, customers will be able to pick it up on the same day at the stores. Given that motors are a low-demand item, customers may be willing to wait the extra day that shipping from the DC will entail.

KEY POINT The higher the coefficient of variation of an item, the greater is the reduction in safety inventories as a result of centralization.

Items with a very low demand are referred to as *slow-moving items* and typically have a high coefficient of variation, whereas items with high demand are referred to as *fast-moving items* and typically have a low coefficient of variation. For many supply chains, specializing the distribution network with fast-moving items stocked at

TABLE 11-4 Value of Aggregation at W.W. Grainger

	Motors	*Cleaner*
Inventory is stocked in each store		
Mean weekly demand per store	20	1,000
Standard deviation	40	100
Coefficient of variation	2.0	0.1
Safety inventory per store	132	329
Total safety inventory	211,200	526,400
Value of safety inventory	$105,600,000	$15,792,000
Inventory is aggregated at the DC		
Mean weekly aggregate demand	32,000	1,600,000
Standard deviation of aggregate demand	1,600	4,000
Coefficient of variation	0.05	0.0025
Aggregate safety inventory	5,264	13,159
Value of safety inventory	$2,632,000	$394,770
Savings		
Total inventory saving on aggregation	$102,968,000	$15,397,230
Total holding cost saving on aggregation	$25,742,000	$3,849,308
Holding cost saving per unit sold	$15.47	$0.046
Savings as a percentage of product cost	3.09%	0.15%

decentralized locations close to the customer and slow-moving items stocked at a centralized location can significantly reduce the safety inventory carried without hurting customer response time or adding to transportation costs. The centralized location then specializes in handling slow-moving items.

Of course, other factors also need to be considered when deciding on the allocation of products to stocking locations. For example, an item that is considered an emergency item because the customer needs it urgently may be stocked at stores even if it has a high coefficient of variation. One also needs to consider the cost of the item. High-value items provide a greater benefit from centralization than low-value items.

It is important for firms with bricks-and-mortar stores to take the idea of specialization into account when they design their e-commerce strategy. Consider, for example, a bookstore chain such as Barnes & Noble. Barnes & Noble is able to carry about a hundred thousand titles at each retail store. The titles carried can be divided into two broad categories—best-sellers with high demand and other books with much lower demand. Barnes & Noble can design an e-commerce strategy under which the retail stores carry primarily best-sellers in inventory. They also carry one or at most two copies of each of the other titles, to allow customers to browse. Customers can access all titles that are not in the store via electronic kiosks in the store, which provide access to barnesandnoble.com inventory. This strategy allows customers to access an increased variety of books from Barnes & Noble stores. Customers place orders for low-volume titles with barnesandnoble.com while purchasing high-volume titles at the store itself. This strategy of specialization allows Barnes & Noble to aggregate all slow-moving items to be sold by the online channel. All best-sellers are decentralized and carried close to the customer. The supply chain thus reduces inventory costs for slow-moving items at the expense of somewhat higher transportation costs. For the fast-moving items, the supply chain provides a lower transportation cost and better response time by carrying the items at retail stores close to the customer.

The Gap follows a similar strategy and integrates its online channel with its retail stores. Terminals are available at the retail stores for placing orders online. The retail stores carry fast-moving items and the customer is able to order slow-moving colors or sizes online. The Gap is thus able to increase the variety of products available to customers while keeping supply chain inventories down. Walmart.com has also employed a strategy of carrying slower-moving items online.

PRODUCT SUBSTITUTION

Substitution refers to the use of one product to satisfy demand for a different product. There are two instances where substitution may occur:

1. ***Manufacturer-driven substitution:*** In this case the manufacturer or supplier makes the decision to substitute. Typically, the manufacturer substitutes a higher-value product for a lower-value product that is not in inventory. For example, Dell may install a 120-gigabyte hard drive into a customer order requiring a 100-gigabyte drive, if the smaller drive is out of stock.
2. ***Customer-driven substitution:*** In this case customers make the decision to substitute. For example, a customer walking into a Wal-Mart store to buy a gallon of detergent may buy the half-gallon size if the gallon size is not available. In this case the customer substitutes the half-gallon size for the gallon size.

In both cases, exploiting substitution allows the supply chain to satisfy demand using aggregate inventories, which permits the supply chain to reduce safety inventories without hurting product availability. In general, given two products or components,

substitution may be one-way (i.e., only one of the products [components] substitutes for the other) or two-way (i.e., either product [component] substitutes for the other). We briefly discuss one-way substitution in the context of manufacturer-driven substitution and two-way substitution in the context of customer-driven substitution.

Manufacturer-Driven One-Way Substitution

Consider a PC manufacturer selling direct to customers that offers drives that vary in size from 10 to 100 gigabytes. Customers are charged according to the size of drive that they select, with larger sizes being more expensive. If a customer orders a 40-gigabyte drive and the PC manufacturer is out of drives of this size, there are two possible choices: (1) delay or deny the customer order or (2) substitute a larger drive that is in stock (say, a 60-gigabyte drive) and fill the customer order on time. In the first case there is potentially a lost sale or loss of future sales because the customer experiences a delayed delivery. In the second case the manufacturer installs a higher-cost component, reducing the company's profit margin. These factors, along with the fact that only larger drives can substitute for smaller drives, must be considered when the manufacturer makes inventory decisions for individual drive sizes.

Substitution allows the PC manufacturer to aggregate demand across the components, reducing safety inventories required. The value of substitution increases as demand uncertainty increases. Thus, the PC manufacturer should consider substitution for components displaying very high demand uncertainty.

The desired degree of substitution is influenced by the cost differential between the higher-value and lower-value component. If the cost differential is very small, the PC manufacturer should aggregate most of the demand and carry most of its inventory in the form of the higher-value component. As the cost differential increases, the benefit of substitution decreases. In this case, the PC manufacturer will find it more profitable to carry inventory of each of the two components and decrease the amount of substitution.

The desired level of substitution is also influenced by the correlation of demand between the products. If demand between two components is strongly positively correlated, there is little value in substitution. As demand for the two components becomes less positively correlated, the benefit of substitution increases.

KEY POINT Manufacturer-driven substitution increases overall profitability for the manufacturer by allowing some aggregation of demand, which reduces the inventory requirements for the same level of availability.

Customer-Driven Two-Way Substitution

Consider W.W. Grainger selling two brands of motors, GE and SE, which have very similar performance characteristics. Customers are generally willing to purchase either brand, depending on product availability. If W.W. Grainger managers do not recognize customer substitution, they will not encourage it. For a given level of product availability they will thus have to carry high levels of safety inventory of each brand. If its managers recognize and encourage customer substitution, they can aggregate the safety inventory across the two brands, thereby improving product availability.

W.W. Grainger does a very good job of recognizing customer substitution. When a customer calls or goes online to place an order and the product she requests is not available, the customer is immediately told the availability of all equivalent products that she may substitute. Most customers ultimately buy a substitute product in this case. W.W. Grainger exploits this substitution by managing safety inventory of all substitutable products jointly. Recognition and exploitation of customer substitution

allows W.W. Grainger to provide a high level of product availability with lower levels of safety inventory.

A good understanding of customer-driven substitution is very important in the retail industry. It must be exploited when merchandising to ensure that substitute products are placed near each other, allowing a customer to buy one if the other is out of stock. In the online channel, substitution requires a retailer to present the availability of substitute products if the one the customer requests is out of stock. The supply chain is thus able to reduce the required level of safety inventory while providing a high level of product availability.

KEY POINT Recognition of customer-driven substitution and joint management of inventories across substitutable products allows a supply chain to reduce the required safety inventory while ensuring a high level of product availability.

The demand uncertainties as well as the correlation of demand between the substitutable products influence the benefit to a retailer from exploiting substitution. The greater the demand uncertainty, the greater is the benefit of substitution. The lower the correlation of demand between substitutable products, the greater is the benefit from exploiting substitution.

COMPONENT COMMONALITY

In any supply chain, a significant amount of inventory is held in the form of components. A single product such as a PC contains hundreds of components. When a supply chain is producing a large variety of products, component inventories can easily become very large. The use of common components in a variety of products is an effective supply chain strategy to exploit aggregation and reduce component inventories.

Dell sells thousands of different PC configurations to customers. An extreme option for Dell is to design distinct components that are suited to the performance of a particular configuration. In this case Dell would use different memory, hard drive, modem, and other components for each distinct finished product. The other option is to design products such that different combinations of the components result in different finished products.

Without common components, the uncertainty of demand for any component is the same as the uncertainty of demand for the finished product in which it is used. Given the large number of components in each finished product, demand uncertainty will be very high, resulting in high levels of safety inventory. When products with common components are designed, the demand for each component is an aggregation of the demand for all the finished products of which the component is a part. Component demand is thus more predictable than the demand for any one finished product. This fact reduces the component inventories carried in the supply chain. This idea has been a key factor for success in the PC industry and has also started to play a big role in the auto industry. With increasing product variety, component commonality is a key to reducing supply chain inventories without hurting product availability. We illustrate the basic idea behind component commonality in Example 11-9.

Example 11-9: **Value of component commonality**
Assume that Dell is to manufacture 27 different PCs with three distinct components: processor, memory, and hard drive. Under the disaggregate option, Dell designs specific components for each PC, resulting in $3 \times 27 = 81$ distinct components. Under the common-component option, Dell designs PCs such that three distinct processors, three distinct memory units, and three distinct hard drives can be combined to create 27 different

PCs. Each component is thus used in nine different PCs. Monthly demand for each of the 27 different PCs is independent and normally distributed, with a mean of 5,000 and a standard deviation of 3,000. The replenishment lead time for each component is one month. Dell is targeting a CSL of 95 percent for component inventory. Evaluate the safety inventory requirements with and without the use of component commonality. Also evaluate the change in safety inventory requirements as the number of finished products of which a component is a part varies from one to nine.

Analysis: We first evaluate the disaggregate option, in which components are specific to a PC. For each component we have

$$\text{Standard deviation of monthly demand} = 3{,}000$$

Given a lead time of one month and a total of 81 components across 27 different PCs, we thus use Equation 11.12 to obtain

$$\text{Total safety inventory required} = 81 \times NORMSINV(0.95) \times \sqrt{1} \times 3{,}000 = 399{,}699 \text{ units}$$

In the case of component commonality, each component ends up in nine different finished products. Therefore, the demand at the component level is the sum of demand across nine different products. Using Equations 11.14 and 11.15, the safety inventory required for each component is thus

$$\begin{aligned}\text{Safety inventory per common component} &= NORMSINV(0.95) \times \sqrt{1} \times \sqrt{9} \times 3{,}000 \\ &= 14{,}804 \text{ units}\end{aligned}$$

With component commonality there are a total of nine distinct components. The total safety inventory across all nine components is thus

$$\text{Total safety inventory required} = 9 \times 14{,}804 = 133{,}236$$

Thus, having each component common to nine different products results in a reduction in safety inventory for Dell from 399,735 to 133,236 units.

In Table 11-5, we evaluate the marginal benefit in terms of reduction in safety inventory as a result of increasing component commonality. Starting with the required safety inventory when each component is used in only one finished product, we evaluate the safety inventory as the number of products in which a component is used increases to nine. Observe that component commonality decreases the required safety inventory for Dell. The marginal benefit of commonality, however, declines as a component is used in more and more finished products.

As a component is used in more finished products, it needs to be more flexible. As a result, the cost of producing the component typically increases with increasing commonality. Given that the marginal benefit of component commonality decreases as we increase commonality, we need to trade off the increase in component cost and the decrease in safety inventory when deciding on the appropriate level of component commonality.

TABLE 11-5 Marginal Benefit of Component Commonality

Number of Finished Products per Component	*Safety Inventory*	*Marginal Reduction in Safety Inventory*	*Total Reduction in Safety Inventory*
1	399,699		
2	282,630	117,069	117,069
3	230,766	51,864	168,933
4	199,849	30,917	199,850
5	178,751	21,098	220,948
6	163,176	15,575	236,523
7	151,072	12,104	248,627
8	141,315	9,757	258,384
9	133,233	8,082	266,466

KEY POINT Component commonality decreases the safety inventory required. The marginal benefit, however, decreases with increasing commonality.

POSTPONEMENT

Postponement is the ability of a supply chain to delay product differentiation or customization until closer to the time the product is sold. The goal is to have common components in the supply chain for most of the push phase and move product differentiation as close to the pull phase of the supply chain as possible. For example, Dell holds all inventory in the form of components that are common across many PC configurations. A PC is assembled in the pull phase of the supply chain, after the customer order arrives. Thus, Dell produces product variety only when demand is known with certainty. Postponement coupled with component commonality allows Dell to carry significantly lower safety inventories than a manufacturer such as HP that sells through retailers. Given that HP must stock finished inventory at the retailer, it assembles to stock. Thus, HP must forecast demand for each individual configuration when assembling. The assemble-to-order direct sales model of Dell relies on aggregate inventories in the form of components, whereas the assemble-to-stock, sell-through retailers model relies on disaggregate inventories for each PC configuration.

Another classic example of postponement is the production process at Benetton to make colored knit garments. The original process called for the thread to be dyed and then knitted and assembled into garments. The entire process required up to six months. Because the color of the final garment was fixed the moment the thread was dyed, demand for individual colors had to be forecast far in advance (up to six months). Benetton developed a manufacturing technology that allowed it to dye knitted garments to the appropriate color. Now *greige* thread (the term used for thread that has not yet been dyed) can be purchased, knitted, and assembled into garments before dyeing. The dyeing of the garments is done much closer to the selling season. In fact, part of the dyeing is done after the start of the selling season, when demand is known with great accuracy. In this case Benetton has postponed the color customization of the knit garments. When thread is purchased, only the aggregate demand across all colors needs to be forecast. Given that this decision is made far in advance, when forecasts are least likely to be accurate, there is great advantage to this aggregation. However, as Benetton moves closer to the selling season, the forecast uncertainty reduces. At the time Benetton dyes the knit garments, demand is known with a high degree of accuracy. Thus, postponement allows Benetton to exploit aggregation and significantly reduce the level of safety inventory carried. Supply chain flows with and without postponement are illustrated in Figure 11-5.

Without component commonality and postponement, product differentiation occurs early on in the supply chain and most of the supply chain inventories are disaggregate. Postponement allows the supply chain to delay product differentiation. As a result, most of the inventories in the supply chain are aggregate. Postponement thus allows a supply chain to exploit aggregation to reduce safety inventories without hurting product availability.

Postponement can be a powerful concept for the e-commerce channel. When ordering over the Internet, customers are implicitly willing to wait a little for the order to arrive. This delay offers the supply chain an opportunity to reduce inventories by postponing product differentiation until after the customer order arrives. It is important that the manufacturing process be designed in a way that enables assembly to be

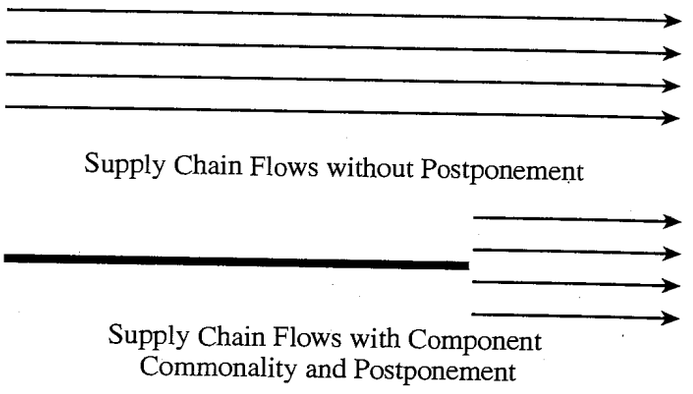


FIGURE 11-5 Supply Chain Flows with Postponement

completed quickly. All PC manufacturers are already postponing assembly for their online orders. Several furniture and window manufacturers have also postponed some of the assembly process for their orders.

11.5 IMPACT OF REPLENISHMENT POLICIES ON SAFETY INVENTORY

In this section we describe the evaluation of safety inventories for both continuous and periodic-review replenishment policies. We highlight the fact that periodic review policies require more safety inventory than continuous review policies for the same level of product availability. To simplify the discussion, we focus on the CSL as the measure of product availability. The managerial implications are the same if we use fill rate; the analysis, however, is more cumbersome.

CONTINUOUS REVIEW POLICIES

Given that continuous review policies were discussed in detail in Section 11.2, we only reiterate the main points here. When using a continuous review policy, a manager orders Q units when the inventory drops to the ROP. Clearly, a continuous review policy requires technology that monitors the level of available inventory. This is the case for many firms such as Wal-Mart and Dell, whose inventories are monitored continuously.

Given a desired CSL, our goal is to identify the required safety inventory *ss* and the ROP. We assume that demand is normally distributed, with the following inputs:

D: Average demand per period
σ_D: Standard deviation of demand per period
L: Average lead time for replenishment

The ROP represents the available inventory to meet demand during the lead time L. A stockout occurs if the demand during the lead time is larger than the ROP. If demand across periods is independent, demand during the lead time is normally distributed with the following:

$$\text{Mean demand during lead time, } D_L = DL$$
$$\text{Standard deviation of demand during lead time, } \sigma_L = \sqrt{L}\sigma_D$$

Given the desired CSL, the required safety inventory (*ss*) given by Equation 11.9 and the ROP given by Equation 11.3 are

$$ss = F_S^{-1}(CSL) \times \sigma_L = NORMSINV(CSL) \times \sigma_L, ROP = D_L + ss$$

A manager using a continuous review policy has to account only for the uncertainty of demand during the lead time. This is because the continuous monitoring of inventory allows the manager to adjust the timing of the replenishment order, depending on the demand experienced. If demand is very high, inventory reaches the ROP quickly, leading to a quick replenishment order. If demand is very low, inventory drops slowly to the ROP, leading to a delayed replenishment order. The manager, however, has no recourse during the lead time once a replenishment order has been placed. The available safety inventory thus must cover for the uncertainty of demand over this period.

Typically, in continuous review policies the lot size ordered is kept fixed between replenishment cycles. The optimal lot size may be evaluated using the EOQ formula discussed in Chapter 10.

PERIODIC REVIEW POLICIES

In periodic review policies, inventory levels are reviewed after a fixed period of time T and an order is placed such that the level of current inventory plus the replenishment lot size equals a prespecified level called the *order-up-to level* (OUL). The *review interval* is the time T between successive orders. Observe that the size of each order may vary, depending on the demand experienced between successive orders and the resulting inventory at the time of ordering. Periodic review policies are simpler for retailers to implement because they do not require that the retailer have the capability of monitoring inventory continuously. Suppliers may also prefer them because they result in replenishment orders placed at regular intervals.

Let us consider the store manager at Wal-Mart who is responsible for designing a replenishment policy for Lego building blocks. He wants to analyze the impact on safety inventory if he decides to use a periodic review policy. Demand for Legos is normally distributed and independent from one week to the next. We assume the following inputs:

D: Average demand per period
σ_D: Standard deviation of demand per period
L: Average lead time for replenishment
T: Review interval
CSL: Desired cycle service level

To understand the safety inventory requirement, we track the sequence of events over time as the store manager places orders. The store manager places the first order at time 0 such that the lot size ordered and the inventory on hand sum to the order-up-to level, OUL. Once an order is placed, the replenishment lot arrives after the lead time L. The next review period is time T, when the store manager places the next order, which then arrives at time $T + L$. The OUL represents the inventory available to meet all demand that arises between periods 0 and $T + L$. The Wal-Mart store will experience a stockout if demand during the time interval between 0 and $T + L$ exceeds the OUL. Thus, the store manager must identify an OUL such that the following is true:

$$\text{Probability}(\text{demand during } L + T \leq OUL) = CSL$$

The next step is to evaluate the distribution of demand during the time interval $T + L$. Using Equation 11.2, demand during the time interval $T + L$ is normally distributed, with

$$\text{Mean demand during } T + L \text{ periods}, D_{T+L} = (T + L)D$$
$$\text{Standard deviation of demand during } T + L \text{ periods}, \sigma_{T+L} = \sqrt{T + L}\sigma_D$$

The safety inventory in this case is the quantity in excess of D_{T+L} carried by Wal-Mart over the time interval $T + L$. The OUL and the safety inventory ss are related as follows:

$$OUL = D_{T+L} + ss \quad \textbf{(11.15)}$$

Given the desired CSL, the safety inventory (ss) required is given by

$$ss = F_S^{-1}(CSL) \times \sigma_{T+L} = NORMSINV(CSL) \times \sigma_{T+L} \quad \textbf{(11.16)}$$

The average lot size equals the average demand during the review period T and is given as

$$\text{Average lot size, } Q = D_T = DT \quad \textbf{(11.17)}$$

We illustrate the periodic review policy for Wal-Mart in Example 11-10.

Example 11-10: **Evaluation safety inventory for a periodic review policy**
Weekly demand for Legos at a Wal-Mart store is normally distributed, with a mean of 2,500 boxes and a standard deviation of 500. The replenishment lead time is two weeks, and the store manager has decided to review inventory every four weeks. Assuming a periodic-review replenishment policy, evaluate the safety inventory that the store should carry to provide a CSL of 90 percent. Evaluate the OUL for such a policy.

Analysis: In this case, we have

Average demand per period, $D = 2{,}500$
Standard deviation of demand per period, $\sigma_D = 500$
Average lead time for replenishment, $L = 2$ weeks
Review interval, $T = 4$ weeks

We first obtain the distribution of demand during the time interval $T + L$. Using Equation 11.2, demand during the time interval $T + L$ is normally distributed, with

$$\text{Mean demand during } T + L \text{ periods, } D_{T+L} = (T + L)D = (2 + 4)2{,}500 = 15{,}000$$
$$\text{Standard deviation of demand during } T + L \text{ periods, } \sigma_{T+L} = \sqrt{T + L}\sigma_D = 500(\sqrt{4 + 2}) = 1{,}225$$

From Equation 11.16 (evaluated using Equation 11.24 in Appendix 11B), the required safety inventory for a $CSL = 0.90$ is given as

$$ss = F_S^{-1}(CSL) \times \sigma_{T+L} = NORMSINV(CSL) \times \sigma_{T+L}$$
$$= NORMSINV(0.90) \times 1{,}225 = 1{,}570 \text{ boxes}$$

Using Equation 11.15, the OUL is given by

$$OUL = D_{T+L} + ss = 15{,}000 + 1{,}570 = 16{,}570$$

The store manager thus orders the difference between 16,570 and current inventory every four weeks.

We can now compare the safety inventory required when using continuous and periodic review policies. With a continuous review policy, the safety inventory is used to cover for demand uncertainty over the lead time L. With a periodic review policy, the safety inventory is used to cover for demand uncertainty over the lead time and the review interval $L + T$. Given that higher uncertainty must be accounted for, periodic review policies require a higher level of safety inventory. This argument can be confirmed by comparing the results in Examples 11.4 and 11.10. For a 90 percent CSL, the store manager requires a safety inventory of 906 boxes when using a continuous review and a safety inventory of 1,570 boxes when using a periodic review.

KEY POINT Periodic review replenishment policies require more safety inventory than continuous review policies for the same lead time and level of product availability.

Of course, periodic review policies are somewhat simpler to implement because they do not require continuous tracking of inventory. Given the broad use of bar codes and point-of-sale systems as well as the emergence of RFID technology, continuous tracking of all inventories is much more commonplace today than it was a decade ago. In some instances companies partition their products based on their value. High-value products are managed using continuous review policies and low-value products are managed using periodic review policies. This makes sense if the cost of perpetual tracking of inventory is more than the savings in safety inventory that result from switching all products to a continuous review policy.

11.6 MANAGING SAFETY INVENTORY IN A MULTIECHELON SUPPLY CHAIN

In our discussion so far, we have assumed that each stage of the supply chain has a well-defined demand and supply distribution that it uses to set its safety inventory levels. In practice, this is not true for multiechelon supply chains. Consider a simple multiechelon supply chain with a supplier feeding a retailer who sells to the final customer. The retailer needs to know demand as well as supply uncertainty to set safety inventory levels. Supply uncertainty, however, is influenced by the level of safety inventory the supplier chooses to carry. If a retailer order arrives when the supplier has enough inventory, the supply lead time is short. In contrast, if the retailer order arrives when the supplier is out of stock, the replenishment lead time for the retailer increases. Thus, if the supplier increases its level of safety inventory, the retailer can reduce the safety inventory it holds. This implies that the level of safety inventory at all stages in a multiechelon supply chain should be related.

All inventory between a stage and the final customer is called the *echelon inventory*. Echelon inventory at a retailer is just the inventory at the retailer or in the pipeline coming to the retailer. Echelon inventory at a distributor, however, includes inventory at the distributor and all retailers served by the distributor. In a multiechelon setting, reorder points and order-up-to levels at any stage should be based on echelon inventory and not local inventory. Thus, a distributor should decide its safety inventory levels based on the level of safety inventory carried by all retailers supplied by it. The more safety inventory retailers carry, the less safety inventory the distributor needs to carry. As retailers decrease the level of safety inventory they carry, the distributor has to increase its safety inventory to ensure regular replenishment at the retailers.

If all stages in a supply chain attempt to manage their echelon inventory, the issue of how the inventory is divided among various stages becomes important. Carrying inventory upstream in a supply chain allows for more aggregation and thus reduces the amount of inventory required. Carrying inventory upstream, however, increases the probability that the final customer will have to wait because product is not available at a stage close to him. Thus, in a multiechelon supply chain a decision must be made with regard to the level of safety inventory carried at different stages. If inventory is very expensive to hold and customers are willing to tolerate a delay, it is better to increase the amount of safety inventory carried upstream, far from the final customer, to exploit the benefits of aggregation. If inventory is inexpensive to hold and customers are very time sensitive, it is better to carry more safety inventory downstream, closer to the final customer.

11.7 THE ROLE OF IT IN INVENTORY MANAGEMENT

It is no exaggeration to state that the use of IT systems to improve inventory management has contributed much of the cost savings achieved so far in most supply chains. Until the 1980s, inventory was generally managed using rules of thumb such as holding three months of demand in the warehouse. These levels were often (although not always) far from appropriate, resulting in too much of the wrong items and too little of the right ones. The errors were often very large when products had high demand variability or varying levels of criticality. A second major contributor to excess inventories was the fact that each location managed its inventories independently, ignoring inventories at other facilities. The end result was a bloated inventory system with relatively poor service levels.

The first contribution of IT systems was to move inventory management from rules of thumb to setting inventories based on historical demand and desired service levels. IT systems allowed this analysis for potentially millions of SKUs and for the inventory levels to be recalculated as demand changed. The ability to analyze and change inventories in response to changes in demand often results in significantly lower inventories and improved service levels at the same time. Over time, IT inventory management systems have evolved to incorporate more sophisticated techniques for managing inventory. They include different types of demand distributions beyond the normal distribution to better model demand.

One of the major improvements since the mid-1990s has been the incorporation of multiechelon modeling that allows the analysis of inventories across the supply chain network rather than at each separate location. Local analysis often leads to duplication of inventories because each location sets its inventory levels independently. Multiechelon analysis, in contrast, attempts to reduce total network inventories by positioning inventories appropriately. More advanced companies have linked their inventory systems to those of their suppliers and customers. This is important, as the amount of inventory you want to hold depends on how much your customer holds and how much your suppliers have or what they are producing. IT systems also allow inventory management applications to be linked to production planning so that inventory decisions are taken in conjunction with production decisions.

With the growth in product variety, decrease in product life cycles, and rapid fluctuations in demand, it is almost impossible to manage inventories today without the use of IT systems. IT systems improve inventory management through their ability to act on a large number of products, to be frequently updated, and finally, to coordinate with other demand and supply planning systems both within the enterprise and across the supply chain.

There is, however, plenty of room for improvement in inventory management systems. One area for improvement is the modeling of demand in different circumstances. The use of oversimplified demand distributions is often inaccurate and can even lead to inventory levels that are worse than the use of rules of thumb. As an example, consider stocking demand for spare parts in a production facility. The mean demand for a part might be quite low, but when it is needed, not only is it critical, but perhaps a specific set of other parts are also needed. Modeling the demand as normal and independent across parts is likely to give poor results.

Another area for improvement in inventory management systems is the integration with other IT systems across the supply chain. Inventory buffers the variation of demand and supply within the supply chain. Thus, if inventory management systems do not communicate seamlessly with other planning and execution systems, inventory

levels are unlikely to be optimal. In particular, it is important that inventory management systems communicate with demand planning systems to incorporate the impact of seasonality and promotions. The inability of inventory management systems to provide visibility and communicate effectively with other IT systems is often the biggest hurdle to their success.

Given the importance of inventories, vendors of inventory management systems are the core supply chain management software providers. These firms include ERP vendors SAP and Oracle and best-of-breed supply chain vendors i2 Technologies and Manugistics. There are also a number of niche companies that focus on various industries, such as retail, high tech, and industrial manufacturing, that have a major inventory management component.

In summary, inventory management systems have played a central role in improving supply chain performance. The significance of IT is likely to grow in the future as more supply chain partners are beginning to set their inventory levels based on their partners' inventory and capabilities.

11.8 ESTIMATING AND MANAGING SAFETY INVENTORY IN PRACTICE

1. ***Account for the fact that supply chain demand is lumpy.*** In practice, a manufacturer or distributor does not order one unit at a time but instead often orders in a large lot. Thus, demand observed by different stages of the supply chain tends to be lumpy. Lumpiness adds to the variability of demand. Lumpiness of demand is not a significant issue when using periodic review policies. When using a continuous review policy, however, lumpiness may lead to inventory dropping far below the ROP before a replenishment order is placed. On average, inventory will drop below the ROP by half the average size of an order. The lumpiness can be accounted for in practice by raising the safety inventory suggested by the models discussed earlier by half the average size of an order.

2. ***Adjust inventory policies if demand is seasonal.*** In practice, demand is often seasonal, with the mean and the standard deviation of demand varying by the time of year. Thus, a given reorder point or order up to level may correspond to ten days of demand during the low-demand season and only two days of demand during the peak demand season. If the lead time is one week, stockouts are certain to occur during the peak season. In the presence of seasonality, it is not appropriate to select an average demand and standard deviation over the year to evaluate fixed reorder points and order-up-to levels. Both the mean and the standard deviation of demand must be adjusted by the time of year to reflect changing demand. Corresponding adjustments in the reorder points, order-up-to levels, and safety inventories must be made over the year. Adjustments for changes in the mean demand over the year are generally more significant than adjustments for changes in variability.

3. ***Use simulation to test inventory policies.*** Given that demand is most likely not normally distributed and may be seasonal, it is a good idea to test and adjust inventory policies using a computer simulation before they are implemented. The simulation should use a demand pattern that truly reflects actual demand, including any lumpiness as well as seasonality. The inventory policies obtained using the models discussed in the chapter can then be tested and adjusted if needed to obtain the desired service levels. Surprisingly powerful simulations can be built using Excel, as we discuss in Chapter 12. Identifying problems in a simulation can save a lot of time and money compared to facing these problems once the inventory policy is in place.

4. ***Start with a pilot.*** Even a simulation cannot identify all problems that may arise when using an inventory policy. Once an inventory policy has been selected and tested using simulation, it is often a good idea to start implementation with a pilot program of products that are representative of the entire set of products in inventory. By starting with a pilot, many of the problems (both in the inventory policies themselves and in the process of applying the policies) can be solved. Getting these problems solved before the policy is rolled out to all the products can save a lot of time and money.

5. ***Monitor service levels.*** Once an inventory policy has been implemented, it is important that its performance be tracked and monitored. Monitoring is crucial because it allows a supply chain to identify when a policy is not working well and make adjustments before supply chain performance is affected significantly. Monitoring requires not just tracking the inventory levels but also tracking any stockouts that may result. Historically, firms have not tracked stockouts very well, partly because stockouts are difficult to track and partly because there is the perception that stockouts affect the customer but not the firm itself. Stockouts can be difficult to measure in a situation such as a supermarket, where the customer simply does not buy the product when it is not on the shelf. However, there are simple ways to estimate stockouts. At a supermarket, the fraction of time that a shelf does not contain a product may be used to estimate the fill rate. Stockouts are in fact easier to estimate online, where the number of clicks on an out-of-stock product can be measured. Given the fraction of clicks that turn into orders and the average size of an order, demand during a stockout can be estimated.

6. ***Focus on reducing safety inventories.*** Given that safety inventory is often a large fraction of the total inventory in a supply chain, the ability to reduce safety inventory without hurting product availability can significantly increase supply chain profitability. This is particularly important in the high-tech industry, where product life cycles are short. In this chapter we discussed a variety of managerial levers that can help reduce safety inventories without hurting availability. Supply chain managers must focus continuously on using these levers to reduce safety inventories.

11.9 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of safety inventory in a supply chain.

   Safety inventory helps a supply chain provide customers a high level of product availability in spite of supply and demand variability. It is carried just in case demand exceeds the amount forecasted or supply arrives later than expected.

2. Identify factors that influence the required level of safety inventory.

   Safety inventory is influenced by demand uncertainty, replenishment lead times, lead time variability, and desired product availability. As any one of them increases, the required safety inventory also increases. The required safety inventory is also influenced by the inventory policy implemented. Continuous review policies require less safety inventory than periodic review policies.

3. Describe different measures of product availability.

   The three basic measures of product availability are product fill rate, order fill rate, and cycle service level. Product fill rate is the fraction of demand for a product that is successfully filled. Order fill rate is the fraction of orders that are completely filled. Cycle service level is the fraction of replenishment cycles in which no stockouts occur.

4. Utilize managerial levers available to lower safety inventory and improve product availability.

   The required level of safety inventory may be reduced and product availability may be improved if a supply chain can reduce demand variability, replenishment lead times, and the

variability of lead times. A switch from periodic monitoring to continuous monitoring can also help reduce inventories. Another key managerial lever to reduce the required safety inventories is to exploit aggregation. This may be achieved by physically aggregating inventories, virtually aggregating inventories using information centralization, specializing inventories based on demand volume, exploiting substitution, using component commonality, and postponing product differentiation.

Discussion Questions

1. What is the role of safety inventory in the supply chain?
2. Explain how a reduction in lead time can help a supply chain reduce safety inventory without hurting product availability.
3. What are the pros and cons of the various measures of product availability?
4. Describe the two types of ordering policies and the impact that each of them has on safety inventory.
5. What is the impact of supply uncertainty on safety inventory?
6. Why can a Home Depot with a few large stores provide a higher level of product availability with lower inventories than a hardware store chain such as Tru-Value, with many small stores?
7. Why is Amazon.com able to provide a large variety of books and music with less safety inventory than a bookstore chain selling through retail stores?
8. In the 1980s, paint was sold by color and size in paint stores. Today, paint is mixed at the paint store according to the color required. Discuss what, if any, impact this change has on safety inventories in the supply chain.
9. A new technology allows books to be printed in ten minutes. Borders has decided to purchase these machines for each store. They must decide which books to carry in stock and which books to print on demand using this technology. Do you recommend it for best-sellers or for other books? Why?

Exercises

1. Weekly demand for Motorola cell phones at a Best Buy store is normally distributed, with a mean of 300 and a standard deviation of 200. Motorola takes two weeks to supply a Best Buy order. Best Buy is targeting a CSL of 95 percent and monitors its inventory continuously. How much safety inventory of cell phones should Best Buy carry? What should its ROP be?
2. Reconsider the Best Buy store in Exercise 1. The store manager has decided to follow a periodic review policy to manage inventory of cell phones. She plans to order every three weeks. Given a desired CSL of 95 percent, how much safety inventory should the store carry? What should its OUL be?
3. Assume that the Best Buy store in Exercise 1 has a policy of ordering cell phones from Motorola in lots of 500. Weekly demand for Motorola cell phones at the store is normally distributed, with a mean of 300 and a standard deviation of 200. Motorola takes two weeks to supply an order. If the store manager is targeting a fill rate of 99 percent, what safety inventory should the store carry? What should its ROP be?
4. Weekly demand for HP printers at a Sam's Club store is normally distributed, with a mean of 250 and a standard deviation of 150. The store manager continuously monitors inventory and currently orders 1,000 printers each time the inventory drops to 600 printers. HP currently takes two weeks to fill an order. How much safety inventory does the store carry? What CSL does Sam's Club achieve as a result of this policy? What fill rate does the store achieve?
5. Return to the Sam's Club store in Exercise 4. Assume that the supply lead time from HP is normally distributed, with a mean of 2 weeks and a standard deviation of 1.5 weeks. How much safety inventory should Sam's Club carry if it wants to provide a CSL of 95 percent?

How does the required safety inventory change as the standard deviation of lead time is reduced from 1.5 weeks to zero in intervals of 0.5 weeks?

6. The Gap has started selling through its online channel along with its retail stores. Management has to decide which products to carry at the retail stores and which products to carry at a central warehouse to be sold only via the online channel. The Gap currently has 900 retail stores in the United States. Weekly demand for size large khaki pants at each store is normally distributed, with a mean of 800 and a standard deviation of 100. Each pair of pants costs $30. Weekly demand for purple cashmere sweaters at each store is normally distributed, with a mean of 50 and a standard deviation of 50. Each sweater costs $100. The Gap has a holding cost of 25 percent. The Gap manages all inventories using a continuous review policy, and the supply lead time for both products is four weeks. The targeted CSL is 95 percent. How much reduction in holding cost per unit sold can the Gap expect on moving each of the two products from the stores to the online channel? Which of the two products should the Gap carry at the stores, and which should it carry at the central warehouse for the online channel? Why? Assume demand from one week to the next to be independent.
7. Epson produces printers for sale in Europe in its Taiwan factory. Printers sold in different countries differ in terms of the power outlet as well as the language of the manuals. Currently, Epson assembles and packs printers for sale in individual countries. The distribution of weekly demand in different countries is normally distributed, with means and standard deviations as shown in Table 11-6.

   Assume demand in different countries to be independent. Given that the lead time from the Taiwan factory is eight weeks, how much safety inventory does Epson require in Europe if it targets a CSL of 95 percent?

   Epson decides to build a central DC in Europe. It will ship base printers (without power supply) to the DC. When an order is received, the DC will assemble power supplies, add manuals, and ship the printers to the appropriate country. The base printers are still to be manufactured in Taiwan with a lead time of eight weeks. How much saving of safety inventory can Epson expect as a result?
8. Return to the Epson data in Exercise 7. Each printer costs Epson $200, and the holding cost is 25 percent. What saving in holding cost can Epson expect as a result of building the European DC? If final assembly in the European DC adds $5 to the production cost of each printer, would you recommend the move? Suppose that Epson is able to cut the production and delivery lead time from its Taiwan factory to four weeks using good information systems. How much savings in holding cost can Epson expect without the European DC? How much savings in holding cost can the firm expect with the European DC?
9. Return to the Epson data in Exercise 7. Assume that demand in different countries is not independent. Demand in any pair of countries is correlated with a correlation coefficient of ρ. Evaluate the holding cost savings that Epson gains as a result of building a European DC as ρ increases from 0 (independent demand) to 1 (perfectly positively correlated demand) in intervals of 0.2.

TABLE 11-6 Weekly Demand for Epson Printers in Europe

Country	*Mean Demand*	*Standard Deviation*
France	3,000	2,000
Germany	4,000	2,200
Spain	2,000	1,400
Italy	2,500	1,600
Portugal	1,000	800
UK	4,000	2,400

10. Motorola obtains cell phones from its contract manufacturer located in China to serve the U.S. market. The U.S. market is served from a warehouse located in Memphis, Tennessee. Daily demand at the Memphis warehouse is normally distributed, with a mean of 5,000 and a standard deviation of 4,000. The warehouse aims for a CSL of 99 percent. The company is debating whether to use sea or air transportation from China. Sea transportation results in a lead time of 36 days and costs $0.50 per phone. Air transportation results in a lead time of 4 days and costs $1.50 per phone. Each phone costs $100, and Motorola uses a holding cost of 20 percent. Given the minimum lot sizes, Motorola would order 100,000 phones at a time (on average, once every 20 days) if using sea transport and 5,000 phones at a time (on average, daily) if using air transport. To begin with, assume that Motorola takes ownership of the inventory on delivery.
    (a) Assuming that Motorola follows a continuous review policy, what reorder point and safety inventory should the warehouse aim for when using sea or air transportation? How many days of safety and cycle inventory will Motorola carry under each policy?
    (b) How many days of cycle inventory does Motorola carry under each policy?
    (c) Under a continuous review policy, do you recommend sea or air transportation if Motorola does not own the inventory while it is in transit? Does your answer change if Motorola has ownership of the inventory while it is in transit?
11. Return to the problem data in Exercise 10. Assume that Motorola follows a periodic review policy. Given lot sizes by sea and air, Motorola would have to place an order every 20 days using sea transport but could order daily using air transport.
    (a) Assume that Motorola follows a periodic review policy. What order-up-to level and safety inventory should the warehouse aim for when using sea or air transportation? How many days of safety inventory will Motorola carry under each policy?
    (b) How many days of cycle inventory does Motorola carry under each policy?
    (c) Under a periodic review policy, do you recommend sea or air transportation? Does your answer change if Motorola has ownership of the inventory while it is in transit?
12. DoorRed Pharmacy replenishes one of its best-selling drugs using a continuous review policy. Daily demand for the drug is normally distributed, with a mean of 300 and a standard deviation of 100. The wholesaler can process a replenishment request in 2 days. The current replenishment policy is to order 1,500 units when there are 750 units on hand.
    (a) What is the cycle service level that DoorRed achieves with its policy?
    (b) What is the fill rate that DoorRed achieves with its policy?
    (c) What change in fill rate would DoorRed achieve if it increased its reorder point from 750 to 800?
13. Return to the DoorRed Pharmacy in Exercise 12. For the drug under discussion, DoorRed wants to adjust its reorder point from 750 to achieve a fill rate of 99.9 percent. What reorder point should it use?
14. The DoorRed pharmacy has 25 retail outlets in the Chicago region. The current policy is to carry every drug in each retail outlet. DoorRed is investigating the possibility of centralizing some of the drugs in one central location. Delivery charge would increase by $0.02 per unit if a drug were centralized. The increase in delivery charge comes from the additional cost of operating the shuttle from the central location to each of the other locations. At each retail outlet, DoorRed has weekly replenishment (a replenishment order is placed once every seven days) and replenishment orders with suppliers must be placed three days before delivery. DoorRed plans to stick to once-a-week ordering even if a drug is centralized. DoorRed uses an inventory holding cost of 20 percent and aims for a cycle service level of 99 percent. Assume that demand across stores is independent.
    (a) Consider a drug with daily demand that is normally distributed, with a mean of 300 and a standard deviation of 50. The drug costs $10 per unit. What is the annual holding cost of safety inventory across all retail stores? If the drug were centralized in

TABLE 11-7 Demand at Car Dealers

	Popular Variant		*Uncommon Variant*	
	Mean	***Standard Deviation***	***Mean***	***Standard Deviation***
Large dealer	50	15	8	5
Small dealer	10	5	2	2

one location, what would the annual cost of holding safety inventory at the central location be? What would the annual increase in delivery charge be? Do you recommend centralization?

(b) Now consider a drug with daily demand that is normally distributed, with a mean of 5 and a standard deviation of 4. The drug costs $10 per unit. What is the annual holding cost of safety inventory across all retail stores? If the drug were centralized in one location, what would the annual cost of holding safety inventory at the central location be? What would the annual increase in delivery charge be? Do you recommend centralization?

(c) Does your answer to (a) and (b) change if the demand across stores has a correlation coefficient of 0.5?

15. Toyota has decided to set up regional warehouses where some variants of the Scion will be customized and shipped to dealers on demand. Customizing and shipping on demand will raise production and transportation cost per car by $100. Each car costs $20,000, and Toyota has a holding cost of 20 percent. Cars at the dealer are owned by Toyota for the fist 90 days. Thus, for all practical purposes, Toyota owns all inventory, whether at the dealers or at the regional warehouse. Consider a region with five large dealers and 30 small dealers. Toyota has partitioned the variants into two groups—popular variants and uncommon variants. Weekly demand for the two types of variants in the two types of dealers is shown in Table 11-7. The goal is to provide a 95 percent cycle service level using a continuous review policy. Replenishment lead times for both dealers and regional warehouses are four weeks. Customization and shipping from a regional warehouse to a dealer can be done in a day, and this time can be ignored. Assume demand to be independent across all dealers.
    (a) How much safety inventory of a popular variant is required at a large or small dealer?
    (b) What is the safety inventory required if inventory for the popular variant (for both large and small dealers) is centralized at the regional warehouse by Toyota?
    (c) What is the safety inventory required if inventory for the popular variant at small dealers is centralized at the regional warehouse but that from large dealers is decentralized?
    (d) Given the additional customization and transportation cost, which structure do you recommend for the popular variant?
    (e) Repeat parts (a)–(d) for the uncommon variant.
    (f) How should Toyota structure inventories given its regional warehouses?
16. Orion is a global company that sells copiers. Orion currently sells 10 variants of a copier, with all inventory kept in finished-goods form. The primary component that differentiates the copiers is the printing subassembly. An idea being discussed is to introduce commonality in the printing subassembly so that final assembly can be postponed and inventories kept in component form. Currently, each copier costs $1,000 in terms of components. Introducing commonality in the print subassembly will increase component costs to $1,025. One of the 10 variants represents 80 percent of the total demand. Weekly demand for this variant is normally distributed, with a mean of 1,000 and a standard deviation of 200. Each of the remaining nine variants has a weekly demand of 28 with a standard deviation of 20. Orion aims to

provide a 95 percent level of service. Replenishment lead time for components is four weeks. Copier assembly can be completed in a matter of hours. Orion manages all inventories using a continuous review policy and uses a holding cost of 20 percent.

(a) How much safety inventory of each variant must Orion keep without component commonality? What is the annual holding cost?
(b) How much safety inventory must be kept in component form if Orion uses common components for all variants? What is the annual holding cost? What is the increase in component cost using commonality? Is commonality justified across all variants?
(c) At what cost of commonality will complete commonality be justified?
(d) Now consider the case in which Orion uses component commonality for only the nine low-demand variants. How much reduction in safety inventory does Orion achieve in this case? What are the savings in terms of annual holding cost? Is this more restricted form of commonality justified?
(e) At what cost of commonality will commonality across the low-volume variants be justified?

Bibliography

Feitzinger, Edward, and Hau L. Lee. "Mass Customization at Hewlett Packard." *Harvard Business Review* (January–February 1997): 116–21.

Geary, Steve, Paul Childerhouse, and Denis Towill. "Uncertainty and the Seamless Supply Chain." *Supply Chain Management Review* (July–August 2002): 52–61.

Kopczak, Laura, and Hau L. Lee. *Hewlett-Packard Co.: Deskjet Printer Supply Chain (A).* Stanford University Case GS3A. 2001.

Lee, Hau L. "Design for Supply Chain Management: Concepts and Examples." In R. Sarin, ed. *Perspectives in Operations Management*, pp 45–65. Norwell, MA: Kluwer Academic Publishers, 1993.

Lee, Hau L., and Corey Billington. "Managing Supply Chain Inventory." *Sloan Management Review* (Spring 1992): 65–73.

Lee, Hau L., Corey Billington, and Brent Carter. "Hewlett-Packard Gains Control of Inventory and Service Through Design for Localization." *Interfaces* (July–August 1993): 1–11.

Nahmias, Steven. *Production and Operations Analysis.* Burr Ridge, IL: Richard P. Irwin, 1997.

Signorelli, Sergio, and James L. Heskett. 1984. *Benetton (A).* Harvard Business School Case 9–685–014, 1984.

Silver, Edward A., David Pyke, and Rein Petersen. *Inventory Management and Production Planning and Scheduling.* New York: Wiley, 1998.

Tayur, Sridhar, Ram Ganeshan, and Michael Magazine, eds. *Quantitative Models for Supply Chain Management.* Boston: Kluwer Academic Publishers, 1999.

Trent, Robert J. "Managing Inventory Investment Effectively." *Supply Chain Management Review* (March–April 2002): 28–35.

Zipkin, Paul H. *Foundations of Inventory Management.* Boston: Irwin McGraw-Hill, 2000.

CASE STUDY

MANAGING INVENTORIES AT ALKO INC.

ALKO began in 1943 in a garage workshop set up by John Williams at his Cleveland home. John had always enjoyed tinkering, and in February 1948 he obtained a patent for one of his designs for lighting fixtures. He decided to produce it in his workshop and tried marketing it in the Cleveland area. The product sold well, and by 1957 ALKO had grown to a $3 million company. Its lighting fixtures were well known for their outstanding quality. By then, it sold a total of five products.

In 1963 John took the company public. Since then ALKO has been very successful, and the company has started distributing its products nationwide. As competition intensified in the 1980s, ALKO introduced many new lighting fixture designs. The company's profitability, however, began to worsen despite the fact that ALKO had taken great care to ensure that product quality did not suffer. The problem was that margins had begun to shrink as competition in the market intensified. At this point the board decided that a complete reorganization was needed, starting at the top. Gary Fisher was hired to reorganize and restructure the company.

When Fisher arrived in 1999, he found a company teetering on the edge. He spent his first few months trying to understand the company business and the way it was structured. Fisher realized that the key was in the operating performance. Although the company had always been outstanding at developing and producing new products, it had historically ignored its distribution system. The feeling within the company was that once you make a good product, the rest takes care of itself. Fisher set up a task force to review the company's current distribution system and come up with recommendations.

THE CURRENT DISTRIBUTION SYSTEM

The task force noted that ALKO had 100 products in its 1999 line. All production occurred at three facilities located in the Cleveland area. For sales purposes, the continental United States was divided into five regions, as shown in Figure 11-6. A DC owned by ALKO operated in each of these regions. Customers placed orders with the DCs, which tried to supply them from product in inventory. As the inventory for any product diminished, the DC in turn ordered from the plants. The plants scheduled production based on DC orders. Orders were transported from plants to the DCs in TL quantities because order sizes tended to be large. On the other hand, shipments from the DC to the customer were LTL. ALKO used a third-party trucking company for both transportation legs. In 1999, TL costs from the plants to DCs averaged $0.09 per unit. LTL shipping costs from a DC to a customer averaged $0.10 per unit. On average, five days were necessary between the time a DC placed an order with a plant and the time the order was delivered from the plant.

The policy in 1999 was to stock each item in every DC. A detailed study of the product line had shown that there were three basic categories of products in terms of the volume of sales. They were categorized as types High,

FIGURE 11-6 Sales Regions for ALKO

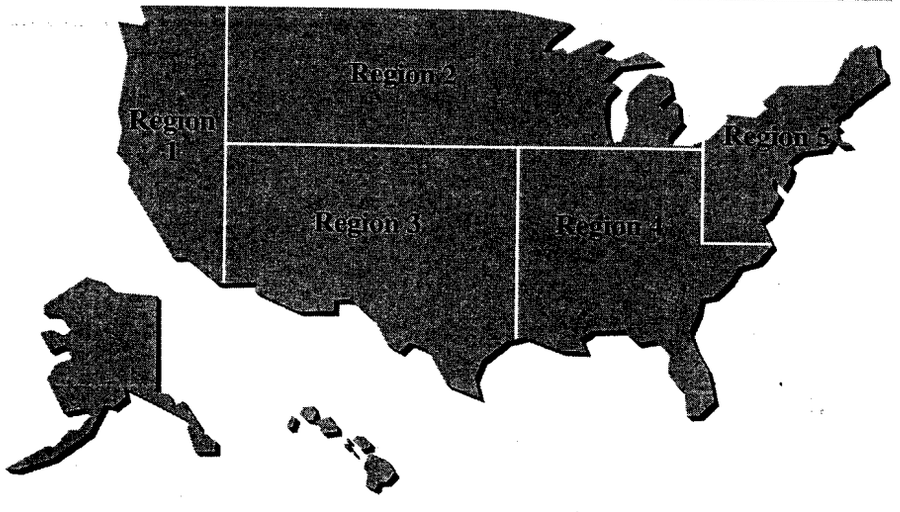


TABLE 11-8 Distribution of Daily Demand at ALKO

	Region 1	*Region 2*	*Region 3*	*Region 4*	*Region 5*
Part 1 M	35.48	22.61	17.66	11.81	3.36
Part 1 SD	6.98	6.48	5.26	3.48	4.49
Part 3 M	2.48	4.15	6.15	6.16	7.49
Part 3 SD	3.16	6.20	6.39	6.76	3.56
Part 7 M	0.48	0.73	0.80	1.94	2.54
Part 7 SD	1.98	1.42	2.39	3.76	3.98

Medium, and Low. Demand data for a representative product in each category is shown in Table 11-8. Products 1, 3, and 7 are representative of High, Medium, and Low products, respectively. Of the 100 products that ALKO sold, 10 were of type High, 20 of type Medium, and 70 of type Low. Each of their demands was identical to those of the representative products 1, 3, and 7, respectively.

The task force identified that plant capacities allowed any reasonable order to be produced in four days. Thus, a plant shipped out an order four days after receiving it. After one day in transit, the order reached the DC. The DCs ordered using a periodic review policy with a reorder interval of six days. The holding cost incurred was $0.15 per unit per day whether the unit was in transit or in storage. All DCs carried safety inventories to ensure a CSL of 95 percent.

ALTERNATIVE DISTRIBUTION SYSTEMS

The task force recommended that ALKO build a national distribution center (NDC) outside Chicago. The task force recommended that ALKO close its five DCs and move all inventory to the NDC. Warehouse capacity was measured in terms of the total number of units handled per year (i.e., the warehouse capacity was given in terms of the demand supplied from the warehouse). The cost of constructing a warehouse is shown in Figure 11-7. However, ALKO expected to recover $50,000 for each warehouse that it closed. The CSL out of the NDC would continue to be 95 percent.

Given that Chicago is close to Cleveland, the inbound transportation cost from the plants to the NDC would fall to $0.05 per unit. The total replenishment lead time for the Chicago NDC would still be five days (four days for production + one day in transit). Given the increased average distance, however, the outbound transportation cost to customers from the NDC would increase to $0.24 per unit.

Other possibilities the task force considered include building a national distribution center while keeping the regional DCs open. In this case, some products would be stocked at the regional DCs, whereas others would be stocked at the NDC.

FISHER'S DECISION

Gary Fisher pondered the task force report. They had not detailed any of the numbers supporting their decision. He decided to evaluate the numbers before making his decision.

QUESTIONS

1. What is the annual inventory and distribution cost of the current distribution system?
2. What are the savings that would result from following the task force recommendation and setting up an NDC? Evaluate the savings as the correlation coefficient of demand in any pair of regions varies from 0 to 0.5 to 1.0. Do you recommend setting up a NDC?
3. Suggest other options that Fisher should consider. Evaluate each option and recommend a distribution system for ALKO that would be most profitable. How dependent is your recommendation on the correlation coefficient of demand across different regions?

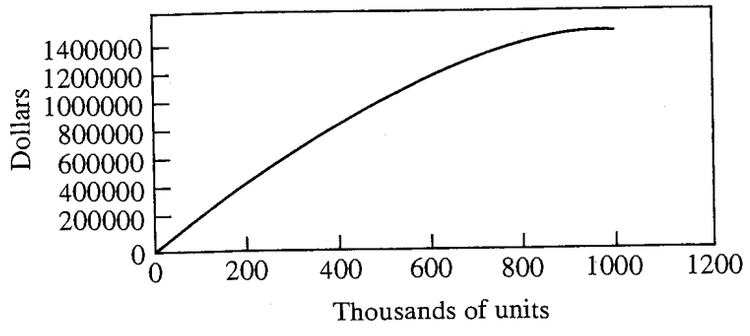


FIGURE 11-7 Construction Costs for NDC

APPENDIX 11A

THE NORMAL DISTRIBUTION

A continuous random variable X has a *normal distribution* with mean μ and standard deviation $\sigma > 0$ if the probability density function $f(x, \mu, \sigma)$ of the random variable is given by

$$f(x, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{(x - \mu)^2}{2\sigma^2}\right] \quad \textbf{(11.18)}$$

The normal density function is as shown in Figure 11-8.

The *cumulative normal distribution function* is denoted by $F(x, \mu, \sigma)$ and is the probability that a normally distributed random variable with mean μ and standard deviation σ takes on a value less than or equal to x. The cumulative normal distribution function and the density function are related as follows:

$$F(x, \mu, \sigma) = \int_{X=-\infty}^{x} f(X, \mu, \sigma)dX$$

A normal distribution with a mean $\mu = 0$ and standard deviation $\sigma = 1$ is referred to as the *standard normal distribution.* The standard normal density function is denoted by $f_S(x)$ and the cumulative standard normal distribution function is denoted by $F_S(x)$. Thus

$$f_S(x) = f(x, 0, 1) \text{ and } F_S(x) = F(x, 0, 1)$$

Given a probability p, the inverse normal $F^{-1}(p, \mu, \sigma)$ is the value x such that p is the probability that the normal random variable takes on a value x or less. Thus, if $F(x, \mu, \sigma) = p$ then $x = F^{-1}(p, \mu, \sigma)$. The inverse of the standard normal distribution is denoted by $F_S^{-1}(p)$. Thus

$$F_S^{-1}(p) = F^{-1}(p, 0, 1).$$

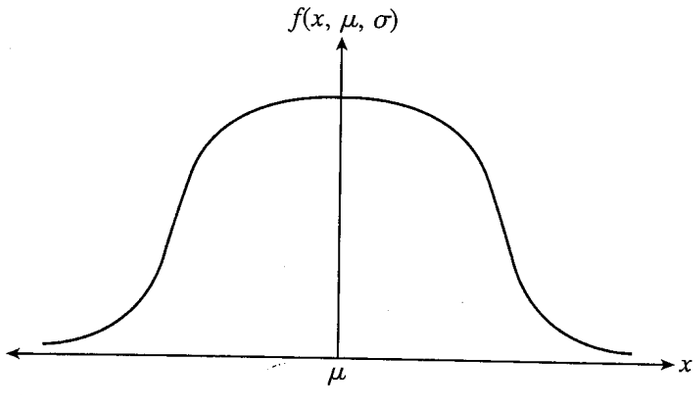


FIGURE 11-8 Normal Density Function

APPENDIX 11B



THE NORMAL DISTRIBUTION IN EXCEL

The following Excel functions can be used to evaluate various normal distribution functions:

$$F(x, \mu, \sigma) = NORMDIST(x, \mu, \sigma, 1) \quad \textbf{(11.19)}$$

$$f(x, \mu, \sigma) = NORMDIST(x, \mu, \sigma, 0) \quad \textbf{(11.20)}$$

$$F^{-1}(p, \mu, \sigma) = NORMINV(p, \mu, \sigma) \quad \textbf{(11.21)}$$

The Excel functions to evaluate various standard normal distribution functions are listed next.

$$F_S(x) = NORMDIST(x, 0, 1, 1) \text{ or } NORMSDIST(x) \quad \textbf{(11.22)}$$

$$f_S(x) = NORMDIST(x, 0, 1, 0) \quad \textbf{(11.23)}$$

$$F_S^{-1}(p) = NORMSINV(p) \quad \textbf{(11.24)}$$

APPENDIX 11C



EXPECTED SHORTAGE COST PER CYCLE

Objective: Establish an alternative formula for expected shortage cost (ESC) to be evaluated using Excel.

Analysis: Given a reorder point of $ROP = D_L + ss$, the ESC is given as

$$ESC = \int_{x=ROP}^{\infty} (x - ROP) f(x) dx$$

$$= \int_{x=D_L+ss}^{\infty} (x - D_L - ss) f(x) dx$$

Given that the demand during lead time is normally distributed with a mean D_L and a standard deviation σ_L, we have (using Equation 11.18)

$$ESC = \int_{x=D_L+ss}^{\infty} (x - D_L - ss) \frac{1}{\sqrt{2\pi}\sigma_L} e^{-(x-D_L)^2/2\sigma_L^2}$$

Substitute the following:

$$z = \frac{(x - D_L)}{\sigma_L}$$

This implies that

$$dx = \sigma_L dz$$

Thus we have

$$ESC = \int_{z=ss/\sigma_L}^{\infty} (z\sigma_L - ss) \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz$$

$$= -ss \int_{z=ss/\sigma_L}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz$$

$$+ \sigma_L \int_{z=ss/\sigma_L}^{\infty} z \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz$$

Recall that $F_S(.)$ is the cumulative distribution function and $f_S(.)$ is the probability density function for the standard normal distribution with mean 0 and standard deviation 1. Using Equation 11.18 and the definition of the standard normal distribution, we have

$$1 - F_S(y) = \int_{z=y}^{\infty} f_s(z) dz = \int_{z=y}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz$$

Substitute $w = z^2/2$ into the expression for ESC. This implies that

$$ESC = -ss[1 - F_S(ss/\sigma_L)] + \sigma_L \int_{w=ss^2/2\sigma_L^2}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-w} dw$$

or

$$ESC = -ss[1 - F_S(ss/\sigma_L)] + \sigma_L f_s(ss/\sigma_L)$$

Using Equations 11.22 and 11.23, ESC may be evaluated using Excel as follows:

$$ESC = -ss[1 - NORMDIST(ss/\sigma_L, 0, 1, 1)] + \sigma_L NORMDIST(ss/\sigma_L, 0, 1, 0)$$

CHAPTER 12
DETERMINING THE OPTIMAL LEVEL OF PRODUCT AVAILABILITY

Learning Objectives

After reading this chapter, you will be able to:

1. Identify the factors affecting the optimal level of product availability and evaluate the optimal cycle service level.
2. Use managerial levers that improve supply chain profitability through optimal service levels.

In this chapter, we explore the process of determining the optimal level of product availability to be offered to customers. The chapter examines the components that go into the calculation of the optimal service level and the various ways that this calculation can be performed. We discuss and demonstrate how different managerial levers can be used to improve supply chain profitability by increasing the level of product availability while reducing inventories.

12.1 THE IMPORTANCE OF THE LEVEL OF PRODUCT AVAILABILITY

The level of product availability is measured using the cycle service level or the fill rate, which are metrics for the amount of customer demand satisfied from available inventory. The level of product availability, also referred to as the customer service level, is one of the primary measures of a supply chain's responsiveness. A supply chain can use a high level of product availability to improve its responsiveness and attract customers, thus increasing revenue for the supply chain. However, a high level of product availability requires large inventories, which raises supply chain costs. Therefore, a supply chain must achieve a balance between the level of availability and the cost of inventory. The optimal level of product availability is one that maximizes supply chain profitability.

Whether the optimal level of availability is high or low depends on where a particular company believes it can maximize profits. For example, Nordstrom has focused on providing a high level of product availability and has used its reputation for responsiveness to become a very successful department store chain. However, prices at Nordstrom are higher than at a discount store, where the level of product availability is lower. Power plants ensure that they (almost) never run out of fuel because a shutdown is extremely expensive, resulting in several days of lost production. Some power plants try to maintain several months of fuel supply to avoid any probability of running out. In contrast, most supermarkets carry only a few days' supply of product, and out-of-stock situations do occur with some frequency.

With e-commerce, the nature of searching on the Web allows a customer to easily shop at an alternative store if one is out of stock. This competitive environment puts pressure on Web retailers to increase their level of availability. Simultaneously, significant price competition has lowered prices on the Web. Web retailers with excess inventory find it difficult to be profitable. Providing the optimal level of product availability is thus a key to success on the Web.

In the examples described earlier, firms provide different levels of product availability. Every supply chain manager must use factors that influence the optimal level of product availability to target the optimal level of product availability and identify managerial levers that increase supply chain surplus. Next we identify factors that affect the optimal level of product availability.

12.2 FACTORS AFFECTING OPTIMAL LEVEL OF PRODUCT AVAILABILITY

To understand the factors that influence the optimal level of product availability, consider L.L.Bean, a large mail-order company that sells apparel. One of the products L.L.Bean sells is ski jackets. The selling season for ski jackets is from November to February. The buyer at L.L.Bean currently purchases the entire season's supply of ski jackets from the manufacturer before the start of the selling season. Providing a high level of product availability requires the purchase of a large number of jackets. Although a high level of product availability is likely to satisfy all demand that arises, it is also likely to result in a large number of unsold jackets at the end of the season, with L.L.Bean losing money on unsold jackets. In contrast, a low level of product availability is likely to result in few unsold jackets. However, it is quite likely that L.L.Bean will have to turn away customers willing to buy jackets because they are sold out. In this scenario, L.L.Bean loses potential profit by losing customers. The buyer at L.L.Bean must balance the loss from having too many unsold jackets (in case the number of jackets ordered is more than demand) and the lost profit from turning away customers (in case the number of jackets ordered is less than demand) when deciding the level of product availability.

The *cost of overstocking* is denoted by C_o and is the loss incurred by a firm for each unsold unit at the end of the selling season. The *cost of understocking* is denoted by C_u and is the margin lost by a firm for each lost sale because there is no inventory on hand. The cost of understocking should include the margin lost from current as well as future sales if the customer does not return. In summary, the two key factors that influence the optimal level of product availability are

- Cost of overstocking the product
- Cost of understocking the product

We illustrate and develop this relationship in the context of a buying decision at L.L.Bean. The first point to observe is that deciding on an optimal level of product availability makes sense only in the context of demand uncertainty. Traditionally, many firms have forecast a consensus estimate of demand without any measure of uncertainty. In this setting, firms do not make a decision regarding the level of availability; they simply order the consensus forecast. Over the last decade, firms have developed a better appreciation for uncertainty and have started developing forecasts that include a measure of uncertainty. Incorporating uncertainty and deciding on the optimal level of product availability can increase profits relative to using a consensus forecast.

TABLE 12-1 Demand Distribution for Parkas at L.L.Bean

Demand D_i (in hundreds)	*Probability p_i*	*Cumulative Probability of Demand Being D_i or Less (P_i)*	*Probability of Demand Being Greater than D_i*
4	0.01	0.01	0.99
5	0.02	0.03	0.97
6	0.04	0.07	0.93
7	0.08	0.15	0.85
8	0.09	0.24	0.76
9	0.11	0.35	0.65
10	0.16	0.51	0.49
11	0.20	0.71	0.29
12	0.11	0.82	0.18
13	0.10	0.92	0.08
14	0.04	0.96	0.04
15	0.02	0.98	0.02
16	0.01	0.99	0.01
17	0.01	1.00	0.00

L.L.Bean has a buying committee that decides on the quantity of each product to be ordered. Based on demand over the past few years, the buyers have estimated the demand distribution for a women's red ski parka to be as shown in Table 12-1. This is a deviation from their traditional practice of using the average historical demand as the consensus forecast. To simplify the discussion, we assume that all demand is in hundreds of parkas. The manufacturer also requires that L.L.Bean place orders in multiples of 100. In Table 12-1, p_i is the probability that demand equals D_i, and P_i is the probability that demand is less than or equal to D_i. From Table 12-1, we evaluate the expected demand of Parkas as

$$\text{Expected demand} = \sum D_i p_i = 1{,}026$$

Under the old policy of ordering the expected value, the buyers would have ordered 1,000 parkas. However, demand is uncertain and Table 12-1 shows that there is a 51 percent probability that demand will be 1,000 or less. Thus, a policy of ordering a thousand parkas results in a cycle service level of 51 percent at L.L.Bean. The buying committee must decide on an order size and cycle service level that maximizes the profits from the sale of parkas at L.L.Bean.

The loss that L.L.Bean incurs from an unsold parka as well as the profit that L.L.Bean makes on each parka it sells influence the buying decision. Each parka costs L.L.Bean $c = \$45$ and is priced in the catalog at $p = \$100$. Any unsold parkas at the end of the season are sold at the outlet store for \$50. Holding the parka in inventory and transporting it to the outlet store costs L.L.Bean \$10. Thus, L.L.Bean recovers a salvage value of $s = \$40$ for each parka that is unsold at the end of the season. L.L.Bean makes a profit of $p - c = \$55$ on each parka it sells and incurs a loss of $c - s = \$5$ on each unsold parka that is sent to the outlet store.

The expected profit from ordering a thousand parkas is given as

$$\text{Expected profit} = \sum_{i=4}^{10} [D_i(p - c) - (1{,}000 - D_i)(c - s)]pi + \sum_{i=11}^{17} 1{,}000(p - c)p_i = \$49{,}900$$

TABLE 12-2 Expected Marginal Contribution of Each Additional 100 Parkas

Additional Hundreds	*Expected Marginal Benefit*	*Expected Marginal Cost*	*Expected Marginal Contribution*
11th	$5{,}500 \times 0.49 = 2{,}695$	$500 \times 0.51 = 255$	$2{,}695 - 255 = 2{,}440$
12th	$5{,}500 \times 0.29 = 1{,}595$	$500 \times 0.71 = 355$	$1{,}595 - 355 = 1{,}240$
13th	$5{,}500 \times 0.18 = 990$	$500 \times 0.82 = 410$	$990 - 410 = 580$
14th	$5{,}500 \times 0.08 = 440$	$500 \times 0.92 = 460$	$440 - 460 = -20$
15th	$5{,}500 \times 0.04 = 220$	$500 \times 0.96 = 480$	$220 - 480 = -260$
16th	$5{,}500 \times 0.02 = 110$	$500 \times 0.98 = 490$	$110 - 490 = -380$
17th	$5{,}500 \times 0.01 = 55$	$500 \times 0.99 = 495$	$55 - 495 = -440$

To decide whether to order 1,100 parkas, the buying committee must determine the impact of buying the extra 100 units. If 1,100 parkas are ordered, the extra 100 are sold (for a profit of $5,500) if demand is 1,100 or higher. Otherwise the extra 100 units are sent to the outlet store at a loss of $500. From Table 12-1, we see that there is a probability of 0.49 that demand is 1,100 or higher and a 0.51 probability that demand is 1,000 or less. Thus, we deduce the following:

$$\text{Expected profit from the extra 100 parkas} = 5{,}500 \times \text{Prob}(\text{demand} \geq 1{,}100) - 500 \times \text{Prob}(\text{demand} < 1{,}100) = \$5{,}500 \times 0.49 - \$500 \times 0.51 = \$2{,}440$$

The total expected profit from ordering 1,100 parkas is thus $52,340, which is almost 5 percent higher than the expected profit from ordering 1,000 parkas. Using the same approach, we evaluate the marginal contribution of each additional 100 parkas as in Table 12-2. Note that the expected marginal contribution is positive up to 1,300 parkas, but it is negative from that point on. Thus the optimal order size is 1,300 parkas. From Table 12-2 we have

$$\text{Expected profit from ordering 1,300 parkas} = \$49{,}900 + \$2{,}440 + \$1{,}240 + \$580 = \$54{,}160$$

This is over an 8 percent increase in profitability relative to the policy of ordering the expected value of 1,000 parkas.

A plot of total expected profits versus the order quantity is shown in Figure 12-1. The optimal order quantity maximizes the expected profit. For L.L.Bean, the optimal order quantity is 1,300 parkas, which provides a CSL of 92 percent. Observe that with a CSL of 0.92, L.L.Bean has a fill rate that is much higher. If demand is 1,300 or less, L.L.Bean achieves a fill rate of 100 percent, because all demand is satisfied. If demand is over 1,300

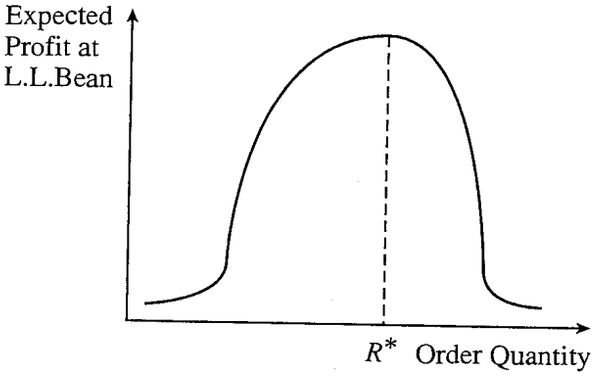


FIGURE 12-1 Expected Profit as a Function of Order Quantity at L.L.Bean

(say, D), part of the demand ($D - 1{,}300$) is not satisfied. In this case a fill rate of $1{,}300/D$ is achieved. Overall, the fill rate achieved at L.L.Bean if 1,300 parkas are ordered is given by

$$fr = 1 \times \text{Prob(demand} \leq 1{,}300) + \sum_{D_i > 1{,}300} (1{,}300/D_i)p_i = 0.99$$

Thus, with a policy of ordering 1,300 parkas, L.L.Bean satisfies, on average, 99 percent of its demand from parkas in inventory.

In the L.L.Bean example we have a cost of overstocking of $C_o = c - s = \$5$ and a cost of understocking of $C_u = p - c = \$55$. As these costs change, the optimal level of product availability also changes. In the next section we develop the relationship between the desired CSL and the cost of overstocking and understocking for seasonal items.

OPTIMAL CYCLE SERVICE LEVEL FOR SEASONAL ITEMS WITH A SINGLE ORDER IN A SEASON

In this section we focus attention on seasonal products such as ski jackets, for which all leftover items must be disposed of at the end of the season. The assumption is that the leftover items from the previous season are not used to satisfy demand for the current season. Assume a retail price per unit of p, a cost of c, and a salvage value of s. We consider the following inputs:

C_o: Cost of overstocking by one unit, $C_o = c - s$
C_u: Cost of understocking by one unit, $C_u = p - c$
CSL^*: Optimal cycle service level
O^*: Corresponding optimal order size

CSL^* is the probability that demand during the season will be at or below O^*. At the optimal cycle service level CSL^*, the marginal contribution of purchasing an additional unit is zero. If the order quantity is raised from O^* to $O^* + 1$, the additional unit sells if demand is larger than O^*. This occurs with probability $1 - CSL^*$ and results in a contribution of $p - c$. We thus have

$$\text{Expected benefit of purchasing extra unit} = (1 - CSL^*)(p - c)$$

The additional unit remains unsold if demand is at or below O^*. This occurs with probability CSL^* and results in a cost of $c - s$. We thus have

$$\text{Expected cost of purchasing extra unit} = CSL^*(c - s)$$

Thus, the expected marginal contribution of raising the order size from O^* to $O^* + 1$ is given by

$$(1 - CSL^*)(p - c) - CSL^*(c - s)$$

Because the expected marginal contribution must be 0 at the optimal cycle service level, we have

$$CSL^* = \text{Prob}(Demand \leq O^*) = \frac{p - c}{p - s} = \frac{C_u}{C_u + C_o} = \frac{1}{1 + (C_o/C_u)} \qquad \textbf{(12.1)}$$

A more rigorous derivation of the aforementioned formula is provided in Appendix 12A. The optimal CSL^* has also been referred to as the *critical fractile*. The resulting optimal order quantity maximizes the firm's profit. If demand during the season is normally distributed, with a mean of μ and a standard deviation of σ, the optimal order quantity is given by

$$O^* = F^{-1}(CSL^*, \mu, \sigma) = NORMINV(CSL^*, \mu, \sigma) \qquad \textbf{(12.2)}$$

When demand is normally distributed, with a mean of μ and a standard deviation of σ, the expected profit from ordering O units is given by

$$\text{Expected profit} = (p - s)\mu F_s\left(\frac{O - \mu}{\sigma}\right) - (p - s)\sigma f_s\left(\frac{O - \mu}{\sigma}\right) - O(c - s)F(O, \mu, \sigma) + O(p - c)[1 - F(O, \mu, \sigma)]$$

The derivation of this formula is provided in Appendix 12B and Appendix 12C. Here F_S is the standard normal cumulative distribution function and f_S is the standard normal density function discussed in Appendix 11A of Chapter 11. The expected profit from ordering O units is evaluated in Excel using Equations 11.19, 11.22, and 11.23 as follows:

$$\begin{aligned}\text{Expected profits} = {} & (p - s)\mu\, NORMDIST((O - \mu)/\sigma, 0, 1, 1) \\ & - (p - s)\sigma\, NORMDIST((O - \mu)/\sigma, 0, 1, 0) \\ & - O(c - s)\, NORMDIST(O, \mu, \sigma, 1) \\ & + O(p - c)\,[1 - NORMDIST(O, \mu, \sigma, 1)] \qquad \textbf{(12.3)}\end{aligned}$$

Example 12-1 illustrates the use of Equations 12.1 and 12.2 to obtain the optimal cycle service level and order quantity.

Example 12-1: **Evaluating the optimal service level for seasonal items**
The manager at Sportmart, a sporting goods store, has to decide on the number of skis to purchase for the winter season. Based on past demand data and weather forecasts for the year, management has forecast demand to be normally distributed, with a mean of $\mu = 350$ and a standard deviation of $\sigma = 100$. Each pair of skis costs $c = \$100$ and retails for $p = \$250$. Any unsold skis at the end of the season are disposed of for \$85. Assume that it costs \$5 to hold a pair of skis in inventory for the season. How many skis should the manager order to maximize expected profits?

Analysis: In this case we have

$$\begin{aligned}\text{Salvage value } s &= \$85 - \$5 = \$80 \\ \text{Cost of understocking} &= C_u = p - c = \$250 - \$100 = \$150 \\ \text{Cost of overstocking} &= C_o = c - s = \$100 - \$80 = \$20\end{aligned}$$

Using Equation 12.1, we deduce that the optimal CSL is

$$CSL^* = \text{Prob}(Demand \le O^*) = \frac{C_u}{C_u + C_o} = \frac{150}{150 + 20} = 0.88$$

Using Equation 12.2, the optimal order size is

$$O^* = NORMINV(CSL^*, \mu, \sigma) = NORMINV(0.88, 350, 100) = 468$$

Thus it is optimal for the manager at Sportmart to order 468 pairs of skis even though the expected number of sales is 350. In this case, because the cost of understocking is much higher than the cost of overstocking, management is better off ordering more than the expected value to cover for the uncertainty of demand.

Using Equation 12.3, the expected profits from ordering O^* units are

$$\begin{aligned}\text{Expected profits} = {} & (p - s)\mu\, NORMDIST((O^* - \mu)/\sigma, 0, 1, 1) \\ & - (p - s)\sigma\, NORMDIST((O^* - \mu)/\sigma, 0, 1, 0) \\ & - O^*(c - s)\, NORMDIST(O^*, \mu, \sigma, 1) \\ & + O^*(p - c)[1 - NORMDIST(O^*, \mu, \sigma, 1)] \\ = {} & 59{,}500\, NORMDIST(1.18, 0, 1, 1) - 17{,}000\, NORMDIST(1.18, 0, 1, 0) \\ & - 9{,}360\, NORMDIST(468, 350, 100, 1) \\ & + 70{,}200\,[1 - NORMDIST(468, 350, 100, 1)] = \$49{,}146\end{aligned}$$

The expected profit from ordering 350 pairs of skis can be evaluated as \$45,718. Thus, ordering 468 pairs results in an expected profit that is almost 8 percent higher than the profit obtained from ordering the expected value of 350 pairs.

When O units are ordered, a firm is left with either too much or too little inventory, depending on demand. When demand is normally distributed, with expected

value μ and standard deviation σ, the expected quantity overstocked at the end of the season is given by

$$\text{Expected overstock} = (O - \mu)F_S\left(\frac{O-\mu}{\sigma}\right) + \sigma f_S\left(\frac{O-\mu}{\sigma}\right)$$

The derivation of this formula is provided in Appendix 12D. The formula can be evaluated using Excel as follows:

$$\begin{aligned}\text{Expected overstock} = {} & (O - \mu)NORMDIST((O - \mu)/\sigma, 0, 1, 1) \\ & + \sigma\, NORMDIST((O - \mu)/\sigma, 0, 1, 0)\end{aligned} \quad \textbf{(12.4)}$$

The expected quantity understocked at the end of the season is given by

$$\text{Expected understock} = (\mu - O)\left[1 - F_S\left(\frac{O-\mu}{\sigma}\right)\right] + \sigma f_S\left(\frac{O-\mu}{\sigma}\right)$$

The derivation of this formula is provided in Appendix 12E. The formula can be evaluated using Excel as follows:

$$\begin{aligned}\text{Expected understock} = {} & (\mu - O)[1 - NORMDIST((O - \mu)/\sigma, 0, 1, 1)] \\ & + \sigma\, NORMDIST((O - \mu)/\sigma, 0, 1, 0)\end{aligned} \quad \textbf{(12.5)}$$

Example 12-2 illustrates the use of Equations 12.4 and 12.5 to evaluate the quantity expected to be overstocked and understocked as a result of an ordering policy.

Example 12-2: **Evaluating expected over- and understock**
Demand for skis at Sportmart is normally distributed with a mean of $\mu = 350$ and a standard deviation of $\sigma = 100$. The manager has decided to order 450 pairs of skis for the upcoming season. Evaluate the expected over- and understock as a result of this policy.

Analysis: In this case we have an order size $O = 450$. An overstock results if demand during the season is less than 450. The expected overstock can be obtained using Equation 12.4 as

$$\begin{aligned}\text{Expected overstock} = {} & (O - \mu)NORMDIST((O - \mu)/\sigma, 0, 1, 1) \\ & + \sigma\, NORMDIST((O - \mu)/\sigma, 0, 1, 0) \\ = {} & (450 - 350) = NORMDIST((450 - 350)/100, 0, 1, 1) \\ & + 100\, NORMDIST((450 - 350)/100, 0, 1, 0) = 108\end{aligned}$$

Thus, the policy of ordering 450 pairs of skis results in an expected overstock of 108 pairs.

An understock occurs if demand during the season is higher than 450 pairs. The expected understock can be evaluated using Equation 12.5 as follows:

$$\begin{aligned}\text{Expected understock} = {} & (\mu - O)[1 - NORMDIST((O - \mu)/\sigma, 0, 1, 1)] \\ & + \sigma\, NORMDIST((O - \mu)/\sigma, 0, 1, 0) \\ = {} & (350 - 450)[1 - NORMDIST((450 - 350)/100, 0, 1, 1)] \\ & + 100 NORMDIST((450 - 350)/100, 0, 1, 0) = 8\end{aligned}$$

Thus the policy of ordering 450 pairs results in an expected understock of 8 pairs. Note that there is a positive expected understock *and* overstock in virtually every case. This result may seem counterintuitive initially, but it makes sense because the values used to calculate an expected understock or overstock are always greater than or equal to zero. For example, if demand is 500 and there are 450 jackets in inventory, there is an understock of 50 and an overstock of 0 (not −50). This guarantees that the expected value will be greater than or equal to zero.

ONE-TIME ORDERS IN THE PRESENCE OF QUANTITY DISCOUNTS

In this section we consider a buyer who has to make a single order when the seller offers a price discount based on the quantity purchased. Such a situation may arise in

the context of seasonal items such as apparel, for which the manufacturer offers a lower price per unit if order quantities exceed a given threshold. Such decisions also arise at the end of the life cycle for a product or spare parts. Future demand for the product or spare parts is uncertain, and the buyer has a single opportunity to order. The buyer must account for the discount when selecting the order size.

Consider a retailer of spare parts who has one last chance to order parts before the manufacturer stops production. The part has a retail price per unit of p, a cost to the retailer (without discount) of c, and a salvage value of s. The manufacturer has offered a discounted price of c_d if the retailer orders at least K units. The retailer can make its order size decision using the following steps:

1. Using $C_o = c - s$ and $C_u = p - c$, evaluate the optimal cycle service level CSL^* and order size O^* without a discount using Equations 12.1 and 12.2, respectively. Evaluate the expected profit from ordering O^* using Equation 12.3.
2. Using $C_o = c_d - s$ and $C_u = p - c_d$, evaluate the optimal cycle service level CSL_d^* and order size O_d^* with a discount using Equations 12.1 and 12.2, respectively. If $O_d^* \geq K$, evaluate the expected profit from ordering O_d^* units using Equation 12.3. If $O_d^* < K$, evaluate the expected profit from ordering K units using Equation 12.3.
3. Order O^* units if the profit in step 1 is higher. If the profit in step 2 is higher, order O_d^* units if $O_d^* \geq K$ or K units if $O_d^* < K$.

We illustrate the procedure in Example 12-3.

Example 12-3: **Evaluating service level with quantity discounts**
SparesRUs, an auto parts retailer, must decide on the order size for a 20-year-old model of brakes. The manufacturer plans to discontinue production of these brakes after this last production run. SparesRUs has forecast remaining demand for the brakes to be normally distributed, with a mean of 150 and a standard deviation of 40. The brakes have a retail price of $200. Any unsold brakes are useless and have no salvage value. The manufacturer plans to sell each brake for $50 if the order is for less than 200 brakes and $45 if the order is for at least 200 brakes. How many brakes should SparesRUs order?

Analysis: The first step is to calculate the optimal order quantity if the discount is not used. In this case we have

$$\text{Cost of understocking} = C_u = p - c = \$200 - \$50 = \$150$$
$$\text{Cost of overstocking} = C_o = c - s = \$50 - \$0 = \$50$$

Using Equation 12.1, we deduce that the optimal CSL is

$$CSL^* = \text{Prob}(Demand \leq R^*) = \frac{C_u}{C_u + C_o} = \frac{150}{150 + 50} = 0.75$$

Using Equation 12.2, the optimal order size is

$$O^* = NORMINV(CSL^*, \mu, \sigma) = NORMINV(0.75, 150, 40) = 177$$

Using Equation 12.3, the expected profit if SparesRUs does not go after the discount is

$$\text{Expected profit from ordering 177 units} = \$19{,}958$$

We next consider the discount and obtain

$$\text{Cost of understocking} = C_u = p - c_d = \$200 - \$45 = \$155$$
$$\text{Cost of overstocking} = C_o = c_d - s = \$45 - \$0 = \$45$$

Using Equation 12.1, we deduce that the optimal CSL is

$$CSL_d^* = \text{Prob}(Demand \leq R^*) = \frac{C_u}{C_u + C_o} = \frac{155}{155 + 45} = 0.775$$

Using Equation 12.2, the optimal order size is

$$O_d^* = NORMINV(CSL_d^*, \mu, \sigma) = NORMINV(0.775, 150, 40) = 180$$

Given that 180 < 200, the retailer must order at least 200 brakes to benefit from the discount. Thus we calculate the expected profit from ordering 200 units using Equation 12.3 as

Expected profits from ordering 200 units at \$45 each = \$ 20,595

It is thus optimal for SparesRUs to order 200 units to take advantage of the quantity discount. The expected overstock can be calculated using Equation 12.4 to be 52.

DESIRED CYCLE SERVICE LEVEL FOR CONTINUOUSLY STOCKED ITEMS

In this section we focus on products such as detergent that are ordered repeatedly by a retail store such as Wal-Mart. In such a situation, Wal-Mart uses safety inventory to increase the level of availability and decrease the probability of stocking out between successive deliveries. If detergent is left over in a replenishment cycle, it can be sold in the next cycle. It does not have to be disposed of at a lower cost. However, a holding cost is incurred as the product is carried from one cycle to the next. The manager at Wal-Mart is faced with the issue of deciding the CSL to aim for.

Two extreme scenarios should be considered:

1. All demand that arises when the product is out of stock is backlogged and filled later, when inventories are replenished.
2. All demand arising when the product is out of stock is lost.

Reality in most instances is somewhere in between, with some of the demand lost and other customers returning when the product is in stock. Here we consider both extreme cases.

We assume that demand per unit time is normally distributed, along with the following inputs:

Q: Replenishment lot size
S: Fixed cost associated with each order
ROP: Reorder point
D: Average demand per unit time
σ: Standard deviation of demand per unit time
ss: Safety inventory (recall that $ss = ROP - D_L$)
CSL: Cycle service level
C: Unit cost
h: Holding cost as a fraction of product cost per unit time
H: Cost of holding one unit for one unit of time. $H = hC$

Demand During Stockout Is Backlogged

We first consider the case in which all demand arising when the product is out of stock is backlogged. Because no demand is lost, minimizing costs becomes equivalent to maximizing profits. As an example, consider a Wal-Mart store selling detergent. The store manager offers a discount of C_u to each customer wanting to buy detergent when it is out of stock. This ensures that all these customers return when inventory is replenished.

If the store manager increases the level of safety inventory, more orders are satisfied from stock, resulting in lower backlogs. This decreases the backlogging cost. However, the cost of holding inventory increases. The store manager must pick a level of safety inventory that minimizes the backlogging and holding costs. In this case, the optimal cycle service level is given by

$$CSL^* = 1 - \frac{HQ}{DC_u} \tag{12.6}$$

Given the optimal cycle service level, the required safety inventory can be evaluated using Equation 11.9 if demand is normally distributed.

From Equation 12.6, observe that increasing the lot size Q allows the store manager at Wal-Mart to reduce the cycle service level and thus the safety inventory carried. This is because increasing the lot size increases the fill rate and thus reduces the quantity backlogged. One should be careful, however, because an increase in lot size raises the cycle inventory. In general, increasing the lot size is not an effective way for a firm to improve product availability.

If the cost of stocking out is known, one can use Equation 12.6 to obtain the appropriate cycle service level (and thus the appropriate level of safety inventory). In many practical settings, it is hard to estimate the cost of stocking out. In such a situation, a manager may want to evaluate the cost of a stockout implied by the current inventory policy. When a precise cost of stockout cannot be found, this implied stockout cost at least gives an idea of whether inventory should be increased, decreased, or kept about the same. In Example 12-4 we show how Equation 12.6 can be used to impute a cost of stocking out given an inventory policy.

Example 12-4: **Imputing cost of stockout from inventory policy**
Weekly demand for detergent at Wal-Mart is normally distributed, with a mean of $\mu = 100$ gallons and a standard deviation of $\sigma = 20$. The replenishment lead time is $L = 2$ weeks. The store manager at Wal-Mart orders 400 gallons when the available inventory drops to 300 gallons. Each gallon of detergent costs $3. The holding cost Wal-Mart incurs is 20 percent. If all unfilled demand is backlogged and carried over to the next cycle, evaluate the cost of stocking out implied by the current replenishment policy.

Analysis: In this case we have

$$\begin{aligned}
\text{Lot size, } Q &= 400 \text{ gallons}\\
\text{Reorder point, } ROP &= 300 \text{ gallons}\\
\text{Average demand per week, } D &= 100 \text{ gallons}\\
\text{Average demand per year, } D_{year} &= 100 \times 52 = 5{,}200\\
\text{Standard deviation of demand per week, } \sigma_D &= 20\\
\text{Unit cost, } C &= \$3\\
\text{Holding cost as a fraction of product cost per year, } h &= 0.2\\
\text{Cost of holding one unit for one year, } H &= hC = \$0.6\\
\text{Lead time, } L &= 2 \text{ weeks}
\end{aligned}$$

We thus have

$$\begin{aligned}
\text{Mean demand over lead time, } D_L &= DL = 200 \text{ gallons}\\
\text{Standard deviation of demand over lead time, } \sigma_L &= \sigma_L\sqrt{L} = 20\sqrt{2} = 28.3
\end{aligned}$$

Because demand is normally distributed, we can use Equation 11.4 to evaluate the CSL under the current inventory policy:

$$CSL = F(ROP, D_L, \sigma_L) = F(300, 200, 28.3)$$

Using Equation 11.19 from Appendix 11B, we obtain

$$CSL = NORMDIST(300, 200, 28.3, 1) = 0.9998$$

We can thus deduce that the imputed cost of stocking out (using Equation 12.6) is given by

$$C_u = \frac{HQ}{(1 - CSL)D_{year}} = \frac{0.6 \times 400}{0.0002 \times 5{,}200} = \$230.8 \text{ per gallon}$$

The implication here is that if each shortage of a gallon of detergent costs Wal-Mart $230.8, the current CSL of 0.9998 is optimal. In this particular example, one can claim that the store manager is carrying too much inventory because the cost of stocking out of detergent is unlikely to be $230.8 per gallon.

A manager can use the aforementioned analysis to decide if the imputed cost of stocking out, and thus the inventory policy, is reasonable.

Demand During Stockout Is Lost

For the case in which unfilled demand during the stockout period is lost, the optimal cycle service level CSL^* is given as

$$CSL^* = 1 - \frac{HQ}{HQ + DC_u} \tag{12.7}$$

In this case we have assumed that C_u is the cost of losing one unit of demand during the stockout period. In Example 12-5, we evaluate the optimal cycle service level if demand is lost during the stockout period.

Example 12-5: **Evaluating optimal service level when unmet demand is lost**
Consider the situation in Example 12-4 but make the assumption that all demand during a stockout is lost. Assume that the cost of losing one unit of demand is $2. Evaluate the optimal cycle service level that the store manager at Wal-Mart should target.

Analysis: In this case we have

$$\begin{aligned} \text{Lot size, } Q &= 400 \text{ gallons} \\ \text{Average demand per year, } D_{year} &= 100 \times 52 = 5{,}200 \\ \text{Cost of holding one unit for one year, } H &= \$0.6 \\ \text{Cost of understocking, } C_u &= \$2 \end{aligned}$$

Using Equation 12.7, the optimal cycle service level is given as

$$CSL^* = 1 - \frac{HQ}{HQ + DC_u} = 1 - \frac{0.6 \times 400}{0.6 \times 400 + 2 \times 5{,}200} = 0.98$$

In this case the store manager at Wal-Mart should target a cycle service level of 98 percent.

In general, the optimal cycle service level will be higher if sales are lost than if sales are backlogged.

12.3 MANAGERIAL LEVERS TO IMPROVE SUPPLY CHAIN PROFITABILITY

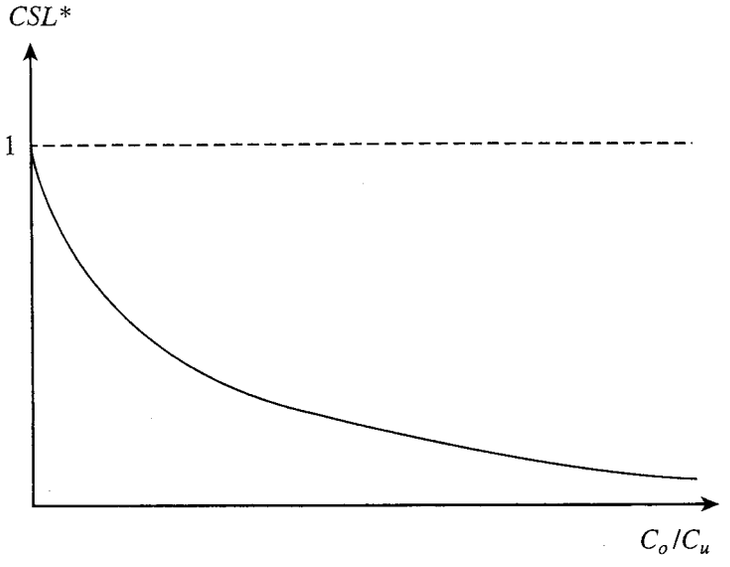
Having identified the factors that influence the optimal level of product availability, we now focus on actions a manager can take to improve supply chain profitability. We have shown in Section 12.2 that the costs of over- and understocking have a direct impact on both the optimal cycle service level and profitability. Two obvious managerial levers to increase profitability are thus

1. Increase the salvage value of each unit increases profitability (as well as the optimal cycle service level).
2. Decrease the margin lost from a stockout increases profitability (as well as the optimal cycle service level).

Strategies to increase the salvage value include selling to outlet stores so that leftover units are not merely discarded. Some companies, such as Sport Obermeyer, which sells winter wear in the United States, sell the surplus in South America, where the winter corresponds to the North American summer. The increased salvage value of the surplus allows Sport Obermeyer to provide a higher level of product availability in the United States and increase its profits.

Strategies to decrease the margin lost in a stockout include arranging for backup sourcing (which may be more expensive) so customers are not lost forever. The practice of purchasing product from a competitor on the open market to satisfy customer demand is observed and justified by the earlier reasoning. In the MRO supply industry,

FIGURE 12-2 Impact of Changing C_o/C_u on Optimal Cycle Service Level



McMaster-Carr and W.W. Grainger, two major competitors, are also large customers for each other. The cost of understocking can also be decreased by providing the customer with a substitute product.

The optimal cycle service level as a function of the ratio of the cost of overstocking and the cost of understocking is shown in Figure 12-2. Observe that as this ratio gets smaller, the optimal level of product availability increases. This fact explains the difference in the level of product availability between a high-end store such as Nordstrom and a discount store. Nordstrom has higher margins and thus a higher cost of understocking. It should thus provide a higher level of product availability than a discount store with lower margins and as a result, a lower cost of stocking out.

Another significant managerial lever to improve supply chain profitability is the reduction of demand uncertainty. With reduced demand uncertainty, a supply chain manager can better match supply and demand by reducing both over- and understocking. A manager can reduce demand uncertainty via the following means:

1. ***Improved forecasting:*** Use better market intelligence and collaboration to reduce demand uncertainty.
2. ***Quick response:*** Reduce replenishment lead time so that multiple orders may be placed in the selling season.
3. ***Postponement:*** In a multiproduct setting, postpone product differentiation until closer to the point of sale.
4. ***Tailored sourcing:*** Use a low lead time, but perhaps an expensive supplier as a backup for a low-cost, but perhaps long-lead-time supplier.

Next we study the impact of each of these on supply chain performance.

IMPROVING FORECASTS: IMPACT ON PROFITS AND INVENTORIES

Companies have tried to better understand their customers and coordinate actions within the supply chain to improve forecast accuracy. The use of demand planning information systems has also helped in this regard. We show that improved forecast accuracy can help a firm significantly increase its profitability while decreasing the

excess inventory overstocked as well as the sales lost because of understocking. We illustrate the impact of improving forecast accuracy in Example 12-6.

Example 12-6: **Impact of improved forecasts**
Consider a buyer at Bloomingdale's who is responsible for purchasing dinnerware with Christmas patterns. The dinnerware sells only during the Christmas season, and the buyer places an order for delivery in early November. Each dinnerware set costs c = \$100 and sells for a retail price of p = \$250. Any sets unsold by Christmas are heavily discounted in the post-Christmas sales and are sold for a salvage value of s = \$80. The buyer has estimated that demand is normally distributed, with a mean of μ = 350. Historically, forecast errors have had a standard deviation of σ = 150. The buyer has decided to conduct additional market research to get a better forecast. Evaluate the impact of improved forecast accuracy on profitability and inventories as the buyer reduces σ from 150 to 0 in increments of 30.

Analysis: In this case we have

$$\text{Cost of understocking} = C_u = p - c = \$250 - \$100 = \$150$$
$$\text{Cost of overstocking} = C_o = c - s = \$100 - \$80 = \$20$$

Using Equation 12.1, we have

$$CSL^* = Prob(Demand \le O^*) \ge \frac{150}{150 + 20} = 0.88$$

The optimal order size is obtained using Equation 12.2 and the expected profit using Equation 12.3. The order size and expected profit as forecast accuracy (measured by standard deviation of forecast error) varies are shown in Table 12-3.

Example 12-6 illustrates that as a firm improves its forecast accuracy, expected quantity over- and understocked declines and expected profit increases. This relationship is shown in Figure 12-3.

KEY POINT An increase in forecast accuracy decreases both the overstocked and understocked quantity and increases a firm's profits.

QUICK RESPONSE: IMPACT ON PROFITS AND INVENTORIES

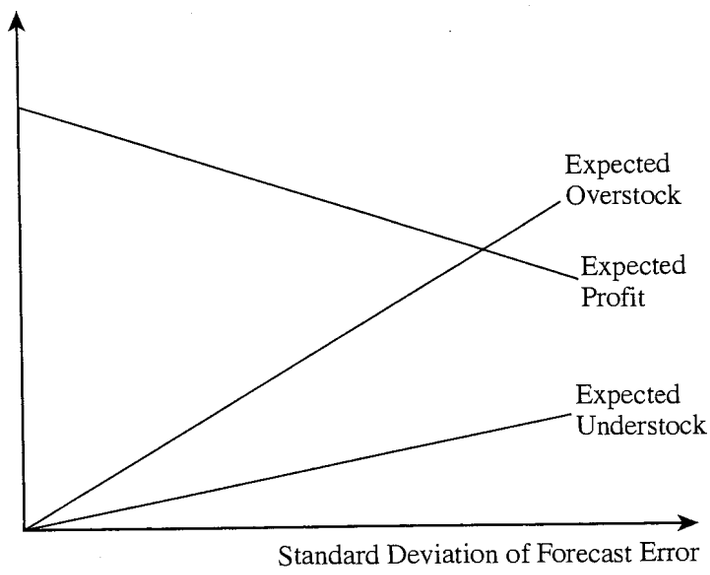
Quick response is the set of actions a supply chain takes to reduce the replenishment lead time. Supply chain managers are able to improve their forecast accuracy as lead times decrease, which allows them to better match supply with demand and increase supply chain profitability.

To illustrate the issues, consider the example of Saks Fifth Avenue, a high-end department store, purchasing cashmere shawls from India and Nepal. The selling season for cashmere shawls is about 14 weeks. Historically, replenishment lead times have

TABLE 12-3 Expected Profit and Order Size at Bloomingdale's

Standard Deviation of Forecast Error σ	*Optimal Order Size* O^*	*Expected Overstock*	*Expected Understock*	*Expected Profit*
150	526	186.7	8.6	\$47,469
120	491	149.3	6.9	\$48,476
90	456	112.0	5.2	\$49,482
60	420	74.7	3.5	\$50,488
30	385	37.3	1.7	\$51,494
0	350	0	0	\$52,500

FIGURE 12-3 Variation of Profit and Inventories with Forecast Accuracy



been on the order of 25 to 30 weeks. With a 30-week lead time, the buyer at Saks must order all the store expects to sell well before the start of the sales season. It is difficult for a buyer to make an accurate forecast of demand this far in advance. This results in high demand uncertainty, leading the buyer to order either too many or too few shawls each year. If the Asian manufacturers decrease the replenishment lead time to 15 weeks, the buyer at Saks must still place the entire order before the start of the sales season. However, the order can now be placed closer to the sales season, resulting in a more accurate forecast. As discussed earlier in the chapter, this reduction in uncertainty increases profits at Saks.

Typically, buyers are able to make very accurate forecasts once they have observed demand for the first week or two in the season. Consider the situation in which manufacturers are able to reduce replenishment lead time to six weeks. This reduction allows the buyer at Saks to break up the entire season's purchase into two orders. The first order is placed six weeks before the start of the sales season. The buyer orders what the store expects to sell over the first seven weeks of the season. Once sales start, the buyer observes demand for the first week and places a second order after the first week. The second order builds inventory up to the level that the buyer wants to order for the entire season. The ability to place the second order allows the buyer to match supply and demand much more effectively, resulting in higher profits.

When multiple orders are placed in the season, it is not possible to provide formulas like Equations 12.1–12.5 that specify the optimal order quantity, the expected profit, expected overstock, and expected understock. Rather, we must use simulation (see Appendix 12F) to identify the impact of different ordering policies. We illustrate the impact of being able to place multiple orders using the Saks example discussed earlier.

The buyer at Saks must decide on the quantity of cashmere shawls to order from India and Nepal for the upcoming winter season. The unit cost of each shawl is $40, and the shawl retails for $150. A discount store purchases any leftover shawls at the end of the season for $30 each. Cost of displaying and holding any unsold shawls is $2 per week in inventory. After the sales season of 14 weeks, any leftover shawls are sold to the discount store.

Before the start of the sales season, the buyer forecasts weekly demand to be normally distributed, with a mean of 20 and a standard deviation of 15. We compare the impact of the following two ordering policies:

1. A single order must be placed at the beginning of the season to cover the entire season's demand.
2. Two orders are placed for the season, one to be delivered at the beginning of the season and the other to be delivered at the beginning of the eighth week.

We consider two scenarios—one in which the buyer's forecast accuracy does not improve for the second order, and another in which it improves and the buyer is able to reduce the standard deviation of the forecast to 3 instead of 15.

The analysis comparing the two policies is done using a simulation. We compare inventory levels as well as profitability for ordering policies in the single- and double-order scenarios that provide the same level of service.

When placing a single order, the ordering policy consists of a quantity to be ordered at the beginning of the season. When placing two orders, the ordering policy consists of an initial order quantity for the first seven weeks, followed by an order-up-to level for the second seven weeks. The idea is that the quantity ordered in the second round should account for sales during the first seven weeks and the inventory remaining. If very little is sold during the first seven weeks, the second order should be small. If a lot has sold during the first seven weeks, the second order should be large. The quantity ordered in the second round is the difference between the order-up-to level and the projected inventory remaining after the first seven weeks.

In the simulation we assume that any unfilled demand is lost. In Table 12-4 we report results for the case in which there is no improvement in forecast accuracy for the second order. The results given are an average of 500 different simulations.

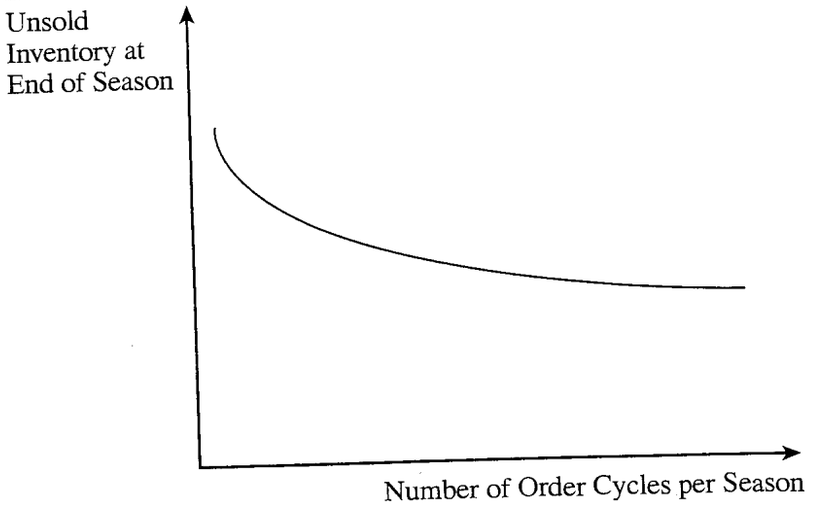
From the results in Table 12-4, we observe three important consequences of being able to place a second order in the season:

1. The expected total quantity ordered during the season with two orders is less than that with a single order for the same cycle service level. In other words, it is possible to provide the same level of product availability to the customer with less inventory if a second, follow-up order is allowed in the sales season.
2. The average overstock to be disposed of at the end of the sales season is less if two orders are allowed.
3. The profits are higher when a second order is allowed during the sales season.

TABLE 12-4 Expected Profit and Overstock at Saks Fifth Avenue with No Improvement in Forecast Accuracy for Second Order

	Single Order for Season			*Two Orders in the Season*				
CSL	*Order Size*	*Average Overstock*	*Expected Profit*	*Initial Order*	*Order-Up-to Level for Second Order*	*Average Total Order*	*Average Overstock*	*Expected Profit*
0.96	378	97	$23,624	209	209	349	69	$26,590
0.94	367	86	$24,034	201	201	342	60	$27,085
0.91	355	73	$24,617	193	193	332	52	$27,154
0.87	343	66	$24,386	184	184	319	43	$26,944
0.81	329	55	$24,609	174	174	313	36	$27,413
0.75	317	41	$25,205	166	166	302	32	$26,915

FIGURE 12-4 Leftover Inventory Versus Number of Order Cycles per Season



In other words, as the total quantity for the season is broken up into multiple smaller orders, the buyer is better able to match supply and demand and increase profitability for Saks. These relationships are shown in Figures 12-4 and 12-5.

We now consider the case in which the buyer improves his or her forecast accuracy for the second order after observing some of the season's demand. As a result, the standard deviation of weekly demand forecast drops from 15 to 3 for the second 10-week period. To provide the same service level, the second order-up-to level is adjusted appropriately. The results of the simulations are shown in Table 12-5.

From Table 12-5, observe that the reduction in demand uncertainty that occurs after the first seven weeks further enhances the benefits of quick response and the ability to place a second order. Profits at Saks increase and the expected overstock quantity decreases.

FIGURE 12-5 Expected Profit Versus Number of Order Cycles per Season

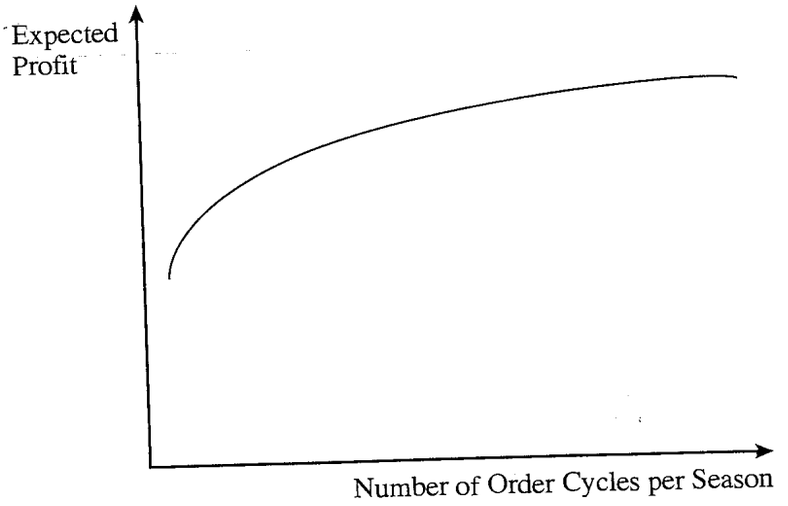


TABLE 12-5 Expected Profit and Overstock at Saks Assuming Forecast Accuracy Improves for Second Order

	Single Order for Season			*Two Orders in the Season*				
CSL	*Order Size*	*Average Overstock*	*Expected Profit*	*Initial Order*	*Order-Up-to Level for Second Order*	*Average Total Order*	*Average Overstock*	*Expected Profit*
0.96	378	96	$23,707	209	153	292	19	$27,007
0.94	367	84	$24,303	201	152	293	18	$27,371
0.91	355	76	$24,154	193	150	288	17	$26,946
0.87	343	63	$24,807	184	148	288	14	$27,583
0.81	329	52	$24,998	174	146	283	14	$27,162
0.75	317	44	$24,887	166	145	282	14	$27,268

KEY POINT If quick response allows multiple orders in the season, profits increase and the overstock quantity decreases.

From our previous discussion, quick response is clearly advantageous to a retailer in a supply chain—with one caveat. As the manufacturer reduces replenishment lead times, allowing for a second order, we have seen that the retailer's order size drops. In effect, the manufacturer sells less to the retailer. Thus, quick response results in the manufacturer making a lower profit in the short term if all else is unchanged. This is an important point to consider, because decreasing replenishment lead times requires tremendous effort from the manufacturer, yet seems to benefit the retailer at the expense of the manufacturer. The benefits resulting from quick response should be shared appropriately across the supply chain.

POSTPONEMENT: IMPACT ON PROFITS AND INVENTORIES

As discussed in Chapter 11, postponement refers to the delay of product differentiation until closer to the sale of the product. With postponement, all activities prior to product differentiation require aggregate forecasts that are more accurate than individual product forecasts. Individual product forecasts are required close to the time of sale when demand is known with greater accuracy. As a result, postponement allows a supply chain to better match supply with demand. Postponement can be a powerful managerial lever to increase profitability. It can be particularly valuable in e-commerce because of the lag that exists between the time customers place an order and when they expect delivery. If the supply chain can postpone product differentiation until after receiving the customer order, a significant increase in profits and reduction in inventories can be achieved.

The major benefit of postponement arises from the improved matching of supply and demand. There is, however, a cost associated with postponement, because the production cost using postponement is typically higher than the production cost without it. For example, the production process at Benetton, where assembled knit garments are dyed, costs about 10 percent more than if dyed thread is knitted. Similarly, when Hewlett-Packard postpones some assembly steps for its European printers to the European DC, manufacturing costs increase because packing, unpacking, and some other steps have to be duplicated. Given the increased production cost from postponement, a company should quantify the benefits and ensure that they are larger than the additional costs.

Postponement is valuable for a firm that sells a large variety of products with demand that is independent and comparable in size. We illustrate this using the Benetton example. A large fraction of Benetton's sales are from knit garments in solid colors. Starting with thread, there are two steps to completing the garment—dyeing and knitting. Traditionally, thread was dyed and then the garment was knitted (Option 1). Benetton developed a procedure whereby dyeing was postponed until after the garment was knitted (Option 2).

Benetton sells each knit garment at a retail price $p = \$50$. Option 1 results in a manufacturing cost of \$20, whereas Option 2 results in a manufacturing cost of \$22 per garment. Benetton disposes of any unsold garments at the end of the season in a clearance for $s = \$10$ each. The knitting or manufacturing process takes a total of 20 weeks. For the sake of discussion, we assume that Benetton sells garments in four colors. Twenty weeks in advance, Benetton forecasts demand for each color to be normally distributed, with a mean of $\mu = 1{,}000$ and a standard deviation of $\sigma = 500$. Demand for each color is independent. With Option 1, Benetton makes the buying decision for each color 20 weeks before the sale period and holds separate inventories for each color. With Option 2, Benetton forecasts only the aggregate uncolored thread to purchase 20 weeks in advance. The inventory held is based on the aggregate demand across all four colors. Benetton decides the quantity for individual colors after demand is known. We now quantify the impact of postponement for Benetton.

With Option 1, Benetton must decide on the quantity of colored thread to purchase for each color. For each color we have

Retail price, $p = \$50$
Manufacturing cost, $c = \$20$
Salvage value, $s = \$10$

Using Equation 12.1, we obtain the optimal cycle service level for each color as

$$CSL^* = \frac{p - c}{p - s} = \frac{30}{40} = 0.75$$

Using Equation 12.2, the optimal purchase quantity of thread in each color is

$$O^* = NORMINV(CSL^*, \mu, \sigma) = NORMINV(0.75, 1000, 500) = 1{,}337$$

Thus, it is optimal for Benetton to produce 1,337 units of each color. Using Equation 12.3, the expected profit from each color is

Expected profits = \$23,644

Using Equations 12.4 and 12.5, the expected over- and understock for each color is

Expected overstock = 412
Expected understock = 75

Using Option 1, across all four colors Benetton thus produces 5,348 sweaters. This results in an expected profit of \$94,576, with an average of 1,648 sweaters sold on clearance at the end of the season and 300 customers turned away for lack of sweaters.

Under Option 2, Benetton has to decide on the total number of sweaters across all four colors to be produced, because they can be dyed to the appropriate color once demand is known. In this case we have

Retail price, $p = \$50$
Manufacturing cost, $c = \$22$
Salvage value, $s = \$10$

Using Equation 12.1, the optimal cycle service level for each color is

$$CSL^* = \frac{p - c}{p - s} = \frac{28}{40} = 0.70$$

Given that demand for each color is independent, total demand across all four colors can be evaluated using Equations 11.12 and 11.13 to be normally distributed, with a mean of μ_A and a standard deviation of σ_A, where

$$\mu_A = 4 \times 1{,}000 = 4{,}000 \qquad \sigma_A = \sqrt{4} \times 500 = 1{,}000$$

Using Equation 12.2, the optimal aggregate production quantity for Benetton is given by O_A^*, where

$$O_A^* = NORMINV(0.7, \mu_A, \sigma_A) = NORMINV(0.7, 4000, 1000) = 4{,}524$$

Under Option 2, it is optimal for Benetton to produce 4,524 undyed sweaters to be dyed as demand by color is available. The expected profit is evaluated using Equation 12.3 as

Expected profits = $98,092

Using Equation 12.4, the expected overstock is 715 and the expected understock is 190. Thus, postponement increases expected profits for Benetton from $94,576 to $98,092. Expected overstock declines from 1,648 to 715, and the expected understock declines from 300 to 190. Clearly, the use of postponement and production using Option 2 is a good choice for Benetton in this case.

KEY POINT Postponement allows a firm to increase profits and better match supply and demand if the firm produces a large variety of products whose demand is not positively correlated and is of about the same size.

Postponement is not very effective if a large fraction of demand comes from a single product. This is because the benefit from aggregation is small in this case, whereas the increased production cost applies to all items produced. We illustrate this idea once again using Benetton as an example.

Assume that demand for red sweaters at Benetton is forecast to be normally distributed, with a mean of $\mu_{red} = 3{,}100$ and a standard deviation of $\sigma_{red} = 800$. Demand for the other three colors is forecast to be normally distributed, with a mean of $\mu = 300$ and a standard deviation of $\sigma = 200$. Observe that red sweaters constitute about 80 percent of demand.

Under Option 1, the optimal cycle service level CSL^* is 0.75, as evaluated earlier. Using Equation 12.2, the optimal production of red sweaters is given by

$$O^* = NORMINV(CSL^*, \mu_{red}, \sigma_{red}) = NORMINV(0.75, 3100, 800) = 3{,}640$$

Using Equation 12.3, the expected profit from red sweaters is $82,831. Using Equation 12.4, the expected overstock of red sweaters is 659; using Equation 12.5, the expected understock of red sweaters is 119. For each of the other three colors, we can similarly evaluate the optimal production to be 435 sweaters. This results in an expected profit of $6,458, an expected overstock of 165, and an expected understock of 30. Across all four colors, Option 1 thus results in the following:

Total production = 4,945
Expected profit = $102,205

Expected overstock = 1,154
Expected understock = 209

Under Option 2, Benetton has to decide only the total production across all four colors. Given that demand for each color is independent, total demand across all four colors can be evaluated using Equations 11.12 and 11.13 to be normally distributed, with a mean of μ_A and a standard deviation of σ_A, where

$$\mu_A = 3{,}100 + 3 \times 300 = 4{,}000 \qquad \sigma_A = 872$$

Under Option 2, we repeat all calculations to obtain the following:

Total production = 4,457
Expected profit = $99,872
Expected overstock = 623
Expected understock = 166

In this case, Benetton sees its profits decline as a result of postponement. This is because a large fraction of demand is from red sweaters, which can already be forecast with reasonably good accuracy. Postponement and the resulting aggregation thus do little to improve the forecasting accuracy of red sweaters. It does, however, improve the forecasting accuracy for the other three colors, but they represent a small fraction of demand. Meanwhile, the production costs increase for all sweaters. As a result, the increased production costs outweigh the benefits from postponement.

KEY POINT Postponement may reduce overall profits for a firm if a single product contributes the majority of the demand because the increased manufacturing expense due to postponement outweighs the small benefit that aggregation provides in this case.

In *tailored postponement,* a firm uses production with postponement to satisfy a part of its demand, with the rest being satisfied without postponement. Tailored postponement produces higher profits than when no postponement is used or all products are manufactured using postponement. Under tailored postponement, a firm produces the amount that is very likely to sell using the lower-cost production method without postponement. The firm produces the portion of demand that is uncertain using postponement. On the portion of the demand that is certain, postponement provides little value in terms of increased forecast accuracy. The firm thus produces it using the lower-cost method to lower manufacturing cost. On the portion of demand that is uncertain, postponement significantly improves forecast accuracy. The firm is thus willing to incur the increased production cost to achieve the benefit from the improved matching of supply and demand. We illustrate the idea of tailored postponement, returning to the example of Benetton.

Consider the scenario in which Benetton is selling four colors and the forecast demand for each color is normally distributed, with a mean of $\mu = 1{,}000$ and a standard deviation of $\sigma = 500$. We have observed earlier that the use of postponement increases profits at Benetton. We now consider a situation in which Benetton applies tailored postponement and uses both Option 1 (dye thread and then knit garment) and Option 2 (dye knit garment) for production. For each color, Benetton identifies a quantity Q_1 to be manufactured using Option 1 and an aggregate quantity Q_A to be manufactured using Option 2, with colors for the aggregate quantity being assigned when demand is known. We now identify the appropriate tailored postponement policy and its impact on profits and inventories. There is no formula that can be used to

TABLE 12-6 Average of 500 Simulations for Tailored Postponement Policies

Manufacturing Policy		*Average Profit*	*Average Overstock*	*Average Understock*
Q_1	Q_A			
0	4,524	$97,847	510	210
1,337	0	$94,377	1,369	282
700	1,850	$102,730	308	168
800	1,550	$104,603	427	170
900	950	$101,326	607	266
900	1,050	$101,647	664	230
1,000	850	$100,312	815	195
1,000	950	$100,951	803	149
1,100	550	$99,180	1,026	211
1,100	650	$100,510	1,008	185

evaluate the optimal policy and profits. We thus resort to simulations to study the impact of different policies. The results of various simulations are shown in Table 12-6. From Table 12-6, we see that Benetton can increase its expected profit to $104,603 by using a tailored postponement policy under which 800 units of each color are produced using Option 1 and 1,550 units are produced using Option 2. The resulting profit is higher than if all units are produced entirely using Option 1 or 2. It is quite likely that demand for each color will be 800 or higher. The tailored postponement policy exploits this fact and produces these units using Option 1, which has a low cost. The remaining units are produced using Option 2 so that demand uncertainty can be reduced by aggregation.

KEY POINT Tailored postponement allows a firm to increase its profitability by postponing only the uncertain part of the demand and producing the predictable part at a lower cost without postponement.

TAILORED SOURCING: IMPACT ON PROFITS AND INVENTORIES

In *tailored sourcing,* firms use a combination of two supply sources, one focusing on cost but unable to handle uncertainty well, and the other focusing on flexibility to handle uncertainty, but at a higher cost. For tailored sourcing to be effective, having supply sources such that one serves as the backup to the other is not sufficient. The two sources must focus on different capabilities. The low-cost source must focus on being efficient and should only be required to supply the predictable portion of the demand. The flexible source should focus on being responsive and be required to supply the uncertain portion of the demand. As a result, tailored sourcing allows a firm to increase its profits and better match supply and demand. The value of tailored sourcing depends on the reduction in cost that can be achieved as a result of one source facing no variability. If this benefit is small, tailored sourcing may not be ideal because of the added complexity of implementation. Tailored sourcing may be volume based or product based, depending on the source of uncertainty.

In *volume-based tailored sourcing,* the predictable part of a product's demand is produced at an efficient facility, whereas the uncertain portion is produced at a flexible facility. Benetton provides an example of volume-based tailored sourcing. Benetton

requires retailers to commit to about 65 percent of their orders about seven months before the start of the sales season. Benetton subcontracts production of this portion without uncertainty to low-cost sources that have long lead times of several months. For the other 35 percent, Benetton allows retailers to place orders much closer to or even after the start of the selling season. All uncertainty is concentrated in this portion of the order. Benetton produces this portion of the order in a plant it owns that is very flexible. Production at the Benetton plant is more expensive than production at the subcontractor's. However, the plant can produce with a lead time of weeks. A combination of the two sources allows Benetton to reduce its inventories while incurring a high cost of production for only a fraction of its demand. This allows it to increase profits.

Volume-based tailored sourcing should be considered by firms that have moved a lot of their production overseas to take advantage of lower costs. The lower costs have also been accompanied by longer lead times. In such a situation, having a flexible local source with short lead times can be very effective even if the local source is more expensive. Long lead times require large safety inventories, and the resulting mismatch of supply and demand hurts profits. The presence of the local source allows the firm to carry low safety inventories and supply any excess demand from the local source. The most effective combination is for the overseas source to focus on replenishing cycle inventories ignoring uncertainty. The local source is used as a backup any time demand exceeds the inventory available.

In *product-based tailored sourcing,* low-volume products with uncertain demand are obtained from a flexible source whereas high-volume products with less demand uncertainty are obtained from an efficient source. An example of product-based tailored sourcing is Levi Strauss. Levi sells standard-sized jeans as well as jeans that can be customized to fit an individual. Standard jeans have relatively stable demand, whereas demand for custom jeans is unpredictable. Custom jeans are produced at a flexible facility, whereas standard jeans are produced at an efficient facility.

In some instances, new products have very uncertain demand while well-established products have more stable demand. Product-based tailored sourcing may be implemented with a flexible facility focusing on new products, and efficient facilities focusing on the well-established products.

12.4 SETTING PRODUCT AVAILABILITY FOR MULTIPLE PRODUCTS UNDER CAPACITY CONSTRAINTS

In our discussion up to this point we have assumed that a firm can set its desired level of product availability and there are no constraints that interfere with this choice. A common scenario in which this assumption fails is when the desired level of product availability results in an order size that exceeds the available capacity at the supplier. When ordering a single product, it is optimal for the buyer to order the minimum of the available capacity and the optimal order quantity. When ordering multiple products, however, the buyer needs to consider the trade-off between ordering more of one product versus another.

Consider a department store that plans to order two styles of sweaters from an Italian supplier. Demand for the high-end sweater is forecast to be normally distributed, with a mean of $\mu_1 = 1{,}000$ and a standard deviation of $\sigma_1 = 300$. Demand for the mid-range sweater is normally distributed, with a mean of $\mu_2 = 2{,}000$ and a standard deviation of $\sigma_2 = 400$. The high-end sweater has a retail price of $p_1 = \$150$, a cost

$c_1 = \$50$, and a salvage value of $s_1 = \$35$. The mid-range sweater has a retail price of $p_2 = \$100$, a cost $c_1 = \$40$, and a salvage value of $s_1 = \$25$. Using Equation 12.1, the optimal level of product availability for the high-end sweater is 0.87 and that for the mid-range sweater is 0.8. Thus, without capacity constraints, it is optimal for the department store to order 1,337 units of the high-end sweater and 2,337 units of the mid-range sweater. If the supplier has a capacity constraint of 3,000 units, the desired ordering policy is not feasible and the department store must decrease the size of its order by a total of at least 674 units. Where should this decrease come from? Should the decrease be evenly divided among the two products?

First let us consider the simplistic approach of decreasing the order size of each product by 337 units to get an order of 1,000 high-end sweaters and 2,000 mid-range sweaters. This order size meets the capacity constraint and the expected profit is \$194,268 (using Equation 12.3). To check whether this order size is optimal, we can think in terms of how capacity is allocated to the two styles. Let us assume that we have decided to allocate 1,000 units to the high-end sweater and 1,999 units to the mid-range sweater. That leaves only the last unit of capacity to be allocated. Which sweater should this unit be assigned to? It is reasonable to make this decision based on the expected marginal contribution to profits if this unit of capacity is allocated to each of the two styles. The last unit of capacity should be allocated to the sweater with the higher expected marginal contribution. Recall that $F_i(Q_i)$ is the probability that demand for product i is Q_i or less and let $MC_i(Q_i)$ be the marginal contribution of a sweater of type i if quantity Q_i is ordered. The expected marginal contribution is evaluated similar to Table 12-2 and is obtained as follows:

$$\begin{aligned}\text{Expected marginal contribution for high-end sweater} &= MC_1(1{,}000)\\ &= p_1[1 - F_1(1{,}000)] + s_1 F_1(1{,}000) - c_1\\ &= 150 \times (1 - 0.5) + 35 \times 0.5 - 50 = \$42.50\\ \text{Expected marginal contribution for mid-range sweater} &= MC_2(1{,}999)\\ &= p_2[1 - F_2(1{,}999)] + s_2 F_2(1{,}999) - c_2\\ &= 100 \times (1 - 0.499) + 25 \times 0.499 - 40 = \$22.57\end{aligned}$$

Clearly, it is better to allocate the last unit of capacity to the high-end sweater rather than the mid-range sweater. In fact, changing the order size to 1,001 high-end sweaters and 1,999 mid-range sweaters increases the expected profits by almost \$20. One can now decrease the order size for the mid-range sweater to 1,998 and ask how the last unit of capacity should be allocated. Repeating the above procedure indicates that the order size for the high-end sweaters should be increased to at least 1,002. In fact, the order size for the high-end sweater should be increased until the expected marginal contribution for the high-end sweater is the same as that for the mid-range sweater. At that point it no longer makes sense to move capacity from one type of sweater to another. The optimal allocation of capacity turns out to be 1,089 high-end sweaters and 1,911 mid-range sweaters. The expected profits for this order size are \$195,152. Observe that at optimality the high-end sweater is allocated a relatively high share of the available capacity. This is because its margin relative to the cost of overstocking is higher than that of the mid-range sweater.

The idea of allocating the available capacity to the product with the highest expected marginal contribution can be converted into a solution procedure. Let each product i have a mean demand of μ_i and a standard deviation of σ_i. Product i has a retail price of p_i, a cost c_i, and a salvage value of s_i. If quantity Q_i is allocated to product i, the expected marginal contribution is obtained as

$$MC_i(Q_i) = p_i[1 - F_i(Q_i)] + s_i F_i(Q_i) - c_i$$

TABLE 12-7 Application of Solution Procedure to Obtain Order Quantities Under Capacity Constraints

	Expected Marginal Contribution		*Order Quantity*	
Capacity Left	*High End*	*Mid Range*	*High End*	*Mid Range*
3,000	99.95	60.00	0	0
2,900	99.84	60.00	100	0
2,100	57.51	60.00	900	0
2,000	57.51	60.00	900	100
800	57.51	57.00	900	1,300
780	54.59	57.00	920	1,300
300	42.50	43.00	1,000	1,700
200	42.50	36.86	1,000	1,800
180	39.44	36.86	1,020	1,800
40	31.89	30.63	1,070	1,890
30	30.41	30.63	1,080	1,890
10	29.67	29.54	1,085	1,905
1	29.23	29.10	1,088	1,911
0	29.09	29.10	1,089	1,911

The following procedure allocates each unit of capacity to the product with the highest expected marginal contribution. Let B be the total available capacity.

1. Set quantity $Q_i = 0$ for all products i.
2. Compute the expected marginal contribution $MC_i(Q_i)$ for each product i.
3. If no expected marginal contribution is positive, stop. Else, let j be the product with the highest expected marginal contribution. Increase Q_j by one unit.
4. If the total quantity across all products is less than B, return to step 2. Else, the capacity constraint has been met and the current quantities are optimal.

Partial results from the application of the procedure described above to the department store data are shown in Table 12-7.

The order quantities under capacity constraints can also be obtained by solving an optimization problem. Let $\Pi_i(Q_i)$ be the expected profit obtained using Equation 12.3 from ordering Q_i units of product i. The appropriate order quantities can be obtained by solving the following optimization problem.

$$\text{Max} \sum_{i=1}^{n} \Pi_i(Q_i)$$

Subject to

$$\sum_{i=1}^{n} Q_i \leq B$$

$$Q_i \geq 0$$

KEY POINT When ordering multiple products under a limited supply capacity, the allocation of capacity to products should be based on their expected marginal contribution to profits. This approach allocates a relatively higher fraction of capacity to products that have a high margin relative to their cost of overstocking.

12.5 SETTING OPTIMAL LEVELS OF PRODUCT AVAILABILITY IN PRACTICE

1. ***Use the analytic frameworks in this chapter to increase profits.*** Many firms set inventory levels without any supporting analysis. Managers can provide significant value to a firm by changing this through the use of concepts discussed in this chapter. The concepts not only provide an approach for a firm to target the optimal level of product availability, they also help identify key managerial levers that may be used to increase profitability.

2. ***Beware of preset levels of availability.*** Often companies have a preset target of product availability without any justification. In such a situation, managers should probe the rationale for the targeted level of product availability. A manager can provide significant value by adjusting the targeted level of product availability to one that maximizes profits.

3. ***Use approximate costs because profit-maximizing solutions are quite robust.*** Companies should avoid spending an inordinate amount of effort to get exact estimates of various costs used to evaluate optimal levels of product availability. Levels of product availability close to optimal will often produce a profit that is very close to the optimal profit. Thus, it is not crucial that all costs be estimated precisely. A reasonable approximation of the costs will generally produce targeted levels of product availability that are close to optimal.

4. ***Estimate a range for the cost of stocking out.*** Firms' efforts to set levels of product availability often get bogged down in debate over the cost of stocking out. The sometimes controversial nature of this cost and its hard-to-quantify components (such as loss of customer goodwill) make it a difficult number for people from different functions to agree on. However, it is often not necessary to estimate a precise cost of stocking out. Using a range of the cost of stocking out, a manager can identify appropriate levels of availability and the associated profits. Often, profits do not change significantly in the range, thus eliminating the need for a more precise estimation of the cost of stocking out.

5. ***Ensure levels of product availability fit with strategy.*** A manager should use the level of product availability suggested by the analysis along with the firm's strategic objectives when setting the targeted level of product availability. In some instances, a firm may find it appropriate to provide a high level of product availability for a low-volume item that is not very profitable but is required by important customers. A firm trying to project a reputation for product availability may find it appropriate to provide a high level of availability for all products, even if the margins of each individual product do not justify it.

12.6 SUMMARY OF LEARNING OBJECTIVES

1. Identify the factors affecting the optimal level of product availability and evaluate the optimal cycle service level.

   The cost of overstocking by one unit and the lost current and future margin from understocking by one unit are the two major factors that affect the optimal level of product availability. The optimal level of availability is obtained by balancing the costs of over- and understocking. As the cost of overstocking increases, it is optimal to lower the targeted level of product availability. As the lost margin from being out of stock increases, it is optimal to raise the targeted level of product availability.

2. Use managerial levers that improve supply chain profitability through optimal service levels.

A manager may increase supply chain profitability by (a) increasing the salvage value of each unit overstocked, (b) decreasing the margin lost from a stockout, (c) using improved forecasting to reduce demand uncertainty, (d) using quick response to reduce lead times and allow multiple orders in a season, (e) using postponement to delay product differentiation, and (f) using tailored sourcing with a flexible short-lead-time supply source serving as a backup for a low-cost supply source.

Discussion Questions

1. Consider two products with the same cost but different margins. Which product should have a higher level of product availability? Why?
2. Consider two products with the same margin carried by a retail store. Any leftover units of one product are worthless. Leftover units of the other product can be sold to outlet stores. Which product should have a higher level of availability? Why?
3. A firm improves its forecast accuracy using better market intelligence. What impact will this have on supply chain inventories and profitability? Why?
4. How can postponement of product differentiation be used to improve supply chain profitability?
5. Mattel has historically allowed toy retailers to place two orders for the holiday shopping season. Mattel is considering allowing retailers to place only one order. What impact will this have on retailer orders? What impact will this have on supply chain profits?
6. Discuss how an expensive supplier with short lead times who is used as a backup for a low-cost supplier with long lead times can result in higher profits than using only the low-cost supplier.

Exercises

1. Green Thumb, a manufacturer of lawn care equipment, has introduced a new product. Each unit costs \$150 to manufacture, and the introductory price is to be \$200. At this price, the anticipated demand is normally distributed, with a mean of $\mu = 100$ and a standard deviation of $\sigma = 40$. Any unsold units at the end of the season are unlikely to be very valuable and will be disposed of in a fire sale for \$50 each. It costs \$20 to hold a unit in inventory for the entire season. How many units should Green Thumb manufacture for sale? What is the expected profit from this policy? On average, how many customers does Green Thumb expect to turn away because of stocking out?
2. The general manager at Green Thumb decides to conduct extensive market research for its new product. At the end of the market research, the manager estimates demand to be normally distributed, with a mean of $\mu = 100$ and a standard deviation of $\sigma = 15$. How should Green Thumb alter its production plans in Exercise 1 as a result of the market research? How much increase in profit is it likely to observe? How does the improved forecast affect the demand lost by Green Thumb because of understocking? Use cost and price information from Exercise 1.
3. The manager at Goodstone Tires, a distributor of tires in Illinois, uses a continuous review policy to manage inventory. The manager currently orders 10,000 tires when the inventory of tires drops to 6,000. Weekly demand for tires is normally distributed, with a mean of 2,000 and a standard deviation of 500. The replenishment lead time for tires is two weeks. Each tire costs Goodstone \$40, and the company sells each tire for \$80. Goodstone incurs a holding cost of 25 percent. How much safety inventory does Goodstone currently carry? At what cost of understocking is the manager's current inventory policy justified? How much safety inventory should Goodstone carry if the cost of understocking is \$80 per tire in lost current and future margin?

4. Champion manufactures winter fleece jackets for sale in the United States. Demand for jackets during the season is normally distributed, with a mean of 20,000 and a standard deviation of 10,000. Each jacket sells for $60 and costs $30 to produce. Any leftover jackets at the end of the season are sold for $25 at the year-end clearance sale. Holding jackets until the year-end sale adds another $5 to their cost. A recent recruit has suggested shipping leftover jackets to South America for sale in the winter there rather than running a clearance. Each jacket will fetch a price of $35 in South America, and all jackets sent there are likely to sell. Shipping costs add $5 to the cost of any jacket sold in South America. Would you recommend the South American option? How will this decision affect production decisions at Champion? How will it affect profitability at Champion? On average, how many jackets will Champion ship to South America each season?
5. Snoblo, a manufacturer of snow blowers, sells four models. The base model, Reguplo, has demand that is normally distributed, with a mean of 10,000 and a standard deviation of 1,000. The three other models have additional features, and each has demand that is normally distributed, with a mean of 1,000 and a standard deviation of 700. Currently all four models are manufactured on the same line at a cost of $100 for Reguplo and $110 for each of the other three models. Reguplo sells for $200, whereas each of the other three models sells for $220. Any unsold blowers are sold at the end of the season for $80. Snoblo is considering the use of tailored sourcing by setting up two separate lines, one for Reguplo and one for the other three. Given that no changeovers will be required on the Reguplo line, the production cost of Reguplo is expected to decline to $90. The production cost of the other three products, however, will now increase to $120. Do you recommend tailored sourcing for Snoblo? How will tailored sourcing affect production and profits? Ignore holding costs for the snow blowers.
6. AnyLogo supplies firms with apparel containing their logo to be used for promotional purposes. AnyLogo has four major customers—IBM, AT&T, HP, and Cisco. During the holiday season, the logos are adorned with a Christmas motif. Demand from each firm for apparel with the Christmas motif is normally distributed, as shown in Table 12-8.

   AnyLogo currently produces all the apparel including the logo embroidery in Sri Lanka in advance of the holiday season. Each unit costs $15 and is sold by AnyLogo for $50. Any leftover inventory at the end of the holiday season is essentially worthless and is donated by AnyLogo to charity. Holding the apparel in inventory adds another $3 to the cost per unit donated to inventory. However, the donation allows AnyLogo to recover $6 per unit in tax savings. What production quantities do you recommend for AnyLogo? What is the expected profit from the policy? On average, how much does AnyLogo expect to donate to charity each year?
7. The manager at AnyLogo is considering the purchase of high-speed embroidery machines that will allow it to embroider on demand. In this case, the apparel will be made in Sri Lanka without any logo; the logo embroidery will be postponed and will be done in the United States on demand. This will raise the cost per unit to $18. However, AnyLogo will not have any holiday or company-specific apparel to be disposed of at the end of the season. The apparel without logos can be sold for $18 a unit to retailers. The cost of holding inventory and shipping adds $4 to the cost of any apparel left over after the holiday season. With all other information as in Exercise 6, do you recommend that the manager at AnyLogo implement postponement? What will be the impact of postponement on profits and inventories?

TABLE 12-8 Demand Distribution for AnyLogo

	IBM	*AT&T*	*HP*	*Cisco*
Mean	5,000	7,000	4,000	4,000
SD	2,000	2,500	2,000	2,200

8. A major fast-food company is running a promotion for children's meals for which they offer a Sharky toy. A single order will be placed for the toys. Each toy costs $0.50, and any unsold toys will have to be scrapped at the end of the promotion. The margin from each meal (including the toy) is $1.00, and children are very likely to go to a competitor if the fast-food company is out of toys. The demand for meals with the toys is forecast to be normally distributed, with a mean of 50,000 and a standard deviation of 15,000.
   (a) How many Sharky toys should be ordered in advance of the promotion?
   (b) An issue has been raised that customers who go to competitors may be lost for the long term. It has been estimated that the cost of not having toys in stock is $5 per stockout because of the loss of current and future sales. How does this information affect the number of Sharky toys to be ordered?
9. The Highland Company (THC) is planning orders for its winter catalog. One order is to be placed at the beginning of the season. The demand forecast for one of its jackets is normal, with a mean of 5,000 and standard deviation of 2,000. Each jacket is purchased for $100, and any unsold jackets at the end of the season will be discounted and sold through the outlet store for $75. At this price, virtually all jackets are expected to sell. It costs another $15 to store an unsold jacket for the season and then move it to the outlet store. There is basic disagreement within the buying committee on the effect of stocking out and the number of jackets to be ordered. One of the members feels that 6,000 jackets should be ordered, whereas another feels that 8,000 jackets should be ordered.
   (a) At what cost of stocking out would each of the member's order size be justified?
   (b) If the planned sale price is $200, describe a situation in which ordering 6,000 jackets makes sense. Describe another situation in which ordering 8,000 jackets makes sense.
10. Sport Obermeyer (SO) is a manufacturer of Ski Apparel. A ski jacket is sourced at a cost of $80 and sold for $125. One order is placed at the beginning of the season. Currently, SO disposes of any unsold jackets at the end of the season to outlet stores at $70. It costs $10 to hold a jacket in inventory for the entire season and then ship it to an outlet store. Demand for ski jackets has been forecast to be normally distributed, with a mean of 4,000 and a standard deviation of 1,750.
   (a) How many jackets should SO order for the season assuming a single order?
   (b) What is the expected profit from this policy?
   (c) What is the expected overstock at the end of the season that will be sent to outlet stores?
   (d) SO is considering an alternative under which it will ship surplus jackets at the end of the season for sale in the Southern Hemisphere. Inclusive of all costs, SO expects the salvage value to increase to $75 under this option. How will this change affect the quantity ordered, expected profits, and expected overstock to be sent to the Southern Hemisphere? Do you recommend this option?
11. Daily demand for aspirin at DoorRed Pharmacy is normally distributed, with a mean of 40 bottles and a standard deviation of 5. The replenishment lead time from the supplier is one day. The current inventory policy at DoorRed is to order 200 bottles when the quantity on hand drops below 45. Each bottle costs DoorRed $4, and the pharmacy uses a holding cost of 25 percent.
   (a) If all unfilled demand is assumed to be backlogged and carried over to the next cycle, what cost of understocking justifies the current policy?
   (b) If all unfilled demand is assumed to be lost, what cost of stocking out justifies the current policy?
   (c) DoorRed feels that all unfilled demand can be backlogged if customers are given a $1.50 discount on their next purchase (effectively making the cost of understocking $1.50). What inventory policy do you recommend for DoorRed?

12. Lake Grove Confectionaries (LGC) sells chocolates for the holiday season in specially designed boxes. The firm sells four different designs, and currently all packaging is done in the plant as chocolates are manufactured. All manufacturing and packaging for the holiday season is completed before the start of the season. The demand forecast for each of the four designs is normal, with a mean of 20,000 and a standard deviation of 8,000. Each box costs $10 and is sold for $20. Any unsold boxes at the end of the season are discounted to $8, and they all sell out at this price. The cost of holding a box in inventory for the entire season before selling it at a discount is $1.
    (a) How many boxes of each design should LGC manufacture?
    (b) What is the expected profit from this policy?
    (c) How many boxes does LGC expect to sell at a discount?
    (d) An option being considered by LGC is to separate chocolate production from packaging. Chocolates will be produced before the start of the season, but packaging will be done on an express line as orders come in. The express line and separation of steps adds $2 to the cost of production. How many boxes of chocolates should LGC manufacture if it decides to postpone packaging? What is the expected profit? How many boxes will LGC sell at a discount if it uses postponement?
    (e) At what additional cost of postponement (instead of the current $2) would LGC be indifferent between operating with and without postponement?
13. The Knitting Company (TKC) is planning production for its four styles that are popular during Christmas. All four styles have demand that is normally distributed. The best-selling style has an expected demand of 30,000 and a standard deviation of 5,000. Each of the other three styles has an expected demand of 10,000 with a standard deviation of 4,000. Currently all sweaters are produced before the start of the season. Production cost is $20 per sweater, and they are sold for a wholesale price of $35. Any unsold sweaters at the end of the season are discounted to $15, and they all sell at that price. It costs $2 to hold the sweater in inventory for the entire season if it does not sell.
    (a) How many sweaters of each type should TKC manufacture?
    (b) What is the expected profit from this policy?
    (c) How many sweaters does TKC expect to sell at a discount?
    (d) TKC is considering the postponement of knitting and using very flexible machines. This will require the base sweaters to be made in advance (identical for each of the four types) and the final patterns to be knit later. This will increase production cost per sweater to $21.40. How many sweaters should TKC manufacture with postponement? What is the expected profit from this policy?
    (e) Another option is to produce the popular style without postponement and the other three styles using postponement. What is the expected profit under this policy?
14. A designer is planning orders for its annual limited-edition ornament. Demand has been forecast to be normally distributed, with a mean of 20,000 and a standard deviation of 8,000. Each ornament costs $30 and is sold for $95. All unsold ornaments are destroyed at the end of the season, to ensure the value of the limited edition.
    (a) How many ornaments should the designer order? What is the expected profit?
    (b) The manufacturer has offered to discount the price to $28 per ornament if at least 25,000 are ordered. How should the designer respond?
15. A publisher is printing calendars for the coming year. Demand for calendars is normally distributed, with a mean of 70,000 and a standard deviation of 25,000. The cost per calendar is $3, and they are sold for $10 each. All unsold calendars are recycled at the end of January.
    (a) How many calendars should the publisher have printed? What is the expected profit?
    (b) The printer has offered to discount the printing cost to $2.75 per calendar if the publisher orders at least 100,000. What should the publisher do?

16. An electronics manufacturer has outsourced production of its latest MP3 players to a contract manufacturer in Asia. Demand for the players has exceeded all expectations, whereas the contract manufacturer has limited production capacity. The electronics manufacturer sells three types of players—a 40-GB player, a 20-GB player, and a 6-GB player. For the upcoming holiday season, the demand forecast for the 40-GB player is normally distributed, with a mean of 20,000 and a standard deviation of 7,000, the demand forecast for the 20-GB player has a mean of 40,000 and a standard deviation of 11,000, and the demand forecast for the 6-GB player has a mean of 80,000 and a standard deviation of 16,000. The 40-GB player has a sale price of $200, a production cost of $100, and a salvage value of $80. The 20-GB player has a sale price of $150, a production cost of $90, and a salvage value of $70. The 6-GB player has a sale price of $100, a production cost of $70, and a salvage value of $50.
    (a) How many units of each type of player should the electronics manufacturer order if there are no capacity constraints?
    (b) The contract manufacturer has available production capacity of only 140,000 units. What is the expected profit if the electronics manufacturer orders 20,000 units of the 40-GB player, 40,000 units of the 20-GB player, and 80,000 units of the 6-GB player?
    (c) How many units of each type of player should the electronics manufacturer order if the available capacity is 140,000? What is the expected profit?

Bibliography

Cachon, Gerard P., and Marshall L. Fisher. "Campbell Soup's Continuous Product Replenishment Program: Evaluation and Enhanced Decision Rules." *Production and Operations Management* 6 (1997): 266–76.

Cachon, Gerard P., and Martin A. Lariviere. "Turning the Supply Chain into a Revenue Chain." *Harvard Business Review* (March 2001): 20–21.

Clark, Theodore H., and Janice H. Hammond. "Reengineering Channel Reordering Processes to Improve Total Supply Chain Performance." *Production and Operations Management* 6 (1997): 248–65.

Fisher, Marshall L., Janice H. Hammond, Walter R. Obermeyer, and Ananth Raman. "Making Supply Meet Demand in an Uncertain World." *Harvard Business Review* (May–June 1994): 83–93.

Nahmias, Steven. *Production and Operations Analysis*. Burr Ridge, IL: Richard P. Irwin, 1997.

Padmanabhan, V., and Ivan P. L. Png. "Returns Policies: Making Money by Making Good." *Sloan Management Review* (Fall 1995): 65–72.

Pasternack, Barry A. "Optimal Pricing and Return Policies for Perishable Commodities." *Marketing Science* 4 (1985): 166–76.

Signorelli, Sergio, and James L. Heskett. *Benetton (A)*. Harvard Business School Case 9–685–014, 1984.

Silver, Edward A., David Pyke, and Rein Petersen. *Inventory Management and Production Planning and Scheduling*. New York: Wiley, 1998.

Tayur, Sridhar, Ram Ganeshan, and Michael Magazine, eds. *Quantitative Models for Supply Chain Management*. Boston: Kluwer Academic Publishers, 1999.

The Critical-Fractile Method for Inventory Planning. Harvard Business School Note 9–191–132, 1991.

APPENDIX 12A

OPTIMAL LEVEL OF PRODUCT AVAILABILITY

Objective: Evaluate the level of product availability that maximizes profit.

Analysis: In this analysis we assume that the demand is a continuous nonnegative random variable with density function $f(x)$ and cumulative distribution function $F(x)$. C_u is the margin per unit and, as a result, the cost of understocking per unit. C_o is the cost of overstocking per unit.

Assume that Q units are purchased and a demand of x units arises. If $Q < x$, all Q units are sold and a profit of QC_u results. On the other hand, if $Q \geq x$, only x units are sold and a profit of $xC_u - (Q - x)C_o$ results. The expected profit $P(Q)$ is thus given by

$$P(Q) = \int_0^Q [xC_u - (Q - x)C_o]f(x)dx + \int_Q^\infty QC_u f(x)dx$$

To determine the value of Q that maximizes the expected profit $P(Q)$, we have

$$\frac{dP(Q)}{d(Q)} = -C_o \int_0^Q f(x)dx + C_u \int_Q^\infty f(x)dx$$
$$= C_u[1 - F(Q)] - C_o F(Q) = 0$$

This implies an optimal order size of Q^*, where

$$F(Q^*) = \frac{C_u}{C_u + C_o}$$

It is easy to verify that the second derivative is negative, implying that the total expected profit is maximized at Q^*.

APPENDIX 12B

AN INTERMEDIATE EVALUATION

Objective: Given that x is normally distributed, with a mean μ and standard deviation σ, show that

$$A = \int_{x=-\infty}^{a} xf(x)dx = \mu F_S\left[\frac{(a-\mu)}{\sigma}\right] - \sigma f_S\left[\frac{(a-\mu)}{\sigma}\right] \tag{12.8}$$

Here $f(x)$ is the normal density function, $f_S(\,)$ is the standard normal density function, and $F_S(\,)$ is the standard normal cumulative distribution function.

Analysis: Using Equation 11.18 we have

$$A = \int_{x=-\infty}^{a} xf(x)dx = \int_{-\infty}^{a} x\frac{1}{\sqrt{2\pi}\sigma}e^{-(x-\mu)^2/2\sigma^2}\,dx$$

Substitute $z = (x-\mu)/\sigma$. This implies that $dx = \sigma\,dz$. Thus, we have

$$A = \int_{z=-\infty}^{(a-\mu)/\sigma} (z\sigma+\mu)\frac{1}{\sqrt{2\pi}}e^{-z^2/2}\,dz$$

$$= \mu\int_{z=-\infty}^{(a-\mu)/\sigma}\frac{1}{\sqrt{2\pi}}e^{-z^2/2}\,dz + \sigma\int_{z=-\infty}^{(a-\mu)/\sigma} z\frac{1}{\sqrt{2\pi}}e^{-z^2/2}\,dz$$

Given the relationship between the cumulative distribution function and the probability density function, we use the definition of the standard normal distribution and Equation 11.18 to obtain

$$F_S(t) = \int_{z=-\infty}^{t} f_S(z)dz = \int_{z=-\infty}^{t}\frac{1}{\sqrt{2\pi}}e^{-z^2/2}\,dz$$

Substitute $w = z^2/2$ into the expression for A. This implies that $dw = z\,dz$. Thus,

$$A = \mu F_S\left[\frac{(a-\mu)}{\sigma}\right] + \sigma\int_{w=\infty}^{(a-\mu)^2/2\sigma^2}\frac{1}{\sqrt{2\pi}}e^{-w}\,dw$$

or

$$A = \mu F_S\left[\frac{(a-\mu)}{\sigma}\right] - \sigma f_S\left[\frac{(a-\mu)}{\sigma}\right]$$

APPENDIX 12C

EXPECTED PROFIT FROM AN ORDER

Objective: Assume demand to be normally distributed, with a mean μ and standard deviation σ. Each unit sells for a price $\$p$ and costs $\$c$. Any unsold units fetch a salvage value of $\$s$. Obtain an expression for the expected profit if O units are ordered.

Analysis: If O units are ordered and demand turns out to be $x < O$, each of the x units sold contributes $p - c$, whereas each of the $(O - x)$ units unsold results in a loss of $c - s$. If demand is larger than O, each of the O units sold contributes $p - c$. We thus obtain

Expected profits

$$= \int_{x=-\infty}^{O} [(p - c)x - (c - s)(O - x)]f(x)dx + \int_{x=O}^{\infty} O(p - c)f(x)dx = \int_{x=-\infty}^{O} [(p - s)x - O(c - s)]f(x)dx + \int_{x=O}^{\infty} O(p - c)f(x)dx$$

Using Equation 12.8, we obtain

$$\int_{x=-\infty}^{O} xf(x)dx = \mu F_S\left[\frac{(O - \mu)}{\sigma}\right] - \sigma f_S\left[\frac{(O - \mu)}{\sigma}\right]$$

We can thus evaluate the expected profits as

Expected profits

$$= (p - s)\mu F_S\left[\frac{(O - \mu)}{\sigma}\right] - (p - s)\,\sigma f_S\left[\frac{(O - \mu)}{\sigma}\right] - O(c - s)\,F(O, \mu, \sigma) + O(p - c)[1 - F(O, \mu, \sigma)]$$

APPENDIX 12D

EXPECTED OVERSTOCK FROM AN ORDER

Objective: Assume demand to be normally distributed, with a mean μ and standard deviation σ. Obtain an expression for the expected overstock if O units are ordered.

Analysis: If O units are ordered, an overstock results only if demand is $x < O$. We thus have

$$\text{Expected overstock} = \int_{x=-\infty}^{O} (O - x) f(x) dx$$

$$= \int_{x=-\infty}^{O} Of(x)dx - \int_{x=-\infty}^{O} xf(x)dx$$

$$= OF_S\left[\frac{O - \mu}{\sigma}\right] - \int_{x=-\infty}^{O} xf(x)dx$$

Using Equation 12.8, we thus obtain

Expected overstock

$$= OF_S\left[\frac{(O - \mu)}{\sigma}\right] - \mu F_S\left[\frac{(O - \mu)}{\sigma}\right] + \sigma f_S\left[\frac{(O - \mu)}{\sigma}\right]$$

$$= (O - \mu)F_S\left[\frac{(O - \mu)}{\sigma}\right] + \sigma f_S\left[\frac{(O - \mu)}{\sigma}\right]$$

APPENDIX 12E

EXPECTED UNDERSTOCK FROM AN ORDER

Objective: Assume demand to be normally distributed, with a mean μ and standard deviation σ. Obtain an expression for the expected understock if O units are ordered.

Analysis: If O units are ordered, an understock results only if demand is $x > O$. We thus have

$$\text{Expected understock} = \int_{x=O}^{\infty} (x - O) f(x) dx$$

$$= \int_{x=O}^{\infty} x f(x) dx - \int_{x=O}^{\infty} O f(x) dx = \int_{x=-\infty}^{\infty} x f(x) dx$$

$$- \int_{x=-\infty}^{O} x f(x) dx - O\left\{1 - F_S\left[\frac{(O - \mu)}{\sigma}\right]\right\} = (\mu - O)$$

$$+ O F_S\left[\frac{(O - \mu)}{\sigma}\right] - \int_{x=-\infty}^{O} x f(x) dx$$

Using Equation 12.8, we thus obtain

$$\text{Expected understock} = (\mu - O) + O F_S\left[\frac{(O - \mu)}{\sigma}\right]$$

$$- \mu F_S\left[\frac{(O - \mu)}{\sigma}\right] + \sigma f_S\left[\frac{(O - \mu)}{\sigma}\right]$$

$$= (\mu - O)\left\{1 - F_S\left[\frac{(O - \mu)}{\sigma}\right]\right\} + \sigma f_S\left[\frac{(O - \mu)}{\sigma}\right]$$

APPENDIX 12F

SIMULATION USING SPREADSHEETS

A simulation is a computer model that replicates a real-life situation, allowing the user to estimate what the potential outcome would be from each of a set of actions. Simulation is a very powerful tool that helps evaluate the impact of business decisions on performance in an uncertain environment. In some instances, future scenarios can be modeled mathematically without simulation and formulas can be obtained for the impact of different policies on performance. In other cases, formulas are difficult or impossible to obtain and one must use simulation. Simulations are powerful because they can accommodate any number of complications. Problems that are impossible to solve analytically can often be solved fairly easily with simulation. A good simulation is an inexpensive way to test different actions and identify the most effective decision given an uncertain future.

Consider Lands' End, a mail-order firm that sells apparel. Lands' End faces uncertain demand and has to make decisions regarding the number of catalogs to print and mail, the number of units of each product to order, and the contracts to enter into with its suppliers. The general manager at Lands' End wants to evaluate different policies before implementing them. A simulation requires the manager to create a computer model that mimics the orders placed, inventory held, customer demand, and other processes that are part of the Lands' End supply chain.

An *instance* of demand refers to random demand obtained from a demand distribution. Each time demand is generated from a distribution, a new instance results. Based on estimates of the future demand distribution, instances of demand for different products are generated randomly. The impact of an ordering policy is evaluated for each instance of demand generated. Based on a large number of demand instances, the manager can evaluate the mean and variability of the performance of a policy. Different policies can then be compared.

Generating Random Numbers Using Excel A fundamental step in any simulation is the generation of random numbers that correspond to the distribution that has been estimated for future demand or some other parameter. For example, if Lands' End has estimated demand for cashmere sweaters from the winter catalog to be normally distributed, with a mean of 3,000 and a standard deviation of 1,000, the manager needs to generate several instances of demand from this distribution. There are several functions available in Excel that generate random numbers.

The *RAND*( ) function generates a random number that is uniformly distributed between 0 and 1. There is thus a 10 percent probability that *RAND*( ) will generate a number between 0 and 0.1, a 50 percent probability that it will generate a random number between 0 and 0.5, and a 90 percent probability that it will generate a random number between 0 and 0.9. The *RAND*( ) function can be used to generate random numbers from a variety of distributions.

The Excel function *NORMINV*(*RAND*( ), μ, σ) generates a random number that is normally distributed, with mean μ and standard deviation σ. The Excel function *NORMSINV*(*RAND*( )) generates a random number that is normally distributed, with a mean of 0 and standard deviation of 1. The fact that both *NORMINV* and *NORMSINV* can generate negative numbers often poses problems when they are used to generate demand. One option is to use a maximum of 0 and *NORMINV*(*RAND*( ), μ, σ) to generate demand. This is appropriate if the coefficient of variation, *cv*, is less than 0.4. For larger coefficients of variation it is better to use the log-normal distribution because it generates only nonnegative numbers. The Excel function *LOGINV*(*RAND*( ), μ, σ) generates a random number X that follows the log-normal distribution, where $\ln(X)$ is normally distributed, with mean μ and standard deviation σ. Several other demand distributions may also be generated, using other Excel functions.

Setting Up a Simulation Model Lands' End plans to sell cashmere sweaters in its winter catalog for \$150 each. The manager expects demand to be normally distributed, with a mean of $\mu = 3{,}000$ and a standard deviation of $\sigma = 1{,}000$. Toward the end of the winter season, Lands' End sends out a sales catalog with discounted prices on unsold items. The discounted price determines the demand in response to the sales catalog. The manager anticipates that the sales catalog will generate demand for cashmere sweaters with a mean of $1{,}000 - 5p$ and a standard deviation of $(1{,}000 - 5p)/3$, where p is the discounted price charged. Any leftover sweaters after the sales catalog are donated to charity. Each sweater costs Lands' End \$50. Thus, the donation to charity fetches \$25 in tax benefits. Lands' End incurs a cost of \$5 per unsold sweater to store and transport them to charity, resulting in a salvage value of $s = \$20$ per sweaters sent to charity. The manager has decided to charge a discount price of $\max(\$25, \$150 - n/20)$, where n is the number of sweaters left over after the winter catalog. The manager wants to identify the number of sweaters that should be purchased at the start of the winter season.

The first step is to set up a simulation model that evaluates the net profit for an instance of demand during the winter season. The model constructed is shown in Figure 12-6.

FIGURE 12-6 Excel Simulation Model for Lands' End

	A	B	C	D	E	F	G	H	I
1	***Ordering and Pricing at Land's End***								
2									
3	Cost of sweaters =			$50					
4	Sale Price in winter catalog =			$150					
5	Mean demand from winter catalog =			3,000					
6	SD of demand from winter catalog =			1,000					
7	Mean discounted demand =			341					
8	SD of discounted demand =			113.58					
9									
10	Initial Quantity ordered =			3000		Cost of sweaters ordered =			$150,000
11	Winter catalog demand =			2637		Revenue from winter sales =			$395,550
12	Sweaters to be discounted =			363		Revenue from discounted sales =			$30,194
13	Discounted price, p =			$131.90		Net benefit from donation =			$2,680
14	Demand at discounted price =			229		Net profit =			**$278,424**
15	Number sold at discount =			229					
16	Number donated to charity =			134					
17									
18	Average profit =			$266,702		Average number of sweaters discounted =			376
19	SD of profit =			$64,939		Average number donated to charity =			180

Cell Number	Cell Formula	Cell Number	Cell Formula
D7	=1000-5*D13	D16	=D12-D15
D8	=D7/3	I10	=D3*D10
D11	=int(max(0,norminv(rand(),D5,D6))	I11	=min(D10,D11)*D4
D12	=max(0,D10-D11)	I12	=D15*D13
D13	=max(25,150-D12/20)	I13	=D16*20
D14	=int(max(0,norminv(rand(),D7,D8))	I14	=sum(I11:I13)-I10
D15	=min(D12,D14)		

Using Data Table to Create Many Instances Having set up the simulation model, the next step is to create many instances of random demand and evaluate the average profits from ordering 3,000 units. In Excel, *Data Tables* can be used to achieve multiple replications of the simulation. The goal is to evaluate the mean and standard deviation of profits, the average number of sweaters discounted, and the average number of sweaters donated to charity over the multiple replications. A data table is constructed in the range A23:D522 to replicate the results of the simulation for 500 instances of demand as follows:

1. Enter formula =I14 in cell B23, =D12 in cell C23, and =D16 in cell D23. As a result, the profit is copied into cell B23, the quantity discounted is copied into cell C23, and the quantity given to charity is copied into cell D23.
2. Select the range A23:D522. From the toolbar select *Data* | *Table*. In the *Table* dialog box, point to cell A23 as the *Column input cell*. Click on OK.

The data table is created in the range A23:D522. Each row of the data table gives the profit, quantity discounted, and quantity given to charity for an instance of random demand. Excel recalculates the simulation using new random numbers for each row in the data table. We can now obtain the average profit, average number of sweaters discounted, and average number of sweaters donated to charity from the data table. These are calculated in cells C18, I18, and I19, respectively, in Figure 12-6.

Each time the F9 key is pressed, new random numbers are generated and all entries are recalculated. The manager at Lands' End can use the simulation to evaluate the impact of different initial ordering policies on performance.

PART V



DESIGNING AND PLANNING TRANSPORTATION NETWORKS

CHAPTER 13
TRANSPORTATION IN A SUPPLY CHAIN

Part V deals with the supply chain driver of transportation, the last of our sections on each of the three logistical drivers. In the chapter, we discuss the strengths and weaknesses of various modes of transportation and different options for designing transportation networks. We also discuss trade-offs among transportation cost, inventory cost, and responsiveness that must be considered when designing a supply chain.

CHAPTER 13
TRANSPORTATION IN A SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of transportation in a supply chain.
2. Evaluate the strengths and weaknesses of different modes of transportation.
3. Discuss the role of infrastructure and policies in transportation.
4. Identify the relative strengths and weaknesses of various transportation network design options.
5. Identify trade-offs that shippers must consider when designing a transportation network.

In this chapter, we discuss the role of transportation within a supply chain and identify trade-offs that must be considered when making transportation decisions. Our goal is to enable managers to make transportation strategy and design, planning, and operational decisions with an understanding of all the important pros and cons of their choices.

13.1 THE ROLE OF TRANSPORTATION IN A SUPPLY CHAIN

Transportation refers to the movement of product from one location to another as it makes its way from the beginning of a supply chain to the customer. Transportation is an important supply chain driver because products are rarely produced and consumed in the same location. Transportation is a significant component of the costs incurred by most supply chains. In fact, transportation activity represented more than 10 percent of the GDP of the United States in 2002.[1] Only three sectors—housing, health care, and food—contributed a larger share to GDP than transportation. Transportation-related jobs employed nearly 20 million people in 2002, accounting for 16 percent of U.S. total occupational employment.

The role of transportation is even more significant in global supply chains. Dell currently has suppliers worldwide and sells to customers all over the world from just a few plants. Transportation allows products to move across Dell's global network. Similarly, global transportation allows Wal-Mart to sell products manufactured all over the world in the United States.

International trade is becoming a bigger part of the world's economic activity. According to the Bureau of Transportation Statistics, total international merchandise

[1] *Freight Shipments in America,* Bureau of Transportation Statistics, 2002.

trade to and from the United States increased at an average annual rate of 9.3 percent between 1990 and 2001.[2] The growth in international merchandise trade was more than three times the growth of the U.S. economy over the same period. Between 1970 and 2001, U.S. international merchandise trade grew by over 20 times, whereas the U.S. economy grew about 10 times over the same period. With the rapid growth in international trade, good multimodal freight transportation systems to move the resulting cargo have become even more significant.

Any supply chain's success is closely linked to the appropriate use of transportation. IKEA, the Scandinavian home furnishings retailer, has built a global network with about 180 stores in 23 countries primarily on the basis of effective transportation. IKEA's sales for the year ending August 2004 reached 12.8 billion euros. IKEA's strategy is built around providing good-quality products at low prices. Their goal is to cut prices by 2 to 3 percent each year. As a result, IKEA works hard to find the most inexpensive global source for each of its products. Modular design of its furniture allows IKEA to transport its goods worldwide much more cost effectively than a traditional furniture manufacturer. The large size of IKEA stores and shipments allows inexpensive transportation of home furnishings all the way to the retail store. Effective sourcing and inexpensive transportation allow IKEA to provide high-quality home furnishings at low prices globally.

Seven-Eleven Japan is another firm that has used transportation to achieve its strategic goals. The company has a goal of carrying products in its stores to match the needs of customers as they vary by geographic location or time of day. To help achieve this goal, Seven-Eleven Japan uses a very responsive transportation system that replenishes its stores several times a day so that the products available match customers' needs. Products from different suppliers are aggregated on trucks according to the required temperature to help achieve very frequent deliveries at a reasonable cost. Seven-Eleven Japan uses a responsive transportation system along with aggregation to decrease its transportation and receiving costs while ensuring that product availability closely matches customer demand.

Supply chains also use responsive transportation to centralize inventories and operate with fewer facilities. For example, Amazon.com relies on package carriers and the postal system to deliver customer orders from centralized warehouses. Dell manufactures in a few locations in the United States and uses responsive transportation provided by package carriers to provide customers with highly customized products at a reasonable price.

The *shipper* is the party that requires the movement of the product between two points in the supply chain. The *carrier* is the party that moves or transports the product. For example, when Dell uses UPS to ship its computers from the factory to the customer, Dell is the shipper and UPS is the carrier. Two other parties have a significant impact on transportation: the owners and operators of transportation infrastructure such as roads, ports, canals, and airports; and the bodies that set transportation policy worldwide. Actions by all four parties influence the effectiveness of transportation.

To understand transportation in a supply chain it is important to consider the perspective of all four parties. A carrier makes investment decisions regarding the transportation equipment (locomotives, trucks, airplanes, etc.) and in some cases infrastructure (rail), and then makes operating decisions to try to maximize the return from these assets. A shipper, in contrast, uses transportation to minimize the total cost (transportation, inventory, information, sourcing, and facility) while providing an appropriate level of responsiveness to the customer.

[2] *U.S. International Trade and Freight Transportation Trends*, Bureau of Transportation Statistics, 2003.

We can think of a transportation network as a collection of nodes and links. Transportation originates and ends at nodes and travels on links. For most modes of transportation, infrastructure such as ports, roads, waterways, and airports is required both at the nodes and links. Most transportation infrastructure is owned and managed as a public good throughout the world. It is very important that infrastructure be managed in such a way that monies are available for maintenance and investment in further capacity as needed. Transportation policy sets direction for the amount of national resources that go into improving transportation infrastructure. Transportation policy also aims to prevent abuse of monopoly power, promote fair competition, and balance environmental, energy, and social concerns in transportation.

In the following sections we discuss issues that are important from the perspective of carriers, infrastructure owners and operators, transportation policy makers, and shippers. In the next section we discuss different modes of transportation and their cost and performance characteristics.

13.2 MODES OF TRANSPORTATION AND THEIR PERFORMANCE CHARACTERISTICS

Supply chains use a combination of the following modes of transportation:

- Air
- Package carriers
- Truck
- Rail
- Water
- Pipeline
- Intermodal

Commercial freight activity in the United States by mode in 2002 is summarized in Table 13-1.

Before discussing the various modes, it is important to highlight a couple of important trends in the U.S. economy. Between 1970 and 2002, U.S. real GDP, measured in year 2000 dollars, grew by 176 percent. Over the same period, U.S. freight transportation measured in ton-miles grew by only 73 percent. In 1970, it took 2.1 ton-miles of freight transportation to produce $1 of goods GDP. In 2002, it took only 1.1 ton-miles to produce $1 of GDP. This trend reflects the downsizing of products with new technology and the improved efficiency of the freight transportation system.

TABLE 13-1 Transportation Facts

Mode	*Freight Value ($ billions)*	*Percent Change Since 1993*	*Freight Tons (billions)*	*Percent Change Since 1993*	*Freight Ton-Miles (millions)*	*Percent Change Since 1993*
Air (includes truck and air)	777	96.7	10	45.9	15	63.2
Truck	6,660	42.2	9,197	26.4	1,449	55.5
Rail	388	39.2	1,895	19.9	1,254	29.9
Water	867	39.9	2,345	10.2	733	−16.9
Pipeline	285	−8.7	1,656	3.8	753	27.0
Multimodal	1,111	67.0	213	−7.5	226	36.7

Adapted from Bureau of Transportation Statistics, *Freight Shipments in America*, 2002.

The effectiveness of any mode of transport is affected by equipment investments and operating decisions by the carrier as well as the available infrastructure and transportation policies. The carrier's primary objective is to ensure good utilization of its assets while providing customers with an acceptable level of service. Carrier decisions are affected by equipment cost, fixed operating cost, variable operating costs, the responsiveness the carrier seeks to provide its target segment, and the prices that the market will bear. For example, FedEx designed a hub-and-spoke airline network for transporting packages to provide fast, reliable delivery times. UPS, in contrast, uses a combination of aircrafts, rail, and trucks to provide cheaper transportation with somewhat longer delivery times. The difference between the two transportation networks is reflected in the pricing schedule. FedEx charges for packages based primarily on size. UPS, in contrast, charges based on both size and destination. From a supply chain perspective, a hub-and-spoke air network is more appropriate when prices are independent of destination and rapid delivery is important, whereas a trucking network is more appropriate when prices vary with destination and a somewhat slower delivery is acceptable.

AIR

Major airlines in the United States that carry both passenger and cargo include American, United, and Delta. Airlines have a high fixed cost in infrastructure and equipment. Labor and fuel costs are largely trip related and independent of the number of passengers or amount of cargo carried on a flight. An airline's goal is to maximize the daily flying time of a plane and the revenue generated per trip. Given the large fixed costs and relatively low variable costs, revenue management (see Chapter 15), in which airlines vary seat prices and allocate seats to different price classes, is a significant factor in the success of passenger airlines. At present, airlines practice revenue management for passengers but much less so for cargo.

Air carriers offer a very fast and fairly expensive mode of transportation. Small, high-value items or time-sensitive emergency shipments that have to travel a long distance are best suited for air transport. Air carriers normally move shipments under 500 pounds, including high-value but lightweight high-tech products. Given the growth in high technology, the weight of freight carried by air has diminished over the last two decades even as the value of the freight has increased somewhat. In 2002, the goods U.S. businesses moved by air were valued at $75,000 per ton, by far the highest among all modes.

The value of international trade moved by air to and from the United States grew significantly, from $10 billion in 1970 to $519 billion in 2001, growing at an average annual rate of 14 percent per year.[3] Between 1980 and 2001, freight operating revenues for U.S. international cargo increased from $1 billion to over $6 billion. Since 2001, however, the challenge of cargo security and the growing cost of fuel have had a significant impact on the financial performance of air carriers. The impact was exacerbated by the significant capacity the industry added by acquiring new aircraft.

Key issues that air carriers face include identifying the location and number of hubs, assigning planes to routes, setting up maintenance schedules for planes, scheduling crews, and managing prices and availability at different prices.

PACKAGE CARRIERS

Package carriers are transportation companies such as FedEx, UPS, and the U.S. Postal Service, which carry small packages ranging from letters to shipments weighing about 150 pounds. Package carriers use air, truck, and rail to transport time-critical smaller

[3] *U.S. International Trade and Freight Transportation Trends,* Bureau of Transportation Statistics, 2003.

packages. Package carriers are expensive and cannot compete with LTL carriers on price for large shipments. The major service they offer shippers is rapid and reliable delivery. Thus, shippers use package carriers for small and time-sensitive shipments. Package carriers also provide other value-added services that allow shippers to speed inventory flow and track order status. By tracking order status, shippers can proactively inform customers about their packages. Package carriers also pick up the package from the source and deliver it to the destination site. With an increase in just-in-time (JIT) deliveries and focus on inventory reduction, demand for package carriers has grown.

Package carriers are the preferred mode of transport for e-businesses such as Amazon.com and Dell, as well as for companies such as W.W. Grainger and McMaster-Carr that send small packages to customers. With the growth in e-business, the use of package carriers has increased significantly over the last few years. Package carriers seek out smaller and more time-sensitive shipments than air cargo, especially where tracking and other value-added services are important to the shipper. FedEx uses trucks to pick up packages at the source and deliver them to the final destination. Air cargo carriers do not provide this combined service. Companies use air cargo carriers for larger shipments and package carriers for smaller, more time-sensitive ones. For example, Dell uses air cargo to bring components from Asia but uses package carriers to deliver PCs to customers.

Given the small size of packages and several delivery points, consolidation of shipments is a key factor in increasing utilization and decreasing costs for package carriers. Package carriers have trucks that make local deliveries and pick up packages. Packages are then taken to large sorting centers from which they are sent by full truckload, rail, or air to the sorting center closest to the delivery point. From the delivery-point sorting center, the package is sent to customers on small trucks making milk runs (discussed later in the chapter). Key issues in this industry include the location and capacity of transfer points as well as information capability to facilitate and track package flow. For the final delivery to a customer, an important consideration is the scheduling and routing of the delivery trucks.

TRUCK

In 2002, trucks moved 64 percent of U.S commercial freight by value and 58 percent by weight.[4] The trucking industry consists of two major segments—TL or LTL. Trucking is more expensive than rail but offers the advantage of door-to-door shipment and a shorter delivery time. It also has the advantage of requiring no transfer between pickup and delivery. Major TL carriers include Schneider National, JB Hunt, Ryder Integrated, Werner, and Swift Transportation.

TL operations have relatively low fixed costs, and owning a few trucks is often sufficient to enter the business. As a result there are many TL carriers in the industry. Schneider National, the largest TL carrier, had only 17 percent of the market share among the top 40 firms in the United States in 1996. The goal of a TL carrier is to schedule shipments to meet service requirements while minimizing both trucks' idle and empty travel time.

TL pricing displays economies of scale with respect to the distance traveled. Given trailers of different size, pricing also displays economies of scale with respect to the size of the trailer used. TL shipping is suited for transportation between manufacturing facilities and warehouses or between suppliers and manufacturers. For example, Proctor & Gamble offers TL shipping to customer warehouses.

[4] *Freight Shipments in America,* Bureau of Transportation Statistics, 2002.

LTL operations are priced to encourage shipments in small lots, usually less than half a TL, as TL tends to be cheaper for larger shipments. Prices display some economies of scale with the quantity shipped as well as the distance traveled. LTL shipments take longer than TL shipments because of other loads that need to be picked up and dropped off. LTL shipping is suited for shipments that are too large to be mailed as small packages but that constitute less than half a TL.

A key to reducing LTL costs is the degree of consolidation that carriers can achieve for the loads carried. LTL carriers use consolidation centers to which trucks bring in many small loads originating from a geographic area and leave with many small loads destined for the same geographic area. This allows LTL carriers to improve their truck use, although it increases delivery time somewhat. Larger firms enjoy an advantage in the LTL industry given the importance of consolidation and the fixed cost of setting up consolidation centers. Strong regional players have developed in the LTL industry because of the advantage offered by a high density of pickup and delivery points in a geographic area.

Key issues for the LTL industry include location of consolidation centers, assigning of loads to trucks, and scheduling and routing of pickup and delivery. The goal is to minimize costs through consolidation without hurting delivery time and reliability.

RAIL

In 2002, rail carried about 4 percent of U.S. shipments by value, 12 percent by weight, and over 25 percent of total ton-miles. These figures reflect the use of rail to move commodities over large distances. Rail carriers incur a high fixed cost in terms of rails, locomotives, cars, and yards. There is also a significant trip-related labor and fuel cost that is independent of the number of cars (fuel costs do vary somewhat with the number of cars) but does vary with the distance traveled and the time taken. Any idle time, once a train is powered, is very expensive because labor and fuel costs are incurred even though trains are not moving. Idle time occurs when trains exchange cars for different destinations. It also occurs because of track congestion. Labor and fuel together account for over 60 percent of railroad expense. From an operational perspective, it is thus important for railroads to keep locomotives and crew well utilized.

The price structure and the heavy load capability makes rail an ideal mode for carrying large, heavy, or high-density products over long distances. Transportation time by rail, however, can be long. Rail is thus ideal for very heavy, low-value shipments that are not very time sensitive. Coal, for example, is a major part of each railroad's shipments. Small, time-sensitive, short-distance or short-lead-time shipments rarely go by rail.

A major goal for railroad firms is to keep locomotives and crews well utilized. Major operational issues at railroads include vehicle and staff scheduling, track and terminal delays, and poor on-time performance. Railroad performance is hurt by the large amount of time taken at each transition. The travel time is usually a small fraction of the total time for a rail shipment. Delays get exaggerated because trains today are typically not scheduled but "built." In other words, a train leaves once there are enough cars to constitute the train. Cars wait for the train to build, adding to the uncertainty of the delivery time for a shipper. A railroad can improve on-time performance by scheduling some of the trains instead of building all of them. In such a setting, a more sophisticated pricing strategy that includes revenue management (see Chapter 15) needs to be instituted for scheduled trains.

WATER

Major ocean carriers include Maersk Sealand, Evergreen Group, American President Lines, and Hanjin Shipping Co. Water transport, by its nature, is limited to certain

areas. Within the United States, water transport takes place via the inland waterway system (the Great Lakes and rivers) or coastal waters. Water transport is ideally suited for carrying very large loads at low cost. Within the United States, water transport is used primarily for the movement of large bulk commodity shipments and is the cheapest mode for carrying such loads. It is, however, the slowest of all the modes, and significant delays occur at ports and terminals. This makes water transport difficult to operate for short-haul trips, though it is used effectively in Japan and parts of Europe for daily short-haul trips of a few miles.

Within the United States, the passage of the Ocean Shipping Reform Act of 1998 has been a significant event for water transport. This act allows carriers and shippers to enter into confidential contracts, effectively deregulating the industry. The act is similar to the deregulation that occurred in the trucking and airline industries over two decades ago and is likely to have a similar impact on the shipping industry.

In global trade, water transport is the dominant mode for shipping all kinds of products. Cars, grain, apparel, and other products are shipped by sea. In 2001, merchandise trade valued at over $718 billion moved between the United States and foreign seaports. Maritime transportation accounted for 78 percent of the U.S. international merchandise freight by weight in 2002. For the quantities shipped and the distances involved in international trade, water transport is by far the cheapest mode of transport. A significant trend in maritime trade worldwide has been the growth in containerization. This has led to a demand for larger, faster, and more specialized vessels to improve the economics of container transport. Delays at ports, customs, security, and the management of containers used are major issues in global shipping. Port congestion in particular has been a big problem in the United States.

PIPELINE

Pipeline is used primarily for the transport of crude petroleum, refined petroleum products, and natural gas. In the United States, pipeline accounted for about 17 percent of total ton-miles in 2002. A significant initial fixed cost is incurred in setting up the pipeline and related infrastructure that does not vary significantly with the diameter of the pipeline. Pipeline operations are typically optimized at about 80 to 90 percent of pipeline capacity. Given the nature of the costs, pipelines are best suited when relatively stable and large flows are required. Pipeline may be an effective way of getting crude oil to a port or a refinery. Sending gasoline to a gas station does not justify investment in a pipeline and is done better with a truck. Pipeline pricing usually consists of two components—a fixed component related to the shipper's peak usage and a second charge relating to the actual quantity transported. This pricing structure encourages the shipper to use the pipeline for the predictable component of demand with other modes often being used to cover fluctuations.

INTERMODAL

Intermodal transportation is the use of more than one mode of transport to move a shipment to its destination. A variety of intermodal combinations are possible, with the most common being truck/rail. Major intermodal providers with rail include CSX Intermodal, Pacer Stacktrain, and Triple Crown. Intermodal traffic has grown considerably with the increased use of containers for shipping and the rise of global trade. Containers are easy to transfer from one mode to another, and their use facilitates intermodal transportation. Containerized freight often uses truck/water/rail combinations, particularly for global freight. For global trade, intermodal is often the only option because factories and markets may not be next to ports. As the quantity shipped

using containers has grown, the truck/water/rail intermodal combination has also grown. In 1996, intermodal activity contributed 16 percent of rail revenues.[5] On land, the rail/truck intermodal system offers the benefit of lower cost than TL and delivery times that are better than rail, thereby bringing together different modes of transport to create a price/service offering that cannot be matched by any single mode. It also creates convenience for shippers who now deal with only one entity representing all carriers who together provide the intermodal service.

Key issues in the intermodal industry involve the exchange of information to facilitate shipment transfers between different modes because these transfers often involve considerable delays, hurting delivery time performance.

13.3 TRANSPORTATION INFRASTRUCTURE AND POLICIES

Roads, seaports, airports, rail, and canals are some of the major infrastructural elements that exist along nodes and links of a transportation network. In almost all countries, the government has either taken full responsibility or played a significant role in building and managing these infrastructure elements. Even in the United States, where a lot of the rail infrastructure was built by private capital under a charter, the cost was subsidized through land grants from the government. Improved infrastructure has played a significant role in the development of transportation and the resulting growth of trade. The role of the railroads and canals in the economic development of the United States is well documented. More recently, the impact of improved road, air, and port infrastructure on the development of China is very visible.

Before considering policy questions related to transportation infrastructures, it is worth looking at the history of rail and road infrastructure in the United States to see some of the issues involved. We summarize some of the discussion by Ellison (2002) of the history of railroads and regulation in the industry. The construction of railroads in the United States occurred rapidly during the 1850s. The railroads were private but were built with significant government subsidy, often in the form of land grants. By the 1870s, the railroad network connected most of the United States. Each railroad was the exclusive provider of carriage over its track. This monopoly allowed railroads to determine the price they charged as well as the level of service they provided their customers. Initial construction of new railroads led to some competition over rates. The railroad companies responded by entering into agreements with each other that effectively ended competition and raised rates. Protests by farmers and other users of the railroads led eventually to the establishment of the Interstate Commerce Commission (ICC), which prohibited discriminatory pricing. The ICC required railroads to file their rates with the ICC and made them public. The railroads responded by forming cartels to restrict supply. This led to the passage of the Sherman Antitrust Act in 1890. Responding to the financial difficulties of railways in the 1940s, the government allowed them some degree of coordination and exempted them from the antitrust regulations. With the growth of other modes of transport and the need to revitalize their assets, the railroads were in bad financial shape in the early 1970s. The Staggers Rail Act of 1980 deregulated the railroads, allowed them some rate-making powers, and eased entry and exit. The act also removed the antitrust immunity of the railroads. Deregulation in the United States was followed by a wave of reorganization and mergers within the railroad industry. Overall, deregulation has resulted in improved financial performance of the railroad industry and increased use of rail by shippers.

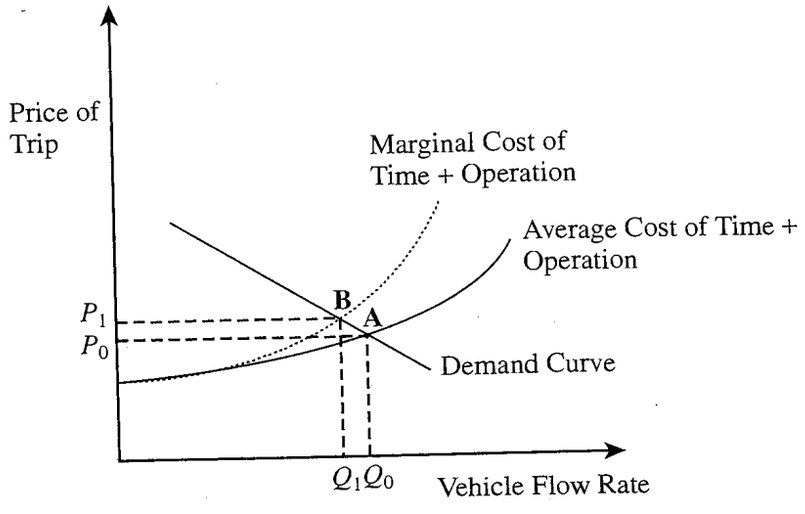
[5] *Distribution*, July 1997.

An excellent discussion of the history of road construction and pricing is given by Levinson (1998). In the late 1700s, turnpikes were built using public funds in Virginia, Maryland, and Pennsylvania but were then turned over to private companies that collected tolls. Over time, other turnpikes were built as a result of competition between towns to gain trade. Other than federal land grants, these roads were typically built with local effort and money. The tolls on these turnpikes were generally structured to keep local travel free and make people traveling across an area pay for this right. With the growth in railroads and canals, turnpikes suffered financially in the mid-1800s and were eventually converted into public roads. In the twentieth century, as the modes of transport changed, there was a need for higher-quality roads. A network of national toll-free highways was built, largely using gasoline taxes as the source of funding. At the same time, other facilities such as tunnels and bridges were often constructed as toll facilities. In many other countries, such as France and Spain, concessions were granted to private companies that received toll revenue. More recently, private toll roads have also been built in Malaysia, Indonesia, and Thailand.

From the above examples it seems reasonable that the government has to either own or regulate a monopolistic transportation infrastructure asset. When the transportation infrastructure asset has competition either within a mode or across modes, private ownership, deregulation, and competition seem to work well. The deregulation of the transportation industry within the United States is a case in point. Keep in mind, however, that roads, ports, and airports are largely public and not private. This is because of the inherently monopolistic nature of these transportation infrastructure assets. In such a setting the public ownership of these assets is justified. This raises the policy question of financing the construction and maintenance of these publicly owned transportation assets. Should roads be financed through a gasoline tax, or is some other form of financing such as tolls more appropriate?

Economists such as Vickrey have argued for public ownership of these assets but the setting of quasi-market prices to improve overall efficiency. Quasi-market prices need to take into account the discrepancy between the incentives of an individual using the transportation infrastructure and the public as a whole that owns the infrastructure. This discrepancy is illustrated in Figure 13-1 in the context of road traffic.

FIGURE 13-1 Impact of Average and Marginal Cost on Vehicle Flow



A vehicle driver bases his decision to use a highway on the cost and benefit of doing so. Figure 13-1 assumes that different people have different value for making the trip and this value is uniformly distributed over an interval. The number of users whose value from a trip exceeds a particular cost is thus defined by the demand curve. The costs incurred by a motorist include the cost of time spent on the highway and the cost of operating and maintaining the vehicle. It is well known that the time spent increases nonlinearly with congestion on a highway. Thus, the average cost to each motorist increases with traffic flow as shown in Figure 13-1. Given people's valuation of the trip, the number of motorists using the road is determined by the intersection of the demand curve with the average cost curve at point A. This results in an average cost to motorists of P_0 and a traffic flow of Q_0. From the perspective of the public, however, it is more appropriate to consider how each additional motorist impacts the total cost. Observe that an additional motorist increases the average cost by a small amount but increases the total cost across all motorists by a much larger amount. This is represented in Figure 13-1 by the marginal cost curve, which measures the marginal increase in total cost as a result of additional traffic flow. Observe that the marginal cost curve is higher than the average cost curve. In other words, the marginal impact of a motorist on total cost is much higher than his or her share of the impact. From a marginal cost perspective, motorists should be charged a toll $P_1 - P_0$ so that the cost they bear is the true cost they are imposing on the highway system. This toll lowers the vehicle flow rate to Q_1. In other words, the absence of a congestion toll results in an overuse of the transportation infrastructure and a resulting congestion cost on all users. The problem is well illustrated by a simple illustration given by Vickrey (see Button and Verhoef, 1998). Each member of a group going out to dinner is likely to order an expensive item if the plan is to share the bill equally at the end instead of having each person pay his or her true charge. Thus, it is fair to say that the overall bill is higher if it is shared equally compared to each person paying based on actual consumption. The same is true with transportation infrastructure if pricing is not linked to congestion.

Quasi-market prices for transportation infrastructure thus result in higher prices at peak locations and times and lower prices otherwise. Such pricing is not commonly observed for transportation infrastructure except for roads in Singapore and city centers in a few European cities. Congestion is a major factor at several ports and airports. The Los Angeles–Long Beach port, for example, experienced significant congestion in 2004. Several factors affected the congestion, including capacity problems on railroads taking containers away, labor shortages, and technology issues. However, congestion was also affected by the desire of many shippers to bring weekly shipments from Asia over the weekend to ensure supply for the entire week. This created a peak time with significant congestion. The peak workload also becomes exaggerated as container ships get larger. In such a situation, the use of peak tolls to level out the arrivals can be an effective policy. Overall, it is important to keep in mind that transportation infrastructure faces congestion-related problems unless users are forced to internalize the marginal impact on society of their actions. It may be most effective to charge a congestion toll and use the money generated to improve the effectiveness of the transportation infrastructure.

KEY POINT Transportation infrastructures often require government ownership or regulation because of its inherently monopolistic nature. In the absence of a monopoly, deregulation and market forces are an effective mechanism. When the infrastructure is publicly owned, it is important to price usage to reflect the marginal impact on the cost to society. If this is not done, overuse and congestion result because the cost borne by a user is less than his or her marginal impact on total cost.

13.4 DESIGN OPTIONS FOR A TRANSPORTATION NETWORK

The design of a transportation network affects the performance of a supply chain by establishing the infrastructure within which operational transportation decisions regarding scheduling and routing are made. A well-designed transportation network allows a supply chain to achieve the desired degree of responsiveness at a low cost. We discuss a variety of design options for transportation networks and the strengths and weaknesses for each option in the context of a buyer with multiple locations sourcing from several suppliers. These design options may be implemented between any two stages of a supply chain.

DIRECT SHIPMENT NETWORK

With the direct shipment network option, the buyer structures his transportation network so that all shipments come directly from each supplier to each buyer location, as shown in Figure 13-2. With a direct shipment network, the routing of each shipment is specified and the supply chain manager only needs to decide on the quantity to ship and the mode of transportation to use. This decision involves a trade-off between transportation and inventory costs, as discussed later in the chapter.

The major advantage of a direct shipment transportation network is the elimination of intermediate warehouses and its simplicity of operation and coordination. The shipment decision is completely local, and the decision made for one shipment does not influence others. The transportation time from supplier to buyer location is short because each shipment goes direct.

A direct shipment network is justified if demand at buyer locations is large enough that optimal replenishment lot sizes are close to a TL from each supplier to each location. With small buyer locations, however, a direct shipment network tends to have high costs. If a TL carrier is used for transportation, the high fixed cost of each truck results in large lots moving from suppliers to each buyer location, resulting in high supply chain inventories. If a LTL carrier is used, the transportation cost and the delivery time increase, though inventories are lower. If package carriers are used, transportation costs are very high. With direct deliveries from each supplier, receiving costs are high because each supplier must make a separate delivery.

FIGURE 13-2 Direct Shipment Network

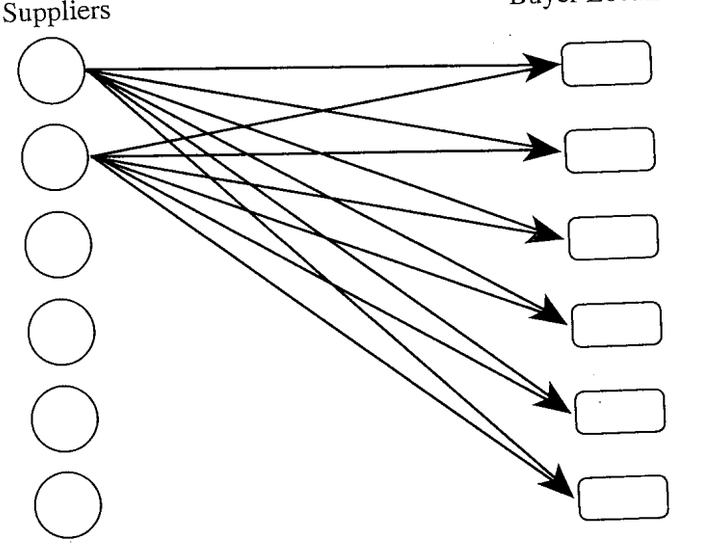
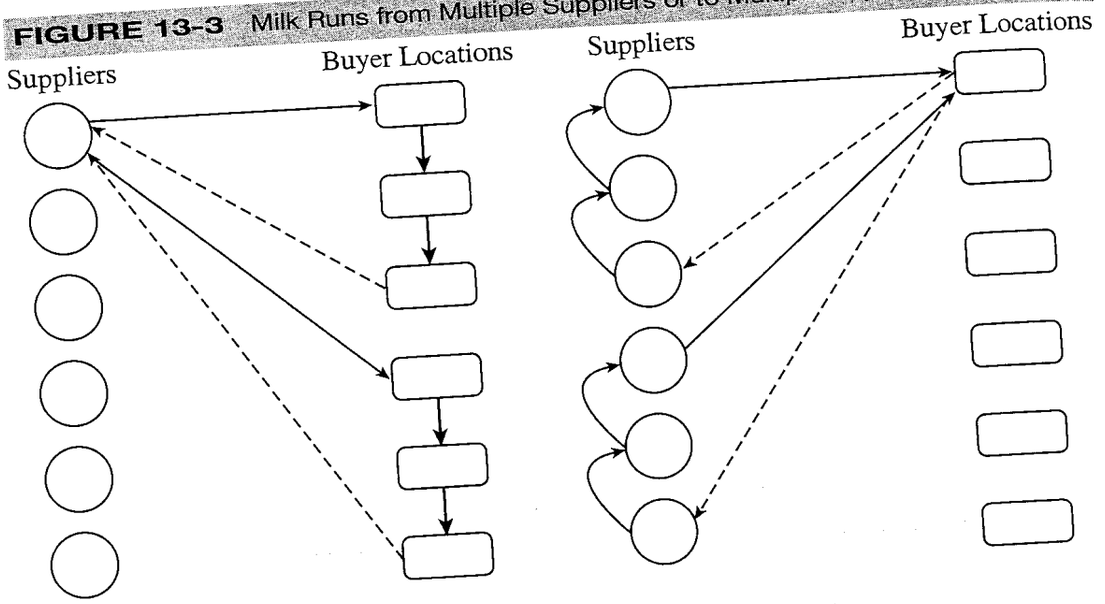


FIGURE 13-3 Milk Runs from Multiple Suppliers or to Multiple Buyer Locations



DIRECT SHIPPING WITH MILK RUNS

A *milk run* is a route on which a truck either delivers product from a single supplier to multiple retailers or goes from multiple suppliers to a single buyer location, as shown in Figure 13-3. In direct shipping with milk runs, a supplier delivers directly to multiple buyer locations on a truck or a truck picks up deliveries destined for the same buyer location from many suppliers. When using this option, a supply chain manager has to decide on the routing of each milk run.

Direct shipping provides the benefit of eliminating intermediate warehouses, whereas milk runs lower transportation cost by consolidating shipments to multiple locations on a single truck. For example, the replenishment lot size for each buyer location may be small and require LTL shipping if sent directly. The use of milk runs allows deliveries to multiple locations to be consolidated on a single truck, resulting in better utilization of the truck and somewhat lower costs. Companies such as Frito-Lay that make direct store deliveries use milk runs to lower their transportation cost. If very frequent small deliveries are needed on a regular basis and either a set of suppliers or a set of retailers is in geographic proximity, the use of milk runs can significantly reduce transportation costs. For example, Toyota uses milk runs from suppliers to support its JIT manufacturing system in both Japan and the United States. In Japan, Toyota has many assembly plants located close together and thus uses milk runs from a single supplier to many plants. In the United States, however, Toyota uses milk runs from many suppliers to each assembly plant.

ALL SHIPMENTS VIA CENTRAL DC

Under this option, suppliers do not send shipments directly to buyer locations. The buyer divides locations by geographic region and a DC is built for each region. Suppliers send their shipments to the DC and the DC then forwards appropriate shipments to each buyer location, as shown in Figure 13-4.

The DC is an extra layer between suppliers and buyer locations and can play two different roles. One is to store inventory and the other is to serve as a transfer location. In either case, the presence of DCs can help reduce supply chain costs when suppliers

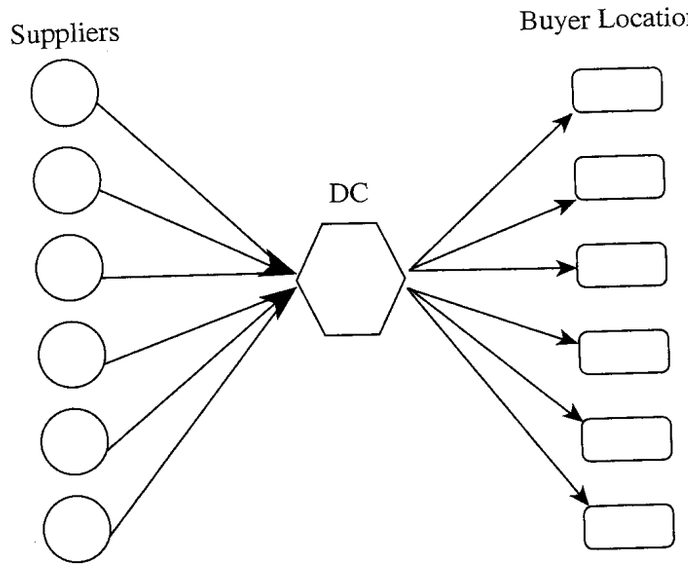


FIGURE 13-4 All Shipments via DC

are located far from the buyer locations and transportation costs are high. The presence of a DC allows a supply chain to achieve economies of scale for inbound transportation to a point close to the final destination, because each supplier sends a large shipment to the DC that contains product for all locations the DC serves. Because DCs serve locations nearby, the outbound transportation cost is not very large. For example, W.W. Grainger has its suppliers ship products to one of nine DCs, which in turn replenish their almost 400 branches.

If transportation economies require very large shipments on the inbound side, DCs hold inventory and send product to buyer locations in smaller replenishment lots. For example, when Wal-Mart sources from an overseas supplier, the product is held in inventory at the DC because the lot size on the inbound side is much larger than the sum of the lot sizes for the stores served by the DC. If replenishment lots for the buyer locations served by a DC are large enough to achieve economies of scale on inbound transportation, the DC does not need to hold inventory. In this case the DC can cross-dock product arriving from many suppliers on inbound trucks by breaking each inbound shipment into smaller shipments that are then loaded onto trucks going to each buyer location. When a DC cross-docks product, each inbound truck contains product from a supplier for several buyer locations, whereas each outbound truck contains product for a buyer location from several suppliers. A major benefit of cross-docking is that little inventory needs to be held and product flows faster in the supply chain. Cross-docking also saves on handling cost because product does not have to be moved into and out of storage. Successful cross-docking, however, does require a significant degree of coordination and synchronization between the incoming and outgoing shipments.

Cross-docking is appropriate for products with large, predictable demands and requires that DCs be set up such that economies of scale in transportation are achieved on both the inbound and outbound sides. Wal-Mart has used cross-docking successfully to decrease inventories in the supply chain without incurring excessive transportation costs. Wal-Mart builds many large stores in a geographic area supported by a DC. As a result, the total lot size to all stores from each supplier fills trucks on the inbound side to achieve economies of scale. On the outbound side, the sum of the lot sizes from all suppliers to each retail store fills up the truck to achieve economies of scale.

SHIPPING VIA DC USING MILK RUNS

As shown in Figure 13-5, milk runs can be used from a DC if lot sizes to be delivered to each buyer location are small. Milk runs reduce outbound transportation costs by consolidating small shipments. For example, Seven-Eleven Japan cross-docks deliveries from its fresh-food suppliers at its DCs and sends out milk runs to the retail outlets because the total shipment to a store from all suppliers does not fill a truck. The use of cross-docking and milk runs allows Seven-Eleven Japan to lower its transportation cost while sending small replenishment lots to each store. The use of cross-docking with milk runs requires a significant degree of coordination and suitable routing and scheduling of milk runs.

The online grocer Peapod uses milk runs from DCs when making customer deliveries to help reduce transportation costs for small shipments to be delivered to homes. OshKosh B'Gosh, a manufacturer of children's wear, has used this idea to virtually eliminate LTL shipments from its DC in Tennessee to retail stores.

TAILORED NETWORK

The tailored network option is a suitable combination of previous options that reduces the cost and improves responsiveness of the supply chain. Here transportation uses a combination of cross-docking, milk runs, and TL and LTL carriers, along with package carriers in some cases. The goal is to use the appropriate option in each situation. High-demand products to high-demand retail outlets may be shipped directly, whereas low-demand products or shipments to low-demand retail outlets are consolidated to and from the DC. The complexity of managing this transportation network is high because different shipping procedures are used for each product and retail outlet. Operating a tailored network requires significant investment in information infrastructure to facilitate the coordination. Such a network, however, allows for the selective use of a shipment method to minimize the transportation as well as inventory costs.

Table 13-2 summarizes the pros and cons of the various transportation network options discussed.

In the next section we discuss a variety of trade-offs that supply chain managers need to consider when designing and operating a transportation network.

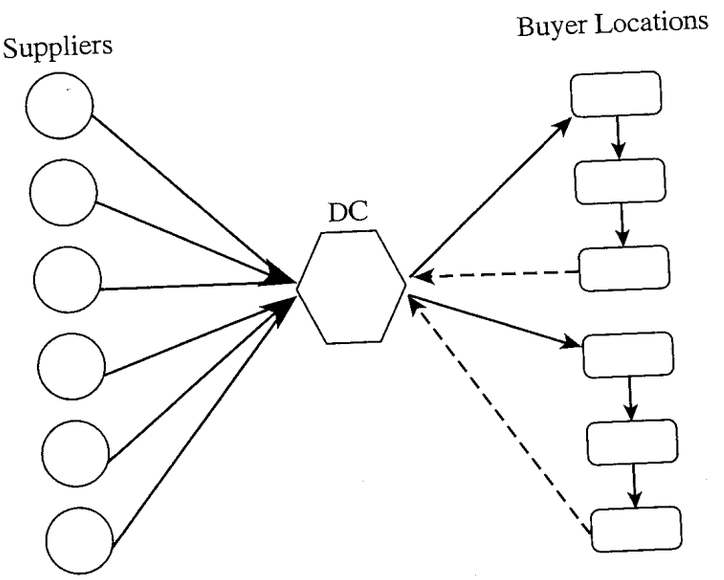


FIGURE 13-5 Milk Runs from DC

TABLE 13-2 Pros and Cons of Different Transportation Networks

Network Structure	*Pros*	*Cons*
Direct shipping	No intermediate warehouse Simple to coordinate	High inventories (due to large lot size) Significant receiving expense
Direct shipping with milk runs	Lower transportation costs for small lots Lower inventories	Increased coordination complexity
All shipments via central DC with inventory storage	Lower inbound transportation cost through consolidation	Increased inventory cost Increased handling at DC
All shipments via central DC with cross-dock	Very low inventory requirement Lower transportation cost through consolidation	Increased coordination complexity
Shipping via DC using milk runs	Lower outbound transportation cost for small lots	Further increase in coordination complexity
Tailored network	Transportation choice best matches needs of individual product and store	Highest coordination complexity

13.5 TRADE-OFFS IN TRANSPORTATION DESIGN

All transportation decisions made by shippers in a supply chain network must take into account their impact on inventory costs, facility and processing costs, the cost of coordinating operations, as well as the level of responsiveness provided to customers. For example, Dell's use of package carriers to deliver PCs to customers increases transportation cost but allows Dell to centralize its facilities and reduce inventory costs. If Dell wants to reduce its transportation costs, the company must either sacrifice responsiveness to customers or increase the number of facilities and resulting inventories to move closer to customers.

The cost of coordinating operations is generally hard to quantify. Shippers should evaluate different transportation options in terms of various costs as well as revenues and then rank them according to coordination complexity. A manager can then make the appropriate transportation decision. Managers must consider the following trade-offs when making transportation decisions:

- Transportation and inventory cost trade-off
- Transportation cost and customer responsiveness trade-off

TRANSPORTATION AND INVENTORY COST TRADE-OFF

The trade-off between transportation and inventory costs is significant when designing a supply chain network. Two fundamental supply chain decisions involving this trade-off are

- Choice of transportation mode
- Inventory aggregation

Choice of Transportation Mode

Selecting a transportation mode is both a planning and an operational decision in a supply chain. The decision regarding carriers with which a company contracts is a planning decision, whereas the choice of transportation mode for a particular shipment is an operational decision. For both decisions, a shipper must balance transportation and inventory costs. The mode of transportation that results in the lowest transportation cost does not necessarily lower total costs for a supply chain. Cheaper modes of

TABLE 13-3 Ranking of Transportation Modes in Terms of Supply Chain Performance

Size	Lot Inventory	Safety Inventory	In-Transit Cost	Transportation Time	Transportation
Rail	5	5	5	2	5
TL	4	4	4	3	3
LTL	3	3	3	4	4
Package	1	1	1	6	1
Air	2	2	2	5	2
Water	6	6	6	1	6

transport typically have longer lead times and larger minimum shipment quantities, both of which result in higher levels of inventory in the supply chain. Modes that allow for shipping in small quantities lower inventory levels but tend to be more expensive. Dell, for example, airfreights several of its components from Asia. This choice cannot be justified on the basis of transportation cost alone. It can only be justified because the use of a faster mode of transportation for shipping valuable components allows Dell to carry low levels of inventory.

The impact of using different modes of transportation on inventories, response time, and costs in the supply chain is shown in Table 13-3. Each transportation mode is ranked along various dimensions, with 1 being the lowest and 6 being the highest.

Faster modes of transportation are preferred for products with a high value-to-weight ratio, for which reducing inventories is important, whereas cheaper modes are preferred for products with a small value-to-weight ratio, for which reducing transportation cost is important. The choice of transportation mode should take into account cycle, safety, and in-transit inventory costs besides the cost of transportation. Ignoring inventory costs when making transportation decisions can result in choices that worsen the performance of a supply chain, as illustrated in Example 13-1.

Example 13-1: **Tradeoffs when selecting transportation mode**

Eastern Electric (EE) is a major appliance manufacturer with a large plant in the Chicago area. EE purchases all the motors for its appliances from Westview Motors, located near Dallas. EE currently purchases 120,000 motors each year from Westview at a price of $120 per motor. Demand has been relatively constant for several years and is expected to stay that way. Each motor averages about 10 pounds in weight, and EE has traditionally purchased lots of 3,000 motors. Westview ships each EE order within a day of receiving it. At its assembly plant, EE carries a safety inventory equal to 50 percent of the average demand for motors during the delivery lead time.

The plant manager at EE has received several proposals for transportation and must decide on the one to accept. The details of various proposals are provided in Table 13-4, where one cwt is equal to a hundred pounds.

Golden's pricing represents a marginal unit quantity discount (see Chapter 10). Golden's representative has proposed lowering the marginal rate for the quantity over

TABLE 13-4 Transportation Proposals for EE Electric

Carrier	Range of Quantity Shipped (cwt)	Shipping Cost ($/cwt)
AM Railroad	200+	6.50
Northeast Trucking	100+	7.50
Golden Freightways	50–150	8.00
Golden Freightways	150–250	6.00
Golden Freightways	250+	4.00

250 cwt in a shipment from \$4/cwt to \$3/cwt and suggested that EE increase its batch size to 4,000 motors to take advantage of the lower transportation cost. What should the plant manager do?

Analysis: Golden's new proposal will result in very low transportation costs for EE if the plant manager orders in lots of 400 motors. The plant manager, however, decides to include inventory costs in the transportation decision. EE's annual cost of holding inventory is 25 percent, which implies an annual holding cost of $H = \$120 \times 0.25 = \$30$ per motor. Shipments by rail require a five-day transit time, whereas shipments by truck have a transit time of three days. The transportation decision affects the cycle inventory, safety inventory, and in-transit inventory for EE. Therefore, the plant manager decides to evaluate the total transportation and inventory cost for each transportation option.

The AM Rail proposal requires a minimum shipment of 20,000 pounds or 2,000 motors. The replenishment lead time in this case is $L = 5 + 1 = 6$ days. For a lot size of $Q = 2{,}000$ motors, the plant manager obtains the following:

$$\begin{aligned}
\text{Cycle inventory} &= Q/2 = 2{,}000/2 = 1{,}000 \text{ motors} \\
\text{Safety inventory} &= L/2 \text{ days of demand} = (6/2)(120{,}000/365) \\
&= 986 \text{ motors} \\
\text{In-transit inventory} &= 120{,}000(5/365) = 1{,}644 \text{ motors} \\
\text{Total average inventory} &= 1{,}000 + 986 + 1{,}644 = 3{,}630 \text{ motors} \\
\text{Annual holding cost using AM Rail} &= 3{,}630 \times \$30 = \$108{,}900
\end{aligned}$$

AM Rail charges \$6.50 per cwt, resulting in a transportation cost of \$0.65 per motor because each motor weighs 10 pounds. Thus,

$$\text{Annual transportation cost using AM Rail} = 120{,}000 \times 0.65 = \$78{,}000$$

The total annual cost for inventory and transportation using AM Rail is thus \$186,900.

The plant manager then evaluates the cost associated with each transportation option as shown in Table 13-5. Based on the analysis in Table 13-5, the plant manager decides to sign a contract with Golden Freightways and order motors in lots of 500. This option has the highest transportation cost but the lowest overall cost. If the selection of the transportation option was made using only the transportation cost incurred, Golden's new proposal lowering the price for large shipments would look attractive. In reality, EE pays a high overall cost for this proposal. Thus, considering the trade-off between inventory and transportation costs allows the plant manager to make a transportation decision that minimizes EE's total cost.

KEY POINT When selecting a mode of transportation, managers must account for cycle, safety, and in-transit inventory costs that result from using each mode. Modes with high transportation cost can be justified if they result in significantly lower inventory costs.

TABLE 13-5 Analysis of Transportation Options for Eastern Electric

Alternative	*Lot Size (Motors)*	*Transportation Cost*	*Cycle Inventory*	*Safety Inventory*	*In-Transit Inventory*	*Inventory Cost*	*Total Cost*
AM Rail	2,000	\$78,000	1,000	986	1,644	\$108,900	\$186,900
Golden	1,000	\$90,000	500	658	986	\$64,320	\$154,320
Golden	500	\$96,000	250	658	986	\$56,820	\$152,820
Golden	1,500	\$96,000	750	658	986	\$71,820	\$167,820
Golden	2,500	\$86,400	1,250	658	986	\$86,820	\$173,220
Golden	3,000	\$78,000	1,500	658	986	\$94,320	\$172,320
Golden (old proposal)	4,000	\$72,000	2,000	658	986	\$109,320	\$181,320
Golden (new proposal)	4,000	\$67,500	2,000	658	986	\$109,320	\$176,820

Inventory Aggregation

Firms can significantly reduce the safety inventory they require by physically aggregating inventories in one location (see Chapter 11). Most e-businesses use this technique to gain advantage over firms with facilities in many locations. For example, Amazon.com has focused on decreasing its facility and inventory costs by holding inventory in a few warehouses, whereas booksellers such as Borders and Barnes & Noble have to hold inventory in many retail stores.

Transportation cost, however, generally increases when inventory is aggregated. If inventories are highly disaggregated, some aggregation can also lower transportation costs. Beyond a point, however, aggregation of inventories raises total transportation costs. Consider a bookstore chain such as Borders. The inbound transportation cost to Borders is due to the replenishment of bookstores with new books. There is no outbound cost because customers transport their own books home. If Borders decides to close all its bookstores and sell only online, it will have to incur both inbound and outbound transportation costs. The inbound transportation cost to warehouses will be lower than to all bookstores. On the outbound side, however, transportation cost will increase significantly because the outbound shipment to each customer will be small and will require an expensive mode such as a package carrier. The total transportation cost will increase on aggregation because each book travels the same distance as when it was sold through a bookstore, except that a large fraction of the distance is on the outbound side using an expensive mode of transportation. As the degree of inventory aggregation increases, total transportation cost goes up. Thus, all firms planning inventory aggregation must consider the trade-offs among transportation, inventory, and facility costs when making this decision.

Inventory aggregation is a good idea when inventory and facility costs form a large fraction of a supply chain's total costs. Inventory aggregation is useful for products with a large value-to-weight ratio and for products with high demand uncertainty. For example, inventory aggregation is very valuable for new products in the PC industry, because PCs have a large value-to-weight ratio and demand for new products is uncertain. Inventory aggregation is also a good idea if customer orders are large enough to ensure sufficient economies of scale on outbound transportation. When products have a low value-to-weight ratio and customer orders are small, however, inventory aggregation may hurt a supply chain's performance because of high transportation costs. Compared to PCs, the value of inventory aggregation is smaller for best-selling books that have a lower value-to-weight ratio and more predictable demand.

We illustrate the trade-off involved in making aggregation decisions in Example 13-2.

Example 13-2: **Tradeoffs when aggregating inventory**

HighMed, a manufacturer of medical equipment used in heart procedures, is located in Madison, Wisconsin, and its products are used by cardiologists all over North America. The medical equipment is not sold through purchasing agents but directly to doctors. HighMed currently divides the United States into 24 territories, each with its own sales force. All product inventories are maintained locally and replenished from Madison every four weeks using UPS. The average replenishment lead time using UPS is one week. UPS charges at a rate of $0.66 + 0.26$x$, where x is the quantity shipped in pounds. The products sold fall into two categories—Highval and Lowval. Highval products weigh 0.1 pounds and cost $200 each. Lowval products weigh 0.04 pounds and cost $30 each.

Weekly demand for Highval products in each territory is normally distributed, with a mean of $\mu_H = 2$ and a standard deviation of $\sigma_H = 5$. Weekly demand for Lowval products in each territory is normally distributed, with a mean of $\mu_L = 20$ and a standard deviation of $\sigma_L = 5$. HighMed maintains sufficient safety inventories in each territory to provide a CSL of 0.997 for each product. Holding cost at HighMed is 25 percent.

In addition to the current approach, the management team at HighMed is considering two other options:

Option A. Keep the current structure but replenish inventory once a week rather than once every four weeks.

Option B. Eliminate inventories in the territories, aggregate all inventories in a finished-goods warehouse at Madison, and replenish the warehouse once a week.

If inventories are aggregated at Madison, orders will be shipped using FedEx, which charges $\$5.53 + 0.53x$ per shipment, where x is the quantity shipped in pounds. The factory requires a one-week lead time to replenish finished-goods inventories at the Madison warehouse. An average customer order is for 1 unit of HighVal and 10 units of LowVal. What should HighMed do?

Analysis: HighMed can reduce transportation cost by aggregating the quantity shipped at a time because prices for both UPS and FedEx display economies of scale. When comparing Option A with the current system, the management team must trade off the savings in transportation cost through less frequent replenishment with the savings in inventory cost with more frequent replenishment. When considering Option B, the management team must trade off the increase in transportation cost upon aggregation of inventories and the use of a faster but more expensive carrier (FedEx) with the decrease in inventory cost.

The management team first analyzes the current situation. For each territory,

Replenishment lead time, $L = 1$ week
Reorder interval, $T = 4$ weeks
$CSL = 0.997$

1. ***HighMed inventory costs (current scenario):*** For HighVal in each territory, the management team obtains the following:

$$\begin{aligned}\text{Average lot size, } Q_H &= \text{expected demand during } T \text{ weeks} \\ &= T\mu_H = 4 \times 2 = 8 \text{ units} \\ \text{Safety inventory, } ss_H &= F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sqrt{T+L} \times \sigma_H \\ &= F^{-1}(0.997) \times \sqrt{4+1} \times 5 = 30.7 \text{ units (see Equation 11.16)} \\ \text{Total HighVal inventory} &= Q_H/2 + ss_H = (8/2) + 30.7 = 34.7 \text{ units}\end{aligned}$$

Across all 24 territories, HighMed thus carries HighVal inventory of $24 \times 34.7 = 832.8$ units.

For LowVal in each territory, the management team obtains the following:

$$\begin{aligned}\text{Average lot size, } Q_L &= \text{expected demand during } T \text{ weeks} = T\mu_L = 4 \times 20 = 80 \text{ units} \\ \text{Safety inventory, } ss_L &= F^{-1}(CSL) \times \sigma_{T+L} = F^{-1}(CSL) \times \sqrt{T+L} \times \sigma_L \\ &= F^{-1}(0.997) \times \sqrt{4+1} \times 5 = 30.7 \text{ units,} \\ \text{Total LowVal inventory} &= Q_L/2 + ss_L = (80/2) + 30.7 = 70.7 \text{ units}\end{aligned}$$

Across all 24 territories HighMed thus carries LowVal inventory $= 24 \times 70.7 = 1696.8$ units.

The management team thus obtains the following:

$$\begin{aligned}\text{Annual inventory holding cost for HighMed} &= (\text{average HighVal inventory} \times \$200 \\ &\quad + \text{average LowVal inventory} \times \$30) \times 0.25 \\ &= (832.8 \times \$200 + 1696.8 \times \$30) \times 0.25 \\ &= \$54{,}366\end{aligned}$$

2. ***HighMed transportation cost (current scenario):*** The average replenishment order from each territory consists of Q_H units of HighVal and Q_L units of LowVal. Thus

$$\begin{aligned}&\text{Average weight of each replenishment order} \\ &= 0.1Q_H + 0.04Q_L = 0.1 \times 8 + 0.04 \times 80 = 4 \text{ pounds} \\ &\text{Shipping cost per replenishment order} \\ &= \$0.66 + 0.26 \times 4 = \$1.7\end{aligned}$$

Each territory has 13 replenishment orders per year and there are 24 territories. Thus

$$\text{Annual transportation cost} = \$1.7 \times 13 \times 24 = \$530$$

3. ***HighMed total cost (current scenario):*** Annual inventory and transportation cost at HighMed = inventory cost + transportation cost = $\$54{,}366 + \$530.4 = \$54{,}896$.

TABLE 13-6 HighMed Costs Under Different Network Options

	Current Scenario	*Option A*	*Option B*
Number of stocking locations	24	24	1
Reorder interval	4 weeks	1 week	1 week
HighVal cycle inventory	96 units	24 units	24 units
HighVal safety inventory	736.8 units	466 units	95.2 units
HighVal inventory	832.8 units	490 units	119.2 units
LowVal cycle inventory	960 units	240 units	240 units
LowVal safety inventory	736.8 units	466 units	95.2 units
LowVal inventory	1,696.8 units	706 units	335.2 units
Annual inventory cost	$54,366	$29,795	$8,474
Shipment type	Replenishment	Replenishment	Customer order
Shipment size	8 HighVal + 80 LowVal	2 HighVal + 20 LowVal	1 HighVal + 10 LowVal
Shipment weight	4 lbs.	1 lb.	0.5 lb.
Annual transport cost	$530	$1,148	$14,464
Total annual cost	$54,896	$30,943	$22,938

The HighMed management team evaluates the costs for Option A and Option B similarly, and the results are summarized in Table 13-6.

From Table 13-6, observe that increasing the replenishment frequency under Option A decreases total cost at HighMed. The increase in transportation costs is much smaller than the decrease in inventory costs resulting from smaller lots. HighMed is able to reduce total cost most by aggregating all inventories and using FedEx for transportation, because the decrease in inventories upon aggregation is larger than the increase in transportation costs.

If customer order sizes are small, the increase in transportation cost upon aggregation can be significant and inventory aggregation may increase total costs. Reconsider the case of HighMed, but now each customer order averages 0.5 HighVal and 5 LowVal (half the size considered earlier). The costs for the current option as well as Option A remain unchanged because HighMed does not pay for outbound transportation and incurs only the cost of transporting replenishment orders under both options. Option B, however, becomes more expensive because outbound transportation costs increase with a decrease in customer order size. With smaller customer orders, the costs under Option B are as follows:

$$\begin{aligned}
\text{Average weight of each customer order} &= 0.1 \times 0.5 + 0.04 \times 5 = 0.25 \text{ pounds} \\
\text{Shipping cost per customer order} &= \$5.53 + 0.53 \times 0.25 = \$5.66 \\
\text{Number of customer orders per territory per week} &= 4 \\
\text{Total customer orders per year} &= 4 \times 24 \times 52 = 4{,}992 \\
\text{Annual transportation cost} &= 4{,}992 \times \$5.66 = \$28{,}255 \\
\text{Total annual cost} &= \text{inventory cost} + \text{transportation cost} \\
&= \$8{,}474 + \$28{,}255 = \$36{,}729
\end{aligned}$$

Thus, with small customer orders, inventory aggregation is no longer the lowest-cost option for HighMed because of the large increase in transportation costs. The company is better off maintaining inventory in each territory and using Option A, which gives a lower total cost.

KEY POINT Inventory aggregation decisions must account for inventory and transportation costs. Inventory aggregation decreases supply chain costs if the product has a high value-to-weight ratio, high demand uncertainty, and customer orders are large. If a product has a low value-to-weight ratio, low demand uncertainty, or customer orders are small, inventory aggregation may increase supply chain costs.

TABLE 13-7 Daily Demand at Alloy Steel over Two-Week Period

	Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*	*Sunday*
Week 1	19,970	17,470	11,316	26,192	20,263	8,381	25,377
Week 2	39,171	2,158	20,633	23,370	24,100	19,603	18,442

TRADE-OFF BETWEEN TRANSPORTATION COST AND CUSTOMER RESPONSIVENESS

The transportation cost a supply chain incurs is closely linked to the degree of responsiveness the supply chain aims to provide. If a firm has high responsiveness and ships all orders within a day of receipt from the customer, it will have small outbound shipments resulting in a high transportation cost. If it decreases its responsiveness and aggregates orders over a longer time horizon before shipping them out, it will be able to exploit economies of scale and incur a lower transportation cost because of larger shipments. *Temporal aggregation* is the process of combining orders across time. Temporal aggregation decreases a firm's responsiveness because of shipping delay but also decreases transportation costs because of economies of scale that result from larger shipments. Thus, a firm must consider the trade-off between responsiveness and transportation cost when designing its transportation network, as illustrated in Example 13-3.

Example 13-3: **Tradeoff between transportation cost and responsiveness**
Alloy Steel is a steel service center in the Cleveland area. All orders are shipped to customers using an LTL carrier that charges $\$100 + 0.01x$, where x is the number of pounds of steel shipped on the truck. Currently, Alloy Steel ships orders on the day they are received. Allowing for two days in transit, this policy allows Alloy to achieve a response time of two days. Daily demand at Alloy Steel over a two-week period is shown in Table 13-7.

The general manager at Alloy Steel feels that customers do not really value the two-day response time and would be satisfied with a four-day response. What are the cost advantages of increasing the response time?

Analysis: As the response time increases, Alloy Steel has the opportunity to aggregate demand over multiple days for shipping. For a response time of three days, Alloy Steel can aggregate demand over two successive days before shipping. For a response time of four days, Alloy Steel can aggregate demand over three days before shipping. The manager evaluates the quantity shipped and transportation costs for different response times over the two-week period as shown in Table 13-8.

From Table 13-8, observe that the transportation cost for Alloy Steel decreases as the response time increases. The benefit of temporal consolidation, however, diminishes rapidly upon increasing the response time. As the response time increases from two to three days, transportation cost over the two-week window decreases by $700. Increasing the response time from three to four days reduces the transportation cost by only $200. Thus, Alloy Steel may be better off offering a three-day response, because the marginal benefit from further increasing the response time is small.

In general, a limited amount of temporal aggregation can be very effective in reducing transportation cost in a supply chain. In choosing response time, however, firms must trade off the decrease in transportation cost upon temporal aggregation with the loss of revenue because of poorer responsiveness. Temporal consolidation also improves transportation performance because it results in more stable shipments. For example, in Table 13-7, when Alloy Steel sends daily shipments, the coefficient of variation is 0.44, whereas temporal aggregation across three days (achieved with a four-day response time) has a coefficient of variation of only 0.16. More stable shipments allow both the shipper and the carrier to better plan operations and improve utilization of their assets.

TABLE 13-8 Quantity Shipped and Transportation Cost as a Function of Response Time

		Two-Day Response		*Three-Day Response*		*Four-Day Response*	
Day	*Demand*	*Quantity Shipped*	*Cost ($)*	*Quantity Shipped*	*Cost ($)*	*Quantity Shipped*	*Cost ($)*
1	19,970	19,970	299.7	0	—	0	—
2	17,470	17,470	274.70	37,440	474.40	0	—
3	11,316	11,316	213.16	0	—	48,756	587.56
4	26,192	26,192	361.92	37,508	475.08	0	—
5	20,263	20,263	302.63	0	—	0	—
6	8,381	8,381	183.81	28,644	386.44	54,836	648.36
7	25,377	25,377	353.77	0	—	0	—
8	39,171	39,171	491.71	64,548	745.48	0	—
9	2,158	2,158	121.58	0	—	66,706	767.06
10	20,633	20,633	306.33	22,791	327.91	0	—
11	23,370	23,370	333.70	0	—	0	—
12	24,100	24,100	341.00	47,470	574.70	68,103	781.03
13	19,603	19,603	296.03	0	—	0	—
14	18,442	18,442	284.42	38,045	480.45	38,045	480.45
			$4,164.46		3,464.46		3,264.46

KEY POINT Temporal aggregation of demand results in a reduction of transportation costs because it entails larger shipments and also reduces the variation in shipment sizes from one shipment to the next. It does, however, hurt customer response time. The marginal benefit of temporal aggregation declines as the time window over which aggregation takes place increases.

In the next section we discuss how transportation networks can be tailored to supply customers with differing needs.

13.6 TAILORED TRANSPORTATION

Tailored transportation is the use of different transportation networks and modes based on customer and product characteristics. Most firms sell a variety of products and serve many different customer segments. For example, W.W. Grainger sells over 200,000 MRO supply products to both small contractors and very large firms. Products vary in size and value and customers vary in the quantity purchased, responsiveness required, uncertainty of the orders, and distance from W.W. Grainger branches and DCs. Given these differences, a firm such as W.W. Grainger should not design a common transportation network to meet all needs. A firm can meet customer needs at a lower cost by using tailored transportation to provide the appropriate transportation choice based on customer and product characteristics. In the following sections we describe various forms of tailored transportation in supply chains.

TAILORED TRANSPORTATION BY CUSTOMER DENSITY AND DISTANCE

Firms must consider customer density and distance from warehouse when designing transportation networks. The ideal transportation options based on density and distance are shown in Table 13-9.

TABLE 13-9 Transportation Options Based on Customer Density and Distance

	Short Distance	*Medium Distance*	*Long Distance*
High density	Private fleet with milk runs	Cross-dock with milk runs	Cross-dock with milk runs
Medium density	Third-party milk runs	LTL carrier	LTL or package carrier
Low density	Third-party milk runs or LTL carrier	LTL or package carrier	Package carrier

When a firm serves a very high density of customers close to the DC, it is often best for the firm to own a fleet of trucks that are used with milk runs originating at the DC to supply customers, because this scenario makes very good use of the vehicles. If customer density is high but distance from the warehouse is large, it does not pay to send milk runs from the warehouse because trucks will travel a long distance empty on the return trip. In such a situation it is better to use a public carrier with large trucks to haul the shipments to a cross-dock center close to the customer area, where the shipments are loaded onto smaller trucks that deliver product to customers using milk runs. In this situation, it may not be ideal for a firm to own its own fleet. As customer density decreases, use of an LTL carrier or a third party doing milk runs is more economical because the third-party carrier can aggregate shipments across many firms. If a firm wants to serve an area with a very low density of customers far from the warehouse, even LTL carriers may not be feasible and the use of package carriers may be the best option. Boise Cascade Office Products, an industrial distributor of office supplies, has designed a transportation network consistent with the suggestion in Table 13-9.

Customer density and distance should also be considered when firms decide on the degree of temporal aggregation to use when supplying customers. Firms should serve areas with high customer density more frequently because these areas are likely to provide sufficient economies of scale in transportation, making temporal aggregation less valuable. To lower transportation costs, firms should use a higher degree of temporal aggregation when serving areas with a low customer density.

TAILORED TRANSPORTATION BY SIZE OF CUSTOMER

Firms must consider customer size and location when designing transportation networks. Very large customers can be supplied using a TL carrier, whereas smaller customers will require an LTL carrier or milk runs. When using milk runs, a shipper incurs two types of costs:

- Transportation cost based on total route distance
- Delivery cost based on number of deliveries

The transportation cost is the same whether going to a large or small customer. If a delivery is to be made to a large customer, including other small customers on the same truck can save on transportation cost. For each small customer, however, the delivery cost per unit is higher than for large customers. Thus, it is not optimal to deliver to small and large customers with the same frequency at the same price. One option firms have is to charge a higher delivery cost for smaller customers. Another option is to tailor milk runs so that they visit larger customers with a higher frequency than smaller customers. Firms can partition customers into large (L), medium (M), and small (S) based on the demand at each. The optimal frequency of visits can be evaluated based on the transportation and delivery costs (see Section 10.2). If large customers are to be visited every milk run, medium customers every other milk run, and low-demand customers every three milk runs, suitable milk runs can be designed by combining large, medium, and small customers on each run. Medium customers would be partitioned into two subsets (M_1, M_2) and small customers would be partitioned into three subsets (S_1, S_2, S_3).

TABLE 13-10 Aggregation Strategies Based on Value/Demand

Product Type	*High Value*	*Low Value*
High demand	Disaggregate cycle inventory. Aggregate safety inventory. Inexpensive mode of transportation for replenishing cycle inventory and fast mode when using safety inventory.	Disaggregate all inventories and use inexpensive mode of transportation for replenishment.
Low demand	Aggregate all inventories. If needed, use fast mode of transportation for filling customer orders.	Aggregate only safety inventory. Use inexpensive mode of transportation for replenishing cycle inventory.

The firm can sequence the following six milk runs to ensure that each customer is visited with the appropriate frequency: (L, M_1, S_1), (L, M_2, S_2), (L, M_1, S_3), (L, M_2, S_1), (L, M_1, S_2), (L, M_2, S_3). This tailored sequence has the advantage that each truck carries about the same load and larger customers are provided more frequent delivery than smaller customers, consistent with their relative costs of delivery.

TAILORED TRANSPORTATION BY PRODUCT DEMAND AND VALUE

The degree of inventory aggregation and the modes of transportation used in a supply chain network should vary with the demand and value of a product, as shown in Table 13-10. The cycle inventory for high-value products with high demand is disaggregated to save on transportation costs because this allows replenishment orders to be transported less expensively. Safety inventory for such products can be aggregated to reduce inventories (see Chapter 11) and a fast mode of transportation can be used if the safety inventory is required to meet customer demand. For high-demand products with low value, all inventories should be disaggregated and held close to the customer to reduce transportation costs. For low-demand, high-value products, all inventories should be aggregated to save on inventory costs. For low-demand, low-value products, cycle inventories can be held close to the customer and safety inventories aggregated to reduce transportation costs while taking some advantage of aggregation. Cycle inventories are replenished using an inexpensive mode of transportation to save costs.

KEY POINT Tailoring transportation based on customer density and distance, customer size, or product demand and value allows a supply chain to achieve appropriate responsiveness and low cost.

13.7 THE ROLE OF IT IN TRANSPORTATION

The complexity and scale of transportation makes it an excellent area within the supply chain for the use of IT systems. The use of software to determine transportation routes has been the most common IT application in transportation. This software takes the location of customers, shipment size, desired delivery times, information on the transportation infrastructure (such as distances between points), and vehicle capacity as inputs. These inputs are formulated into an optimization problem whose solution is a set of routings and a packing list for each vehicle that minimize costs while meeting delivery constraints.

Along with routing, vehicle packing software helps improve fleet utilization. By accounting for the size of the container and the size and sequence of each delivery, this

software develops a plan to pack the vehicle efficiently while allowing for the greatest ease of unloading and/or loading along the route. Synchronization between the packing and routing software is important because how much is packed on a truck affects the routing, while the routing obviously affects what is packed on a truck.

IT also comes into play in the use of Global Positioning Systems (GPS) and electronic notification of impending arrivals. GPS systems monitor the real-time location of vehicles. This real-time information improves a firm's response to customer questions regarding deliveries. Electronic notifications are useful in a wide variety of situations, ranging from U.S. Customs receiving a ship's manifest days, or even weeks, before the ship docks in a U.S. port to a truck notifying a warehouse's receiving department that it expects to arrive 30 minutes early. Notification tools allow those receiving goods to be prepared when the vehicle arrives and thus to perform all the loading, unloading, and corresponding administrative work in a more efficient manner.

The most common problems in the use of IT in transportation relate to cross-enterprise collaboration and the narrow view taken by some transportation software. Collaboration across enterprises is crucial in transportation because this is a function that is often outsourced and does not directly involve either the shipper or the customer. Thus, successful collaboration in transportation requires three or more firms to work together, making it much more difficult. Other problems arise because much of the transportation software is very focused on efficient routings. The software often overlooks other factors such as customer service and promised delivery times, which should constrain the route selected.

The players in this space include virtually all the major supply chain vendors, including the ERP firms and the supply chain–focused best-of-breed firms. There has also been a large amount of in-house development that has focused on the transportation management process.

13.8 RISK MANAGEMENT IN TRANSPORTATION

There are three main types of risk to consider when transporting a shipment between two nodes on the network:

1. The risk that the shipment is delayed
2. The risk that the shipment does not reach its destination because intermediate nodes or links are disrupted by external forces
3. The risk of hazardous material

In each case it is important to identify the sources of risk and their consequences and plan suitable mitigation strategies.

Delay arises either because of congestion along links such as roads or nodes such as ports and airports. When congestion is the cause of delay, mitigation strategies for the shipper include moving inventories closer to the destination, using alternative lanes, and building a buffer into the lead time. Congestion delays can be mitigated by designing a network with multiple routes to the destination and changing routes based on congestion. Congestion delays can also be mitigated through the use of congestion pricing by the owner of the transportation node or link. Delay may also arise because of the limited availability of transportation or infrastructure capacity. Such delays are more likely when the assets are owned by a third party that is serving multiple customers. These delays may be mitigated by owning some transportation capacity or by signing long-term contracts for transportation capacity with the third party. Given the high cost of owning these assets, it is best to do so for parts of the network where utilization is high.

Disruption at transportation links or nodes may occur because of natural events such as hurricanes or man-made events such as terrorism. The best mitigation strategy in this case is to design alternative routings into the transportation network. For example, the 1994 Kobe earthquake in Japan disrupted flow for all firms using the port. Some companies, such as Toyota, were able to recover quickly because they increased the flow through alternative ports in their network. Similarly, during the California dockworkers' strike in 2002, many companies arranged for alternative ports to bring in product.

When considering both delay and disruption risk, it is important to identify sources that are likely to be correlated across the network. For example, the events on September 11, 2001, caused a disruption in air transportation across the entire United States. Alternative routings were useless as mitigation strategies in this case because no alternative route was available. For such correlated sources of risk, the only option is to decrease the probability of such a disruption.

Hazardous material can be harmful when people or the environment are exposed. The goal of risk mitigation here is to minimize the probability of exposure, and in the event of exposure, to minimize the impact. Mitigation strategies include the use of modified containers, low-risk transportation modes, selecting routes with low accident probability or reduced population and environmental exposure, or modification of the physical or chemical properties of the material being transported to make it less dangerous.

13.9 MAKING TRANSPORTATION DECISIONS IN PRACTICE

1. ***Align transportation strategy with competitive strategy.*** Managers should ensure that a firm's transportation strategy supports its competitive strategy. They should design functional incentives that help achieve this goal. Historically, the transportation function within firms has been evaluated based on the extent to which it can lower transportation costs. Such a focus leads to decisions that lower transportation costs but hurt the level of responsiveness provided to customers and may raise the firm's total cost. If the dispatcher at a DC is evaluated based solely on the extent to which trucks are loaded, he or she is likely to delay shipments and hurt customer responsiveness to achieve a larger load. Firms should evaluate the transportation function based on a combination of transportation cost, inventory cost, and the level of responsiveness achieved with customers.

2. ***Consider both in-house and outsourced transportation.*** Managers should consider an appropriate combination of company-owned and outsourced transportation to meet their needs. This decision should be based on a firm's ability to handle transportation profitably as well as the strategic importance of transportation to the success of the firm. In general, outsourcing is a better option when shipment sizes are small, whereas owning the transportation fleet is better when shipment sizes are large and responsiveness is important. For example, Wal-Mart uses responsive transportation to reduce inventories in its supply chain. Given the importance of transportation to the success of its strategy, it owns its transportation fleet and manages it itself. This is made easier by the fact that it achieves good utilization from its transportation assets because most of its shipments are large. In contrast, firms such as W.W. Grainger and McMaster-Carr send small shipments to customers; inventory management rather than transportation is the key to their success. A third-party carrier can lower costs for them by aggregating their shipments with those of other companies. As a result, both companies use third-party carriers for their transportation.

3. ***Use technology to improve transportation performance.*** Managers must use information technology to decrease costs and improve responsiveness in their transportation networks. Software helps managers do transportation planning, modal selection, and build delivery routes and schedules. Available technology allows carriers to identify the precise location of each vehicle as well as the shipments the vehicle carries. Satellite-based communication systems allow carriers to communicate with each vehicle in their fleet. These technologies help carriers lower costs and become more responsive to changes.
4. ***Design flexibility into the transportation network.*** When designing transportation networks, managers should take into account uncertainty in demand as well as availability of transportation. Ignoring uncertainty encourages a greater use of inexpensive and inflexible transportation modes that perform well when everything goes as planned. Such networks, however, perform very poorly when plans change. When managers account for uncertainty, they are more likely to include flexible, though more expensive, modes of transportation within their network. Although these modes may be more expensive for a particular shipment, including them in the transportation options allows a firm to reduce the overall cost of providing a high level of responsiveness.

13.10 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of transportation within a supply chain.

   Transportation refers to the movement of product from one location to another within a supply chain. The importance of transportation has grown with the increasing globalization in supply chains as well as the growth in e-commerce because both trends increase the distance products travel. Transportation decisions impact supply chain profitability and influence both inventory and facility decisions within a supply chain.
2. Evaluate the strengths and weaknesses of different modes of transportation.

   The various modes of transportation include water, rail, intermodal, truck, air, pipeline, and package carriers. Water is typically the least expensive mode but is also the slowest, whereas air and package carriers are the most expensive and the fastest. Rail and water are best suited for low-value, large shipments that do not need to be moved in a hurry. Air and package carriers are best suited for small, high-value, emergency shipments. Intermodal and TL carriers are faster than rail and water but somewhat more expensive. LTL carriers are best suited for small shipments that are too large for package carriers but much less than a TL.
3. Discuss the role of infrastructure and policies in transportation.

   Infrastructure such as ports, roads, and airports has a significant impact on transportation. Given their inherent monopolistic nature, most transportation infrastructure requires public ownership or regulation. In the case of public ownership, pricing based on average cost leads to overutilization and congestion. It is important to use some form of congestion pricing under which users are forced to internalize the increase in network cost they cause.
4. Identify the relative strengths and weaknesses of various transportation network design options.

   Networks are designed to either ship directly from origin to destination or move the product through a consolidation point. Direct shipments are most effective when large quantities are to be moved. When shipments are small, use of an intermediate warehouse or DC lowers transportation cost by aggregating smaller shipments even though it takes longer and is more complex. Shipments may also be consolidated with a single vehicle either picking up from multiple locations or dropping off in multiple locations.

5. Identify trade-offs that shippers need to consider when designing a transportation network.

   When designing transportation networks, shippers must consider the trade-offs among transportation cost, inventory cost, operating cost, and customer responsiveness. The supply chain goal is to minimize the total cost while providing the desired level of responsiveness to customers.

Discussion Questions

1. What modes of transportation are best suited for large, low-value shipments? Why?
2. Why is it important to account for congestion when pricing the use of transportation infrastructure?
3. Wal-Mart designs its networks so that a DC supports several large retail stores. Explain how the company can use such a network to reduce transportation costs while replenishing inventories frequently.
4. Compare the transportation costs for an e-business such as Amazon.com and a retailer such as Home Depot when selling home-improvement materials.
5. What transportation challenges does Peapod face? Compare transportation costs at online grocers and supermarket chains.
6. Do you expect aggregation of inventory at one location to be more effective when a company such as Dell sells computers or when a company such as Amazon.com sells books? Explain by considering transportation and inventory costs.
7. Discuss key drivers that may be used to tailor transportation. How does tailoring help?

Exercises

1. A power plant in California uses coal at the rate of 100,000 pounds each day. It also uses MRO material at the rate of 1,000 pounds each day. The coal comes from Wyoming and the MRO material comes from Chicago. Coal costs $0.01 per pound, whereas MRO material costs $10 per pound, on average. Holding costs at the power plant are 25 percent. Transportation choices available are as follows:

   Train
   Lead time = 15 days
   Carload (100,000 pounds) at $400 per carload
   Full train (70 cars) at $15,000 per train

   Truck
   Lead time = 4 days
   Minimum cost = $100
   Up to 10,000 pounds at $0.08 per pound
   Between 10,000 and 20,000 pounds at $0.07 per pound for entire load
   Between 25,000 and 40,000 pounds at $0.06 per pound for entire load
   Small TL (40,000 pounds) for $2,000
   Large TL (60,000 pounds) for $2,600

   Safety inventory of coal and MRO materials is kept at twice the consumption during the lead time of supply. What mode of transport do you recommend for each of the two products? Why?
2. Books-On-Line, an online bookseller, charges its customers a shipping charge of $4 for the first book and $1 for each additional book. The average customer order contains four books. Books-On-Line currently has one warehouse in Seattle and ships all orders from there. For shipping purposes, Books-On-Line divides the United States into three zones—Western, Central, and Eastern. Shipping cost incurred by Books-On-Line per customer order (average four books) is $2 within the same zone, $3 between adjacent zones, and $4 between nonadjacent zones.

Weekly demand from each zone is independent and normally distributed, with a mean of 50,000 and a standard deviation of 25,000. Each book costs on average $10, and the holding cost incurred by Books-On-Line is 25 percent. Books-On-Line replenishes inventory every week and aims for a 99.7 percent CSL. Assume a replenishment lead time of one week.

A warehouse is designed to carry 50 percent more than the replenishment order + safety stock. The fixed cost of a warehouse is $\$200{,}000 + x$, where x is its capacity in books. The weekly operating cost of a warehouse is $\$0.01y$, where y is the number of books shipped. Books-On-Line is planning its network strategy. Which zones should have warehouses? Detail all costs involved.

3. A European manufacturer of industrial furniture has a factory located in Munich and four warehouses in Western Europe. The warehouses collect customer orders, which are then shipped from the factory. Upon receipt, the warehouse distributes customer orders using small trucks. Daily demand at each of the four warehouses along with distance from Munich is as shown following:

Warehouse	*Daily Demand (kg)*	*Distance (km)*
Milan	25,000	800
Paris	35,000	1,000
Copenhagen	20,000	600
Madrid	20,000	1,300

All shipments are by truck. Three truck sizes are available, with capacities of 40,000 (small), 60,000 (medium), and 80,000 kg (large). Transportation costs for the three types of trucks are:

Small: $100 + 0.1x$ euros
Medium: $125 + 0.1x$ euros
Large: $150 + 0.1x$ euros

where x is the distance to be traveled in kilometers. For replenishment frequency varying between one and four days for each warehouse, identify the optimal transportation option and the associated cost. What other factors should be considered before deciding on the replenishment frequency?

Bibliography

Ampuja, Jack, and Ray Pucci. "Inbound Freight: Often a Missed Opportunity." *Supply Chain Management Review* (March–April 2002): 50–7.

Ballou, Ronald H. *Business Logistics Management*. Upper Saddle River, NJ: Prentice Hall, 1999.

Bowersox, Donald J., David J. Closs, and Omar K. Helferich. *Logistical Management*. New York: Macmillan, 1986.

Button, Kenneth J., and Erik T. Verhoef. *Road Pricing, Traffic Congestion and the Environment*. Northampton, MA: Edward Elgar, 1998.

Coyle, John J., Edward J. Bardi, and Robert A. Novack. *Transportation*. Cincinnati, OH: South-Western College Publishing, 2000.

Ellison, Anthony P. *Entrepreneurs and the Transformation of the Global Economy*. Northampton, MA: Edward Elgar, 2002.

Hammond, Janice H., and John E. P. Morrison. *Note on the U.S. Transportation Industry*. Harvard Business School Note 688080, 1988.

Levinson, David M. "Road Pricing in Practice." *In Road Pricing, Traffic Congestion and the Environment*, Kenneth J. Button and Robert A. Novack (eds.). Northampton, MA: Edgar Elgar, 1998.

Robeson, J. F., and W. C. Copacino. *The Logistics Handbook*. New York: The Free Press, 1994.

Shapiro, R. D., and J. L. Heskett. *Logistics Strategy: Cases and Concepts*. St. Paul, MN: West, 1985.

Transportation in America 1998. Washington, DC: Eno Transportation Foundation, 1998.

Tyworth, J. E., J. L. Cavinato, and C. J. Langley, Jr. *Traffic Management: Planning, Operations, and Control*. Prospect Heights, IL: Waveland, 1991.

PART VI

MANAGING CROSS-FUNCTIONAL DRIVERS IN A SUPPLY CHAIN

CHAPTER 14
SOURCING DECISIONS IN A SUPPLY CHAIN

CHAPTER 15
PRICING AND REVENUE MANAGEMENT IN A SUPPLY CHAIN

CHAPTER 16
INFORMATION TECHNOLOGY IN A SUPPLY CHAIN

CHAPTER 17
COORDINATION IN A SUPPLY CHAIN

The goal of the chapters in Part VI is to move from discussing the impact of the traditional logistical drivers of supply chain performance—facilities, inventory, and transportation—to the cross-functional drivers of sourcing, pricing, and information. These drivers have grown in importance over the past decade and serve as an important point of differentiation between supply chain management and logistics.

Chapter 14 focuses on sourcing strategies for a firm, beginning with how to make the decision of whether to outsource an activity or to perform it in-house. A full life cycle of actions is discussed, from product design to steady-state procurement procedures. In addition, a framework is presented to grade and select, contract with, and procure from suppliers.

Chapter 15 discusses the role of pricing and revenue management in maximizing profitability from supply chain assets. Conditions under which revenue management is applicable are discussed, and in each case the basic trade-offs are identified.

Chapter 16 discusses the impact of information technology on the success of a supply chain. A framework is presented to describe the landscape of enterprise software and the role played by each type of software system when designing, planning, and operating a supply chain.

Chapter 17 deals with coordination in a supply chain—not a driver in itself but something many drivers try to create. Coordination helps ensure that each part of a supply chain takes actions that increase total supply chain profits and avoids actions that improve its local profits but hurt total profits. We discuss how the lack of coordination across different members of a supply chain can result in poor performance, even when each stage is doing the best it can given its own objectives. The bullwhip effect is described, and the primary causes of this phenomenon are identified. Ideas discussed in all previous chapters are brought together to identify managerial actions that can help a supply chain dampen the bullwhip effect and achieve coordination.

CHAPTER 14
SOURCING DECISIONS IN A SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of sourcing in a supply chain.
2. Discuss factors that affect the decision to outsource a supply chain function.
3. Identify dimensions of supplier performance that affect total cost.
4. Structure successful auctions and negotiations.
5. Describe the impact of different contracts on supplier performance and information distortion.
6. Categorize purchased products and services and identify the desired focus of procurement in each case.

14.1 THE ROLE OF SOURCING IN A SUPPLY CHAIN

Purchasing, also called procurement, is the process by which companies acquire raw materials, components, products, services, or other resources from suppliers to execute their operations. Sourcing is the entire set of business processes required to purchase goods and services. For any supply chain function, the most significant decision is whether to outsource the function or perform it in-house. *Outsourcing* results in the supply chain function being performed by a third party. Outsourcing is one of the most important issues facing a firm, and actions across industries tend to be varied. For example, W.W. Grainger, a MRO distributor, has consistently owned and managed its distribution centers. In contrast, outbound transportation of packages from distribution centers to customers has consistently been outsourced to a third party. For less-than-truckload outbound transportation, Grainger is moving from a scenario under which it was all outsourced to a third party to a hybrid model under which Grainger owns some trucks. What factors can explain Grainger's decisions? Dell is credited with improving profits by keeping the retail function in-house and selling directly to customers. In contrast, Proctor & Gamble (P&G) has never attempted to sell detergent directly to customers, and nobody is calling on it to bring the retail function in-house. What makes vertical integration into retailing a good idea for Dell but a bad idea for P&G? Motorola uses a distributor for the sale of its cell phones in most of Latin America. In contrast, most of its sales in the United States do not go through distributors. Why is the outsourcing of distribution for Motorola beneficial in Latin America but not in the United States?

It is important to clarify the distinction between outsourcing and off-shoring before we proceed. A firm *off-shores* a supply chain function if it maintains ownership but moves the production facility offshore. In contrast, a firm *outsources* if the firm

hires an outside firm to perform an operation rather than executing the operation within the firm. In this chapter our focus is on the issue of outsourcing rather than offshoring. We address the outsourcing of supply chain activities based on the following two questions:

1. Will the third party increase the supply chain surplus relative to performing the activity in house?
2. To what extent do risks grow upon outsourcing?

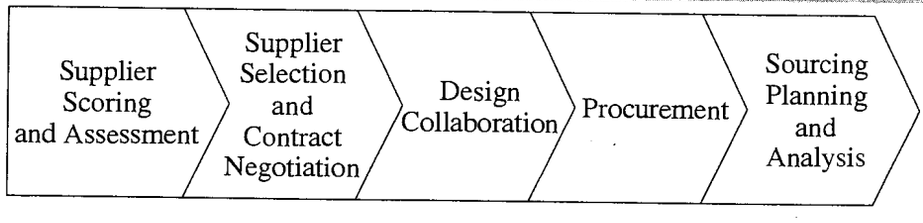
Recall that the supply chain surplus is the difference between the value of a product for the customer and the total cost of all supply chain activities involved in bringing the product to the customer. The supply chain surplus is the total size of the pie that all supply chain participants (including the customer) get to share. Our basic premise is that outsourcing makes sense if it increases the supply chain surplus without significantly affecting risks. We go further and claim that a supply chain participant can survive in the long term only if its presence increases the supply chain surplus. One can then argue that each party's profit in a supply chain is correlated with the extent to which it increases the surplus.

Once a decision to outsource has been made, sourcing processes include the selection of suppliers, design of supplier contracts, product design collaboration, procurement of material or services, and evaluation of supplier performance, as shown in Figure 14-1.

Supplier scoring and assessment is the process used to rate supplier performance. Suppliers should be compared based on their impact on the supply chain surplus and total cost. Unfortunately, sourcing decisions are often driven based solely on the price charged by a supplier. Many other supplier characteristics, such as lead time, reliability, quality, and design capability, also affect the total cost of doing business with a supplier. A good supplier scoring and assessment process must identify and track performance along all dimensions that affect the total cost of using a supplier. *Supplier selection* uses the output from supplier scoring and assessment to identify the appropriate supplier(s). A supply contract is then negotiated with the supplier. A good contract should account for all factors that affect supply chain performance and should be designed to increase supply chain profits in a way that benefits both the supplier and the buyer.

Given that about 80 percent of the cost of a product is determined during design, it is crucial that suppliers be actively involved at this stage. *Design collaboration* allows the supplier and the manufacturer to work together when designing components for the final product. Design collaboration also ensures that any design changes are communicated effectively to all parties involved with designing and manufacturing the product. Once the product has been designed, *procurement* is the process whereby the supplier sends product in response to orders placed by the buyer. The goal of procurement is to enable orders to be placed and delivered on schedule at the lowest possible overall cost. Finally, the role of *sourcing planning and analysis* is to analyze spending

FIGURE 14-1 Key Sourcing-Related Processes



across various suppliers and component categories to identify opportunities for decreasing the total cost.

Cost of goods sold (COGS) represents well over 50 percent of sales for most major manufacturers. Within COGS, purchased parts are a much higher fraction than they were several decades ago. This change has occurred because companies have reduced vertical integration and outsourced manufacture of many components. Companies such as Cisco have gone further and also outsourced a significant fraction of the assembly capacity. As there is greater pressure on firms to achieve lower costs and the suppliers' share of the COGS grows, good sourcing decisions will have greater impact on the cost leadership and competitive advantage enjoyed by a firm.

Effective sourcing processes within a firm can improve profits for the firm and total supply chain surplus in a variety of ways. It is important that the drivers of improved profits be clearly identified when making sourcing decisions. Some of the benefits from effective sourcing decisions are the following:

- Better economies of scale can be achieved if orders within a firm are aggregated.
- More efficient procurement transactions can significantly reduce the overall cost of purchasing. This is most important for items for which a large number of low-value transactions occur.
- Design collaboration can result in products that are easier to manufacture and distribute, resulting in lower overall costs. This factor is most important for supplier products that contribute a significant amount to product cost and value.
- Good procurement processes can facilitate coordination with the supplier and improve forecasting and planning. Better coordination lowers inventories and improves the matching of supply and demand.
- Appropriate supplier contracts can allow for the sharing of risk, resulting in higher profits for both the supplier and the buyer.
- Firms can achieve a lower purchase price by increasing competition through the use of auctions.

When designing a sourcing strategy, it is important for a firm to be clear on the factors that have the greatest influence on performance and target improvement on those areas. For example, if most of the spending for a firm is on materials with only a few high-value transactions, improving the efficiency of procurement transactions will provide little value, whereas improving design collaboration and coordination with the supplier will provide significant value. In contrast, when sourcing items with many low-value transactions, increasing the efficiency of procurement transactions will be very valuable.

In the next section we discuss factors that influence the outsourcing decision.

14.2 IN-HOUSE OR OUTSOURCE

The decision to outsource is based on the growth in supply chain surplus provided by the third party and the increase in risk incurred by using a third party. A firm should consider outsourcing if the growth in surplus is large with a small increase in risk. Performing the function in-house is preferable if the growth in surplus is small or the increase in risk is large.

HOW DO THIRD PARTIES INCREASE THE SUPPLY CHAIN SURPLUS

Third parties increase the supply chain surplus if they either increase value for the customer or decrease the supply chain cost relative to a firm performing the task in-house.

Third parties can increase the supply chain surplus effectively if they are able to aggregate supply chain assets or flows to a higher level than a firm itself. We discuss various mechanisms that third parties can use to grow the surplus.

1. ***Capacity aggregation.*** A third party can increase the supply chain surplus by aggregating demand across multiple firms and gaining production economies of scale that no single firm can on its own. This is the most common reason for outsourcing production in a supply chain. One of the reasons that Dell outsources design and production of the processors in its PCs to Intel is that Intel supplies many computer manufacturers and gains economies of scale that are not available to Dell if it designs and produces its own processors. The growth in surplus from outsourcing is highest when the needs of the firm are significantly lower than the volumes required to gain economies of scale. A good example in this context is Magna Steyr, a third party that has taken over assembly of automobiles for several manufacturers. Magna Steyr has developed very flexible capacity and labor that allows it to produce economically cars that sell in low volumes. It produces the X3 for BMW, the G class for Mercedes, and the Grand Cherokee for Chrysler. In each case, the models have relatively low demand volume. Each firm would not be able to gain sufficient economies of scale for assembling their model. There is a cost to this flexibility that cannot be justified based on one model, but Magna Steyr gains economies by serving many auto firms. A third party is unlikely to increase the surplus through capacity aggregation if the volume requirements of a firm are large and stable. This is substantiated by the fact that no auto manufacturer outsources production of its best-selling cars to a third party.

2. ***Inventory aggregation.*** A third party can increase the supply chain surplus by aggregating inventories across a large number of customers. W.W. Grainger and McMaster-Carr are MRO suppliers that provide value primarily by aggregating inventory for hundreds of thousands of customers. Aggregation allows them to significantly lower overall uncertainty and improve economies of scale in purchasing and transportation. As a result, these MRO distributors carry significantly less safety and cycle inventory than would be required if each customer decided to carry inventory on its own. Another example of inventory aggregation is Brightstar, a distributor that facilitates postponement for cell phones. These phones are manufactured in the Far East and shipped to the Brightstar warehouse in Miami, where software and accessories are added as customer orders arrive from South America. High product variety and many small customers allow Brightstar to increase the supply chain surplus through inventory aggregation and postponement. The third party performing inventory aggregation adds most to the supply chain surplus when demand from customers is fragmented and uncertain. When demand is large and predictable, an intermediary adds little to the surplus by holding inventory. The consolidation of retailing and the resulting scale and predictability of demand explains why distributors play a much smaller role in the United States compared to developing countries.

3. ***Transportation aggregation by transportation intermediaries.*** A third party may increase the surplus by aggregating the transportation function to a higher level than any shipper can on its own. UPS, FedEx, and a host of LTL carriers are examples of transportation intermediaries that increase the supply chain surplus by aggregating transportation across a variety of shippers. The value provided in each case is driven by the inherent economies of scale in transportation. Each shipper wants to send less than the capacity of the transportation mode. The transportation intermediary aggregates shipments across multiple shippers, thus lowering the cost of each shipment below what could be achieved by the shipper alone. A transportation intermediary increases the supply chain surplus when shippers are sending packages or LTL quantities to customers that

are geographically distributed. A transportation intermediary can also grow the surplus for TL shipping by aggregating backhauls to a higher level than the shipper can. This is particularly true if the shipper's transportation flows are highly unbalanced, with the quantity coming into a region very different from the quantity leaving the region. An excellent example of a transportation intermediary increasing the supply chain surplus is provided by a pilot program involving DaimlerChrysler and Ford. Exel, a third-party logistics (3PL) provider, operated a dedicated fleet for the distribution of spare parts for Chrysler. In tests in Michigan and Mexico, Ford added its own truck parts for delivery on the same fleet. Given the relatively low density of dealers in Northern Michigan and Mexico (outside Mexico City), the aggregation provided by Exel was a benefit for both Ford and DaimlerChrysler. A transportation intermediary is likely to add the least to the supply chain surplus for a company such as Wal-Mart, for whom shipment sizes are large and the company also achieves aggregation across the many retail stores that it owns. The only possibility for a transportation intermediary in such a setting would be to obtain better backhauls than Wal-Mart.

4. ***Transportation aggregation by storage intermediaries.*** A third party that stores inventory can also increase the supply chain surplus by aggregating inbound and outbound transportation. For example, storage intermediaries such as W.W. Grainger and McMaster-Carr stock products from over a thousand manufacturers each and sell to hundreds of thousands of customers. On the inbound side they are able to aggregate shipments from several manufacturers onto a single truck. This results in a lower transportation cost than could be achieved by each manufacturer independently. On the outbound side they aggregate packages for customers at a common destination, resulting in a significantly lower transportation cost than can be achieved by each customer separately. For example, the Chicago distribution center for Grainger fills separate trucks with packages destined for each adjacent state. As soon as a truck destined for Michigan (for instance) is filled, it is sent to the UPS sorting facility in Michigan. This level of aggregation cannot be achieved by customers on their own. Thus, the storage of goods by Grainger and McMaster-Carr increases the supply chain surplus by aggregating inbound and outbound transportation. A similar service is provided by distributors in countries such as India. Given the small size of retail outlets, a distributor aggregates delivery for several manufacturers, significantly lowering the outbound transportation cost. This form of aggregation is most effective if the intermediary stocks products from many suppliers and serves many customers, each ordering in small quantities. This form of aggregation becomes less effective as the scale of shipment from a supplier to customer grows. This is seen in the decreased use of distributors by U.S. supermarket chains. The supermarkets typically get full trucks delivered on their own and do not need a distributor for further aggregation.

5. ***Warehousing aggregation.*** A third party may increase the supply chain surplus by aggregating warehousing needs over several customers. The growth in surplus is achieved in terms of lower real estate costs as well as lower processing costs within the warehouse. Savings through warehousing aggregation arise if a supplier's warehousing needs are small or if its needs fluctuate over time. In either case, the intermediary with the warehouse can exploit economies of scale in warehouse construction and operation by aggregating across multiple customers. An example is Safexpress, a third-party logistics provider in India. Safexpress owns warehouses distributed throughout the country that are used by many of their customers. Most of its customers do not have warehousing needs that are large enough to justify a warehouse of their own in each region. Warehousing aggregation by an intermediary adds a lot to the surplus for small suppliers and for companies that are starting out in a geographic location. Warehousing aggregation

is unlikely to add much to the surplus for a large supplier or customer whose warehousing needs are relatively stable over time. For example, the warehousing needs for Wal-Mart and Grainger are sufficiently large and stable to justify their own warehouse, and a third party is unlikely to increase the surplus.

6. ***Procurement aggregation.*** A third party increases the supply chain surplus if it aggregates procurement for many small players and facilitates economies of scale in production and inbound transportation. Procurement aggregation is most effective across many small buyers. A good example is FleetXchange, a firm that offers small truck fleets lower prices for truck equipment and services through aggregate buying. Procurement aggregation is not likely to be a big factor in a situation with a few large customers. For example, contract manufacturers in the electronics industry have not convinced their large customers, such as HP and Motorola, to outsource the procurement function. Both HP and Motorola are large enough that there is very little marginal benefit from further aggregation, whereas there is a potential downside in that they would cede the relationship with the supplier to the contract manufacturer if they outsourced procurement. For a small electronics company, however, the procurement aggregation offered by a contract manufacturer could add significantly to the supply chain surplus.

7. ***Information aggregation.*** A third party may increase the surplus by aggregating information to a higher level than can be achieved by a firm performing the function in-house. All retailers aggregate information on products from many manufacturers in a single location. This information aggregation reduces search costs for customers. eBags is an example of a retailer that provides primarily information aggregation, and little else. eBags hold very little inventory but is a single point of display for information on bags from many manufacturers. By aggregating product information, eBags significantly reduces search costs for the online customer. Relative to eBags, if each manufacturer set up its own Web site and online store, search costs for the customer would be higher and each manufacturer would have to invest in the information infrastructure. Thus, eBags increases the supply chain surplus through information aggregation by making search cheaper and reducing investment in information technology. Two other examples of information aggregation include W.W. Grainger and McMaster-Carr. Both provide a product catalog and a very detailed Web site. This simplifies search by the customer and aggregates product information for over a thousand manufacturers. Another excellent example of information aggregation is provided by the various online sites, such as America's Loads On-Line, that bring together shippers and truckers looking for backhauls. Information aggregation reduces search costs and allows better matching of truckers and shipments. Information aggregation increases the surplus if both buyers and sellers are fragmented and buying is sporadic. Information aggregation is not likely to be a big factor for a car manufacturer that regularly buys steel from a single supplier.

8. ***Receivables aggregation.*** A third party may increase the supply chain surplus if it can aggregate the receivables risk to a higher level than the firm or it has a lower collection cost than the firm. BrightStar is a distributor for Motorola in most Latin American countries other than Brazil. Cell phones in the area are sold through many small, independently owned retail outlets. Collecting receivables from each retail outlet is a very expensive proposition for a manufacturer. Given that a retailer buys from many manufacturers, the power of each manufacturer to collect is also reduced. Brightstar, as a distributor, is able to aggregate collection across all manufacturers (that it serves), reducing the collection cost. By aggregating collection to a greater extent than any one manufacturer can, Brightstar also lowers the default risk. Reduced

collection cost and risk allows Brightstar to increase the supply chain surplus relative to having this activity performed by manufacturers. The same is true with distributors in India that often distribute for a large number of manufacturers to the same retailer. Given their ability to aggregate across many manufacturers and small retailers, distributors in India typically take responsibility for managing receivables from the retailers. Receivables aggregation is likely to increase the supply chain surplus if retail outlets are small and numerous and each outlet stocks products from many manufacturers that are all served by the same distributor. Such a scenario is more likely in developing countries where retailing is fragmented. It is less likely in developed countries such as the United States and most of Western Europe, where retailing is consolidated.

9. ***Relationship aggregation.*** An intermediary can increase the supply chain surplus by decreasing the number of relationships required between multiple buyers and sellers. Without an intermediary, connecting a thousand sellers to a million buyers requires a billion relationships. The presence of an intermediary lowers the number of relationships required to just over a million. Most retailers and MRO distributors such as W.W. Grainger improve supply chain surplus through relationship aggregation. Relationship aggregation increases the supply chain surplus by increasing the size of each transaction and decreasing their number. Relationship aggregation is most effective when many buyers sporadically purchase small amounts at a time but each order often has products from multiple suppliers. Thus, Grainger can increase the surplus by being a relationship aggregator for MRO products. A third party, however, does not increase the surplus by being a relationship aggregator between a few buyers and sellers where the relationships are longer term and large. For example, Covisint has failed to become a relationship aggregator in the automotive industry, especially for direct materials.

10. ***Lower costs and higher quality.*** A third party can increase the supply chain surplus if it provides lower cost or higher quality relative to the firm. If these benefits come from specialization and learning, they are likely to be sustainable over the longer term. A specialized third party that is further along the learning curve for some supply chain activity is likely to maintain its advantage over the long term. A common scenario, however, is one in which the third party has a low-cost location that the firm does not. In such a situation, lower labor and overhead costs are temporary reasons for outsourcing, because if the wage differential is persistent and the third party offers none of the other advantages discussed earlier, it is best for the firm to maintain ownership and off-shore production to the low-cost location.

KEY POINT A third party may be able to provide a sustainable growth of the surplus by aggregating to a higher level than the firm itself. The growth in surplus comes from aggregating capacity, inventory, inbound or outbound transportation, warehousing, procurement, information, receivables, or relationships to a level that the firm cannot on its own. A growth in surplus may also occur if the third party has lower costs or higher quality because of specialization or learning.

Three important factors that affect the increase in surplus that a third party provides: scale, uncertainty, and the specificity of assets. If the scale is large, it is very likely that sufficient economies of scale are achieved internal to the firm itself. In this case it is very unlikely that a third party can achieve further scale economies and increase the surplus. Wal-Mart has sufficient scale in terms of its transportation needs that it achieves economies of scale on trucking by itself. Going to a third party would not increase the surplus and would result in some loss of control. In contrast, if a firm's

needs do not provide sufficient economies of scale, the third party can increase the su plus by a large amount. For its outbound packages, even though Grainger has a larg number going out, they are distributed geographically and Grainger would not be abl to achieve economies of scale for door-to-door delivery. A third party package carrie adds to the surplus in this case.

The second important factor is the uncertainty of a firm's needs. If the needs are ver predictable, the increase in surplus from a third party is limited, especially if the firn has sufficient scale. In contrast, if the firm's needs are highly variable over time, th third party can increase the surplus through aggregation with other customers. Fo example, Grainger has predictable needs in terms of warehouse space required. Giver sufficient scale, it owns and operates its own distribution centers. In contrast, mos firms have very uncertain demand for MRO products. They prefer not to hold these items in stock and use Grainger as an intermediary.

Finally, the growth in surplus is influenced by the specificity of assets required by the third party. If the assets required are specific to a firm and cannot be used for oth- ers, a third party is unlikely to increase the surplus because all it does is move the assets from one firm to another. The third party has no opportunity to aggregate across other customers. For example, if a distributor holds inventory that is specific to a customer, the distributor is unable to aggregate it to a higher level than the customer. The pres- ence of the distributor does not increase the surplus in this case. Similarly, if a third- party logistics provider manages a warehouse exclusively for a single firm, it has few opportunities to increase the surplus unless it can aggregate the use of management or information systems across other warehouses. In contrast, if assets (inventory or ware- houses in the above examples) are less specific and can be used across multiple firms, a third party can increase the surplus by aggregating uncertainty across multiple customers or improving economies of scale. The above discussion on how and when a third party can increase the supply chain surplus is summarized in Table 14-1.

KEY POINT A firm gains the most by outsourcing to a third party if its needs are small, highly uncertain, and shared by other firms sourcing from the same third party.

RISKS OF USING A THIRD PARTY

Firms must evaluate the following risks when they move any function to a third party.

1. ***The process is broken.*** The biggest problems arise when a firm outsources supply chain functions simply because it has lost control of the process. Keep in mind that introducing a third party into a broken supply chain process only makes it worse and

TABLE 14-1 Growth in Surplus by Third Party as a Function of Scale, Uncertainty, and Specificity

		Specificity of Assets Involved in Function	
		Low	***High***
Firm scale	Low	High growth in surplus	Low–medium growth in surplus
	High	Low growth in surplus	No growth in surplus
Demand uncertainty for firm	Low	Low–Medium growth in surplus	Low growth in surplus
	High	High growth in surplus	Low–medium growth in surplus

harder to control. The first step should be to get the process under control, then do a cost–benefit analysis, and only then decide on outsourcing.

2. ***Underestimation of the cost of coordination.*** A common mistake when outsourcing is to underestimate the effort required to coordinate activities across multiple entities performing supply chain tasks. This is especially true if a firm plans to outsource specific supply chain functions to different third parties. Outsourcing functions to many third parties is feasible (and can be very effective) if the firm views being a coordinator as one of its core strengths. A good example of a strong coordinator is Cisco. However, even Cisco ran into trouble in the early 2000s and was left with a lot of surplus inventory because of coordination problems. An example where coordination caused problems was between Nike and i2 Technologies in 2000. Nike blamed its loss of $100 million on inventory management glitches that it attributed to the supply chain planning software from i2. i2 in turn blamed the problems on Nike's execution of the software. Clearly, insufficient coordination between the two firms played a role in this failure.

3. ***Reduced customer/supplier contact.*** A firm may lose customer/supplier contact by introducing an intermediary. The loss of customer contact is particularly significant for firms that sell directly to consumers but decide to use a third party to either collect incoming orders or deliver outgoing product. A good example is Boise Cascade, which outsourced all its outbound distribution to third parties. This led to a significant loss of customer contact. Boise Cascade decided to bring outbound delivery for customers located close to their distribution centers in-house. Given the high density of customers around their distribution centers, the additional gain in surplus that a third party could provide was minimal, while the gain from improved customer contact was significant. Boise Cascade did not bring distribution beyond this point in-house because the gain in surplus provided by a third party was significant.

4. ***Loss of internal capability and growth in third-party power.*** A firm may choose to keep a supply chain function in-house if outsourcing will significantly increase the third party's power. An example can be found in the electronics industry. Companies such as HP and Motorola have moved most of their manufacturing to contract manufacturers but are reluctant to move either procurement or design, even though contract manufacturers have developed both capabilities. Given the commonality of components, it can be argued that a contract manufacturer can achieve a higher level of aggregation in procurement as well as design assets. HP and Motorola, however, are reluctant to move procurement to contract manufacturers because the potential loss in power is large whereas the aggregation gains are small given the relatively large size of both firms. Keeping part of a supply chain function in-house is also important if a complete loss of capability significantly strengthens the third party's bargaining position. The in-house capability then serves as an option that can be exercised when the need arises. The option also limits how much of the supply chain surplus the third party can keep for itself.

5. ***Leakage of sensitive data and information.*** Using a third party requires a firm to share demand information and in some cases intellectual property. If the third party also serves competitors, there is always the danger of leakage. Firms have often insisted on firewalls within the third party, but a firewall increases the specificity of assets, limiting the growth in surplus that the third party can provide. When leakage is an issue, especially with regard to intellectual property, firms often choose to keep the function in-house.

6. ***Ineffective contracts.*** Contracts with performance metrics that distort the third party's incentives often significantly reduce any gains from outsourcing. For example,

cost-plus pricing of third-party services presents incentive problems even if the third party opens its books. This form of pricing eliminates incentives for the third party to innovate further to reduce costs. The onus for improvement falls back on the firm. Another example is when firms require suppliers or distributors to maintain a certain number of days of inventory as part of the contract. Such a contract reduces the third party's incentive to take actions that reduce inventories. In such a situation it is better for the firm to contract on a desired service level and leave the third party more freedom with regard to the amount of inventory. The third party then has an incentive to work on reducing the inventory required to provide a given level of service.

14.3 THIRD- AND FOURTH-PARTY LOGISTICS PROVIDERS

A *third-party logistics* (3PL) provider performs one or more of the logistics activities relating to the flow of product, information, and funds that could be performed by the firm itself. Traditionally, 3PLs focused on specific functions such as transportation, warehousing, and information technology within the supply chain. *Armstrong's Guide to 3PLs & Global Logistics Services* (Armstrong & Associates, Inc., 2001) describes some of the services offered by 3PLs, as shown in Table 14-2.

Most 3PLs started out by focusing on one of the functions in the supply chain. For example, UPS started out as a small-package carrier. Schneider started out as a truckload carrier. Over the years, however, as the basic functions have become commoditized, 3PLs have expanded their range of services. There are still several customers that use 3PLs to perform a specific function. For example, Grainger handles most of the order-to delivery-cycle itself, except for outbound transportation, which is outsourced to UPS. UPS clearly increases the surplus in this case given the geographic distribution of Grainger's customers and the small order sizes. UPS has now expanded to include warehousing, information technology, international, and a variety of other services and

TABLE 14-2 Services Provided by 3PLs

Service Category	*Basic Service*	*Some Specific Value-Added Services*
Transportation	Inbound, outbound by ship, truck, rail, air	Tendering, track/trace, mode conversion, dispatch, freight pay, contract management
Warehousing	Storage, facilities management	Cross-dock, in-transit merge, pool distribution across firms, pick/pack, kitting, inventory control, labeling, order fulfillment, home delivery of catalog orders
Information technology	Provide and maintain advanced information/computer systems	Transportation management systems, warehousing management, network modeling and site selection, freight bill payment, automated broker interfaces, end-to-end matching, forecasting, EDI, worldwide track and trace, global visibility
Reverse logistics	Handle reverse flows	Recycling, used-asset disposition, customer returns, returnable container management, repair/refurbish
Other 3PL services		Brokering, freight forwarding, purchase-order management, order taking, loss and damage claims, freight bill audits, consulting, time-definite delivery
International		Customs brokering, port services, export crating, consolidation
Special skills/handling		Hazardous materials, temperature controlled, package/parcel delivery, food-grade facilities/ equipment, bulk

aims to perform a broader range of functions for its customers. The wide range of service allowed UPS to sign a contract to manage the global supply chain for National Semiconductor Corporation. UPS manages the movement of chips from National Semiconductor's plants to a global distribution center and on to customers around the world. Similarly, Schneider Logistics offers a wide variety of services beyond truckload transportation. For the General Motors Spare Parts Operations (GMSPO), Schneider provides comprehensive logistics services from order placement to final payment.

The trend of outsourcing a broader range of supply chain services has been growing since the late 1990s. With the increased globalization of supply chains, customers are looking for players that can manage virtually all aspects of their supply chain. This has led to the concept of a *fourth-party logistics* (4PL) provider. A 4PL was first defined by Andersen Consulting (now Accenture) as "an integrator that assembles the resources, capabilities and technology of its own organization and other organizations to design, build and run comprehensive supply chain solutions."[1] Whereas a 3PL targets a function, a 4PL targets management of the entire process. Some have described a 4PL as a general contractor who manages other 3PLs, truckers, forwarders, custom brokers, and others, essentially taking responsibility of a complete process for the customer. When the idea was first formulated, Andersen conceived a neutral 4PL that did not own any logistics assets itself but only managed various logistics providers. The reality has been somewhat different. Hardly any neutral 4PLs have managed to establish themselves. Many 3PLs, however, have started providing integrated services by which they serve as a 4PL and a lead logistics provider, covering some of the functions themselves.

One example of a lead logistics provider is Menlo Logistics, which manages all aspects of the supply chain for HomeLife, a national home furnishings retail chain. Menlo designs the supply chain and information systems and integrates transportation, warehousing, home delivery, product setup and repair, and reverse logistics for HomeLife. The solution involves some distribution centers that are operated by Menlo and other distribution centers that are operated by other third parties managed by Menlo. Menlo also has a centralized command center to manage and track other supply chain activities. Menlo has also supplied HomeLife with information systems to manage orders, warehouses, transportation, and home delivery. Another example is Kuehne & Nagel AG, a Swiss freight forwarder. It has formed Kuehne & Nagel Lead Logistics (K&N), which is positioned as a 4PL. In 2002 Nortel Networks hired K&N to handle all its outbound logistics from factories to customers. K&N now manages 35 to 40 forwarders, warehouse managers, truckers, and other logistics providers worldwide for Nortel. K&N itself provides some of these services to Nortel.

A fundamental question is how a 4PL adds value relative to a firm managing its own logistics providers. This is particularly relevant in the case of K&N and Nortel because K&N took on nearly 100 Nortel employees who were managing the supply chain earlier. One answer often put forth is that outsourcing to someone like K&N allows Nortel to apply its limited capital toward its core business. Keep in mind, however, that outsourcing a noncore activity such as logistics does not guarantee any growth in the supply chain surplus. The K&N and Nortel relationship can survive in the long term only if K&N can increase the surplus in a way that Nortel cannot. The fundamental advantage that a 4PL may provide comes from greater visibility and coordination over a firm's supply chain and improved handoffs between logistics providers. Greater visibility and coordination requires the use of sophisticated information technology. Given the high cost of development or purchase of this technology, and the

[1]Retrieved from http://en.wikipedia.org/wiki/4PL on January 29, 2006.

expertise required for implementation, a 4PL can increase the surplus by spreading this cost across multiple customers. Many 4PLs have developed their own suite of IT applications, whereas others integrate across IT applications from multiple providers. For example, Schneider Logistics has a suite called SUMIT, whereas Exel plc Americas uses applications from a variety of providers such as i2 Technologies and CAPS. A 4PL can also increase the supply chain surplus by effectively aggregating demands from customers and capacity of logistics providers.

An excellent example of a firm that does both is Li & Fung, which has built a $2 billion business helping global companies such as Reebok manage sourcing and production across many locations in the developing world. The company has been an intermediary between suppliers in the developing world and global buyers since it was founded in 1906. Li & Fung originally exported jade, porcelain, and silk from China to the United States. In the 1970s the firm expanded its network of suppliers and is now able to get around regional trade umbrellas such as the European Union and NAFTA by sourcing appropriately. Li & Fung is an information hub that is able to link thousands of factories in 32 countries to almost a thousand customers in an optimal manner. Li & Fung reserves 30 to 70 percent of a supplier's capacity. These factories are accustomed to reliable repeat business from Li & Fung and are thus willing to commit this capacity. Li & Fung maintains detailed capability information for each factory that is used to match it to appropriate customer orders as they arrive. For its customers, Li & Fung facilitates short-lead-time production. This allows customers to observe sales trends before committing to an order. When an order arrives, Li & Fung procures yarn from one supplier, gets on the production schedule of a weaving mill, and finally farms out production of the garment to ensure that the delivery schedule is met. All of this is done to minimize production cost while meeting delivery schedules. Clearly Li & Fung is an integrator that adds to the supply chain surplus in ways that no individual customer or supplier can. The firm aggregates demand across hundreds of customers, capacity across thousands of suppliers, and uses detailed information on both to match supply and demand in the most cost-effective manner.

As supply chains become more global, 3PLs with a broad range of services are enjoying an advantage in the market place. This has led to a series of mergers, with large 3PLs getting even larger. With the increasing use of postponement, especially in the electronics industry, intermediaries are being asked to take on partial manufacturing responsibilities. This has led to a blurring of the distinction between 3PLs and contract manufacturers. The larger 3PLs are increasingly trying to offer some form of final assembly as part of their service. Contract manufacturers in turn are expanding their logistics capabilities by either buying or partnering with logistics providers. For example, Celestica, a contract manufacturer, has partnered with Exel Logistics, FedEx, Kuehne & Nagel, and Panalpina as its logistics providers. Another contract manufacturer, Flextronics bought a few logistics providers in the early 2000s. In either case, the goal was to provide a complete production and distribution service to the customer.

14.4 SUPPLIER SCORING AND ASSESSMENT

When comparing suppliers, many firms make the fundamental mistake of focusing only on the quoted price, ignoring the fact that suppliers may differ on other important dimensions that affect the total cost of using a supplier. For instance, suppliers have different replenishment lead times. Does it pay to select a more expensive supplier with a

shorter lead time? Or consider suppliers that have different on-time performance. Is the more reliable supplier worth the few extra pennies it charges per piece?

In each of the aforementioned instances, the price charged by the supplier is only one of many factors that affect the supply chain surplus. When scoring and assessing suppliers, the following factors other than quoted price must be considered:

- Replenishment lead time
- On-time performance
- Supply flexibility
- Delivery frequency/minimum lot size
- Supply quality
- Inbound transportation cost
- Pricing terms
- Information coordination capability
- Design collaboration capability
- Exchange rates, taxes, and duties
- Supplier viability

Supplier performance must be rated on each of these factors because they all affect the total supply chain cost. Next we discuss how each factor affects total supply chain cost and how a supplier's rating on the factor can be used to infer a total cost of using the supplier.

1. ***Replenishment lead time.*** As the replenishment lead time from a supplier grows, the amount of safety inventory that needs to be held by the buyer also grows proportional to the square root of the replenishment lead time (see Chapter 11). Lead-time performance by a supplier can be translated directly into the required safety inventory using Equation 11.9. Scoring the performance of suppliers in terms of replenishment lead time thus allows the firm to evaluate the impact each supplier has on the cost of holding safety inventory.

2. ***On-time performance.*** On-time performance affects the variability of the lead time. A reliable supplier has low variability of lead time, whereas an unreliable supplier has high variability. As the variability of lead time grows, the required safety inventory at the firm grows very rapidly (see Chapter 11). On-time performance can be translated into lead-time variability, which is converted to required safety inventory using Equation 11.11. A firm can use the discussion in Chapter 11 to evaluate the impact of poor on-time performance by a supplier on the cost of holding safety inventory.

3. ***Supply flexibility.*** Supply flexibility is the amount of variation in order quantity that a supplier can tolerate without letting other performance factors deteriorate. The less flexible a supplier is, the more lead-time variability it will display as order quantities change. Supply flexibility thus affects the level of safety inventory that the firm will have to carry.

4. ***Delivery frequency/minimum lot size.*** The delivery frequency and the minimum lot size offered by a supplier affect the size of each replenishment lot ordered by a firm. As the replenishment lot size grows, the cycle inventory at the firm grows, thus increasing the cost of holding inventory (see Chapter 10). Delivery frequency is converted to cycle inventory using Equation 10.1. For a firm using a periodic review policy, delivery frequency also affects the required safety inventory (see Equation 11.16). Thus, delivery frequency of a supplier can be converted into the cost of holding cycle and safety inventory.

5. ***Supply quality.*** A worsening of supply quality increases the variability of the supply of components available to a firm. Quality affects the lead time taken by the supplier

to complete the replenishment order and also the variability of this lead time because follow-up orders often need to be fulfilled to replace defective products. As a result, the firm has to carry more safety inventory (see Chapter 11) from a low-quality supplier compared to a high-quality supplier. Once a relationship among supply quality, lead time, and lead time variability is established, each supplier's quality level can be converted to the required safety inventory and the associated holding cost. The component quality also affects customer satisfaction and product cost because of rework, lost material, and the cost of inspection.

6. ***Inbound transportation cost.*** The total cost of using a supplier includes the inbound transportation cost of bringing material in from the supplier. Sourcing a product overseas may have lower product cost but generally incurs a higher inbound transportation cost, which must be accounted for when comparing suppliers. The distance, mode of transportation, and delivery frequency affect the inbound transportation cost associated with each supplier.

7. ***Pricing terms.*** Pricing terms include the allowable time delay before payment has to be made and any quantity discounts offered by the supplier. Allowable time delays in payment to suppliers save the buyer working capital. The cost of working capital savings for each supplier can be quantified. Price terms also include discounts for purchases above certain quantities. Quantity discounts lower the unit cost but tend to increase the required batch size and as a result the cycle inventory (see Chapter 10). As discussed in Chapter 10, the impact of quantity discounts on material cost and inventory cost can be quantified for each supplier.

8. ***Information coordination capability.*** The information coordination capability of a supplier is harder to quantify, but it affects the ability of a firm to match supply and demand. Good coordination results in better replenishment planning, thus decreasing both the inventory carried as well as the sales lost because of lack of availability. Good information coordination also decreases the bullwhip effect (see Chapter 17) and results in lower production, inventory, and transportation costs while improving responsiveness to the customer. The value of better coordination is linked to the amount of variability introduced into the supply chain as a result of the bullwhip effect.

9. ***Design collaboration capability.*** Given that a large part of product cost is fixed at design, collaboration capability of a supplier is significant. Good design collaboration for manufacturability and supply chain can also decrease required inventories and transportation cost. As manufacturers are increasingly outsourcing both the design and manufacture of components, their ability to coordinate design across many suppliers is critical to the ultimate success of the product and the speed of introduction. As a result, design collaboration capability of suppliers is becoming increasingly important.

10. ***Exchange rates, taxes, and duties.*** Although exchange rates, taxes, and duties are not supplier dependent, they can be significant for a firm with a global manufacturing and supply base. In many instances, currency fluctuations affect component price more than all other factors put together. Financial hedges can be put into place to counter exchange-rate fluctuations. It is important, however, to analyze various supply options in a global supply chain to account for demand and macroeconomic variability, as discussed in Chapter 6. Similarly, the level of taxes and duties can make a significant difference on total cost, depending on the location of the supplier.

11. ***Supplier viability.*** Given the impact that suppliers have on a company's performance, an important factor in picking a supplier is the likelihood that it will be around to fulfill the promises it makes. This consideration can be especially important if the supplier is providing mission-critical products and it would be difficult to find a

TABLE 14-3 Supplier Performance Factors and Their Impact on Total Cost

	Purchase Price of Component	*Inventory*		*Transportation Cost*	*Product Introduction Time*
		Cycle	*Safety*		
Replenishment lead time			X		
On-time performance			X		
Supply flexibility			X		
Delivery frequency		X	X	X	
Supply quality	X		X		
Inbound transport cost				X	
Pricing terms	X	X			
Information coordination			X	X	
Design collaboration	X	X	X	X	X
Exchange rates and taxes	X				
Supplier viability			X		X

replacement for. Note that this is not necessarily a bias for larger companies—many small companies, and even some start-ups, can provide an acceptable level of viability.

Each supplier should be rated on all the aforementioned dimensions besides the price charged per unit. The impact of each factor on total cost is summarized in Table 14-3. The factors in Table 14-3 allow a firm to rate and compare various suppliers with different performance on each dimension. We have discussed how performance along most of the factors can be quantified in terms of impact on cost. The overall performance of each supplier can thus be characterized in terms of total cost and a rating on the nonquantifiable factors.

KEY POINT Supplier performance should be compared based on the impact on total cost. In addition to purchase price, the total cost is influenced by replenishment lead time, on-time performance, supply flexibility, delivery frequency, supply quality, inbound transportation cost, pricing terms, the ability of the supplier to coordinate forecasting and planning, the design collaboration capability of the supplier, exchange rates and taxes, and supplier viability.

In Example 14-1, we illustrate the comparison of two suppliers with different prices and other performance characteristics.

Example 14-1: **Comparing suppliers based on total cost**

Green Thumb, a manufacturer of lawn mowers and snow blowers, has historically purchased a thousand bearings per week from a local supplier who charges $1.00 per bearing. The purchasing manager has identified another potential source willing to supply the bearings at $0.97 per bearing. Before making his decision, the purchasing manager evaluates the performance of the two suppliers. The local supplier has an average lead time of two weeks and has agreed to deliver the bearings in batches of 2,000. Based on past on-time performance, the purchasing manager estimates that the lead time has a standard deviation of one week. The new source has an average lead time of six weeks with a standard deviation of four weeks. The new source requires a minimum batch size of 8,000 bearings. Which supplier should the purchasing manager go with? Green Thumb has a holding cost of 25 percent. It currently uses a continuous review policy for managing inventory and aims for a cycle service level of 95 percent. Weekly demand has a mean of 1,000 and a standard deviation of 300.

Analysis: The suppliers' performance along lead time and lead time variability affects the safety inventory that Green Thumb must hold, and the minimum batch-size requirement affects the cycle inventory held. Thus, the purchasing manager should evaluate the total cost of using each supplier. First consider the cost of using the current local supplier:

$$\begin{aligned}
\textit{Annual material cost} &= 1{,}000 \times 52 \times 1 = \$52{,}000\\
\text{Average cycle inventory (using Equation 10.1)} &= 2{,}000/2 = 1{,}000\\
\text{Annual cost of holding cycle inventory} &= 1{,}000 \times 1 \times 0.25 = \$250\\
\text{Standard deviation of demanded during lead time (using Equation 11.11)} &= \sqrt{2 \times 300^2 + 1{,}000^2 \times 1^2} = 1{,}086.28\\
\text{Safety inventory required with current supplier (using Equation 11.9)} &= \textit{NORMSINV}(0.95) \times 1086.28 = 1{,}787\\
\text{Annual cost of holding safety inventory} &= 1{,}787 \times 1 \times 0.25 = \$446.75\\
\text{Annual cost of using current supplier} &= 52{,}000 + 250 + 446.75 = \$52{,}696.75
\end{aligned}$$

Next consider the cost of using the new supplier:

$$\begin{aligned}
\text{Annual material cost} &= 1{,}000 \times 52 \times 0.97 = \$50{,}440\\
\text{Average cycle inventory (using Equation 10.1)} &= 8{,}000/2 = 4{,}000\\
\text{Annual cost of holding cycle inventory} &= 4{,}000 \times 0.97 \times 0.25 = \$970\\
\text{Standard deviation of demanded during lead time (using Equation 11.11)} &= \sqrt{6 \times 300^2 + 1{,}000^2 \times 4^2} = 4{,}066.94\\
\text{Safety inventory required with current supplier (using Equation 11.9)} &= \textit{NORMSINV}(0.95) \times 4{,}066.94 = 6{,}690\\
\text{Annual cost of holding safety inventory} &= 6{,}690 \times 0.97 \times 0.25 = \$1{,}622\\
\text{Annual cost of using current supplier} &= 50{,}440 + 970 + 1{,}622 = \$53{,}032
\end{aligned}$$

Observe that the new supplier has a lower annual material cost but a higher annual total cost. Taking all performance characteristics into account, the purchasing manager should continue to use the current supplier.

14.5 SUPPLIER SELECTION—AUCTIONS AND NEGOTIATIONS

Before selecting suppliers, a firm must decide whether to use single sourcing or multiple suppliers. Single sourcing guarantees the supplier sufficient business when the supplier has to make a significant buyer-specific investment. The buyer-specific investment may take the form of plant and equipment designed to produce a part that is specific to the buyer or may take the form of expertise that needs to be developed. Single sourcing is also used in the automotive industry for parts such as seats that must arrive in the sequence of production. Coordinating such sequencing is impossible with multiple sources. As a result, auto companies have a single seat source for each plant but multiple seat sources across their manufacturing network. Having multiple sources ensures a degree of competition and also the possibility of a backup should a source fail to deliver.

A good test of whether a firm has the right number of suppliers is to analyze what impact deleting or adding a supplier will have. Unless each supplier has a somewhat different role, it is very likely that the supply base is too large. In contrast, unless adding a supplier with a unique and valuable capability clearly adds to total cost, the supply base may be too small.

The selection of suppliers is done using a variety of mechanisms, including offline competitive bids, reverse auctions, or direct negotiations. No matter what mechanism is used, supplier selection should be based on the total cost of using a supplier and not just the purchase price. Next we discuss some auction mechanisms that are often used in practice and highlight some of their properties.

AUCTIONS IN THE SUPPLY CHAIN

When outsourcing to a third party, firms have historically obtained competitive bids and in recent years have used reverse auctions on the Internet. Competitive bids are a form of auction in which the bids are not revealed to the other bidders. In the following discussion we treat them as auctions. An excellent discussion on auctions can be found in Krishna (2002) and Milgrom (2004). Much of the following discussion is a summary of their ideas.

In many supply chain settings, a buyer looks to outsource a supply chain function such as production or transportation. Potential suppliers are first qualified and then allowed to bid on how much they would charge to perform the function. The qualification process is important because there are multiple attributes of performance (as outlined in Table 14-3) that the buyer cares about. When conducting an auction based primarily on unit price, it is thus important for the buyer to specify performance expectations along all dimensions other than price. In reality a buyer may be better off with a multiattribute auction, but in most cases buyers end up with specifications on various attributes and a price-only auction. The qualification process is used to identify suppliers that meet performance expectations along the nonprice attributes. From the buyer's perspective, the purpose of the auction is to get bidders to reveal their underlying cost structure so that the buyer can select the supplier with the lowest costs. Commonly used mechanisms for these auctions are as follows.

- *Sealed-bid first-price auctions* require each potential supplier to submit a sealed bid for the contract by a specified time. These bids are then opened and the contract is assigned to the lowest bidder.
- In *English auctions,* the auctioneer starts with a price and suppliers can make bids as long as each successive bid is lower than the previous bid. The supplier with the last (lowest) bid receives the contract. The difference in this case is that all suppliers get to see the current lowest bid as the auction unfolds.
- In *Dutch auctions,* the auctioneer starts with a low price and then raises it slowly until one of the suppliers agrees to the contract at that price.
- In *second-price (Vickrey) auctions,* each potential supplier submits a bid. The contract is assigned to the lowest bidder but at the price quoted by the second-lowest bidder.

When identifying the auction to use, the firm wants to minimize the price it pays. The firm may also care about ending up with the supplier with the lowest underlying costs because it makes it more likely that the supplier will actually be able to supply at the price it has committed to. A related issue is whether suppliers have any incentive to make false bids that are not consistent with their cost structure. Such bids may increase what the firm pays and also lead to the contract being given to a firm that does not have the lowest costs.

An important issue with the sealed-bid first-price auction is what is known as the winner's curse. Once selected based on sealed bids, the winner quickly realizes that it could have raised its bid slightly and still won, because other suppliers bid at a higher level. In this sense, winning the bid leads the winner to realize that it left money on the table. Thus, bidders adjust their initial sealed bids upward, taking this phenomenon into account. This issue does not arise in any open auction, where bidders see the current best bid when planning their next bid. This issue also does not arise in the second-price auction because the winner gets the price quoted by the second-lowest bidder and thus has no incentive to hide its true cost.

The following factors influence the performance of an auction:

- Is the supplier's cost structure private (not affected by factors that are common to other bidders)?
- Are suppliers symmetric or not, that is, ex ante, are they expected to have similar cost structures?

- Do suppliers have all the information they need to estimate their cost structure?
- Does the buyer specify a maximum price it is willing to pay for the supply chain?

Let us start with the cost structures for suppliers. In most instances it is reasonable to assume that part of the supplier's cost arises from how it has structured its processes and part of its cost arises from market factors such as raw material and labor cost that are common across suppliers. In other words, the suppliers' cost structure is likely to be interdependent and correlated to some extent. This interdependence and correlation is likely to be higher for suppliers with similar processes located in similar markets. If suppliers are symmetric with costs that are interdependent and correlated, the expected price that a firm has to pay using an English auction is no more than that in a second-price auction, which is no more than in a sealed-bid first-price auction. In other words, under these conditions the English auction is likely to fetch the lowest price for the firm. If suppliers are asymmetric, however, it is possible that a second-price auction may do better than an English auction.

If the buyer firm has some information that has a direct bearing on suppliers' costs and the suppliers are aware that the firm has this information but do not know the information itself, it is in the best interest of the firm to reveal this information. Under all auction mechanisms (with symmetric bidders), the buyer pays less with all information revealed than with less information revealed. Thus, it is in the best interest of the buyer to specify its needs clearly and reveal all information related to the supply chain task of which it is aware. Not revealing this information leads the bidders to shade their bids to guard against the winner's curse, resulting in an increase in the price paid by the buyer. Thus, it is in the buyer's interest not only to reveal all public information before bidding but also to convince potential suppliers that all information has been revealed.

A very significant factor that must be accounted for when designing an auction is the possibility of collusion among bidders. Second-price auctions are particularly vulnerable to collusion among bidders. Consider an agreement among bidders under which the bidder with the lowest cost agrees to bid its true cost, with all other bidders bidding a high number (say, the cost of the most expensive bidder or the reserve price of the buyer). In a second-price auction, the lowest-cost bidder gets to perform the supply chain function but the buyer has to a pay a higher price than the cost of the second-lowest-cost supplier. This collusion strategy is an equilibrium because none of the other bidders has anything to gain by deviating from the collusion agreement. Observe that this collusion strategy can be avoided with any first-price auction, either sealed bid or English. In either case, a collusion agreement with a very high price will not hold, because many bidders will have the temptation to join the bidding if they have a lower cost. Ultimately, any first-price auction will bring more than the lowest-cost bidder in to the auction.

Collusion results in suppliers suppressing their desire to provide the supply chain function and raising their bids from what would be appropriate given their cost. This is often the case in multiunit auctions, in which the buyer wants suppliers to bid on a certain quantity of the supply chain function. In *multiunit Dutch auctions,* the buyer starts by announcing a high price and then lowers it slowly until a supplier is willing to provide one unit of the goods or services. The price is lowered slowly until suppliers have committed to all units of goods or services desired by the buyer. In this auction, each unit is supplied at a different price. In a *multiunit English auction,* the buyer starts at a high price and bidders announce the quantity they are willing to supply. If the total quantity that suppliers are willing to supply exceeds the desired quantity, the buyer lowers the price until the quantity for which suppliers bid equals the desired quantity.

All suppliers then get to supply at this price. This auction is also referred to as the *uniform-price auction*. Suppliers in either auction can raise the final price by colluding and forming a bidding ring that assigns only one bidder to enter the auction process for the entire ring. After the initial auction the ring then has a separate auction to divide up the quantity they have been assigned among themselves. An excellent discussion on collusion can be found in Porter (2004).

KEY POINT Buyers should structure auctions to minimize their cost and have the lowest-cost supplier(s) win with their bid. Open auctions such as the English auction are likely to achieve this outcome. Sealed first-price auctions are subject to the winner's curse because the winner knows ex poste that it could have lowered its bid and still won. This causes it to adjust its initial bid higher. Auctioneers must take care to avoid collusion among bidders and make an effort to detect collusion if it has occurred.

BASIC PRINCIPLES OF NEGOTIATION

In some instances, the third party that will perform a given supply chain function has been identified and the firm enters into a negotiation to set the terms of the contract. Negotiation is likely to result in a positive outcome only if the value the buyer places on outsourcing the supply chain function to this supplier is at least as large as the value the supplier places on performing the function for the buyer. The value that a supplier places on performing a function is influenced by its cost as well as other alternatives that are available for its existing capacity. Similarly, the value that the buyer places is influenced by the cost of performing the function in-house and the price available from alternative suppliers. The difference between the values of the buyer and seller is referred to as the *bargaining surplus*. The goal of each negotiating party is to capture as much of the bargaining surplus as possible.

An excellent discussion on negotiations is available in Thompson (2005). We mention some of the highlights from her discussion. The first recommendation is to have a clear idea of your own value and as good an estimate of the third party's value as possible. A good estimate of the bargaining surplus improves the chance of a successful outcome. Suppliers of Toyota have often mentioned that "Toyota knows our costs better than we do," which leads to better negotiations. The second recommendation is to look for a fair outcome based on equally or equitably dividing the bargaining surplus or dividing it based on needs. Equity here refers to a division of the surplus in proportion to the contribution by each party.

The key to a successful negotiation, however, is to make it a win–win outcome. It is impossible to obtain a win–win outcome if the two parties are negotiating on a single dimension such as price. In this setting, one party can only "win" at the expense of the other. To create a win–win negotiation, the two parties have to identify more than one issue to negotiate. Identifying multiple issues allows the opportunity to expand the pie if the two parties have different preferences. This is often easier than it seems in a supply chain setting. A buyer typically cares not just about the price of performing the supply chain function but also about the responsiveness and quality (two of the dimensions identified in Table 14-3). If the supplier finds it harder to lower the price but easier to reduce the response time, there is an opportunity for a win–win resolution in which the supplier offers better responsiveness without changing the price. Thompson discusses many hurdles in the negotiation process and also suggests effective strategies.

14.6 CONTRACTS AND SUPPLY CHAIN PERFORMANCE

A supply contract specifies parameters governing the buyer–supplier relationship. In addition to making the terms of the buyer–supplier relationship explicit, contracts have significant impact on the behavior and performance of all stages in a supply chain. Contracts should be designed to facilitate desirable supply chain outcomes and minimize actions that hurt performance. A manager should ask the following three questions when designing a supply chain contract:

1. How will the contract affect the firm's profits and total supply chain profits?
2. Will the incentives in the contract introduce any information distortion?
3. How will the contract influence supplier performance along key performance measures?

Ideally, a contract should be structured to increase the firm's profits and supply chain profits, discourage information distortion, and offer incentives to the supplier to improve performance along key dimensions. Many shortcomings in supply chain performance occur because the buyer and supplier are two different entities, each trying to optimize its own profits.

CONTRACTS FOR PRODUCT AVAILABILITY AND SUPPLY CHAIN PROFITS

Actions taken by the two parties in the supply chain often result in profits that are lower than what could be achieved if the supply chain were to coordinate its actions with a common objective of maximizing supply chain profits. Consider a product whose demand is significantly affected by the retail price. The retailer decides its price (and thus sales quantity) based on its margin. The retailer's margin is only a fraction of the supply chain margin, leading to a retail price that is higher than optimal and a sales quantity that is lower than optimal for the supply chain. This phenomenon is referred to as double marginalization (see Chapter 10). As discussed in Chapter 10, the supplier can increase supply chain profits by offering a volume discount, where the retailer pays a lower price if the total quantity purchased exceeds a threshold.

Another example of double marginalization arises in the presence of demand uncertainty. A manufacturer wants the retailer to carry a large inventory of its product to ensure that any surge in demand can be satisfied. The retailer, on the other hand, loses money on any unsold inventory. As a result, the retailer prefers to carry a lower level of inventory. This tension leads to a supply chain outcome that is suboptimal.

In a contract in which the supplier specifies a fixed price and the buyer decides on the quantity to be purchased, the most common cause for suboptimal supply chain performance is double marginalization. The retailer makes its buying decision before demand is realized and thus bears all the demand uncertainty. If demand is less than the retailer's inventory, the retailer has to liquidate unsold product at a discount. Given uncertain demand, the retailer decides on the purchase quantity based on its margin and the cost of overstocking. The retailer's margin, however, is lower than the contribution margin for the entire supply chain, whereas its cost of overstocking is higher than that for the entire supply chain. As a result, the retailer is conservative and aims for a lower level of product availability than is optimal for the supply chain.

Consider a music store that sells compact discs. The supplier buys (or manufactures) compact discs at $1 per unit and sells them to the music store at $5 per unit. The retailer sells each disc to the end consumer at $10. At this retail price, market demand is normally distributed, with a mean of 1,000 and a standard deviation of 300. The

retailer has a margin of \$5 per disc and can potentially lose \$5 for each unsold disc. Using Equation 12.1, it is optimal for the retailer to aim for a service level of 0.5 and order 1,000 discs. From Equation 12.3, the retailer's expected profits are \$3,803 and the manufacturer makes \$4,000 from selling 1,000 discs. For the supply chain, however, the supplier and the retailer together have a margin of \$9 and can lose a maximum of only \$1 per unsold disc. For the entire supply chain it is thus optimal to aim for a service level of 0.9 and stock 1,384 discs. The expected supply chain profit in this case is \$8,474. The music store is thus conservative and carries fewer discs than are optimal for the supply chain. As a result, the supply chain makes \$670 less than it would expect to if the retailer and the supplier worked together.

To improve overall profits, the supplier must design a contract that encourages the buyer to purchase more and increase the level of product availability. This requires the supplier to share in some of the buyer's demand uncertainty. Three contracts that increase overall profits by making the supplier share some of the buyer's demand uncertainty are as follows:

1. Buyback or returns contracts
2. Revenue-sharing contracts
3. Quantity flexibility contracts

We illustrate each of the three contracts using the example of the music store and discuss their performance in terms of the three questions raised earlier.

Buyback Contracts

A buy-back or returns clause in a contract allows a retailer to return unsold inventory up to a specified amount, at an agreed-upon price. In a *buy-back contract,* the manufacturer specifies a wholesale price c along with a buy-back price b at which the retailer can return any unsold units at the end of the season. The manufacturer can salvage $\$s_M$ for any units that the retailer returns.

The optimal order quantity O^* for a retailer in response to a buy-back contract is evaluated using Equations 12.1 and 12.2, where the salvage value for the retailer is $s = b$. The expected retailer profit is evaluated using Equation 12.3. The expected profit at the manufacturer depends on the overstock at the retailer (evaluated using Equation 12.4) that is returned. We obtain

$$\text{Expected manufacturer profit} = O^*(c - v) - (b - s_M) \times \text{expected overstock at retailer}$$

For example, the supplier to the music store may agree to buy back discs that have not sold at \$3 per disc. This lowers the loss to the retailer for each unsold disc from \$5 to \$2. The supplier absorbs the \$3 per unsold disc as a reduction in margin. The presence of the buy-back clause makes it optimal for the retailer to increase the order size from 1,000 to 1,170, resulting in higher product availability and higher profits for both the retailer (\$4,286 instead of \$3,803) and the supplier (\$4,009 instead of \$4,000). Buy-back contracts are most effective for products with a low variable cost. Examples include music, software, books, magazines, and newspapers.

Table 14-4 provides the outcome for different buy-back contracts that the supplier offers the music store. The sale price of compact discs at the music store is $p = \$10$ and demand at this price is normally distributed, with a mean of $\mu = 1{,}000$ and a standard deviation of $\sigma = 300$. At this stage we assume that there is no transportation or other cost associated with any returns.

From Table 14-4, observe that a buy-back contract allows both the supplier and the retailer to increase their profits. In Table 14-4, the use of buy-back contracts

TABLE 14-4 Order Sizes and Profits in Music Supply Chain Under Different Buy-Back Contracts

Wholesale Price c	*Buy-Back Price b*	*Optimal Order Size for Music Store*	*Expected Profit for Music Store*	*Expected Returns to Supplier*	*Expected Profit for Supplier*	*Expected Supply Chain Profit*
$5	$0	1,000	$3,803	120	$4,000	$7,803
$5	$2	1,096	$4,090	174	$4,035	$8,125
$5	$3	1,170	$4,286	223	$4,009	$8,295
$6	$0	924	$2,841	86	$4,620	$7,461
$6	$2	1,000	$3,043	120	$4,761	$7,804
$6	$4	1,129	$3,346	195	$4,865	$8,211
$7	$0	843	$1,957	57	$5,056	$7,013
$7	$4	1,000	$2,282	120	$5,521	$7,803
$7	$6	1,202	$2,619	247	$5,732	$8,351

increases total supply chain profits by about 20 percent when the wholesale price is $7 per disc. Observe that as the wholesale price increases, it is optimal for the manufacturer to increase the buy-back price as well. For a fixed wholesale price, as the buy-back price increases, the retailer orders more and also returns more. In our analysis in Table 14-4, we have not considered the cost associated with a return. As the cost associated with a return increases, buy-back contracts become less attractive because the cost of returns reduces supply chain profits. If return costs are very high, buy-back contracts can reduce the total profits of the supply chain far more than is the case without any buyback.

For a fixed wholesale price, increasing the buy-back price always increases retailer profits. In general, there exists a positive buy-back price that is a fraction of the wholesale price, at which the manufacturer makes a higher profit compared to offering no buyback. Also observe that buybacks increase profits for the manufacturer more as the manufacturer's margin increases. Thus, the greater the manufacturer's margin, the more they stand to benefit through the use of some mechanism such as buybacks.

In 1932, Viking Press was the first book publisher to accept returns. Today, buy-back contracts are very common in the book industry, and publishers accept unsold books from retailers. To minimize the cost associated with a return, retailers do not have to return the book, only the cover. This provides publishers with proof that the book did not sell while reducing the cost of the return. Over the years, there has been considerable debate about the impact of publishers' returns policy on profits in the industry. Our discussion provides some justification for the approach taken by the publishers.

KEY POINT Manufacturers can use buy-back contracts to increase their own profits as well as total supply chain profits. Buybacks encourage retailers to increase the level of product availability.

In some instances, manufacturers use holding-cost subsidies or price protection to encourage retailers to order more. With *holding-cost subsidies,* manufacturers pay retailers a certain amount for every unit held in inventory over a given period. Holding-cost subsidies are prevalent in automotive supply chains. In the high-tech

industry, in which products lose value rapidly, manufacturers share the risk of product becoming obsolete by providing *price support* to retailers. Many manufacturers guarantee that in the event they drop prices, they will also lower prices for all inventories that the retailer is currently carrying. As a result, the cost of overstocking at the retailer is limited to the cost of capital and physical storage and does not include obsolescence, which can be over 100 percent a year for high-tech products. The retailer thus increases the level of product availability in the presence of price support. Both holding-cost subsidies and price support are forms of buyback.

A downside to the buy-back clause (or any equivalent practice such as holding-cost subsidy or price support) is that it leads to surplus inventory that must be salvaged or disposed. The task of returning unsold product increases supply chain costs. The cost of returns can be eliminated if the manufacturer gives the retailer a markdown allowance and allows it to sell the product at a significant discount. Publishers today generally do not ask retailers to return unsold books. Instead, they give a markdown allowance for unsold books. Retailers mark them down and sell them for a considerable discount.

For a given level of product availability at the retailer, the presence of a buy-back clause can also hurt sales because it leads the retailer to exert less effort to sell than it would if there were no buybacks. The reduction in retailer effort in the presence of buyback occurs because its loss from unsold inventory is higher when there is no buyback, leading to a higher sales effort. The supplier can counter the reduction in sales effort by limiting the amount of buyback permitted.

The structure of a buy-back clause leads to the entire supply chain reacting to the order placed by the retailer and not actual customer demand. If a supplier is selling to multiple retailers, it produces based on the orders placed by each retailer. Each retailer bases its order on its cost of over- and understocking (see Chapter 12). After actual sales materialize, unsold inventory is returned to the supplier separately from each retailer. The structure of the buy-back clause increases information distortion when a supplier is selling to multiple retailers. At the end of the sales season, however, the supplier does obtain information on actual sales. Information distortion is driven primarily by the fact that inventory is disaggregated at the retailers. If inventory is centralized at the supplier and sent out only as needed to the retailers, information distortion can be reduced. With centralized inventory, the supplier can exploit independence of demand across retailers to carry a lower level of inventory. In practice, most buy-back contracts, however, have decentralized inventory at retailers. As a result, there is a high level of information distortion.

KEY POINT Buy-back contracts lead to a lower retailer effort in case of overstocking and increased information distortion within the supply chain.

Revenue-Sharing Contracts

In *revenue-sharing* contracts, the manufacturer charges the retailer a low wholesale price c, and shares a fraction f of the retailer's revenue. Even if no returns are allowed, the lower wholesale price decreases the cost to the retailer in case of an overstock. The retailer thus increases the level of product availability resulting in higher profits for both the manufacturer and the retailer.

Assume that the manufacturer has a production cost v; the retailer charges a retail price p and can salvage any leftover units for s_R. The optimal order quantity O^* ordered by the retailer is evaluated using Equations 12.1 and 12.2, where the cost of

understocking is $C_u = (1 - f)p - c$ and the cost of overstocking is $C_u = c - s_R$. We thus obtain

$$CSL^* = \text{probability(demand} \leq O^*) = \frac{C_u}{C_u + C_o} = \frac{(1 - f)p - c}{(1 - f)p - s_R}$$

The manufacturer obtains the wholesale price c for each unit purchased by the retailer and a share of the revenue for each unit sold by the retailer. The expected overstock at the retailer is obtained using Equation 12.4. The manufacturer's profits are thus evaluated as

$$\text{Expected manufacturer's profits} = (c - v)\,O^* + fp(O^* - \text{expected overstock at retailer})$$

The retailer pays a wholesale price c for each unit purchased and obtains a revenue of $(1 - f)p$ for each unit sold and a revenue of s_R for each unit overstocked. The retailer's expected profit is thus evaluated as

$$\text{Expected retailer profit} = (1 - f)p(O^* - \text{expected overstock at retailer}) + s_R \times \text{expected overstock at retailer} - cO^*$$

We return to the example of the music store. The supplier agrees to sell each disc to the music store at $c = \$1$, but the music store agrees to share 45 percent of the revenue from each disc sold. If each disc is priced at \$10, the supplier gets \$4.5 for each disc sold and the music store keeps \$5.5. The music store targets a service level of 81.8 percent (see Equation 12.1) and increases the number of discs they order from 1,000 (when the supplier priced at \$5 without revenue sharing) to 1,273. The increase in order size occurs because the retailer loses only \$1 per unsold disc (instead of \$5 per disc without revenue sharing), while making a margin of \$4.5 for each disc that sells. As a result, profits for both the retailer (\$4,064) and the manufacturer (\$4,367) increase.

Table 14-5 provides the outcome for different revenue-sharing fractions f when demand for discs is normally distributed, with a mean of $\mu = 1{,}000$ and a standard deviation of $\sigma = 300$.

From Tables 14-4 and 14-5, observe that revenue sharing allows both the manufacturer and retailer to increase their profits in the absence of buybacks compared to the case in which the wholesaler sells for a fixed price of \$5 without buybacks. When charging a wholesale price of \$5, the supplier makes profit of \$4,000 and the music store makes a profit of \$3,803 (see Table 14-4). With a revenue-sharing contract that shares 45 percent of the revenue (the supplier gets revenue of \$4.5 for each jacket sold), however, the supplier makes a profit of \$4,064 and the retailer makes a

TABLE 14-5 Order Sizes and Profits in Music Supply Chain Under Different Revenue-Sharing Contracts

Wholesale Price c	*Revenue-Sharing Fraction f*	*Optimal Order Size for Retailer*	*Expected Overstock at Retailer*	*Expected Profit for Retailer*	*Expected Profit for Supplier*	*Expected Supply Chain Profit*
\$1	0.30	1,320	342	\$5,526	\$2,934	\$8,460
\$1	0.45	1,273	302	\$4,064	\$4,367	\$8,431
\$1	0.60	1,202	247	\$2,619	\$5,732	\$8,350
\$2	0.30	1,170	223	\$4,286	\$4,009	\$8,395
\$2	0.45	1,105	179	\$2,881	\$5,269	\$8,150
\$2	0.60	1,000	120	\$1,521	\$6,282	\$7,803

profit of $4,367. As a result of revenue sharing, the retailer increases the quantity ordered from 1,000 to 1,273.

Revenue-sharing contracts also result in lower retailer effort compared to the case when the retailer pays an up-front wholesale price and keeps the entire revenue from a sale. The drop in effort results because the retailer gets only a fraction of the revenue from each sale. One advantage of revenue-sharing contracts over buy-back contracts is that no product needs to be returned, thus eliminating the cost of returns. Revenue-sharing contracts are best suited for products with low variable cost and a high cost of return. A good example of revenue-sharing contracts is between Blockbuster video rentals and movie studios. A studio sells each cassette to Blockbuster at a low price and then shares in the revenue generated from each rental. Given the low price, Blockbuster purchases many copies, resulting in more rentals and higher profits for both Blockbuster and the studio.

The revenue-sharing contract does require an information infrastructure that allows the supplier to monitor sales at the retailer. Such an infrastructure can be expensive to build. As a result, revenue-sharing contracts may be difficult to manage for a supplier selling to many small buyers.

As in buy-back contracts, revenue-sharing contracts also result in the supply chain producing to retailer orders rather than actual consumer demand. This information distortion results in excess inventory in the supply chain and a greater mismatch of supply and demand. The information distortion increases as the number of retailers to which the supplier sells grows. As with buy-back contracts, information distortion from revenue-sharing contracts can be reduced if retailers reserve production capacity or inventory at the supplier rather than buying product and holding it in inventory themselves. This allows aggregation of the variability across multiple retailers and the supplier has to hold a lower level of capacity or inventory. In practice, however, most revenue-sharing contracts are implemented with the retailer buying and holding inventory.

KEY POINT Revenue-sharing contracts counter double marginalization by decreasing the cost per unit charged to the retailer, thus effectively decreasing the cost of overstocking. Revenue-sharing contracts increase information distortion and lead to a lower retailer effort in case of overstocking, just as buy-back contracts do.

Quantity Flexibility Contracts

Under *quantity flexibility contracts*, the manufacturer allows the retailer to change the quantity ordered after observing demand. If a retailer orders O units, the manufacturer commits to providing $Q = (1 + \alpha)O$ units, whereas the retailer is committed to buying at least $q = (1 - \beta)O$ units. Both α and β are between 0 and 1. The retailer can purchase up to Q units, depending on the demand it observes. These contracts are similar to buy-back contracts in that the manufacturer now bears some of the risk of having excess inventory. Because no returns are required, these contracts can be more effective than buy-back contracts when the cost of returns is high. Quantity flexibility contracts increase the average amount the retailer purchases and may increase total supply chain profits.

Assume that the manufacturer incurs a production cost of $\$v$ per unit and charges a wholesale price of $\$c$ from the retailer. The retailer in turn sells to customers for a price of $\$p$. The retailer salvages any leftover units for s_R. The manufacturer salvages any leftover units for s_M. If retailer demand is normally distributed, with a mean of μ

and a standard deviation of σ, we can evaluate the impact of a quantity flexibility contract. If the retailer orders O units, the manufacturer is committed to supplying Q units. As a result, we assume that the manufacturer produces Q units. The retailer purchases q units if demand D is less than q, D units if demand D is between q and Q, and Q units if demand is greater than Q. Note that in the following formulas, F_S is the standard normal cumulative distribution function and f_S is the standard normal density function discussed in Appendix 11A of Chapter 11. We thus obtain

$$\text{Expected quantity purchased by retailer, } Q_R = qF(q) + Q[1 - F(Q)] + \mu\left[F_s\left(\frac{Q-\mu}{\sigma}\right) - F_s\left(\frac{q-\mu}{\sigma}\right)\right] - \sigma\left[f_s\left(\frac{Q-\mu}{\sigma}\right) - f_s\left(\frac{q-\mu}{\sigma}\right)\right]$$

$$\text{Expected quantity sold by retailer, } D_R = Q[1 - F(Q)] + \mu F_s\left(\frac{Q-\mu}{\sigma}\right) - \sigma f_s\left(\frac{q-\mu}{\sigma}\right)$$

$$\text{Expected overstock at manufacturer} = Q_R - D_R$$

$$\text{Expected retailer profit} = D_R \times p + (Q_R - D_R)s_R - Q_R \times c$$

$$\text{Expected manufacturer profit} = Q_R \times c + (Q - Q_R)s_M - Q \times v$$

In our example, the music store would place an initial order for, say, 1,000 discs. Closer to the release date, as the store got a better idea of actual demand, it would be allowed to modify its order to any number between (say) 950 and 1,050. In this contract, the retailer modifies its order as it gains better market intelligence over time. The supplier in turn sends only the modified order quantity. The amount ordered by the retailer is more in line with actual demand, resulting in higher profits for the supply chain. For a supplier, the quantity flexibility contract makes sense if it has flexible capacity that can be used to produce at least the uncertain part of the order after the retailer has decided on the modification. A quantity flexibility contract is also very effective if a supplier is selling to multiple retailers with independent demand.

In Table 14-6, we show the impact of different quantity flexibility contracts on profitability for the music supply chain when demand is normally distributed, with a mean of $\mu = 1{,}000$ and a standard deviation of $\sigma = 300$. We assume a wholesale price of $c = \$5$ and a retail price of $p = \$10$. All contracts considered are such that $\alpha = \beta$.

From Table 14-6, observe that for wholesale prices of \$6 and \$7, quantity flexibility contracts allow both the manufacturer and the retailer to increase their profits.

TABLE 14-6 Profits at Music Supply Chain Under Different Quantity Flexibility Contracts

α	β	*Wholesale Price c*	*Order Size O*	*Expected Purchase by Retailer*	*Expected Sale by Retailer*	*Expected Profits for Retailer*	*Expected Profits for Supplier*	*Expected Supply Chain Profit*
0.00	0.00	\$5	1,000	1,000	880	\$3,803	\$4,000	\$7,803
0.20	0.20	\$5	1,047	1,023	967	\$4,558	\$3,858	\$8,416
0.40	0.40	\$5	1,068	1,011	994	\$4,884	\$3,559	\$8,443
0.00	0.00	\$6	924	924	838	\$2,841	\$4,620	\$7,461
0.20	0.20	\$6	1,000	1,000	955	\$3,547	\$4,800	\$8,347
0.30	0.30	\$6	1,021	1,006	979	\$3,752	\$4,711	\$8,463
0.00	0.00	\$7	843	843	786	\$1,957	\$5,056	\$7,013
0.20	0.20	\$7	947	972	936	\$2,560	\$5,666	\$8,226
0.40	0.40	\$7	1,000	1,000	987	\$2,873	\$5,600	\$8,473

Observe that as the manufacturer increases the wholesale price, it is optimal for it to offer greater quantity flexibility to the retailer.

Quantity flexibility contracts are common for components in the electronics and computer industry. In the previous discussion, we considered fairly simple quantity flexibility contracts. Benetton has used sophisticated quantity flexibility contracts with its retailers successfully to increase supply chain profits. We describe such a contract in the context of colored knit garments.[2]

Seven months before delivery, Benetton retailers are required to place their orders. Consider a retailer placing an order for 100 sweaters each in red, blue, and yellow. One to three months before delivery, retailers may alter up to 30 percent of the quantity ordered in any color and assign it to another color. The aggregate order, however, cannot be adjusted at this stage. Potentially the retailer may change the order to 70 red, 70 blue, and 160 yellow sweaters. After the start of the sales season, retailers are allowed to order up to 10 percent of their previous order in any color. Potentially the retailer can order another 30 yellow sweaters. In this quantity flexibility contract, Benetton retailers have a flexibility of up to 10 percent on the aggregate order across all colors and of about 40 percent for individual colors. Retailers can increase the aggregate quantity ordered by up to 10 percent and the quantity for any individual color can be adjusted by up to 40 percent. This flexibility is consistent with the fact that aggregate forecasts are more accurate than forecasts for individual colors. As a result, retailers can better match product availability with demand. The guaranteed portion of the order is manufactured by Benetton using an inexpensive but long-lead-time production process. The flexible part of the order (about 35 percent) is manufactured using postponement. The result is a better matching of supply and demand at lower cost than in the absence of such a contract. The quantity flexibility contract Benetton offers allows both the retailers and Benetton to increase their profits.

If the supplier has flexible capacity, a quantity flexibility contract increases profits for the entire supply chain and also each party. The quantity flexibility contract requires either inventory or excess flexible capacity to be available at the supplier. If the supplier is selling to multiple retailers with independent demand, the aggregation of inventory leads to a smaller surplus inventory (see Chapter 11) with a quantity flexibility contract compared to either a buy-back or revenue-sharing contract. Inventories can be further reduced if the supplier has excess flexible capacity. Quantity flexibility contracts are thus preferred for products with high marginal cost or in instances where surplus capacity is available. To be effective, quantity flexibility contracts require the retailer to be good at gathering market intelligence and improving its forecasts closer to the point of sale.

Relative to buy-back and revenue-sharing contracts, quantity flexibility contracts have less information distortion. Consider the case with multiple retailers. With a buy-back contract, the supply chain must produce based on the retailer orders that are placed well before actual demand arises. This leads to surplus inventory being disaggregated at each retailer. With a quantity flexibility contract, retailers specify only the range within which they will purchase, well before actual demand arises. If demand at various retailers is independent, the supplier does not need to plan production to the high end of the order range for each retailer. It can aggregate uncertainty across all retailers and build a lower level of surplus inventory than would be needed if inventory were disaggregated at each retailer. Retailers then order closer to the point of sale, when demand is more visible and less uncertain. The aggregation of uncertainty results in less information distortion with a quantity flexibility contract.

[2]See Heskett and Signorelli (1984).

Like the other contracts discussed, quantity flexibility contracts result in lower retailer effort. In fact, any contract that gets retailers to provide a higher level of product availability by not making them fully responsible for overstocking will result in a lowering of retailer effort for a given level of inventory.

KEY POINT Quantity flexibility contracts counter double marginalization by giving the retailer the ability to modify the order based on improved forecasts closer to the point of sale. These contracts result in lower information distortion than buy-back or revenue-sharing contracts when a supplier sells to multiple buyers or the supplier has excess, flexible capacity.

CONTRACTS TO COORDINATE SUPPLY CHAIN COSTS

Differences in costs at the buyer and supplier also lead to decisions that increase total supply chain costs. An example is the replenishment lot size decision typically made by the buyer. The buyer decides on its optimal lot size based on its fixed cost per lot and the cost of holding inventory. The buyer does not account for the supplier's costs. If the supplier has a high fixed cost per lot, the optimal lot size for the buyer increases total cost for the supplier and the supply chain. In such a situation, the supplier can use a quantity discount contract to encourage the buyer to order in lot sizes that minimize total costs (see Chapter 10). The objective of such a contract is to encourage the retailer to buy in larger lot sizes that lower cost for the supplier and the entire supply chain.

A quantity discount contract decreases overall costs but leads to higher lot sizes and thus higher levels of inventory in the supply chain. It is typically justified only for commodity products for which the supplier has high fixed costs per lot. It is important to modify the terms of the contract as operational improvements are made at the supplier, resulting in lower fixed costs per batch.

Quantity discounts increase information distortion in the supply chain because such contracts increase order batching. Retailers order less frequently, and any demand variations are exaggerated when orders are placed. The supplier receives information less frequently and all variations are increased because of this batching. This information distortion is discussed in greater detail in Chapter 17.

KEY POINT Quantity discounts can coordinate supply chain costs if the supplier has large fixed costs per lot. Quantity discounts, however, increase information distortion as a result of order batching.

CONTRACTS TO INCREASE AGENT EFFORT

In many supply chains, agents act on behalf of a principal and the agents' effort affects the reward for the principal. As an example, consider a car dealer (the agent) selling cars for DaimlerChrysler (the principal). The dealer also sells other brands and used cars. Every month the dealer allocates its sales effort (advertising, promotions, etc.) across all brands it sells and the used cars. Earnings for DaimlerChrysler are based on sales of its brands, which in turn are affected by the effort exerted by the dealer. Sales can be observed directly, whereas effort is hard to observe and measure. Given double marginalization, the dealer always exerts less effort than is optimal from the perspective of DaimlerChrysler and the supply chain. Thus, DaimlerChrysler must offer an incentive contract that encourages the dealer to increase effort.

In theory, a two-part tariff offers the right incentives for the dealer to exert the appropriate amount of effort. In a two-part tariff, DaimlerChrysler extracts its profits up front as a franchise fee and then sells cars to the dealer at cost. The dealer's margin is then the same as the supply chain margin, and the dealer exerts the right amount of effort.

Another contract, observed more frequently in practice, increases the margin for the dealer as sales cross certain thresholds. DaimlerChrysler offered such a contract to dealers in the first quarter of 2001, which was structured roughly as follows. Dealers would keep the margin made from customers if sales for the month were under 75 percent of an agreed-upon target. However, if sales exceeded 75 percent but were less than 100 percent, the dealer would get an additional $150 per car sold. If sales exceeded 100 percent but were less than 110 percent, the dealer would get an additional $250 per car sold. If sales exceeded 110 percent, the dealer would get an additional $500 per car sold. DaimlerChrysler's hope was that by increasing the margin for higher thresholds, the dealer would have an incentive to increase effort on sales of DaimlerChrysler cars.

Although threshold contracts clearly encourage the dealer to try and reach higher thresholds, they can significantly increase information distortion by encouraging the agent to exacerbate demand variability. The first month after the new contract was announced, the U.S. car industry saw sales drop. DaimlerChrysler, however, saw sales drop by twice the industry average. There are two potential causes for this behavior. First, under the contract, the dealer makes more money selling 900 cars one month and 1,100 the next month compared to selling a thousand cars each month. The dealer has an incentive to shift demand over time to achieve such an outcome, thus increasing information distortion and observed demand variation. The second cause is that within the first week of the month the dealer has an idea of the threshold range it is likely to reach. For example, if the dealer feels that it can easily cross the 75 percent threshold but has little chance of crossing the 100 percent threshold, it will decrease his effort for the month and save it for later, because the marginal benefit of selling an additional car is only $150. In contrast, if demand for the month is high and the dealer feels it can easily cross the 100 percent threshold, it is likely to exert additional effort to reach the 110 percent threshold because the marginal benefit from reaching that threshold is very high. Thus, DaimlerChrysler's incentive contract increases variation in dealer effort, further exaggerating any existing demand variation.

Information distortion is also observed in threshold contracts often offered by companies to their sales staff. Under these contracts, staff is offered rewards for crossing sales thresholds during a specified period of time (e.g., a quarter). The problem observed is that sales effort and orders peak during the last week or two of the quarter, as salespeople try to cross the threshold. Observed sales are thus highly uneven during the quarter. This information distortion arises because the incentive is offered over a fixed time period, making the last week or two of each quarter a period of intense activity for all sales staff.

Given the information distortion arising from threshold contracts, a key question is how a firm can decrease information distortion while maintaining the incentive for the agent to exert extra effort. One approach is to offer threshold incentives over a rolling horizon. For example, if a firm offers its sales staff weekly incentives based on sales over the last 13 weeks, each week becomes the last week of a 13-week period. Sales effort thus becomes more even compared to the case when the entire sales staff has the same last week for their bonus evaluation. Given the presence of ERP systems, implementing a rolling horizon contract is much easier today than it once was.

KEY POINT Two-part tariffs and threshold contracts can be used to counter double marginalization and increase agent effort in a supply chain. Threshold contracts, however, increase information distortion and are best implemented on a rolling horizon.

CONTRACTS TO INDUCE PERFORMANCE IMPROVEMENT

In many instances a buyer wants performance improvement from a supplier that has little incentive to do so. A buyer with sufficient power in the supply chain may be able to force the supplier to comply. A buyer without sufficient power requires an appropriate contract to induce the supplier to improve performance. Even for a powerful buyer, however, an appropriate contract designed to encourage supplier cooperation results in a better outcome.

As an example, consider a buyer that wants the supplier to improve performance by reducing lead time for a seasonal item. This is an important component of all quick response (QR) initiatives in a supply chain. With a shorter lead time, the buyer hopes to have better forecasts and be better able to match supply and demand. Most of the work to reduce lead time has to be done by the supplier, whereas most of the benefit accrues to the buyer. In fact, the supplier will lose sales because the buyer will now carry less safety inventory because of shorter lead times and better forecasts. To induce the supplier to reduce lead time, the buyer can use a *shared-savings contract,* with the supplier getting a fraction of the savings that result from reducing lead time. As long as the supplier's share of the savings compensates for any effort it has to put in, its incentive will be aligned with that of the buyer, resulting in an outcome that benefits both parties.

A similar issue arises when a buyer wants to encourage the supplier to improve quality. Improving supply quality improves the buyer's costs but requires additional effort from the supplier. Once again, a shared-savings contract is a good way to align incentives between the buyer and supplier. The buyer can share savings from improved quality with the supplier. This will encourage the supplier to improve quality to a higher level than what the supplier would choose in the absence of the shared savings.

Another example arises in the context of toxic chemicals that may be used by a manufacturer. The manufacturer would like to decrease the use of these toxic chemicals. Generally, the supplier is better equipped to identify ways of reducing use of these chemicals because this is its core business. It has no incentive to work with the buyer on reducing use of these chemicals because that will reduce the supplier's sales. A shared-savings contract can be used to align incentives between the supplier and the manufacturer. If the manufacturer shares the savings that result from a reduction in the use of toxic chemicals with the supplier, the supplier will make the effort to reduce use of the chemicals as long as its share of the savings compensates for the loss in margin from reduced sales.

In general, shared-savings contracts are effective in aligning supplier and buyer incentives when the supplier is required to improve performance along a particular dimension and most of the benefits of improvement accrue to the buyer. A powerful buyer may couple shared savings with penalties for a lack of improvement, to further encourage the supplier to improve performance. Such contracts will increase profits for both the buyer and the supplier while achieving outcomes that are beneficial to the supply chain.

KEY POINT Shared-savings contracts can be used to induce performance improvement from a supplier along dimensions, such as lead time, where the benefit of improvement accrues primarily to the buyer, whereas the effort for improvement comes primarily from the supplier.

14.7 DESIGN COLLABORATION

Two important statistics highlight the importance of design collaboration between a manufacturer and suppliers. Today, typically between 50 and 70 percent of the spending at a manufacturer is through procurement, compared to only about 20 percent several decades ago. It is generally accepted that about 80 percent of the cost of a purchased part is fixed during the design stage. Thus, it is crucial for a manufacturer to collaborate with suppliers during the design stage if product costs are to be kept low. Design collaboration can lower the cost of purchased material and also lower logistics and manufacturing costs. Design collaboration is also important for a company trying to provide a lot of variety and customization, because failure to do so can significantly raise the cost of variety.

Working with suppliers can speed up product development time significantly. This is crucial in an era when product life cycles are shrinking and bringing a product to market before the competition offers a significant competitive advantage. Finally, integrating the supplier into the design phase allows the manufacturer to focus on system integration, resulting in a higher quality product at lower cost. For example, auto manufacturers are increasingly playing the role of system integrators rather than component designers. This is an approach that has been used even more extensively in the high-tech industry.

As suppliers take on a bigger design role, it is important for manufacturers also to become design coordinators for the supply chain. Common part descriptions should be available to all parties involved in the design, and any design changes by one party should be communicated to all suppliers affected. A good database of existing parts and designs can save significant amounts of money and time. For example, when Johnson Controls finds a seat frame from its database that fulfills all customer requirements, it saves the customer about $20 million on the design, development, tooling, and prototyping expense.

A survey by the Procurement and Supply Chain Benchmarking Consortium at Michigan State University dramatically demonstrates the impact of successfully integrating suppliers in product design. The most successful integration efforts have seen costs decrease by 20 percent, quality improve by 30 percent, and time-to-market decrease by 50 percent.

Key themes that must be communicated to suppliers as they take greater responsibility for design are design for logistics and design for manufacturability. Design for logistics attempts to reduce transportation, handling, and inventory costs during distribution by taking appropriate actions during design. To reduce transportation and handling costs, the manufacturer must convey expected order sizes from retailers and the end consumer to the designer. Packages can then be designed so that transportation costs are lowered and handling is minimized. To reduce transportation cost, packaging is kept as compact as possible and is also designed to ensure easy stacking. To reduce handling costs, package sizes are designed to minimize the need to break open a pack to fulfill an order.

To reduce inventory costs, the primary approach is to design the product for postponement and mass customization (see Chapter 11). Postponement strategies aim to design a product and production process so that features that differentiate end products are introduced late in the manufacturing phase. As discussed in Chapter 11, Dell designs its PCs so that all components about which customers have a choice are assembled after the customer order arrives. This allows Dell to lower inventories by aggregating them as components. Mass customization strategies use a similar approach by designing the product so that inventory can be carried in a form that aggregates across multiple end products. The goal is to design a product so that customization occurs

along a combination of the following three customization categories: modular, adjustable, and dimensional. To provide *modular customization,* the product is designed as an assembly of modules that fit together. All inventory is then maintained as modules that are assembled to order. A good example of modular customization is PC assembly at Dell. An example of *adjustable customization* is a washing machine designed by Matsushita that can automatically select from among 600 different cycles. All inventory is thus maintained as a single product, and each customer uses the machine to match its specific needs. An example of *dimensional customization* given by Joseph Pine (1999) is a machine that makes custom house gutters on site, which can then be cut to fit the dimensions of the house. Another example is National Bicycle, which cuts the frame tubing to fit the body size of the customer.

Design for manufacturability attempts to design products for ease of manufacture. Some of the key principles used include part commonality, eliminating right-hand and left-hand parts, designing symmetrical parts, combining parts, using catalog parts rather than designing a new part, and designing parts to provide access for other parts and tools.

KEY POINT Design collaboration with suppliers can help a firm reduce cost, improve quality, and decrease time-to-market. As design responsibility moves to suppliers, it is important to ensure that design for logistics and design for manufacturability principles are followed. To be successful, manufacturers must become effective design coordinators in the supply chain.

A good area in which to view design collaboration efforts is in the automotive industry. Car manufacturers all over the world are asking suppliers to participate in every aspect of product development, from conceptual design to manufacturing. Ford, for example, asked suppliers for the Thunderbird not only to manufacture the components and subsystems, but also to be responsible for their design. Solid integration throughout the supply chain allowed Ford to bring the new model to market within 36 months of program approval. To ensure effective communication, Ford required all its vendors to be on the same software platform for design. Ford also opened all its internal databases to its suppliers and collocated many of the suppliers at its offices. Ford engineers were in constant communication with the suppliers and helped coordinate the overall design. The result was a significant improvement in cost, time, and quality.

14.8 THE PROCUREMENT PROCESS

Once suppliers have been selected, contracts are in place, and the product has been designed, the buyer and suppliers engage in procurement transactions that begin with the buyer placing the order and end with the buyer receiving and paying for the order. In designing the procurement process, it is important to consider goods that the process will be used to purchase. There are two main categories of purchased goods: direct and indirect materials. *Direct materials* are components used to make finished goods. For example, memory, hard drives, and CD drives are direct materials for a PC manufacturer. *Indirect materials* are goods used to support the operations of a firm. PCs are examples of indirect materials for an automotive manufacturer. All procurement processes within a company relate to the purchase of direct and indirect materials. Important differences between direct and indirect materials that affect procurement are shown in Table 14-7.

TABLE 14-7 Differences Between Direct and Indirect Materials

	Direct Materials	*Indirect Materials*
Use	Production	Maintenance, repair, and support operations
Accounting	Cost of goods sold	SG&A
Impact on production	Any delay will delay production	Less direct impact
Processing cost relative to value of transaction	Low	High
Number of transactions	Low	High

Given the direct link to production, the procurement process for direct materials should be designed to ensure that components are available in the right place, in the right quantity, and at the right time. The primary goal of the procurement process for direct materials is to coordinate the entire supply chain and ensure matching of supply and demand. The procurement process should thus be designed to make production plans and current levels of component inventory at the manufacturer visible to the supplier. This visibility allows suppliers to schedule component production to match the needs of the manufacturer. The available capacity at the suppliers should be made visible to the manufacturer so that orders for components may be allocated to the appropriate supplier to ensure on-time delivery. The procurement process should also have alerts that warn both the buyer and the supplier of potential mismatches between supply and demand built into it.

A good example of a procurement process that focuses on these objectives is the eHub initiative at Cisco. eHub is designed to provide synchronized planning and end-to-end supply chain visibility. Ultimately, Cisco plans to include more than 2,000 of its suppliers, distributors, and contract electronic manufacturers in its private trading network. Another example is the relationship between Johnson Controls and DaimlerChrysler for the 2002 Jeep Liberty. Johnson Controls integrated components from 35 suppliers and delivered the assembly to Chrysler as a cockpit module. As soon as Chrysler notified it of an order for a Jeep, Johnson Controls had 204 minutes in which to build and deliver the module. This was done 900 times every day for about 200 different color and interior combinations. The focus of the procurement process was to completely synchronize production at DaimlerChrysler and Johnson Controls. The result was a significant reduction in inventory and a better matching of product supply with end customer demand.

Given the focus on numerous low-value transactions, the procurement process for indirect materials should focus on reducing the transaction cost of each order. Transaction costs for indirect materials are high because of the difficulty of selecting goods (many catalogs, which are often out of date), getting approval, and creating and sending a purchase order. The problem is often exaggerated because companies do not have one system for indirect materials. Instead, they use several processes that are not streamlined or integrated. A good e-procurement process that makes search easy and automates approval and transmission of the purchase order can help reduce transaction costs. The e-procurement process should also update other interested parties such as accounts payable and receiving. Clearly this is possible only with suppliers that implement online catalogs and automate all transactions with the buyer. Successful examples of e-procurement implementations for indirect materials include Johnson Controls and Pfizer. Both firms built their e-procurement solutions by integrating existing software. Johnson Controls integrated a Commerce One solution with existing

Oracle accounting software, whereas Pfizer integrated an Ariba system with an American Express corporate purchasing card program. Both claim to have seen significant savings as a result.

Another important requirement for the procurement process for both direct and indirect materials is to be able to aggregate orders by product and supplier. For direct materials, the consolidation of orders improves economies of scale at the supplier and during transport and allows the firm to take advantage of any quantity discounts that may be offered by the supplier. For indirect materials, the consolidation of spending with a supplier often allows the firm to negotiate better purchasing discounts.

KEY POINT The procurement process for direct materials should focus on improving coordination and visibility with the supplier. The procurement process for indirect materials should focus on decreasing the transaction cost for each order. The procurement process in both cases should consolidate orders to take advantage of economies of scale and quantity discounts.

In addition to the categorization of materials into direct and indirect, all products purchased may also be categorized as shown in Figure 14-2, based on their value/cost and how critical they are.

Most indirect materials are included in general items. The goal of procurement in this case should be to lower the cost of acquisition or the transaction cost. Direct materials can be further classified into bulk purchase, critical, and strategic items. For most bulk purchase items, such as packaging materials and bulk chemicals, suppliers tend to have the same selling price. It is thus important for purchasing to make a distinction between suppliers based on the services they provide and their performance along all dimensions that affect the total cost of ownership. The use of well-designed auctions is likely to be most effective for bulk purchase items. Critical items include components with long lead times and specialty chemicals. The key sourcing objective for critical items is not low price but to ensure availability. In this case, purchasing should work to improve coordination of production plans at both the buyer and supplier. The presence of a responsive, even if high-cost, supply source as an alternative can be very valuable for critical items. The last category, strategic items, includes examples such as electronics

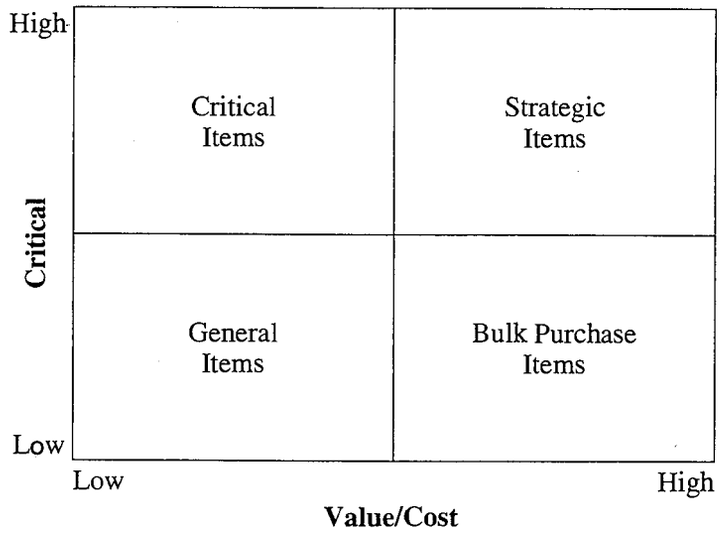


FIGURE 14-2 Product Categorization by Value and Criticality

for an auto manufacturer. For strategic items, the buyer–supplier relationship is long term. Thus suppliers should be evaluated based on the lifetime cost/value of the relationship. Purchasing should look for suppliers that can collaborate in the design phase and coordinate design and production activities with other players in the supply chain.

14.9 SOURCING PLANNING AND ANALYSIS

Periodically, each firm must analyze its procurement spending and supplier performance and use this as input for future sourcing decisions. One important analysis is the aggregation of spending across and within categories and suppliers. Aggregation provides visibility into what a company is purchasing and from whom the product is being purchased. Managers can use this information to determine economic order quantities, volume discounts, and projected quantity discounts on future volumes. A simple step is to consolidate spending and ensure that the firm's economic order quantity matches the supplier's economic production quantity. Managers can thus realize better economies of scale and utilize resources more effectively.

The second piece of analysis relates to supplier performance. Supplier performance should be measured against plan on all dimensions that affect total cost, such as responsiveness, lead times, on-time delivery, quality, and delivery accuracy.

Spending and supplier performance analysis should be used to decide on the portfolio of suppliers to be used and the allocation of demand among the chosen suppliers. As discussed in Chapter 12, the portfolio generally should not consist of similar suppliers. The portfolio should be constructed so that one supply source performs very well on one dimension, whereas another source performs very well on a complementary dimension. For example, a company can source more effectively using a low-cost supplier with longer lead times along with a high-cost supplier with short lead times compared to using only one type of supplier. Similarly, one should not ignore a somewhat lower-quality source if it is much cheaper than other sources. It is also not effective to use only the cheaper but lower-quality source. It may be very effective to use the cheaper but lower-quality source along with a higher-quality but more expensive source.

Once a supplier portfolio has been determined, the next question is the allocation of demand among the suppliers. The allocation should be related to the economic manufacturing quantity for each source and its cost of supply. The low-cost supplier is given large, steady orders independent of demand, whereas the flexible source is given small orders that fluctuate with demand. The flexible source has smaller economic order quantities and is better able to adjust to the fluctuations. The combination of suppliers results in a better matching of supply and demand at lower cost than using one type of supplier.

KEY POINT Procurement spending should be analyzed by part and supplier to ensure appropriate economies of scale. Supplier performance analysis should be used to build a portfolio of suppliers with complementary strengths. Cheaper, but lower-performing, suppliers should be used to supply the base demand, whereas higher-performing, but more expensive, suppliers should be used to buffer against variation in demand and supply from the other source.

14.10 THE ROLE OF IT IN SOURCING

Sourcing-related IT has had the most ups and downs of any supply chain software sector. The sourcing software world created many electronic marketplaces in the late 1990s that were expected to transform the purchase of goods and services. Firms such as Chemdex and VerticalNet promised to be the one-stop shop where all members of an industry would buy and sell their goods. For a time, it seemed that sourcing software firms would create the tools of these new hubs of commerce through which every transaction would flow. They were selling the picks and shovels to all the metaphorical gold mining marketplaces.

Alas, the electronic marketplace has, in most cases, come and gone, rendering the vast majority of these electronic marketplaces useless. That does not mean that the use of IT in sourcing has come and gone. There are a wide variety of areas in which IT can and is used in sourcing today. In fact, there is a greater diversity of IT sourcing products than in most supply chain IT areas. All processes within the supplier relationship management process are supported by IT software. Here is a discussion of some of the major IT product areas within sourcing.

Design collaboration. This software aims to improve the design of products through collaboration between manufacturers and suppliers. The software facilitates the joint selection (with suppliers) of components that have positive supply chain characteristics such as ease of manufacturability or commonality across several end products. Other design collaboration activities include the sharing of engineering change orders between a manufacturer and its suppliers. This eliminates the costly delays that occur when several suppliers are designing components for the manufacturer's product concurrently.

Source. Sourcing software assists in the qualification of suppliers and helps in supplier selection, contract management, and supplier evaluation. An important objective is to analyze the amount that an enterprise spends with each supplier, often revealing valuable trends or areas for improvement. Suppliers are evaluated along several key criteria, including lead time, reliability, quality, and price. This evaluation helps improve supplier performance and aids in supplier selection. Contract management is also an important part of sourcing, as many supplier contracts have complex details that must be tracked (such as volume-related price reductions). Successful software in this area helps analyze supplier performance and manage contracts.

Negotiate. Negotiations with suppliers involve many steps, starting with a request for quote (RFQ). The negotiation process may also include the design and execution of auctions. The goal of this process is to negotiate an effective contract that specifies price and delivery parameters for a supplier in a way that best matches the enterprise's needs. Successful software automates the RFQ process and the execution of auctions.

Buy. "Buy" software executes the actual procurement of material from suppliers. This includes the creation, management, and approval of purchase orders. Successful software in this area automates the procurement process and helps decrease processing cost and time.

Supply collaboration. Once an agreement for supply is established between the enterprise and a supplier, supply chain performance can be improved by collaborating on forecasts, production plans, and inventory levels. The

goal of collaboration is to ensure a common plan across the supply chain. Good software in this area should be able to facilitate collaborative forecasting and planning in a supply chain.

The most significant hurdle to success of sourcing software is that employees often just do not want to use the software. As sourcing software often limits what can be purchased, many people bristle at the loss of freedom to purchase what they feel are the best items for their company. In many cases, people just go around the system and buy the products they want even if they are not purchasable within the system. Another typical difficulty arises when successful use of the IT system requires collaboration among different enterprises. This is always difficult to bring about, as all the firms must be convinced of the benefits of using the system and often each firm is suspicious of the others. However, if collaboration is successful, the benefits can be significant.

The supplier relationship management space has three groups of competitors. Two best-of-breed groups focus exclusively on sourcing, one focusing on design collaboration and another focusing on procurement. Leading design collaboration firms include Agile and Matrix One, whereas the leading procurement firm is Ariba. The third category consists, as usual, of the ERP players, with SAP and Oracle being the strongest.

14.11 RISK MANAGEMENT IN SOURCING

Sourcing risks may result in an inability to meet demand on time, an increase in procurement costs, or the loss of intellectual property. It is important to develop mitigation strategies that help mitigate a significant part of the risk.

An inability to meet demand on time arises because of disruption or delay from the supply source. The risk of supply disruption may be serious, especially with a single or very few sources. This was particularly evident when one of two suppliers of flu vaccine to the United States was unable to do so in 2004 because of contamination. Disruption risk can be mitigated by developing multiple sources. Given the high cost of developing multiple sources and the resulting loss of economies of scale, it is best to do so for products with relatively high demand. Developing multiple sources is very expensive for products with low demand. Delays from a supply source can be mitigated by carrying inventory or developing a backup source that is more responsive. Carrying inventory is best for low-value products that do not become obsolete quickly, whereas developing a responsive backup source is preferred for high-value, short-life-cycle products.

The risk of higher procurement costs can be significant when industry-wide demand for the product exceeds available supply, exchange rates are unfavorable, or there is a single supply source. For example, commodity prices for steel and crude oil were very high in 2004–2005 because of high global demand in the face of limited supply capacity. A portfolio of long- and short-term contracts can help mitigate the risk of higher procurement costs. For example, a significant contributor to the profits at Southwest Airlines in 2004–2005 was the long-term contracts it had in place for the purchase of fuel. Exchange-rate risk can be mitigated using financial hedges or by developing a global supply network that is flexible enough to be reconfigured based on exchange-rate fluctuations. The risk of holdup because of a single source can be countered by developing alternative sources or bringing part of the supply capability in-house.

Intellectual property risk can be mitigated by bringing or keeping sensitive production in-house. Even when production is outsourced, firms can maintain ownership of part of the equipment if it is viewed as having significant intellectual property value. This is a reason that Motorola owns some testing equipment at its contract manufacturers.

14.12 MAKING SOURCING DECISIONS IN PRACTICE

1. ***Use multifunctional teams.*** Effective strategies for sourcing result from multifunctional collaboration within the firm. A sourcing strategy from the purchasing group is likely to be relatively narrow and focus on purchase price. A strategy developed with the collaboration of purchasing, manufacturing, engineering, and planning is much more likely to identify the correct drivers of total cost. The collaboration must be continued beyond strategy formulation to the procurement phase, because that is where manufacturing and engineering are most likely to realize the full benefits of good sourcing strategy.

2. ***Ensure appropriate coordination across regions and business units.*** Coordination of purchasing across all regions and business units allows a firm to maximize economies of scale in purchasing and also to reduce transaction costs. Other opportunities from improved sourcing, such as better supply chain coordination and design collaboration, however, may require strong involvement at the business-unit level to be really effective. Mandating global coordination across all business units may complicate these efforts. Items such as MRO supplies, for which transaction costs and total purchase volume have a significant impact on total cost, benefit most from coordinated purchasing across geography and business units. On the other hand, items for which most of the value is extracted from better design collaboration and coordinated supply chain forecasting and fulfillment are better served with somewhat more decentralized sourcing.

3. ***Always evaluate the total cost of ownership.*** An effective sourcing strategy should not make price reduction its sole objective. All factors that influence the total cost of ownership should be identified and used in selecting suppliers. Supplier performance along all relevant dimensions should be measured, and its impact on total cost should be quantified. Focusing on the total cost of ownership also allows a buyer to better identify opportunities for better collaboration in design, planning, and fulfillment.

4. ***Build long-term relationships with key suppliers.*** A basic principle of good sourcing is that a buyer and supplier working together can generate more opportunities for savings than the two parties working independently. Solid cooperation is likely to result only when the two parties have a long-term relationship and a degree of trust. A long-term relationship encourages the supplier to expend greater effort on issues that are important to a particular buyer. This includes investment in buyer-specific technology and design collaboration. A long-term relationship also improves communication and coordination between the two parties. These capabilities are very important when sourcing direct materials. Thus, long-term relationships should be nurtured with suppliers of critical and strategic direct materials.

14.13 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of sourcing in a supply chain.

   Sourcing encompasses all processes required for a firm to purchase goods from suppliers. Over the last decade, manufacturing firms have increased the fraction of purchased

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14.13 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of sourcing in a supply chain.

   Sourcing encompasses all processes required for a firm to purchase goods from suppliers. Over the last decade, manufacturing firms have increased the fraction of purchased

parts. Effective sourcing decisions thus have a significant impact on financial performance. Good sourcing decisions can improve supply chain performance by aggregating orders, making procurement transactions more efficient, achieving design collaboration with suppliers, facilitating coordinated forecasting and planning with suppliers, designing supply chain contracts that increase profitability while minimizing information distortion, and decreasing the purchase price through increased competition among suppliers.

2. Discuss factors that affect the decision to outsource a supply chain function.

   A supply chain function should be outsourced if the third party can increase the supply chain surplus without significant risk. A third party may increase the surplus by aggregating capacity, inventory, warehousing, transportation, information, receivables, and other factors to a higher level than the firm can on its own. Outsourcing generally makes sense if a firm's needs are small, highly uncertain, and can be served using resources that can serve other firms as well.

3. Identify dimensions of supplier performance that affect total cost.

   In addition to the quoted price, the total cost of using a supplier is affected by the replenishment lead time, on-time performance, supply flexibility, delivery frequency/minimum lot size, supply quality, inbound transportation cost, pricing terms, the information coordination capability, the design collaboration capability of the supplier, and the supplier's viability. These factors must be evaluated when comparing different suppliers to get a real measure of their effectiveness.

4. Structure successful auctions and negotiations.

   Buyers may use sealed-bid first-price, Dutch, English, or second-price (Vickrey) auctions. Successful auctions minimize the cost for the buyer and result in the lowest-cost supplier winning the bid. Under many circumstances, open English auctions achieve this outcome. When running an auction, buyers must work to avoid collusion among bidders. Successful negotiations are most likely when both parties are well informed about each other's positions and have multiple dimensions they can use to increase the size of the pie, resulting in a win–win outcome.

5. Describe the role of supply contracts and their impact on supplier performance and information distortion.

   Supply contracts must take into account the desired objective of the buyer and supplier and the resulting impact on supply chain performance. Contracts can be designed to increase product availability, coordinate supply chain costs, increase agent effort, and induce performance improvement from the supplier. Contracts to increase product availability include buy-back, revenue-sharing, and quantity flexibility contracts. They are designed to counter the problem of double marginalization. Buy-back and revenue-sharing contracts increase information distortion relative to quantity flexibility contracts. Quantity discounts coordinate supply chain costs when the supplier has significant fixed costs per lot. Quantity discounts increase information distortion because of order batching. Two-part tariffs and threshold contracts are designed to increase agent effort. Threshold contracts can significantly increase information distortion and are best implemented over a rolling horizon. Shared-savings contracts are most effective when a buyer wants the supplier to improve performance along dimensions such as lead time and quality.

6. Categorize purchased products and services and identify the desired focus of procurement in each case.

   Direct materials are components that are used to make the finished product. Indirect materials and services are used to support the main production process. Direct materials can be further categorized into bulk purchase, critical, and strategic items, based on the value of the item and how critical it is for the buyer. Procurement should focus on aggregating the spending and reducing transaction costs when purchasing indirect materials. For bulk purchase items, procurement should focus on the value-added service provided and

performance along other dimensions that affect total cost. For critical items, procurement should focus on improving coordination of forecasting and fulfillment with the supplier. For strategic items, procurement should focus on improving design and manufacturing collaboration with the supplier.

Discussion Questions

1. What are some ways that a firm such as Wal-Mart benefits from good sourcing decisions?
2. What factors lead Wal-Mart to own its trucks although many retailers outsource all their transportation?
3. How can a supplier with a lower price end up costing the buyer more than a supplier with a higher price?
4. Explain why, for the same inventory level, a revenue-sharing contract results in a lower sales effort from the retailer than if the retailer has paid for the product and is responsible for all remaining inventory.
5. For a manufacturer that sells to many retailers, why does a quantity flexibility contract result in less information distortion than a buy-back contract?
6. Most firms offer their sales force monetary incentives based on exceeding a specified target. What are some pros and cons of this approach? How would you modify these contracts to rectify some of the problems?
7. An auto manufacturer sources both office supplies and subsystems such as seats. What, if any, difference in sourcing strategy would you recommend for the two types of products?
8. How can design collaboration with suppliers help a PC manufacturer improve performance?

Exercises

1. A publisher sells books to Borders at $12 each. The marginal production cost for the publisher is $1 per book. Borders prices the book to its customers at $24 and expects demand over the next two months to be normally distributed, with a mean of 20,000 and a standard deviation of 5,000. Borders places a single order with the publisher for delivery at the beginning of the two-month period. Currently, Borders discounts any unsold books at the end of two months down to $3, and any books that did not sell at full price sell at this price.
   (a) How many books should Borders order? What is its expected profit? How many books does it expect to sell at a discount?
   (b) What is the profit that the publisher makes given Borders' actions?
   (c) A plan under discussion is for the publisher to refund Borders $5 per book that does not sell during the two-month period. As before, Borders will discount them to $3 and sell any that remain. Under this plan, how many books will Borders order? What is the expected profit for Borders? How many books are expected to be unsold? What is the expected profit for the publisher? What should the publisher do?
2. A movie studio sells the latest movie on DVD to Blockbuster at $10 per DVD. The marginal production cost for the movie studio is $1 per DVD. Blockbuster prices each DVD at $19.99 to its customers. DVDs are kept on the regular rack for a one-month period, after which they are discounted down to $4.99. Blockbuster places a single order for DVDs. Their current forecast is that sales will be normally distributed, with a mean of 10,000 and a standard deviation of 5,000.
   (a) How many DVDs should Blockbuster order? What is its expected profit? How many DVDs does it expect to sell at a discount?
   (b) What is the profit that the studio makes given Blockbuster's actions?
   (c) A plan under discussion is for the studio to refund Blockbuster $4 per DVD that does not sell during the one-month period. As before, Blockbuster will discount

them to $4.99 and sell any that remain. Under this plan, how many DVDs should Blockbuster order? What is the expected profit for Blockbuster? How many DVDs are expected to be unsold at the end of the month? What is the expected profit for the studio? What should the studio do?

3. Topgun Records and several movie studios have decided to sign a revenue-sharing contract for CDs. Each CD costs the studio $2 to produce. The CD will be sold to Topgun for $3. Topgun in turn prices a CD at $15 and forecasts demand to be normally distributed, with a mean of 5,000 and a standard deviation of 2,000. Any unsold CDs are discounted to $1, and all sell at this price. Topgun will share 35 percent of the revenue with the studio, keeping 65 percent for itself.
   (a) How many CDs should Topgun order?
   (b) How many CDs does Topgun expect to sell at a discount?
   (c) What is the profit that Topgun expects to make?
   (d) What is the profit that the studio expects to make?
   (e) Repeat parts (a)–(d) if the studio sells the CD for $2 (instead of $3) but gets 43 percent of revenue?
4. Benetton has entered into a quantity flexibility contract with a retailer for a seasonal product. If the retailer orders O units, Benetton is willing to provide up to another 35 percent if needed. Benetton's production cost is $20, and it charges the retailer a wholesale price of $36. The retailer prices to customers at $55 per unit. Any unsold units can be sold by the retailer at a salvage value of $25. Benetton can salvage only $10 per unit for its leftover inventory. The retailer forecasts demand to be normally distributed, with a mean of 4,000 and a standard deviation of 1,600.
   (a) How many units O should the retailer order?
   (b) What is the expected quantity purchased by the retailer (recall that the retailer can increase the order by up to 35 percent after observing demand)?
   (c) What is the expected quantity sold by the retailer?
   (d) What is the expected overstock at the retailer?
   (e) What is the expected profit for the retailer?
   (f) What is the expected profit for Benetton?
5. You are a purchasing manager for a large electric utility in charge of stocking a certain type of transformer. Weekly demand among your field crews for these transformers is normally distributed, with a mean of 100 and a standard deviation of 50. Holding costs are 25%, and you must hold a level of inventory corresponding to a cycle service level of 95%. You are faced with two suppliers, Reliable Components and Value Electric, who offer the following terms. Reliable sells the transformer for $5,000 with a minimum order of 100, and a lead time of 1 week with a standard deviation of 0.1 week. Value sells the transformer for $4,800, has a minimum batch of 1000, a lead time of 5 weeks, and a lead-time standard deviation of 4 weeks.
   (a) What is the annual cost of using Reliable Components as a supplier?
   (b) What is the annual cost of using Value Electric as a supplier?
   (c) What supplier would you choose?
   (d) If you could use both suppliers, how would you structure your orders?
6. In Exercise 14-5, imagine that you have chosen Reliable as your supplier. Value Electric very much wants your business and offers you the choice of three mutually exclusive alternatives: a reduced lead time of 1 week, a reduced minimum batch of 800, or a reduction in standard deviation of lead time by 1 week.
   (a) What are the expected annual costs of undertaking each of these options?
   (b) What is the expected annual cost if all three could be put into effect?
   (c) Would you change your decision to go with Reliable for any of these options?
7. Consider the retailer's position in the quantity flexibility contract problem discussed in the chapter with results in Table 14-6. Consider the base contract one in which $\alpha = \beta = 0.2$, the

order size is 1,000, and the wholesale price is $6. For the following questions, you will need to build a quantity flexibility model. Assume that salvage value is zero for both the retailer and the manufacturer.

(a) How much will profit increase for the retailer if α increases to 0.5?
(b) How much will profit increase for the retailer if β increases to 0.5 (keeping α at 0.2)?
(c) Why would you expect these to be different?

8. Imagine that you have acquired both the retailer and manufacturer discussed in Exercise 14-7. Your interests now are in maximizing profitability for your new firm and in setting up an incentive system to make this happen. You have chosen to keep the quantity flexibility contract in place to provide incentive to both your retailer and your manufacturer.
   (a) How does increasing α to 0.5 affect your firm's profitability?
   (b) How does increasing β to 0.5 affect your firm's profitability?
   (c) Why does one of these changes have no effect on profitability?

Bibliography

Armstrong & Associates, Inc. *Who's Who in Logistics? Armstrong's Guide to 3PLs & Global Logistics Services,* 2001.

Banfield, Emiko. *Harnessing Value in the Supply Chain: Strategic Sourcing in Action.* New York: Wiley, 1999.

Cavinato, Joseph L., and Ralph Kauffman. *The Purchasing Handbook: A Guide for the Purchasing and Supply Professional.* New York: McGraw-Hill, 2000.

Chopra, Sunil, Darren Dougan, and Gareth Taylor. "B2B E-Commerce Opportunities." *Supply Chain Management Review* (May–June 2001): 50–8.

Grosvenor, Franklin, and Terrence A. Austin. "Cisco's eHub Initiative." *Supply Chain Management Review* (July–August 2001): 18–26.

Heskett, James L., and Sergio Signorelli. *Benetton (A).* Harvard Business School Case 685014, 1984.

Krishna, Vijay. *Auction Theory.* San Diego: Academic Press, 2002.

Laseter, Timothy M. *Balanced Sourcing: Cooperation and Competition in Supplier Relationships.* San Francisco: Jossey-Bass, 1998.

Martin, Lisa. "Charting Pfizer's Path to E-Procurement." *Supply Chain Management Review* (May–June 2002): 20–6.

Milgrom, Paul. *Putting Auction Theory to Work.* Cambridge: Cambridge University Press, 2004.

Monczka, Robert H., Gary L. Ragatz, Robert B. Handfield, Robert J. Trent, and David J. Frayer. "Executive Summary: Supplier Integration into New Product Development: A Strategy for Competitive Advantage." The Global Procurement and Supply Chain Benchmarking Initiative, Michigan State University, The Eli Broad Graduate School of Management, 1997.

Monczka, Robert, Robert Trent, and Robert Handfield. *Purchasing and Supply Chain Management.* Cincinnati, OH: South-Western, 2002.

Neef, Dale. *E-Procurement: From Strategy to Implementation.* Upper Saddle River, NJ: Prentice Hall, 2001.

Pierson, John C. "Johnson Controls' Journey to E-Procurement." *Supply Chain Management Review* (January–February 2002): 56–62.

Pine, Joseph B. *Mass Customization: The New Frontier in Business Competition.* Boston: Harvard Business School Press, 1999.

Porter, Robert H. "Detecting Collusion." Working Paper #0051, The Center for the Study of Industrial Organization, Northwestern University, 2004.

Smeltzer, Larry R., and Joseph R. Carter. "How to Build an E-Procurement Strategy." *Supply Chain Management Review* (March–April 2001): 76–83.

Thompson, Leigh L. *The Mind and Heart of the Negotiator.* Upper Saddle River, NJ: Prentice Hall, 2005.

Toupin, Laurie. "Needed: Suppliers Who Can Collaborate Throughout the Supply Chain." Special Advertising Section: Automotive. *Supply Chain Management Review* (July–August 2002): 5–8.

CHAPTER 15
PRICING AND REVENUE MANAGEMENT IN A SUPPLY CHAIN

Learning Objectives

After reading this chapter, you will be able to:

1. Understand the role of revenue management in a supply chain.
2. Identify conditions under which revenue management tactics can be effective.
3. Describe trade-offs that must be considered when making revenue management decisions.

15.1 THE ROLE OF PRICING AND REVENUE MANAGEMENT IN A SUPPLY CHAIN

So far in this book we have focused on managing demand and supply to increase supply chain profits. Altering inventories and capacity can change available supply. Advertising and marketing can be used to spur demand. Beyond these levers, pricing is an important lever to increase supply chain profits by better matching supply and demand. Pricing influences the amount of product demanded and the total revenue generated. *Revenue management* is the use of pricing to increase the profit generated from a limited supply of supply chain assets. Supply chain assets exist in two forms—capacity and inventory. Capacity assets in the supply chain exist for production, transportation, and storage. Inventory assets exist throughout the supply chain and are carried to improve product availability.

To increase the total margin earned from these assets, managers must use all available levers, including price. This is the primary role of revenue management. Traditionally, firms have often invested in or eliminated assets to reduce the imbalance between supply and demand. Firms build additional capacity during the growth part of a business cycle and shut down some capacity during a downturn. Ideas from revenue management suggest that a firm should first use pricing to achieve some balance between supply and demand and only then invest in or eliminate assets. An excellent discussion of revenue management techniques in theory and practice can be found in Talluri and Van Ryzin (2004).

Consider a trucking company that owns 10 trucks. One approach that the firm can take is to set a fixed price for its services and use advertising to spur demand in case surplus capacity is available. Using revenue management, however, the firm would seek to do much more. One approach is to charge a lower price to customers willing to commit their orders far in advance and a higher price to customers looking for transportation capacity at the last minute. Another approach is to charge a lower price to customers with long-term contracts and a higher price to customers looking to purchase capacity at the last minute. A third approach is to charge a higher price during periods of high demand and lower prices during periods of low demand. Another

example is a retailer that purchases seasonal apparel for sale. A strategy that adjusts prices based on product availability, customer demand, and remaining duration of the sales season will result in higher supply chain profits than a strategy that fixes price for the duration of the sales season.

All of these are revenue management strategies that use differential pricing as a critical lever to maximize earnings. Revenue management may also be defined as the use of differential pricing based on customer segment, time of use, and product or capacity availability to increase supply chain surplus. The impact of revenue management on supply chain performance can be significant. One of the most often cited examples is the successful use of revenue management by American Airlines to counter and finally defeat PeopleExpress in the mid-1980s. PeopleExpress started in Newark, New Jersey, and offered fares that were 50 to 80 percent lower than other carriers. At first the other airlines ignored PeopleExpress because they were not interested in the low-fare market segment. By 1983, however, PeopleExpress was flying 40 aircraft and achieving load factors of more than 74 percent. PeopleExpress and other new entrants were making significant inroads into the turf of existing airlines. The existing airlines could not compete by cutting prices to the level of PeopleExpress because they had higher operating costs. American Airlines was the first to come up with an effective countermeasure using revenue management. Rather than lower the price of all its seats, American lowered prices of a portion of the seats to prices at or below PeopleExpress. Soon other airlines, such as United, followed suit, attracting many of PeopleExpress's passengers. This was sufficient to drive down load factors for PeopleExpress to below 50 percent, a level at which the airline could not survive. Before the end of 1986, PeopleExpress collapsed.

American Airlines succeeded primarily because it used differential pricing to lower prices for a fraction of the seats and attract passengers who would otherwise have flown PeopleExpress. American did not lower prices for the fraction of seats used by business travelers who were not flying with PeopleExpress. Targeted differential pricing is at the heart of successful revenue management.

Revenue management adjusts the pricing and available supply of assets to maximize profits. Revenue management has a significant impact on supply chain profitability when one or more of the following four conditions exist:

1. The value of the product varies in different market segments.
2. The product is highly perishable or product wastage occurs.
3. Demand has seasonal and other peaks.
4. The product is sold both in bulk and on the spot market.

Airline seats are a good example of a product whose value varies by market segment. A business traveler is willing to pay a higher fare for a flight that matches his or her schedule. In contrast, a leisure traveler will often alter his or her schedule to get a lower fare. An airline that can extract a higher price from the business traveler compared to the leisure traveler will always do better than an airline that charges the same price to all travelers.

Fashion and seasonal apparel are examples of highly perishable products. Production, storage, and transportation capacity are examples of inventory or capacity that is wasted if not utilized. The goal of revenue management in such a setting is to adjust the price over time to maximize the profit obtained from the available inventory or capacity.

Orders at Amazon.com follow a seasonal pattern, with a peak in December prior to Christmas. Serving this peak would require Amazon.com to deploy a significant amount of temporary processing capacity at high cost. Amazon.com uses revenue management ideas to offer free shipping prior to the December peak. This shifts some of the demand

from the peak to the off-peak period and increases total profit for Amazon.com. Some commuter railroads use a similar strategy to deal with the distinct peaks in passenger travel. They charge higher fares during peak periods and lower fares for off-peak travel. Differential pricing for peak and off-peak periods results in significantly higher profits.

Every product and every unit of capacity can be sold both in bulk and in the spot market. An example is the owner of a warehouse who must decide whether to lease the entire warehouse to customers willing to sign long-term contracts or to save a portion of the warehouse for use in the spot market. The long-term contract is more secure but typically fetches a lower average price than the spot market. Revenue management increases profits by finding the right portfolio of long-term and spot-market customers.

Revenue management can be a powerful tool for every owner of assets in a supply chain. Owners of any form of capacity (production, transportation, or storage) can use revenue management if there is seasonal demand or if there are segments that are willing to pay different prices for different lead times to use the capacity. Revenue management can be effective if there is a segment that wants to use capacity at the last minute and is willing to pay for it, and there is another segment that wants a lower price and is willing to commit far in advance. Revenue management is essential for owners of any perishable inventory. Most successful examples of the use of revenue management are from the travel and hospitality industry and include airlines, car rentals, and hotels. American Airlines has stated that revenue management techniques increase their revenues by over $1 billion each year. Revenue management techniques at Marriott raise annual revenues by over $100 million. Revenue management can have a similar impact on all stages of a supply chain that satisfy one or more of the four conditions identified earlier.

In the following sections we discuss various situations in which revenue management is effective and the techniques used in each case.

15.2 PRICING AND REVENUE MANAGEMENT FOR MULTIPLE CUSTOMER SEGMENTS

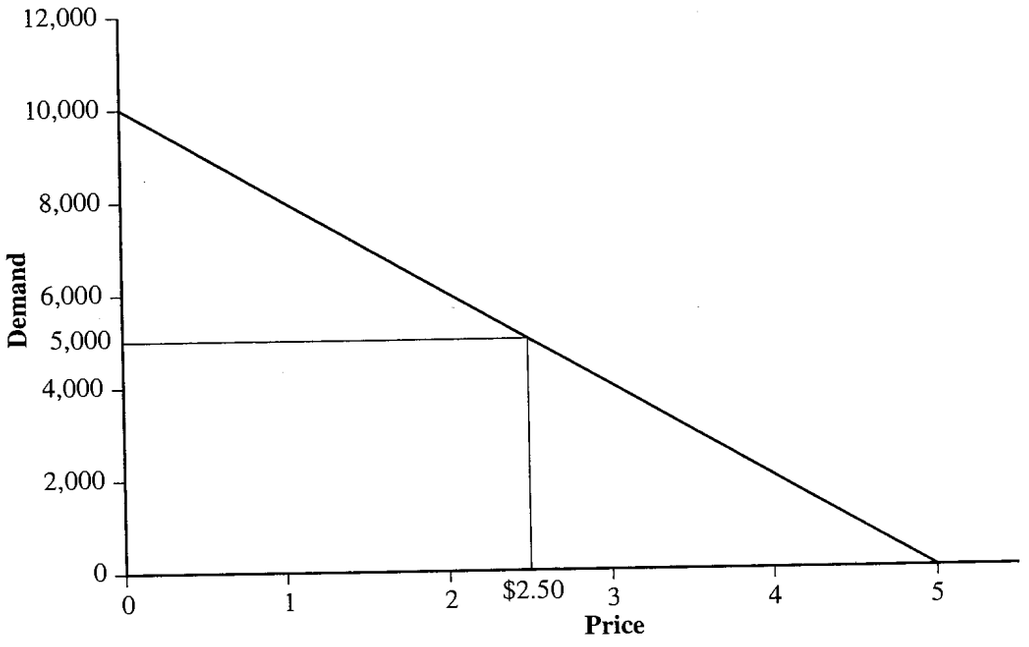
A classic example of a market with multiple customer segments is the airline industry, where business travelers are willing to pay a higher fare to travel a specific schedule, whereas leisure travelers are willing to shift their schedule to take advantage of lower fares. Many similar instances arise in a supply chain. Consider ToFrom, a trucking firm that has purchased six trucks, with a total capacity of 6,000 cubic feet, to use for transport between Chicago and St. Louis. The monthly lease charge, driver, and maintenance expense is $1,500 per truck. Market research has indicated that the demand curve for trucking capacity is

$$d = 10{,}000 - 2{,}000p$$

where d is the demand from each segment and p is the transport cost per cubic foot. A price of $2 per cubic foot results in a demand of 6,000 cubic feet, revenue of $12,000, and a profit of $3,000, whereas a price of $3.50 per cubic foot results in a demand of 3,000, revenue of $10,500, and a profit of $1,500. The real question is whether the 3,000 cubic feet of demand at a price of $3.50 is from a different segment than the 3,000 additional cubic feet of demand generated at a price of $2 per cubic foot. If ToFrom assumes that all demand comes from a single segment, the optimal price is $2.50 per cubic foot, resulting in a demand of 5,000 cubic feet and revenue of $12,500, as shown in Figure 15-1.

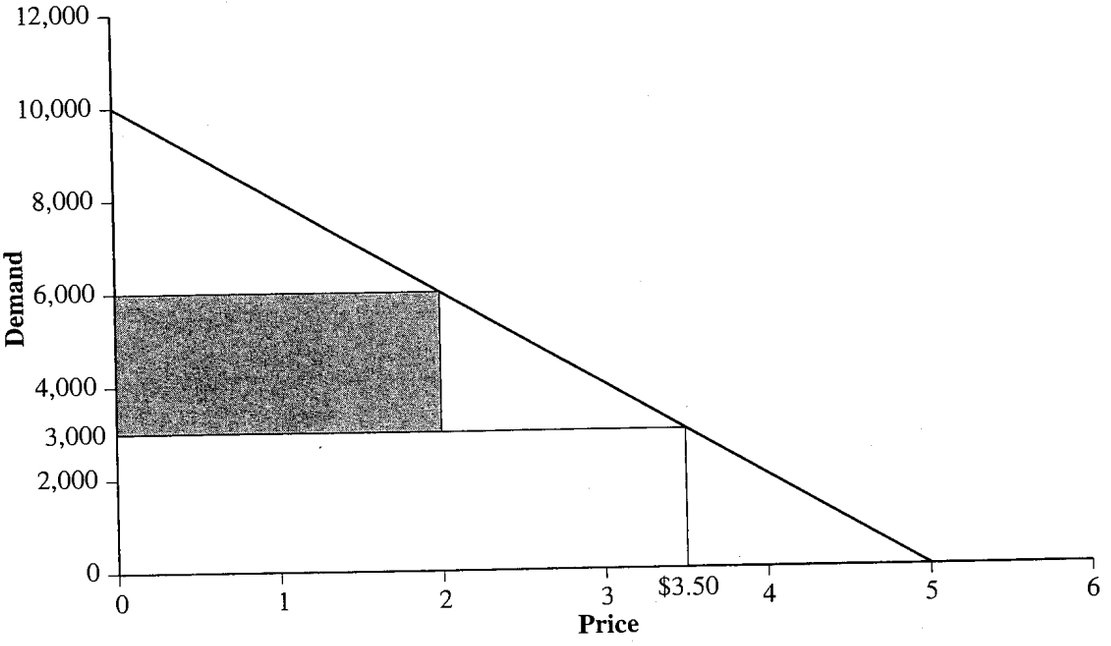
However, if ToFrom can differentiate the segment that buys 3,000 cubic feet at $3.50 from the segment that buys 3,000 cubic feet only at $2.00, the firm can use revenue

FIGURE 15-1 Revenue Generated by ToFrom Pricing for One Segment



management to improve revenues and profits. ToFrom should charge $3.50 for the segment willing to pay that price and $2.00 for the 3,000 cubic feet that sells only at that price. The firm thus extracts revenue of $10,500 from the segment willing to pay $3.50 and revenue of $6,000 from the segment willing to pay only $2.00 per cubic foot, as shown in Figure 15-2. In the presence of different segments that have different values

FIGURE 15-2 Revenue Generated by ToFrom Pricing for Two Segments



for trucking capacity, revenue management increases the revenue from $12,500 to $16,500 and results in a significant improvement in profits.

In theory, the concept of differential pricing increases total profits for a firm. There are two fundamental issues, however, that must be handled in practice. First, how can the firm differentiate between the two segments and structure its pricing to make one segment pay more than the other? Second, how can the firm control demand such that the lower-paying segment does not utilize the entire availability of the asset?

To differentiate between the various segments, the firm must create barriers by identifying product or service attributes that the segments value differently. For example, business travelers on an airline want to book at the last minute and stay only as long as they must. Leisure travelers, on the other hand, are willing to book far in advance and adjust the duration of their stay. Plans for business travelers are also subject to change. Thus, advance booking, a required Saturday-night stay, and a penalty for changes on the lower fare separate the leisure traveler from the business traveler. For a transportation provider such as ToFrom, the segments can be differentiated based on how far in advance a customer is willing to commit and pay for the transportation capacity. Similar separation can also occur for production- and storage-related assets in a supply chain.

In the presence of multiple segments that can be separated, the firm must solve the following two problems:

1. What price to charge each segment
2. How to allocate limited capacity among the segments

PRICING TO MULTIPLE SEGMENTS

Let us start by considering the simple scenario in which the firm has identified criteria on which it can separate the various customer segments. One such criterion may be an airline requiring a Saturday-night stayover. Another might be a trucking company separating customers based on the advance notice with which they are willing to commit to a shipment. The firm now wishes to identify the appropriate price for each segment. Consider a supplier (of product or some other supply chain function) that has identified k distinct customer segments that can be separated. Assume that the demand curve for segment i is given by (we assume linear demand curves to simplify the analysis)

$$d_i = A_i - B_i p_i$$

The supplier has a cost c of production per unit and must decide on the price p_i to charge each segment; d_i is the resulting demand from segment i. The goal of the supplier is to price so as to maximize its profits. The pricing problem can be formulated as follows:

$$\text{Max} \sum_{i=1}^{k} (p_i - c)(A_i - B_i p_i)$$

Without a capacity constraint, the problem separates by segment, and for segment i, the supplier attempts to maximize

$$(p_i - c)(A_i - B_i p_i)$$

The optimal price for each segment i is given by

$$p_i = \frac{A_i}{2B_i} + \frac{c}{2} \qquad \textbf{(15.1)}$$

If the available capacity is constrained by Q, the optimal prices are obtained by solving

$$\text{Max} \sum_{i=1}^{k} (p_i - c)(A_i - B_i p_i) \tag{15.2}$$

subject to

$$\sum_{i=1}^{k} (A_i - B_i p_i) \leq Q$$

$$A_i - B_i p_i \geq 0 \quad \text{for} \quad i = 1, \ldots, k$$

Both formulations are simple enough to be solved in Excel.

Example 15-1: **Pricing to multiple segments**

A contract manufacturer has identified two customer segments for its production capacity—one willing to place an order more than one week in advance and the other willing to pay a higher price as long as it can provide less than one week's notice for production. The customers that are unwilling to commit in advance are less price sensitive and have a demand curve $d_1 = 5{,}000 - 20p_1$. Customers willing to commit in advance are more price sensitive and have a demand curve of $d_2 = 5{,}000 - 40p_1$. Production cost is $c = \$10$ per unit. What price should the contract manufacturer charge each segment if its goal is to maximize profits? If the contract manufacturer were to charge a single price over both segments, what should it be? How much increase in profits does differential pricing provide? If total production capacity is limited to 4,000 units, what should the contract manufacturer charge each segment?

Analysis: Without capacity constraints, the differential prices to be charged each segment are given by Equation 15.1. We thus obtain

$$p_1 = \frac{5{,}000}{2 \times 20} + \frac{10}{2} = 125 + 5 = \$130 \quad \text{and} \quad p_2 = \frac{5{,}000}{2 \times 40} + \frac{10}{2} = 62.5 + 5 = \$67.5$$

The demand from the two segments is given by

$$d_1 = 5{,}000 - 20 \times 130 = 2{,}400 \quad \text{and} \quad d_2 = 5{,}000 - 40 \times 67.5 = 2{,}300$$

The total profit is

$$\text{Total profit} = 130 \times 2{,}400 + 67.5 \times 2{,}300 = \$467{,}250$$

If the contract manufacturer charges the same price p to both segments, he is attempting to maximize

$$(p - 10)(5{,}000 - 20p) + (p - 10)(5{,}000 - 40p) = (p - 10)(10{,}000 - 60p)$$

The optimal price in this case is given by

$$p = \frac{10{,}000}{2 \times 60} + \frac{10}{2} = \$88.33$$

The demand from the two segments is given by

$$d_1 = 5{,}000 - 20 \times 83.33 = 3{,}333.4 \quad \text{and} \quad d_2 = 5{,}000 - 40 \times 83.33 = 1{,}666.8$$

The total profit is

$$\text{Total profit} = 83.33 \times (3{,}333.4 + 1{,}666.8) = \$416{,}667$$

Differential pricing thus raises the profits by more than $50,000 relative to offering a fixed price.

Now let us consider the case in which total production capacity is limited to 4,000 units. The optimal differential price results in demand that exceeds total production capacity. Thus we resort to the formulation in Equation 15.2 and solve

$$\text{Max}(p_1 - 10)(5{,}000 - 20p_1) + (p_2 - 10)(5{,}000 - 40p_2)$$

FIGURE 15-3 Solver Spreadsheet for Example 15-1

	A	B	C	D
3	Production Capacity =	4000		
4	**Segment**	**Price**	**Demand**	**Profit**
5	1	$ 141.7	2166.67	$ 285,277.8
6	2	$ 79.2	1833.33	$ 126,805.6
7	Total		4000	$ 412,083.3

Cell	Cell Formula	Copied to
C5	= 5000 – 20*B5	
C6	= 5000 – 40*B6	
D5	= B5*C5	D6
C8	= sum(C5:C6)	
D8	= sum(D5:D6)	

Subject to

$$(5{,}000 - 20p_1) + (5{,}000 - 40p_2) \leq 4{,}000$$
$$(5{,}000 - 20p_1), (5{,}000 - 40p_2) \geq 0$$

The results are shown in Figure 15-3. Observe that the limited capacity leads the contract manufacturer to charge a higher price to each of the two segments relative to the case when there was no capacity limit.

The methodology we have described has two important assumptions that are unlikely to hold in practice. The first assumption is that nobody from the higher-price segment decides to shift to the lower-price segment after prices are announced. In other words, we have assumed that the attribute such as lead time used to separate the segments works perfectly. In practice this is unlikely to be the case. Our second assumption is that once prices are decided, customer demand is predictable. In practice there will always be uncertainty associated with demand. Talluri and Van Ryzin (2004) have an excellent discussion of several models for revenue management that account for uncertainty and a few models that account for customers being strategic and deciding on their actions after prices are announced.

ALLOCATING CAPACITY TO A SEGMENT UNDER UNCERTAINTY

In most instances of differential pricing, demand from the segment paying the lower price arises earlier in time than demand from the segment paying the higher price. A supplier may charge a lower price to a buyer willing to commit far in advance and a higher price to buyers wanting to place their orders at the last minute. To take advantage of revenue management, the supplier must limit the amount of capacity committed to lower-price buyers even if sufficient demand exists from the lower-price segment to use the entire available capacity. This raises the question of how much capacity to save for the higher-price segment. The answer would be simple if demand were predictable. In practice, demand is uncertain and firms must make this decision taking uncertainty into account.

The basic trade-off to be considered by the supplier with production capacity is between committing to an order from a lower-price buyer or waiting for a high-price

buyer to arrive later on. The two risks in such a situation are *spoilage* and *spill*. Spoilage occurs when the capacity reserved for higher-price buyers is wasted because demand from the higher-price segment does not materialize. Spill occurs if higher-price buyers have to be turned away because the capacity has already been committed to lower-price buyers. The supplier should decide on the capacity to commit for the higher-price buyers so as to minimize the expected cost of spoilage and spill. A current order from a lower price buyer should be compared with the expected revenue from waiting for a higher-price buyer. The order from the lower-price buyer should be accepted if the expected revenue from the higher-price buyer is lower than the current revenue from the lower-price buyer.

We now develop the aforementioned trade-off in terms of a formula that can be used when the supplier is working with two customer segments. Let p_L be the price charged to the lower-price segment and p_H be the price charged to the higher-price segment. Assume that the anticipated demand for the higher-price segment is normally distributed, with a mean of D_H and a standard deviation of σ_H. If we reserve a capacity C_H for the higher-price segment, the expected marginal revenue $R_H(C_H)$ from reserving more capacity is given by

$$R_H(C_H) = \text{Prob(demand from higher-price segment} > C_H) \times p_H$$

The reserved quantity for the higher-price segment should be chosen so that the expected marginal revenue from the higher-price segment equals the current marginal revenue from the lower-price segment; that is, $R_H(C_H) = p_L$. In other words, the quantity C_H reserved for the higher-price segment should be such that

$$\text{Prob(demand from higher-price segment} > C_H) = p_L/p_H \quad \textbf{(15.3)}$$

If demand for the higher-price segment is normally distributed, with a mean of D_H and a standard deviation of σ_H, we can obtain the quantity reserved for the higher price segment as

$$C_H = F^{-1}(1 - p_L/p_H, D_H, \sigma_H) = NORMINV(1 - p_L/p_H, D_H, \sigma_H) \quad \textbf{(15.4)}$$

If there are more than two customer segments, the same philosophy can be used to obtain a set of nested reservations. The quantity C_1 reserved for the highest-price segment should be such that the expected marginal revenue from the highest-priced segment equals the price of the next-highest-priced segment. The quantity C_2 reserved for the two highest-priced segments should be such that the expected marginal revenue from the two highest-priced segments equals the price of the third-highest-priced segment. This sequential approach can be used to obtain a set of nested reservations of capacity for all but the lowest-priced segment.

An important point to observe is that the use of differential pricing increases the level of asset availability for the high-priced segment. Capacity is being saved for these customers because of their willingness to pay more for the asset. Thus, effective use of revenue management increases firm profits and also improves service for the more valuable customer segment.

Example 15-2: **Allocating capacity to multiple segments**

ToFrom Trucking serves two segments of customers. One segment (A) is willing to pay $3.50 per cubic foot but wants to commit to a shipment with only 24 hours notice. The other segment (B) is willing to pay only $2.00 per cubic foot and is willing to commit to a shipment with up to one week notice. With two weeks to go, demand for segment A is forecast to be normally distributed, with a mean 3,000 cubic feet and a standard deviation of 1,000. How much of the available capacity should be reserved for segment A? How should ToFrom change its decision if segment A is willing to pay $5 per cubic foot?

Analysis: In this case we have

Revenue from segment A, p_A = \$3.50 per cubic foot
Revenue from segment B, p_B = \$2.00 per cubic foot
Mean demand for segment A, D_A = 3,000 cubic feet
Standard deviation of demand for segment A, σ_A = 1,000 cubic feet

Using Equation 15.4, the capacity to be reserved for segment A is given by

$$C_A = NORMINV(1 - p_B/p_A, D_A, \sigma_A) = NORMINV(1 - 2.00/3.50, 3{,}000, 1{,}000)$$
$$= 2{,}820 \text{ cubic feet}$$

Thus, ToFrom should reserve 2,820 cubic feet of production capacity for segment A when customers from this segment are willing to pay \$3.50 per cubic foot. If the amount customers are willing to pay increases from \$3.50 to \$5.00, the reserved capacity should be increased to

$$C_A = NORMINV(1 - p_B/p_A, D_A, \sigma_A) = NORMINV(1 - 2.00/5.00, 3{,}000, 1{,}000)$$
$$= 3{,}253 \text{ cubic feet}$$

Ideally, the demand forecast for all customer segments should be revised and a new reservation quantity calculated each time a customer order is processed. In practice, such a procedure would be very difficult to implement. It is more practical to revise the forecast and the reservation quantity after a period of time over which either the forecast demand or the forecast accuracy has changed by a significant amount.

Another approach to differential pricing is to create different versions of a product targeted at different segments. Publishers introduce new books from best-selling authors as hardcover editions and charge a higher price. The same books are introduced later as paperback editions at a lower price. The two versions are used to charge a higher price to the segment that wants to read the book as soon as it is introduced. Different versions can also be created by bundling different options and services with the same basic product. Automobile manufacturers create a high-end, a mid-level, and a low-end version of the most popular models based on the options provided. This policy allows them to charge differential prices to different segments for the same core product. Many contact lens manufacturers sell the same lens with a one-week, one-month, and six-month warranty. In this instance, the same product with different services in the form of warranty is used to charge differential prices.

To use revenue management successfully when serving multiple customer segments, a firm must use the following tactics effectively:

- Price based on the value assigned by each segment
- Use different prices for each segment
- Forecast at the segment level

Freight railroads and trucking firms have not used revenue management with multiple segments effectively. Airlines, in contrast, have been much more effective in using this approach. A major hindrance for railroads is the lack of scheduled trains. Without scheduled trains it is hard to separate the higher-price and lower-price segments. To take advantage of revenue management opportunities, owners of transportation assets in the supply chain have to offer some scheduled services as a mechanism for separating the higher- and lower-price segments. Without scheduled services it is difficult to separate customers that are willing to commit early from those that want to use the service at the last minute.

KEY POINT If a supplier serves multiple customer segments with a fixed asset, it can improve revenues by setting different prices for each segment. Prices must be set with barriers such that the segment willing to pay more is not able to pay the lower price. The amount of the asset reserved for the higher-price segment is such that the expected marginal revenue from the higher-price segment equals the price to the lower-price segment.

15.3 PRICING AND REVENUE MANAGEMENT FOR PERISHABLE ASSETS

Any asset that loses value over time is perishable. Clearly, fruits, vegetables, and pharmaceuticals are perishable. This list also includes products such as computers and cell phones that lose value as new models are introduced. High-fashion apparel is perishable because it cannot be sold at full price once the season is past. Perishable assets also include all forms of production, transportation, and storage capacity that is wasted if not fully utilized. Unused capacity from the past has no value. Thus all unutilized capacity is equivalent to perished capacity.

Dell uses revenue management when selling PCs. The year is divided into short sales cycles of about two weeks. Once the sales organization makes a forecast for the next sales cycle, operations ensures the availability of components and production capacity. At this point the investment in inventory and capacity assets for the next sales cycle is fixed. Sales then attempts to maximize the revenue that can be obtained from the available assets by adjusting price and availability.

A well-known example of revenue management in retailing of apparel was the original Filene's Basement in Boston. Merchandise was first sold at the main store at full price. Leftover merchandise was moved to the basement and its price reduced incrementally over a 35-day period until it sold. Any unsold merchandise was then given away to charity. Today, most department stores progressively discount merchandise over the sales season and then sell any remaining inventory to an outlet store, which follows a similar pricing strategy.

Another example of revenue management for a perishable asset is the use of overbooking by the airline industry. An airplane seat loses all value once the plane takes off. Given that people often do not show up for a plane even when they have a reservation, airlines sell more reservations than the capacity of the plane, to maximize expected revenue.

The two revenue management tactics used for perishable assets are

1. Vary price dynamically over time to maximize expected revenue
2. Overbook sales of the asset to account for cancellations

DYNAMIC PRICING

Dynamic pricing, the tactic of varying price over time, is suitable for assets such as fashion apparel that have a clear date beyond which they lose a lot of their value. Apparel designed for the winter does not have much value by April. A retailer that has purchased 100 ski jackets in October has many options with regard to its pricing strategy. It can charge a high price initially. This strategy will result in fewer sales early in the

season (though at a higher price), leaving more jackets to be sold later during the season, when they have lower value to customers. Another option is to charge a lower price initially, selling more jackets early in the season (though at a lower price) and leaving fewer jackets to be sold at a discount. This trade-off determines the profits for the retailer. To vary price effectively over time for a perishable asset, the asset owner must be able to estimate the value of the asset over time and forecast the impact of price on customer demand effectively. Effective differential pricing over time generally increases the level of product availability for the consumer willing to pay full price and also increases total profits for the retailer.

We now discuss a simple methodology for dynamic pricing in the context where the seller has a specified quantity Q of a single product at the start of the season. We assume that the seller is able to divide the selling season into k periods and can forecast the demand curve for each period. The underlying assumption here is that customers' response to pricing can be predicted over time and customers will not change their behavior in response to anticipated price changes. For simplicity, we assume that, given a price p_i in period i, the demand d_i in period i is given by

$$d_i = A_i - B_i p_i$$

This is a linear demand curve, but in general the demand curve need not be linear. We present the linear case here because it is easier to understand and solve. The retailer wants to vary the price over time to maximize the revenue it can extract from the Q units it has on hand at the beginning of the season. The dynamic pricing problem faced by the retailer can then be formulated as follows:

$$\text{Max} \sum_{i=1}^{k} p_i(A_i - B_i p_i) \tag{15.5}$$

subject to

$$\sum_{i=1}^{k} (A_i - B_i p_i) \leq Q$$
$$A_i - B_i p_i \geq 0 \quad \text{for} \quad i = 1, \ldots, k$$

As formulated, the problem is simple enough that it can be solved directly using Excel.

Example 15-3: **Dynamic Pricing**
A retailer has purchased 400 ski parkas before the start of the winter season at a cost of $100 each. The season lasts three months and the retailer has forecast demand in each of the three months to be $d_1 = 300 - p_1$, $d_2 = 300 - 1.3p_2$, and $d_3 = 300 - 1.8p_3$. How should the retailer vary the price of the parka over the three months to maximize revenue? If the retailer charges a constant price over the three months, what should it be? How much gain in revenue results from dynamic pricing?

Analysis: Observe that customers who buy at the beginning of the season are forecast to be less price sensitive and customers who buy toward the end of the season are more price sensitive. Using Equation 15.5, the retailer's problem can be formulated as follows:

$$\text{Max}\, p_1(300 - p_1) + p_2(300 - 1.3p_2) + p_3(300 - 1.8p_3)$$

subject to

$$(300 - p_1) + (300 - 1.3p_2) + (300 - 1.8p_3) \leq 400$$
$$300 - p_1, 300 - 1.3p_2, 300 - 1.8p_3 \geq 0$$

This problem can be formulated using Solver in Excel as shown in Figure 15-4. The cells B5:B7 contain the price variables, cells C5:C7 contain the resulting demand from the respective demand curves, and cells D5:D7 contain the revenue in each period. The total

FIGURE 15-4 Solver Spreadsheet for Example 15-3 for Dynamic Pricing

	A	B	C	D
3	Quantity at beginning of season =	400		
4	**Period**	**Price**	**Demand**	**Revenue**
5	1	$ 162.20	137.80	$ 22,351.28
6	2	$ 127.58	134.15	$ 17,114.36
7	3	$ 95.53	128.05	$ 12,232.30
8	Total		400	$ 51,697.94

Cell	Cell Formula	Copied to
C5	= 300 – B5	
C6	= 300 – 1.3*B6	
C7	= 300 – 1.8*B7	
D5	= B5*C5	D6:D7
C8	= sum(C5:C7)	
D8	= sum(D5:D7)	

demand across the three periods is in cell C8 and the total revenue is in cell D8. The quantity at the beginning of the season is in cell B3.

As shown in Figure 15-4, the optimal strategy for the retailer is to price at $162.20 in the first month, $127.58 in the second month, and $95.53 in the third month. This gives total revenue of $51,697.94 for the retailer.

The problem of obtaining the optimal fixed price over the three-month season can be formulated in Excel as shown in Figure 15-5. All cells except B6 and B7 are as in Figure 15-4.

If the retailer wants to have a fixed price over the three months it should price the jackets at $121.95 for resulting revenue of $48,780.49. We can see that dynamic pricing allows the retailer to increase profits by almost $3,000, from $8,780 to $11,698.

Once we have understood how to price the product dynamically over the season, we can go back and ask how many units the retailer should purchase at the beginning of the season to maximize profits, as described in Example 15-4.

Example 15-4: **Evaluating quantity with dynamic pricing**

Return to the retailer in Example 15-3. How many parkas should the retailer purchase at the beginning of the season, and how should they be priced over the three months of the season to maximize profits?

Analysis: In this case, the quantity at the beginning of the season is also a decision variable. The retailer's problem can now be formulated as follows:

$$\text{Max}\, p_1(300 - p_1) + p_2(300 - 1.3p_2) + p_3(300 - 1.8p_3) - 100Q$$

FIGURE 15-5 Solver Spreadsheet for Example 15-3 for Fixed Price Over Season

	A	B	C	D
3	Quantity at beginning of season =	400		
4	**Period**	**Price**	**Demand**	**Revenue**
5	1	$ 121.95	178.05	$ 21,713.27
6	2	$ 121.95	141.46	$ 17,251.64
7	3	$ 121.95	80.49	$ 9,815.59
8	Total		400	$ 48,780.49

Cell	Cell Formula	Copied to
B6	= B5	B7

FIGURE 15-6 Solver Spreadsheet for Example 15-4 for Optimal Quantity and Dynamic Prices

	A	B	C	D
2	Cost per unit =	$ 100.00		
3	Quantity at beginning of season =	245		
4	**Period**	**Price**	**Demand**	**Revenue**
5	1	$ 200.00	100.00	$ 20,000.00
6	2	$ 165.38	85.00	$ 14,057.70
7	3	$ 133.33	60.00	$ 8,000.01
8	Total		245.0002	$ 42,057.71
9			Profit =	$ 17,557.69

Cell	Cell Formula	Copied to
D9	= D8-B2*B3	

subject to

$$(300 - p_1) + (300 - 1.3p_2) + (300 - 1.8p_3) \leq Q$$
$$300 - p_1, 300 - 1.3p_2, 300 - 1.8p_3, Q \geq 0$$

The problem can be formulated in Excel as shown in Figure 15-6 to obtain the optimal initial quantity and dynamic prices over the season. All cells except cell B2 and D9 are as in Figure 15-4.

It is optimal for the retailer to order 245 jackets at the beginning of the season. They are then priced at $200 for the first month, $165.38 for the second month, and $133.33 for the third month. The total profit for the retailer with the optimal order quantity and dynamic pricing is $17,557.69.

In reality, the dynamic pricing problem is more complicated because demand is unpredictable and customers behave strategically in that they may decide to delay their purchase if they know that prices will drop over time. An excellent discussion of models that can be used in this more complex setting can be found in Talluri and Van Ryzin (2004).

KEY POINT Dynamic pricing can be a powerful tool to increase profits if the customers' sensitivity to price changes in the course of the season. This is often the case for fashion products, for which customers are less price sensitive early in the season but become more price sensitive toward the end of the season.

OVERBOOKING

The tactic of overbooking or overselling of the available asset is suitable in any situation in which customers are able to cancel orders and the value of the asset drops significantly after a deadline. Examples include airline seats, items designed specially for Christmas, and production capacity. In each case there is a limited amount of the asset available, customers are allowed to cancel orders, and the asset loses value beyond a certain date. If the cancellation or the return rate can be predicted accurately, the overbooking level is easy to determine. In practice, however, the cancellation or return rate is uncertain.

The basic trade-off to consider during overbooking is between having wasted capacity (or inventory) because of excessive cancellations or having a shortage of capacity (or inventory) because of few cancellations, in which case an expensive

backup needs to be arranged. The cost of wasted capacity is the margin that would have been generated if the capacity had been used for production. The cost of a capacity shortage is the loss per unit that results from having to go to a backup source. The goal when making the overbooking decision is to maximize supply chain profits by minimizing the cost of wasted capacity and the cost of capacity shortage.

We now develop this trade-off in terms of a formula that can be used to set overbooking levels for an asset. Let p be the price at which each unit of the asset is sold and let c be the cost of using or producing each unit of the asset. In case of asset shortage, let b be the cost per unit at which a backup can be used. Thus, the marginal cost of having wasted capacity is $C_w = p - c$, and the marginal cost of having a capacity shortage is $C_s = b - p$. If the cost of backup capacity is less than the sale price, there is no reason to limit the overbooking. The interesting case arises when the cost of backup capacity exceeds the sale price. The trade-off to obtain the optimal overbooking level is very similar to the trade-off in Chapter 12 to obtain the optimal cycle service level for seasonal items given by Equation 12.1. Let O^* be the optimal overbooking level and let s^* be the probability that cancellations will be less than or equal to O^*. Similar to the derivation of Equation 12.1, the optimal overbooking level is obtained as

$$s^* = \text{Prob}(\text{cancellations} \leq O^*) = \frac{C_w}{C_w + C_s} \quad \textbf{(15.6)}$$

If the distribution of cancellations is known in absolute terms to be normally distributed, with a mean of μ_c and a standard deviation of σ_c, the optimal overbooking level is evaluated as

$$O^* = F^{-1}(s^*, \mu_c, \sigma_c) = NORMINV(s^*, \mu_c, \sigma_c) \quad \textbf{(15.7)}$$

If the cancellation distribution is known only as a function of the booking level (capacity L + overbooking O) to have a mean of $\mu(L + O)$ and a standard deviation of $\sigma(L + O)$, the optimal overbooking level is obtained as a solution to the following equation:

$$O = F^{-1}(s^*, \mu(L+O), \sigma(L+O)) = NORMINV(s^*, \mu(L+O), \sigma(L+O)) \quad \textbf{(15.8)}$$

Observe that the optimal level of overbooking should increase as the margin per unit increases and the level of overbooking should decrease as the cost of replacement capacity goes up. Also observe that the use of overbooking increases asset utilization by customers. The use of overbooking decreases the number of customers that are turned away and thus improves asset availability to the customer, while improving profits for the asset owner.

Example 15-5: **Overbooking**

Consider an apparel supplier that is taking orders for dresses with a Christmas motif. The production capacity available from the supplier is 5,000 dresses, and it makes $10 for each dress sold. The supplier is currently taking orders from retailers and must decide on how many orders to commit to at this time. If it has orders that exceed capacity, it has to arrange for backup capacity that results in a loss of $5 per dress.

Retailers have been known to cancel their orders near the winter season as they have better visibility into expected demand. How many orders should the supplier accept if cancellations are normally distributed, with a mean of 800 and a standard deviation of 400? How many orders should the supplier accept if cancellations are normally distributed, with a mean of 15 percent of the orders accepted and a coefficient of variation of 0.5?

Analysis: The supplier has the following parameters:

Cost of wasted capacity, C_w = $10 per dress
Cost of capacity shortage, C_s = $5 per dress

Using Equation 15.6, we thus obtain

$$s^* = \frac{C_w}{C_w + C_s} = \frac{10}{10 + 5} = 0.667$$

If cancellations are normally distributed, with a mean of 800 and a standard deviation of 400, the optimal overbooking level is obtained using Equation 15.7 as

$$O^* = NORMINV(s^*, \mu_c, \sigma_c) = NORMINV(0.667, 800, 400) = 973$$

In this case, the supplier should overbook by 973 dresses and take orders for a total of 5,973 dresses.

If cancellations are normally distributed with a mean of 15 percent of the booking level and a coefficient of variation of 0.5, the optimal overbooking level is obtained using Equation 15.8 to be the solution of the following equation:

$$O = NORMINV(0.667, 0.15(5000 + O), 0.075(5000 + O))$$

This equation can be solved using the Excel tool Solver to obtain the optimal overbooking level:

$$O^* = 1{,}115$$

In this case, the supplier should overbook by 1,115 dresses and take an order for up to 6,115 dresses.

Overbooking as a tactic has been used in the airline, passenger rail, and hotel industries. It has not, however, been used to the extent it should be in many supply chain scenarios including production, warehousing, and transportation capacity. There is no reason that a third-party warehouse that rents to multiple customers should not sell total space that exceeds the available space. A backup will clearly be needed if all customers use warehouse space to capacity. In all other cases, the available warehouse capacity will cover the need for space. Overbooking in this case will improve revenues for the warehouse while allowing more customers to use the available warehouse space.

KEY POINT Overbooking or overselling of a supply chain asset is a valuable tactic if order cancellations occur and the asset is perishable. The level of overbooking is based on the trade-off between the cost of wasting the asset if too many cancellations lead to unused assets and the cost of arranging a backup if too few cancellations lead to committed orders being larger than the available capacity.

15.4 PRICING AND REVENUE MANAGEMENT FOR SEASONAL DEMAND

Seasonal peaks of demand are a common occurrence in many supply chains. Most retailers in the United States achieve a significant fraction of their annual sales during the month of December. One such example is Amazon.com. As a result of the seasonal peak, there is a significant increase in the requirement for picking and packing as well as transportation capacity at Amazon.com. Bringing in short-term capacity is expensive and decreases Amazon's margins. As discussed in Chapter 9, off-peak discounting is an effective method of shifting demand from the peak to the off-peak period. Amazon.com typically offers free shipping for orders that are placed in November. The price discount encourages some customers to shift their demand from December to November, thereby reducing the December peak for Amazon.com and allowing it to

extract a higher profit. Simultaneously, this strategy offers a price break to customers who are willing to order early.

Faced with seasonal peaks, an effective revenue management tactic is to charge a higher price during the peak period and a lower price during off-peak periods. The result is a demand shift from peak to off-peak periods. Such an outcome is beneficial if the discount given during the off-peak period is more than offset by the decrease in cost because of a smaller peak and the increase in revenue during the off-peak period. See Chapter 9 for a detailed discussion of the trade-offs involved when a firm uses pricing to deal with seasonal peaks.

The hotel industry uses differential pricing by day of week and time of year. Here the goal is not to shift demand but to increase demand during periods of low demand by attracting price-sensitive customers, such as vacationing families, with a price discount. The Marriott Corporation has been quite successful in this effort. Demand for hotel rooms is known to vary by day of the week. For Marriott, which targets business customers, peak demand days occur in the middle of the week. Marriott offers lower rates during the weekend to encourage families to use the hotel during that time. Another revenue management tactic that Marriott uses is to charge customers a lower rate if they stay over a longer period that also covers low-demand days.

Off-peak discounting can be an effective revenue management tactic for owners of production or transportation capacity in any supply chain facing seasonal peak demand, because changing capacity over time is expensive. This tactic increases profits for the owner of assets, decreases the price paid by a fraction of customers, and also brings in potentially new customers during the off-peak discount period.

15.5 PRICING AND REVENUE MANAGEMENT FOR BULK AND SPOT CONTRACTS

Most firms face a market in which some customers purchase in bulk at a discount and others buy single units or small lots at a higher price. Consider an owner of warehousing capacity in a supply chain. Warehousing capacity may be leased in bulk to a large company or in small amounts to large companies for their emergency needs or to small companies. The large company leasing space in bulk typically gets a discount compared to the others. The owner of warehousing space thus faces the following trade-off. It could lease the space to the bulk buyer at a discount or save some of the space for higher price demand for small amounts of warehouse space that may or may not arise.

In most instances, owners of supply chain assets prefer to fulfill all demand that arises from bulk sales and try to serve small customers only if any assets are left over. In contrast, a firm such as McMaster-Carr targets only customers with emergency demand for MRO goods. McMaster-Carr will turn down any bulk buyer seeking a discount. Using this strategy, McMaster-Carr is a very profitable firm. For a firm that wants to be a niche player, targeting one of the two extremes is a sensible strategy. It allows the firm to focus its operations on serving either only the bulk segment or only the spot market. For other firms, however, a hybrid strategy of serving both segments is appropriate. In this case, firms must decide what fraction of the asset to sell in bulk and what fraction of the asset to save for the spot market. The fundamental trade-off is similar to the case in which a firm serves two market segments (see Section 15.2). The firm needs to decide on the prices to the bulk and spot segments and the amount of the asset to reserve for the spot market. The prices to each segment can be determined using Equations 15.1 and 15.2. The amount reserved for the spot market should be such

that the expected marginal revenue from the spot market equals the current revenue from a bulk sale. The reserved quantity is affected by the difference in margin between the spot market and the bulk sale and also the distribution of demand from the spot market. If we consider the spot market to be the higher-price segment and the bulk purchasers to be the lower-price segment, the amount of asset to be saved for the spot market can be obtained using Equations 15.3 and 15.4.

A similar decision needs to be made by each purchaser of production, warehousing, and transportation assets in a supply chain. Consider a company looking for shipping capacity for global operations. One option is for it to sign a long-term bulk contract with a shipping firm. Another option is to purchase shipping capacity on the spot market. The long-term bulk contract has the advantage of a fixed, low price but has the disadvantage of being wasted if it is not utilized. The spot market has the disadvantage of a higher average price but has the advantage of never being wasted. The purchaser must consider this trade-off when deciding the amount of long-term bulk shipping contracts to sign.

Given that both the spot market price and the purchaser's need for the asset are uncertain, a decision tree approach as discussed in Chapter 6 should be used to evaluate the amount of long-term bulk contract to sign. For the simple case in which the spot market price is known but demand is uncertain, the extent of the bulk contract can be evaluated using a formula. Let c_B be the bulk rate and let c_S be the spot market price for the asset. Let Q^* be the optimal amount of the asset to be purchased in bulk and let p^* be the probability that demand for the asset does not exceed Q^*. The marginal cost of purchasing another unit in bulk is c_B. The expected marginal cost of not purchasing another unit in bulk and then purchasing it in the spot market is $(1 - p^*)c_S$. If the optimal amount of the asset is purchased in bulk, the marginal cost of the bulk purchase should equal the expected marginal cost of the spot market purchase; that is, $c_B = (1 - p^*)c_S$. Thus, the optimal value p^* is obtained as

$$p^* = \frac{c_S - c_B}{c_S} \tag{15.9}$$

If demand is normally distributed, with a mean of μ and a standard deviation of σ, the optimal amount, Q^*, of the asset purchased in bulk is obtained as

$$Q^* = F^{-1}(p^*, \mu, \sigma) = NORMINV(p^*, \mu, \sigma) \tag{15.10}$$

Observe that the amount of bulk purchase increases if either the spot market price increases or the bulk price decreases.

Example 15-6: **Long-term bulk contracts versus the spot market**
A manufacturer sources several components from China and has monthly transportation needs that are normally distributed, with a mean of $\mu = 10$ million units and a standard deviation of $\sigma = 4$ million units. The manufacturer must decide on the portfolio of transportation contracts to carry. A long-term bulk contract costs $10,000 per month for a million units. Transportation capacity is also available in the spot market at an average price of $12,500 per million units. For how much transportation capacity should the manufacturer sign a long-term bulk contract?

Analysis: In this case we have

Bulk contract cost, c_B = $10,000 per million units
Spot market cost, c_S = $12,500 per million units

Using Equation 15.9, we obtain

$$p^* = \frac{c_S - c_B}{c_S} = \frac{12{,}500 - 10{,}000}{12{,}500} = 0.2$$

The optimal amount to be purchased using the long-term bulk contract is thus obtained using Equation 15.10 to be

$$Q^* = NORMINV(p^*, \mu, \sigma) = NORMINV(0.2, 10, 4) = 6.63$$

Thus, the manufacturer should sign a long-term bulk contract for 6.63 million units per month and purchase any transportation capacity beyond that on the spot market.

KEY POINT Most consumers of production, warehousing, and transportation assets in a supply chain face the problem of constructing a portfolio of long-term bulk contracts and spot market contracts. The basic decision is the size of the bulk contract. The fundamental trade-off is between wasting a portion of a low-cost bulk contract and paying more for the asset on the spot market.

15.6 THE ROLE OF IT IN PRICING AND REVENUE MANAGEMENT

The role of IT in pricing and revenue management (PRM) has a long history that is, for the most part, independent of supply chain software. The leading software companies in this area evolved primarily from the airline industry and are generally not the leaders in supply chain software. There are three major areas in which PRM software has had a major impact.

Pricing of perishable assets, pioneered by the travel industry, is where revenue management software originated. Even back in the 1980s, airlines became sophisticated users of revenue management to improve profitability. Many airlines developed their own revenue management systems, with American Airlines as one of the leaders. Sabre, a spin-off of American Airlines, is now one of the leading revenue management firms. The use of revenue management systems has now spread to include hotels and car rental companies.

The second area of impact for IT within PRM is the pricing of retail goods in the consumer packaged-goods category. The leaders here have been grocery stores and drug stores that have utilized this technology to price their products at the retail level. The pricing problem they tackle involves both the regular as well as promotional pricing of products. Firms such as DemandTec have been pioneers in this area.

PRM systems have also had a significant impact on fashion goods, particularly clothing. Here the challenge revolves around how to optimally mark down the price of goods as the styles and seasons change. The goal is to mark down the price enough to sell most of the product but without marking it down so much that profit is thrown away. Software firms such as ProfitLogic offer products in this area.

The major pitfalls in the pricing and revenue management area of IT revolve around linking PRM decisions with other areas and systems of the company. Pricing is generally determined within a relatively well-defined area of a company, making it easy to set up pricing software. This ease of installation, however, can cause problems if there is no integration with inventory, distribution, and production systems. A common problem is a software recommendation of a price reduction, which in turn brings on a surge in demand. This leads to dissatisfied customers if there is insufficient inventory because the pricing systems did not communicate with the inventory management system. This lack of coordination can be quite harmful and greatly dilute the benefits of PRM.

Many of the mainstream supply chain software vendors have tried to enter the PRM arena, either through internal development or through acquisition. Eventually, as has been the case for virtually all supply chain segments, the larger players will gain in this area and become a significant force. At this stage, however, niche players are doing well.

15.7 USING PRICING AND REVENUE MANAGEMENT IN PRACTICE

1. ***Evaluate your market carefully.*** The first step in revenue management is to identify the customer segments being served and their needs. The goal is to understand what the customer is buying, as opposed to what you are selling. If an airline thinks of itself as only selling seats, it cannot use revenue management. It has to think of itself as selling seats, the ability to book at the last minute, the ability to alter flight plans, and the ability to pick a convenient flight schedule. Only then do revenue management opportunities present themselves.

Having identified the market needs, it is crucial to gather accurate and complete data relating to products offered, prices, competition, and most important, customer behavior. Information about customer behavior is a valuable asset that helps identify consumer preferences. Ultimately, a proper understanding of customer preferences and a quantification of the impact of various tactics on consumer behavior are at the core of successful revenue management.

2. ***Quantify the benefits of revenue management.*** It is critical to quantify the expected benefits from revenue management before starting the project. Ideally, historical data and a good model of customer preferences should be used to estimate the benefits through a simulation. The outcome of this step should be explicit revenue targets that are to be achieved as a result of revenue management. The revenue targets should be such that all people involved believe in them. The revenue management effort should then be compared to the expected benefit.

3. ***Implement a forecasting process.*** The foundation of any revenue management system is the forecasting function. To use overbooking with any degree of success, an airline must be able to forecast cancellation patterns. By forecasting we do not mean obtaining an estimate that is always accurate. Forecasting involves estimating demand and also attributing an expected error to the forecast itself. Both the estimated value and the expected error are important inputs into any revenue management model.

It is generally very difficult to forecast at a micro level, where all behavior is essentially idiosyncratic. For example, an airline with 100 fare classes will find it very difficult to forecast demand for each class and also forecast the behavior of customers when they find a fare class full. It is thus important to ensure that revenue management tactics are planned over an aggregate enough level that effective forecasting is possible.

Finally, as new information becomes available, reforecast to see if the revenue management tactics currently in place are still appropriate. The frequency of forecasting will depend on the amount of market activity. Ideally, the forecast and the revenue management decision should be evaluated after every transaction.

4. ***Apply optimization to obtain the revenue management decision.*** The goal of optimization is to use forecasts of customer behavior to identify a revenue management tactic that will be most effective. The decision to use overbooking by a hotel is only the beginning of the revenue management process. The ultimate success of this effort depends on the level of overbooking used by the hotel. Too high a level of overbooking will lead to upset customers and a high cost of providing them space. Too low a

level of overbooking will lead to empty rooms and lost revenue. Optimization allows the hotel to identify the level of overbooking that maximizes profits.

5. ***Involve both sales and operations.*** Salespeople must understand the revenue management tactic in place so they can align their sales pitch accordingly. It makes no sense for a firm to offer an off-peak discount if the sales force continues to push people toward the period with highest prices. The sales force must differentiate between those customers who truly need the supply chain asset during the peak period and those that will benefit from moving their order to the off-peak period. Such an approach will increase profits for the firm while also satisfying customers. Operations must understand the potential outcomes of the revenue management tactics in place and be informed of actual outcomes taking place. For example, operations in an airline using overbooking must be ready to book passengers who are unable to depart on the full flight onto other feasible flights.

6. ***Understand and inform the customer.*** Customers will have a negative perception of revenue management tactics if they are simply presented as a mechanism for extracting maximum revenue. Such a perception is likely to diminish customer loyalty in the long term. Thus, it is important for the firm to structure its revenue management program in a way that revenue increases while improving service along some dimension that is important to customers that pay the highest price. As discussed earlier in the chapter, a proper implementation of revenue management tactics should achieve both outcomes. It is important for the firm to convey this information to its most valuable customers. Remember, a change in behavior by this set of customers can destroy any potential benefit of a revenue management program!

7. ***Integrate supply planning with revenue management.*** Although the supply planning and revenue management ideas we discuss in this book are valuable in their own right, combining them can create significantly more value. The point here is not to use revenue management in isolation, but rather to combine it with decisions on the supply side. For instance, if, after applying revenue management, a manufacturer finds that the production of a short-lead-time facility provides the majority of its profit, it should look into adding more short-lead-time capacity. Understanding and acting on the interactions among supply, demand, and pricing can bring about powerful results.

15.8 SUMMARY OF LEARNING OBJECTIVES

1. Understand the role of revenue management in a supply chain.

   Revenue management uses differential pricing to better match supply and demand and increase supply chain profits. Traditionally, firms have changed the availability of assets to match supply and demand. Revenue management aims to reduce any supply/demand imbalance by using pricing as a lever. A big advantage of using revenue management is that a change in pricing is much easier to reverse compared to an investment in supply chain assets. When it is used properly, revenue management increases firm profits while leaving valuable customers more satisfied through greater asset availability.
2. Identify conditions under which revenue management tactics can be effective.

   Revenue management tactics can be very effective if the firm serves multiple segments, each placing a different value on the supply chain asset, or the asset is perishable and loses value over time, or demand for the asset has distinct seasonal peaks, or the asset can be bought and sold both using long-term bulk contracts and on the spot market.
3. Describe trade-offs that must be considered when making revenue management decisions.

When serving multiple customer segments, the basic revenue management decision is the amount of the asset to save for the higher-price segment. The trade-off is between saving too much and spoiling the asset if the higher-price demand does not materialize and turning away higher-price customers because too little of the asset was saved. When the asset is perishable, the basic revenue management decisions are about how to change the asset price over time and the degree to which the asset should be overbooked or oversold. When changing the asset price over time, the trade-off is between charging a higher price initially and having too much inventory left over to discount later on, and charging a low initial price and having little inventory left over. When overbooking, the trade-off is between not overbooking enough and wasting the available asset and overbooking too much and having to arrange for backup capacity at high cost. When demand has distinct seasonal peaks, the basic revenue management decision is the timing and extent of the off-peak discount. The trade-off is between the additional cost of serving the seasonal peak, and the impact on demand and thus revenue from offering an off-peak discount. For a seller using both long-term bulk contracts and the spot market, the basic revenue management decision is the fraction of the asset to save for the spot market. The basic trade-off is between getting a committed demand at a lower price with the bulk contract and potentially getting a high price on the spot market. For a buyer, the basic decision is the fraction of anticipated demand to purchase from a long-term bulk contract. The basic trade-off is between getting a long-term bulk contract at a low price that may not be fully used, and purchasing only the amount required from the spot market but at a higher price.

Discussion Questions

1. In what ways can a retailer such as Nordstrom take advantage of revenue management opportunities?
2. What revenue management opportunities are available to a manufacturer? How can it take advantage of these opportunities?
3. What revenue management opportunities are available to a trucking firm? How can it take advantage of these opportunities?
4. What revenue management opportunities are available to the owner of a warehouse and how can it take advantage of them?
5. Explain the use of outlet stores by retailers such as Saks Fifth Avenue in the context of revenue management. How does the presence of outlet stores help Saks? How does it help its more valuable customer, who is willing to pay full price?
6. Demand for hairdressers is much higher over the weekend, when people are not at work. What revenue management techniques can be used by such a business?
7. How can a golf course use revenue management to improve financial performance?

Exercises

1. Felgas, a manufacturer of felt gaskets, has production capacity of 1,000 units per day. Currently, the firm sells production capacity for $5 per unit. At this price, all production capacity gets booked about one week in advance. A group of customers have said that they would be willing to pay twice as much ($10 per unit) if Felgas had capacity available on the last day. About 10 days in advance, demand for the high-price segment is normally distributed, with a mean of 250 and a standard deviation of 100. How much production capacity should Felgas reserve for the last day?
2. The GoGo Bunny is a very hot toy this Christmas, and the manufacturer has decided to ration supply to all retailers. A large retail chain owns two channels—a discount channel and a high-service channel. The retailer plans to sell the toy at a margin of $4 in the discount

channel and a margin of $8 in the high-service channel. The manufacturer sends 100,000 GoGo Bunnies to the retailer. The retailer has forecast that the demand for the toy at the high-service channel is normally distributed, with a mean of 400,000 and a standard deviation of 150,000. How many toys should the retailer send to the high-service channel?

3. A small warehouse has 100,000 square feet of capacity. The manager at the warehouse is in the process of signing contracts for storage space with customers. The contract has an up-front monthly fee of $200 per customer and then a fee of $3 per square foot based on actual usage. The warehouse guarantees the contracted amount even if it has to arrange for extra space at a price of $6 per square foot. The manager feels that customers are unlikely to use the full contracted amount at all times. Thus, he is thinking of signing contracts that exceed 100,000 square feet. He forecasts that unused space will be normally distributed, with a mean of 20,000 square feet and a standard deviation of 10,000 square feet. What is the total size of the contracts he should sign? If he forecasts that unused space will be normally distributed with a mean of 15 percent of the contracted amount and a coefficient of variation of 0.6, what is the total space that he should sign contracts for?
4. A trucking firm has current capacity of 200,000 cubic feet. A large manufacturer is willing to purchase the entire capacity at $0.10 per cubic foot per day. The manager at the trucking firm has observed that on the spot market, trucking capacity sells for an average of $0.13 per cubic foot per day. Demand, however, is not guaranteed at this price. The manager forecasts daily demand on the spot market to be normally distributed, with a mean of 60,000 cubic feet and a standard deviation of 20,000. How much trucking capacity should the manager save for the spot market?
5. The manager at a large manufacturer is planning warehousing needs for the coming year. She predicts that warehousing needs will be normally distributed, with a mean of 500,000 square feet and a standard deviation of 150,000. The manager can obtain a full-year lease at $0.50 per square foot per month or purchase storage space on the spot market. Spot market rates have averaged $0.70 per square foot per month. How large an annual contract should the manager sign?
6. NatBike, a bicycle manufacturer, has identified two customer segments, one that prefers a customized bicycle and is willing to pay a higher price and another that is willing to take a standardized bicycle but is more price sensitive. Assume that the cost of manufacturing either bicycle is $200. Demand from the customized segment has a demand curve of $d_1 = 20{,}000 - 10p_1$ and demand from the price-sensitive standard segment is $d_2 = 40{,}000 - 30p_2$. What price should NatBike charge each segment if there is no capacity constraint? What price should NatBike charge each segment if the total available capacity is 20,000 bicycles? What is the total profit in each case?
7. Return to the bicycle manufacturer NatBike in Exercise 6. Now assume that a customized bicycle costs $300 to manufacture, whereas a standardized bicycle costs $200 to manufacture, with all other data as in Exercise 6. What price should NatBike charge each segment if there is no capacity constraint? What price should NatBike charge each segment if the total available capacity is 20,000 bicycles? What is the total profit in each case?
8. Return to the bicycle manufacturer NatBike in Exercise 6. Assume that the plant has a capacity of 20,000 bicycles. If additional capacity can be added at a cost of $25 per bicycle, how should NatBike price to each of the two segments and how much capacity should it add? How are profits affected relative to Exercise 6?
9. A department store has purchased 5,000 swimsuits to be sold during the summer sales season. The season lasts three months and the store manager forecasts that customers buying early in the season are likely to be less price sensitive and those buying later in the season are likely to be more price sensitive. The demand curves in each of the three months are forecast to be as follows: $d_1 = 2{,}000 - 10p_1$, $d_2 = 2{,}000 - 20p_2$, and $d_3 = 2{,}000 - 30p_3$. If the department store is to charge a fixed price over the entire season, what should it be?

What is the resulting revenue? If the department store wants dynamic prices that vary by month, what should they be? How does this affect profits relative to charging fixed prices? If each swimsuit costs $40 and the store plans to charge dynamic prices, how many swimsuits should it purchase at the beginning of the season?

Bibliography

Cross, Robert G. *Revenue Management.* New York: Bantam Doubleday Dell, 1997.

Daudel, Sylvain, and Georges Vialle. *Yield Management: Applications to Air Transport and Other Service Industries*. Paris: Institut du Transport Aerien, 1994.

Talluri, Kalyan T., and Garrett J. Van Ryzin. *The Theory and Practice of Revenue Management*. Boston: Kluwer Academic, 2004.

Tayur, Sridhar, Ram Ganeshan, and Michael Magazine, eds. *Quantitative Models for Supply Chain Management.* Boston: Kluwer Academic, 1999.

CHAPTER 16
INFORMATION TECHNOLOGY IN A SUPPLY CHAIN



Learning Objectives

After reading this chapter, you will be able to:

1. Understand the importance of information and information technology in a supply chain.
2. Know at a high level how the supply chain drivers use information.
3. Understand the major applications of supply chain information technology and the processes that they enable.

Information is crucial to the performance of a supply chain because it provides the basis on which supply chain managers make decisions. Information technology consists of the tools used to gain awareness of information, analyze this information, and execute on it to increase the performance of the supply chain. In this chapter we explore the importance of information, its uses, and the technologies that enable supply chain managers to use information to make better decisions.

16.1 THE ROLE OF IT IN A SUPPLY CHAIN

Information is a key supply chain driver because it serves as the glue that allows the other supply chain drivers to work together with the goal of creating an integrated, coordinated supply chain. Information is crucial to supply chain performance because it provides the foundation on which supply chain processes execute transactions and managers make decisions. Without information, a manager cannot know what customers want, how much inventory is in stock, and when more product should be produced or shipped. In short, without information, a manager can only make decisions blindly. Therefore, information makes the supply chain visible to a manager. With this visibility, a manager can make decisions to improve the supply chain's performance.

Given the role of information in a supply chain's success, managers must understand how information is gathered and analyzed. This is where IT comes into play. IT consists of the hardware, software, and people throughout a supply chain that gather, analyze, and execute upon information. IT serves as the eyes and ears (and sometimes a portion of the brain) of management in a supply chain, capturing and analyzing the information necessary to make a good decision. For instance, an IT system at a PC manufacturer may tell a manager how many processors are currently in stock. IT is also used to analyze the information and recommend an action. In this role, an IT system could take the number of processors in inventory, look at demand forecasts, and determine whether to order more processors from Intel.

Using IT systems to capture and analyze information can have a significant impact on a firm's performance. For example, a major manufacturer of computer workstations and servers found that most of its information on customer demand was not being used to set production schedules and inventory levels. The manufacturing group lacked this demand information, which essentially forced them to make inventory and production decisions blindly. By installing a supply chain software system, the company was able to gather and analyze demand data to produce recommended stocking levels. Using the IT system enabled the company to cut its inventory in half, because managers could now make decisions based on customer demand information rather than manufacturing's educated guesses. Large impacts like this underscore the importance of IT as a driver of supply chain performance.

Information is the key to the success of a supply chain because it enables management to make decisions over a broad scope that crosses both functions and companies. As discussed in Chapter 2, successful supply chain strategy results from viewing the supply chain as a whole rather than looking only at the individual stages. By considering a global scope across the entire supply chain, a manager is able to craft strategies that take into account all factors that affect the supply chain rather than just those factors that affect a particular stage or function within the supply chain. Taking the entire chain into account maximizes the profit of the total supply chain, which then leads to higher profits for each individual company within the supply chain.

How does a manager get this broad scope? The supply chain scope is made up entirely of information, and the breadth of this information determines whether the scope is global or local. To obtain a global scope of the supply chain, a manager needs accurate and timely information on all company functions and organizations in the supply chain. For example, in trying to determine production schedules, it is not enough for the workstation manufacturer mentioned earlier to know how much inventory is on hand within the company. The manager also needs to know the downstream demand and even the upstream supplier lead times and variability. With this broader scope, the company is able to set production schedules and inventory levels that maximize profitability.

Information must have the following characteristics to be useful when making supply chain decisions:

1. ***Information must be accurate.*** Without information that gives a true picture of the state of the supply chain, it is very difficult to make good decisions. That is not to say that all information must be 100 percent correct, but rather that the data available paint a picture that is at least directionally correct.
2. ***Information must be accessible in a timely manner.*** Often, accurate information exists, but by the time it is available, it is either out of date or, if it is current, it is not in an accessible form. To make good decisions, a manager needs to have up-to-date information that is easily accessible.
3. ***Information must be of the right kind.*** Decision makers need information that they can use. Often companies have large amounts of data that is not helpful in making a decision. Companies must think about what information should be recorded so that valuable resources are not wasted collecting meaningless data while important data goes unrecorded.

Information is a key ingredient not just at each stage of the supply chain, but also within each phase of supply chain decision making—from the strategic phase to the planning phase to the operational phase (see Chapter 1). For instance, information and its analysis play a significant role during the formulation of supply chain strategy by providing the basis for decisions such as the location of the push/pull boundary of the

supply chain. Information also plays a key role at the other end of the spectrum, in operational decisions such as what products will be produced during today's production run. Managers need to be able to understand how to analyze information to make good decisions. Much of this book deals with just that idea—how to identify a supply chain problem that needs to be solved, obtain information, analyze it, and then make a good decision to act on that information.

For example, Wal-Mart has been a pioneer not only in capturing information, but also in understanding how to analyze that information to make good supply chain decisions. Wal-Mart collects data in real time on what products are being purchased at each of its stores and then sends these data to the manufacturers. Wal-Mart analyzes this demand information to determine how much inventory to hold at each store and to decide when to order new loads of product from the manufacturer. The manufacturer uses this information to set its production schedules to meet Wal-Mart's demand on time. Both Wal-Mart and its key suppliers do not just capture the information they have; they analyze it and base their actions on this analysis.

Information is used when making a wide variety of decisions about each of the supply chain drivers, as discussed here.

1. ***Facility.*** Determining the location, capacity, and schedules of a facility requires information on the trade-offs among efficiency and flexibility, demand, exchange rates, taxes, and so on (see Chapters 4, 5, and 6). Wal-Mart's suppliers use the demand information from Wal-Mart's stores to set their production schedules. Wal-Mart uses this information to determine where to place its new stores and cross-docking facilities.
2. ***Inventory.*** Setting optimal inventory policies requires information that includes demand patterns, cost of carrying inventory, costs of stocking out, and costs of ordering (see Chapters 10, 11, and 12). For example, Wal-Mart collects detailed demand, cost, margin, and supplier information to make these inventory policy decisions.
3. ***Transportation.*** Deciding on transportation networks, routings, modes, shipments, and vendors requires information including costs, customer locations, and shipment sizes to make good decisions (see Chapter 13). Wal-Mart uses information to tightly integrate its operations with those of its suppliers. This integration allows Wal-Mart to implement cross-docking in its transportation network, saving on both inventory and transportation costs.
4. ***Sourcing.*** Information on product margins, prices, quality, delivery lead times, and so on, are all important in making sourcing decisions. Given sourcing deals with inter-enterprise transactions, there is also a wide range of transactional information that must be recorded in order to execute operations, even once sourcing decisions have been made.
5. ***Pricing and revenue management.*** To set pricing policies, one needs information on demand, both its volume and various customer segment's willingness to pay, as well as many supply issues such as the product margin, lead time, and availability. Using this information, firms can make intelligent pricing decisions to improve their supply chain profitability.

In summary, information is crucial to making good supply chain decisions at all three levels of decision making (strategy, planning, and operations) and in each of the other supply chain drivers (facilities, inventory, transportation, sourcing, and pricing). IT enables not only the gathering of these data to create supply chain visibility, but also the analysis of these data so that the supply chain decisions made will maximize profitability.

16.2 THE SUPPLY CHAIN IT FRAMEWORK

Given the wide realm of information we have discussed, it is important to develop a framework that helps a manager understand how this information is utilized by the various segments of IT within the supply chain. Our vision of this framework is presented in the next several sections of this chapter. It is important to note that the use of information in the supply chain has increasingly been enabled by enterprise software. Enterprise software collects transaction data, analyzes these data to make decisions, and executes on these decisions both within an enterprise and across a supply chain. Certainly other parts of IT beyond enterprise software, such as hardware, implementation services, and support, are all crucial to making IT effective. Within a supply chain, however, the different capabilities provided by IT have as their most basic building block the capabilities of the supply chain's enterprise software. In many ways, software shapes the entire industry of enterprise IT as the other components follow the software lead. It is for this reason that we use enterprise software and its evolution as the primary guide in analyzing IT and its impact on the supply chain. The evolution of enterprise software provides insights not only into the future of IT, but also into what the key supply chain processes are. We now discuss this evolution and its impact on companies' supply chain processes.

The enterprise software landscape became increasingly overpopulated during the late 1990s. The unprecedented flow of venture capital into new software companies led not just to an increase in the number of software companies, but also to the proliferation of entire categories of software. The growth of the number of software companies, the emergence of new categories, and the expansion of software product lines combined to create an enterprise software landscape that was not only much more crowded than in the past, but also much more dynamic. It was an environment ripe for significant evolutionary change.

The downturn in technology spending in the early 2000s brought about this evolutionary pressure, causing many software companies to cease operations or merge with existing software firms. Some entire software categories are now extinct or close to it, with many recently created categories landing on this endangered species list.

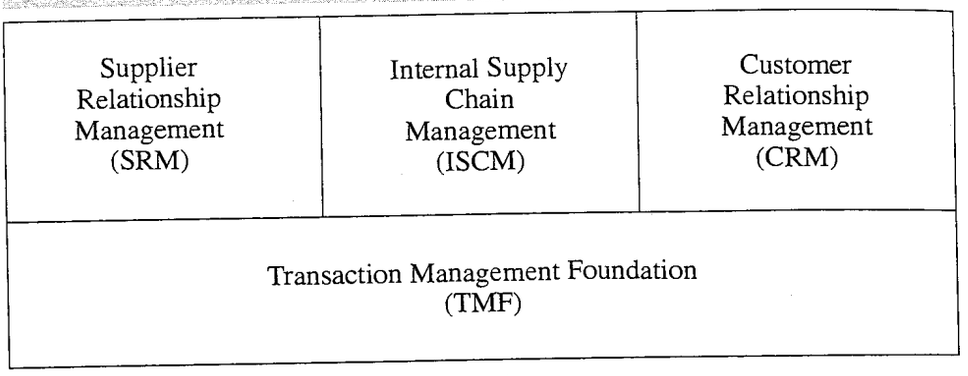
What drives this evolution of the enterprise software landscape? Why are some categories of software companies headed for a profitable long-term future, whereas others have failed? Certainly there are a wide variety of factors that affect the natural selection of software companies. We propose, however, that three of the main drivers of the evolution taking place in enterprise software are the three major groups of supply chain processes, which we call supply chain *macro processes*. The successful categories of software will be those that focus on the macro processes. The failures, on the other hand, will not have such a focus.

THE SUPPLY CHAIN MACRO PROCESSES

The emergence of supply chain management has broadened the scope across which companies make decisions. This scope has expanded from trying to optimize performance across the division, to the enterprise, and now to the entire supply chain. This broadening of scope emphasizes the importance of including processes all along the supply chain when making decisions. From an enterprise's perspective, all processes within its supply chain can be categorized into three main areas: processes focused downstream, processes focused internally, and processes focused upstream. We use this classification to define the three macro supply chain processes (see Chapter 1) as follows.

- ***Customer relationship management (CRM).*** Processes that focus on downstream interactions between the enterprise and its customers.

FIGURE 16-1 The Macro Processes in a Supply Chain



- ***Internal supply chain management (ISCM).*** Processes that focus on internal operations within the enterprise. Note that the software industry commonly calls this "supply chain management" (without the word "internal"), even though the focus is entirely within the enterprise. In our definition, supply chain management includes all three macro processes, CRM, ISCM, and SRM.
- ***Supplier relationship management (SRM).*** Processes that focus on upstream interactions between the enterprise and its suppliers.

We must also note that there is a fourth important building block that provides the foundation on which the macro processes rest. We call this category the *transaction management foundation (TMF),* which includes basic ERP systems (and its components, such as financials and human resources), infrastructure software, and integration software. TMF software is necessary for the three macro processes to function and to communicate with each other. The relationship between the three macro processes and the transaction management foundation can be seen in Figure 16-1.

WHY FOCUS ON THE MACRO PROCESSES?

As the performance of an enterprise becomes more closely linked to the performance of its supply chain, it is crucial that firms focus on these macro processes. After decades of focusing on internal processes, a firm must expand the scope beyond internal processes and look at the entire supply chain to achieve breakthrough performance. As we have discussed, the goal should be to increase the total profitability of the supply chain (also referred to as the supply chain surplus). Good supply chain management is not a zero-sum game in which one stage of the supply chain increases profits at the expense of another. As discussed in Chapter 2, good supply chain management is instead a positive-sum game in which supply chain partners can increase their overall level of profitability by working together. Therefore, to increase the supply chain surplus (and therefore their firm's own profitability) most effectively, firms must expand their scope beyond their enterprise and think in terms of all three macro processes.

MACRO PROCESSES APPLIED TO THE EVOLUTION OF SOFTWARE

As the downturn in technology spending in the early 2000s applied evolutionary pressure on the enterprise software landscape, a distinct pattern emerged. The majority of survivors have chosen to focus their products on improving their customers' macro processes. Larger software firms cross over into more than one macro process, whereas others address only a small portion of a macro process. However, the common theme we see is that to survive, and particularly to thrive, enterprise software firms must focus on one or

more of these macro processes. Almost all areas of enterprise software growth exist within CRM, ISCM, or SRM. Both new companies and large firms within enterprise software are now targeting these three macro processes much more sharply. In the future, we see the ability to improve the three macro processes driving the growth of enterprise software.

Examples of failures that did not focus on these macro processes are B2B marketplaces and the software companies providing marketplace software that proliferated during 1999 and 2000. Marketplaces focused more on creating whole new information intermediaries within the supply chain rather than on improving the performance of the macro processes within supply chains. This lack of focus on the macro processes was a key contributor to the downfall of marketplaces.

The software firms behind the marketplaces have also had a difficult time, with the major players Ariba and Commerce One losing well over 99 percent of their peak market capitalization. To survive, these companies have evolved away from being marketplace providers and toward being software firms focused on a macro process. Ariba now focuses almost exclusively on the SRM macro process, and Commerce One is struggling to maintain its existence. The few surviving marketplaces have also focused on improving the performance of a macro process within the supply chain, rather than trying to be independent intermediaries as marketplace operators.

A third example of a software category that is being transformed by a focus on macro processes is the ERP category. ERP software has been successful in improving data availability and integrity within the supply chain, but by itself, data availability and integrity provide only a portion of the value potentially available. The real value from these data comes about only when the data can be used to improve decision making. This is where the three macro processes enter the picture. The real value from having ERP systems in place can only be obtained if these systems can be used to improve decision making in the three macro processes. Every major ERP player has realized this and is remaking itself into a company emphasizing products focused on the macro processes.

The drivers of the software landscape are not just important to software providers. Companies that are users of software must understand these macro processes as well. By understanding whether software companies are addressing the macro processes and actually enabling improvements in performance in these areas, a company can better gauge whether a particular type of software is valuable for it.

The Software Winners in a Macro Process

Among software firms focused on a macro process, the following three factors determine their success:

1. Functional performance (including ease of use)
2. Integration with other macro processes
3. Strength of the software firm's ecosystem

Functional performance is important to customers because it provides them with capabilities to create a competitive advantage. In addition to raw functional performance (qualities such as the ability to optimize both price and supply in an integrated fashion), we believe that ease of use is crucial to success in this category. Some software has very advanced functionality but is very difficult to use. As a result, the advanced functionality is rarely utilized. Software firms with lower levels of functionality but with high ease of use can, in essence, provide more "usable" functionality to their customers and therefore gain an edge.

The ability to integrate is important to a customer for a variety of reasons. Applications that are easy to integrate are generally easier to implement and produce value. Integration is also crucial across different macro processes. Applications that

integrate across macro processes are able to provide the benefits of making decisions for the extended supply chain. This gives an edge to firms that offer a full line of integrated solutions in all three macro processes.

Finally, a firm's ecosystem—the network of software partners and, more important, systems integrators and installed base—provides assistance in selling and implementing software. Firms that work well with implementation partners and build up large groups of customers trained on their solutions have built a highly defensible position. For another firm to capture this business requires that it be so superior that it is worth the retraining and reintegration effort, which is often quite significant. For a customer, a strong ecosystem means a strong network to provide support both during implementation and down the road.

As we stressed earlier, these criteria are also important for customers of supply chain software. These criteria are the key to success for software companies precisely because they improve supply chain performance for firms. Thus, companies should evaluate software providers along these lines to determine their choice of software vendor.

We now discuss each of the macro processes, what segments they consist of, who the players are, and what the future will look like.

16.3 CUSTOMER RELATIONSHIP MANAGEMENT

The CRM macro process consists of processes that take place between an enterprise and its customers downstream in the supply chain. The goal of the CRM macro process is to generate customer demand and facilitate transmission and tracking of orders. Weakness in this process results in demand being lost and a poor customer experience because orders are not processed and executed effectively. The key processes under CRM are as follows.

- ***Marketing.*** Marketing processes involve decisions regarding which customers to target, how to target customers, what products to offer, how to price products, and how to manage the actual campaigns targeting customers. Successful software vendors in the marketing area within CRM provide analytics that improve the marketing decisions on pricing, product profitability, and customer profitability, among other functions.
- ***Sell.*** The sell process focuses on making an actual sale to a customer (compared to marketing, in which processes are more focused on planning who to sell to and what to sell). The sell process includes providing the sales force the information it needs to make a sale and then execute the actual sale. Executing the sale may require the salesperson (or the customer) to build and configure orders by choosing among a variety of options and features. The sell process also requires such functionality as the ability to quote due dates and access information related to a customer order. Successful software providers have targeted sales force automation, configuration, and personalization to improve the sell process.
- ***Order management.*** The process of managing customer orders as they flow through an enterprise is important for the customer to track his order and for the enterprise to plan and execute order fulfillment. This process ties together demand from the customer with supply from the enterprise. Order management software has traditionally been handled by legacy systems or been a part of an ERP system. Recently, new order management systems have emerged with additional functionality that enables visibility of orders across the often numerous order management systems that exist within a company.

- ***Call/service center.*** A call/service center is often the primary point of contact between a company and its customers. A call/service center helps customers place orders, suggests products, solves problems, and provides information on order status. Successful software providers have helped improve call/service center operations by facilitating and reducing work done by customer service representatives, often by allowing customers to do the work themselves.

The aforementioned CRM processes are crucial to the supply chain, as they cover a vast amount of interaction between an enterprise and its customers. The customer must be the starting point when trying to increase the supply chain surplus because all demand, and therefore revenue, ultimately arises from them. Thus, the CRM macro process is often the starting point when improving supply chain performance. It is also important to note that CRM processes (and also CRM software) must be integrated with internal operations to optimize performance. Too often, companies operate with their customer-focused units working independently from their internal operations. The need for integration between CRM and internal operations emphasizes the importance of CRM to an effective supply chain.

CRM software has been the fastest-growing, and is now the largest, category of the three macro processes. Software providers in the CRM space have focused on improving CRM processes themselves, but have more work to do to improve integration between CRM and internal operational processes. Future success will be partially driven by the ability to integrate CRM applications into internal operations.

The CRM software landscape consists of three categories of companies: the best-of-breed winner, the best-of-breed start-ups, and the ERP players. CRM as an enterprise software segment was created by Siebel Systems, the sole company in the best-of-breed winner category. Siebel rose to prominence in the late 1990s and the early 2000s but has struggled lately against the larger software firms with broader product lines. Siebel faces serious competition from both best-of-breed start-ups, such as Salesforce.com, as well as from the ERP players, such as SAP and Oracle, which provide a powerful integration story and strong ecosystems.

Looking forward, it appears that Siebel, the last remaining large best-of-breed software vendor, faces a difficult future. While it has successfully fended off threats from the ERP players and the smaller best-of-breed players over the years, these firms are finally catching up to Siebel and now pose a very serious threat. The future of the CRM software landscape will likely be dominated by the ERP players SAP and Oracle, with some innovative smaller firms having limited success as well. Perhaps Siebel will remain an independent firm, but its influence will likely shrink. It may also be acquired by one of the larger players we mentioned. Either way, it does appear that here in this segment, the last segment where the best-of-breed versus the ERP battle still rages, the ERP players will win, as they have done in every other segment.

16.4 INTERNAL SUPPLY CHAIN MANAGEMENT

ISCM, as we discussed earlier, is focused on operations *internal* to the enterprise. ISCM includes all processes involved in planning for and fulfilling a customer order. The various processes included in ISCM are as follows.

- ***Strategic planning.*** This process focuses on the network design of the supply chain. For more discussion of this process and the use of IT in it, see Chapter 5 on network design in the supply chain.

- ***Demand planning.*** Demand planning consists of forecasting demand and analyzing the impact on demand of demand management tools such as pricing and promotions. For more discussion of this process and the use of IT in it, see Chapter 7 on demand forecasting as well as Chapters 9 and 15 on pricing.
- ***Supply planning.*** The supply planning process takes as an input the demand forecasts produced by demand planning and the resources made available by strategic planning, and then produces an optimal plan to meet this demand. Factory planning and inventory planning capabilities are typically provided by supply planning software. For more discussion of this process and the use of IT in it, see Chapter 8 on aggregate planning and Chapters 10 and 11 on inventory management.
- ***Fulfillment.*** Once a plan is in place to supply the demand, it must be executed. The fulfillment process links each order to a specific supply source and means of transportation. The software applications that typically fall into the fulfillment segment are transportation and warehousing applications. For more discussion of this process and the use of IT in it, see Chapter 13 on transportation.
- ***Field service.*** Finally, after the product has been delivered to the customer, it eventually must be serviced. Service processes focus on setting inventory levels for spare parts as well as scheduling service calls. Some of the scheduling issues here are handled in a similar manner to aggregate planning, and the inventory issues are the typical inventory management problems. For more discussion of IT's role in this process, see our Chapter 8 on aggregate planning and Chapters 10 and 11 on inventory management.

Given that the ISCM macro process aims to fulfill demand that is generated by CRM processes, there needs to be strong integration between the ISCM and CRM macro processes. When forecasting demand, interaction with CRM is essential, as the CRM applications are touching the customer and have the most data and insight on customer behavior. Similarly, the ISCM processes should have strong integration with the SRM macro process. Supply planning, fulfillment, and field service are all dependent on suppliers and therefore the SRM processes. It is of little use for your factory to have the production capacity to meet demand if your supplier cannot supply the parts to make your product. Order management, which we discussed under CRM, must integrate closely with fulfillment and be an input for effective demand planning. Again, extended supply chain management requires that we integrate across the macro processes.

Successful ISCM software providers have helped improve decision making within ISCM processes. Good integration with CRM and SRM, however, is still largely inadequate at both the organizational and software levels. Future opportunities are likely to arise partly in improving each ISCM process, but even more so in improving integration with CRM and SRM.

Like CRM, today's ISCM landscape consists of three categories—the former best-of-breed winners, the best-of-breed start-ups, and the ERP players. The ERP players dominate this segment, although this was not always the case. There were two best-of-breed winners, i2 Technologies and Manugistics, which were ISCM pioneers and basically built the category. They showed the power of IT in supply chain management. However, they grew too quickly and spread their product lines across too many products, causing them to lose focus. This allowed the ERP players to improve their functionality relative to the best-of-breed players and eventually to take the supply chain leadership role away from them. Today, these ERP players are the only large players in supply chain IT. Manugistics, i2, and some start-ups still

exist, but the landscape looks to be dominated by SAP and Oracle for the foreseeable future.

16.5 SUPPLIER RELATIONSHIP MANAGEMENT

SRM includes those processes focused on the interaction between the enterprise and suppliers that are upstream in the supply chain. There is a very natural fit between SRM processes and the ISCM processes, as integrating supplier constraints is crucial when creating internal plans. The major SRM processes and the impact of IT on them are discussed in detail in Chapter 14 on sourcing. These processes are the design collaboration, sourcing, negotiation, buy, and supply collaboration processes.

Significant improvement in supply chain performance can be achieved if SRM processes are well integrated with appropriate CRM and ISCM processes. For instance, when designing a product, incorporating input from customers is a natural way to improve the design. This requires inputs from processes within CRM. Sourcing, negotiating, buying, and collaborating tie primarily into ISCM, as the supplier inputs are needed to produce and execute an optimal plan. However, even these segments need to interface with CRM processes such as order management. Again, the theme of integrating the three macro processes is crucial for improved supply chain performance.

As we mentioned in Chapter 14, the SRM space has three groups of competitors. The best-of-breed design collaboration group is headed by Agile and MatrixOne. The best-of-breed "buy" firm is Ariba. And finally, the ERP players SAP and Oracle are major players as well.

Given the youth of the SRM space, the best-of-breed SRM players have not had a chance to develop large functional leads, and their ecosystems are virtually nonexistent. SRM has already attracted all the big players from ERP. As with the other spaces, although best-of-breed players have defined the space and shown where the value can be created, the ERP players have slowly gained in functionality and used their integration and ecosystems to become major players. Therefore, the future SRM landscape is likely to be dominated by these ERP players.

All three macro processes and their processes can be seen in Figure 16-2.

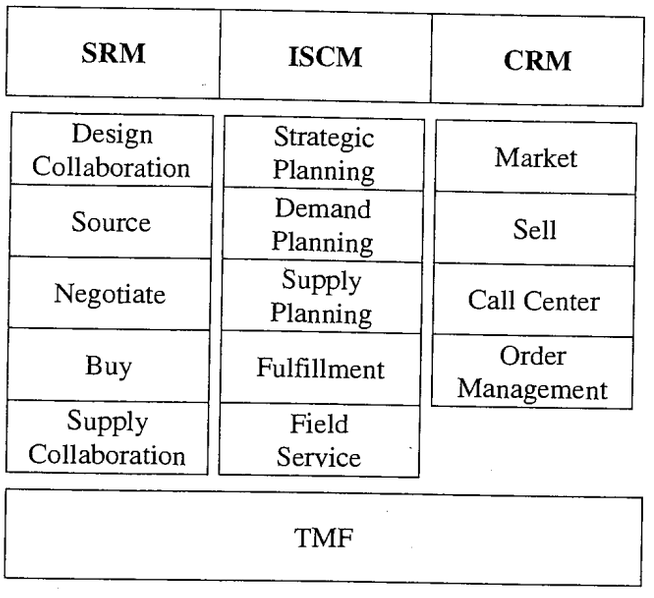


FIGURE 16-2
The Macro Processes and Their Processes

16.6 THE TRANSACTION MANAGEMENT FOUNDATION

The transaction management foundation is the historical home of the largest enterprise software players. In the early 1990s, when much of the thinking in supply chain management was just getting off the ground and ERP systems were rapidly gaining popularity, there was little focus on the three macro processes we discussed earlier. In fact, there was little emphasis on software applications focused on improving decisions. Instead, the focus at that time was on building transaction management and process automation systems that proved to be the foundation for future decision support applications. These systems excelled at the automation of simple transactions and processes as well as the creation of an integrated way to store and view data across the division (and sometimes the enterprise).

The huge demand for these systems during the 1990s drove the ERP players to become the largest enterprise software companies. SAP continued as the market leader, but other powerful ERP players included Oracle, Peoplesoft, JD Edwards, and Baan. Eventually, however, ERP sales slowed, and today, of the former big five, only SAP and Oracle exist as independent entities.

The real value of the transaction management foundation can only be extracted if decision making within the supply chain is improved. Thus, most recent growth in enterprise software has come from companies focused on improving decision making in the three macro processes. This has set the stage for what we are seeing today and will continue to see in the future—the realignment of the ERP companies into CRM, ISCM, and SRM companies. Already, the majority of ERP players' revenue comes from applications in the three macro processes. A major advantage that ERP players have relative to best-of-breed providers is the inherent ability to integrate across the three macro process, often through the transaction management foundation. ERP players that focus on integrating across the macro processes along with developing good functionality in one or more macro process will continue to occupy a position of strength.

16.7 THE FUTURE OF IT IN THE SUPPLY CHAIN

At the highest level, we believe that the three SCM macro processes will continue to drive the evolution of enterprise software. To this end, we expect to see software focused on the macro processes become a larger and larger share of the total enterprise software landscape and software firms that focus on the macro processes to be much more successful than those that focus elsewhere. For firms targeting a macro process, we see functionality, the ability to integrate across macro processes, and the strength of their ecosystems as the keys to success.

This conclusion has important implications for companies that are users of software. As we mentioned earlier, the criteria for successful software companies were chosen precisely because they are the characteristics of software that improve the performance of its users. Thus, a user of supply chain software should first identify areas within the three macro processes where improvement will provide the maximum leverage. Software and IT decisions should then support the goal of improving performance along these processes.

There is one final note worth mentioning with regard to the future of new software players in this area. One might conclude from our analysis that it will be very difficult for a new company to break into the ranks of successful enterprise software companies, given the lead in functionality, integration, and ecosystems that existing firms

already have. We believe, however, that there are two potential paths for a company to enter the market. The first is through superior functionality, whether it be specific functionality needed by a particular industry or an application with vastly improved ease of use. In this area, we see start-ups adding value to enterprise software, although it is a very difficult path to take given the advantages the ERP players hold today.

The other path consists of providing an integrated product that increases the linkages between the macro processes. Certainly, it will be difficult for a start-up to garner the resources to build an integrated product across CRM, ISCM, and SRM. However, a large software company with tremendous resources and a history of pulling disparate products into an integrated package could take this path. The one obvious company here is Microsoft. Microsoft has certainly noticed the growth and size of the enterprise software market and has begun to make a significant effort to enter this space. It has made two acquisitions of over $1B and is showing more signs that this will be a focus in the future. Even with these acquisitions, Microsoft is not yet a significant player in supply chain software and has targeted only small companies as its customers, leaving the large customers and the large revenues to the existing players. Given Microsoft's tried-and-true strategy of going in on the low end and expanding upward, however, it is certainly a company to watch for on the enterprise software landscape.

16.8 RISK MANAGEMENT IN IT

There are several risks associated with the use of IT in the supply chain, and the process of adding new supply chain capabilities with IT can be fraught with danger. The larger the change in the IT system, the greater is the risk of a negative impact on operations. The more ingrained IT becomes in companies, the greater is the risk that the firm will not be able to function properly if IT suffers a major failure. Here we discuss some of the major risks posed by using IT in the supply chain and some ideas for mitigating these risks.

The major areas of risk in IT can be divided into two broad categories. The first, and potentially the greatest, is the risk involved with installing new IT systems. During the process of getting new IT systems running, a firm is forced to transition from the old processes it used in its operations to the new processes in its IT system. Here trouble can be found in both business processes and in technical issues. On the business process side, new IT systems often require employees to operate according to new processes. These may be difficult to learn, take training to execute correctly, or may even be outright resisted by employees who prefer the old way of doing business. Getting the entire organization on board with the changes brought about by a new IT system is particularly difficult because top management is often not actively involved in making this transition. In addition to business process adjustments, there are tremendous technical hurdles to overcome in getting new IT systems operational. The amount of integration that needs to take place between disparate systems is often overwhelming. When a firm switches over to a new system without proper integration, the new system is unable to perform all that was promised and sometimes even performs worse than the system it was replacing. Even when the employees are bought into the new process and all the technical hurdles are overcome, it is often a delicate balance to actually make the transition over to the new system.

A firm still faces risks once its IT systems are operating. This is the second of the two broad categories we mentioned above. The more a firm relies on IT to make decisions and execute processes, the higher is the risk that any sort of IT problem, ranging

from software glitches to power outages to viruses, can completely shut down a firm's operations. These are serious risks that a firm must plan to face. IT also poses a risk in that it tends to set processes in stone. Perhaps a system only allows a process to be executed one way. Then the firm settles into a pattern of always doing this process that way. Obviously, there are great efficiency benefits to this, but the firm also runs the risk that the process is not of the performance level of its competitors and that its systems make it difficult to change to newer, more effective processes.

Each of the major risk categories above has its own mitigation strategies. With regard to implementing IT systems, there are three ideas to keep in mind. The first is to install new IT systems in an incremental fashion rather than in a "big bang" approach. This allows a firm to limit the damage should things go wrong as well as to pinpoint problem areas during the installation process. Second, firms can run duplicate systems to make sure the new system is performing well. By this we mean that the firm can keep its old system running at the same time the new one is running. If new system runs into trouble or if the results seem too far off from the old one, the old system can be utilized as it still exists. In fact, even before the new system is actually executing, it can be simulating (in parallel with the existing system) all the actions it would take. These proposed actions can be monitored to test how the new system will perform when it is actually activated. Finally, implement only the level of complexity that one needs. If you don't need certain capabilities or added complexities, leave them out of the picture, as they can often increase the risk of the project without increasing the potential benefits. In essence, we want to tailor our IT systems to our supply chain needs, with risk reduction being one of those needs.

On the operational side, mitigation strategies include data backup systems, systems running in parallel in case one should suffer a problem, and a range of security software products that can help to keep a company's systems safe. In addition, picking systems that have the flexibility to change if need be can be important.

16.9 SUPPLY CHAIN IT IN PRACTICE

In addition to the sets of practical suggestions for each supply chain macro process discussed earlier, managers need to keep in mind several general ideas when they are making a decision regarding supply chain IT.

1. ***Select an IT system that addresses the company's key success factors.*** Every industry and even companies within an industry can have very different key success factors. By key success factors, we mean the two or three elements that really determine whether or not a company is going to be successful. It is important to select supply chain IT systems that are able to give a company an advantage in the areas most crucial to the success of the business. For instance, the ability to set inventory levels optimally is crucial in the PC business, where product life cycles are short and inventory becomes obsolete very quickly. However, inventory levels are not nearly as crucial for a chemical company, where demand is fairly stable and the product has a very long life cycle. For the chemical company, the key to success depends more on utilization of the production facility. Given these success factors, a PC company might pick a package that is strong in setting inventory levels even if it is weak in maximizing utilization of production capacity. However, the chemical company should choose a different product, one that excels at maximizing utilization even if its inventory components are not especially strong.

2. ***Take incremental steps and measure value.*** Some of the worst IT disasters are due to the fact that companies try to implement IT systems in a wide variety of processes at

the same time and end up with their projects being failures (often called the "big bang" approach). The impact of these failures is amplified by the fact that many of a company's processes are tied up in the same debugging cycle all at once, causing productivity to come to a standstill. One way to help ensure success of IT projects is to design them so that they have incremental steps. For instance, instead of installing a complete supply chain system across your company all at once, start first by getting your demand planning up and running and then move on to supply planning. Along the way, make sure each step is adding value through increases in the performance of the three macro processes. This incremental approach does not mean that one should not take a big-picture perspective (in fact, one *must* take a big-picture perspective) but rather that the big-picture perspective should be implemented in digestible pieces.

3. ***Align the level of sophistication with the need for sophistication.*** Management must consider the depth to which an IT system deals with the firm's key success factors. There is a trade-off between the ease of implementing a system and the system's level of complexity. Therefore, it is important to consider just how much sophistication a company needs to achieve its goals and then ensure that the system chosen matches that level. This is important because erring on the less sophisticated side leaves the firm with a competitive weakness, whereas trying to be too sophisticated leads to a higher possibility of the entire system failing.

4. ***Use IT systems to support decision making, not to make decisions.*** Although the software available today can make many supply chain decisions for management, this does not mean that IT applications can make all of the decisions. A mistake companies can make is installing a supply chain system and then reducing the amount of managerial effort it spends on supply chain issues. Management must keep its focus on the supply chain because as the competitive and customer landscape changes, there needs to be a corresponding change in the supply chain.

5. ***Think about the future.*** Although it is more difficult to make a decision about an IT system with the future in mind than the present, it is very important that managers include the future state of the business in the decision process. If there are trends in a company's industry indicating that insignificant characteristics will become crucial in the future, managers need to make sure their IT choices take these trends into account. As IT systems often last for many more years than was originally planned, managers need to spend time exploring how flexible the systems will be if, or rather when, changes are required in the future. This exploration can go so far as to include the viability of the supply chain software developer itself. If it is unclear whether a company will be able to get support from a software company in the future, management needs to be sure that the other advantages of this product outweigh this disadvantage. The key here is to ensure that the software not only fits a company's current needs but also, and even more important, that it will meet the company's future needs.

16.10 SUMMARY OF LEARNING OBJECTIVES

1. Understand the importance of information and IT in a supply chain.

   Information is essential to making good supply chain decisions because it provides the broad view needed to make optimal decisions. IT provides the tools to gather this information and analyze it to make the best supply chain decisions.

2. Know at a high level how each supply chain driver uses information.

   Each of the supply chain drivers that we have discussed in previous chapters (facilities, inventory, transportation, sourcing, and pricing) require information for decisions to be

made. Information is the factual component on which decisions about each of the other drivers are based. In essence, information is the glue that holds the entire supply chain together and allows it to function, making information the most important supply chain driver.

3. Understand the major applications of supply chain IT and the processes that they enable.

A company's supply chain processes can be grouped into three main macro processes. CRM includes processes that enable interaction between an enterprise and its customers. ISCM includes processes focused on the internal operations of an enterprise. SRM includes processes that enable interaction between an enterprise and its suppliers. IT enables these processes as well as the integration across these processes. Good IT systems allow not only the collection of data across the supply chain, but also the analysis of decisions that maximize supply chain profitability.

Discussion Questions

1. What processes within each macro process are best suited to being enabled by IT? What processes are least suited?
2. What are the key advantages that best-of-breed software companies provide?
3. What are the key advantages that large software companies, such as the ERP players, provide?
4. What types of industries would be most likely to choose a best-of-breed approach to their IT systems? What types would be more likely to choose a single large integrated solution?
5. Discuss why the high-tech industry has been the leader in adopting supply chain IT systems.
6. Are manufacturers better candidates for IT enablement than service organizations? Why or why not?

Bibliography

Chopra, Sunil, and Peter Meindl. "What Will Drive the Enterprise Software Shakeout?" *Supply Chain Management Review* (January–February 2003): 50–6.

Chopra, Sunil, and ManMohan Sodhi. "Managing Supply Chain Risk." *Sloan Management Review* (Fall 2004): 53–61.

Drayer, Ralph, and Robert Wright. "Getting the Most from Your ERP System." *Supply Chain Management Review* (May–June 2002): 44–52.

Escalle, Cedric X., Mark Cotteleer, and Robert D. Austin. *Enterprise Resource Planning, Technology Note.* Harvard Business School Note 9–699–020, 1999.

Meyer, Michelle M. "Why IBM Is Linking Logistics and Information." *Supply Chain Management Review* (September–October 2001): 56–62.

Rutner, Stephen M., Brian J. Gibson, Kate L. Vitasek, and Craig M. Gustin. "Is Technology Filling the Information Gap?" *Supply Chain Management Review* (March–April 2001): 58–64.

Shankar, Venkatesh, and Tony O'Driscoll. "How Wireless Networks Are Reshaping the Supply Chain." *Supply Chain Management Review* (July–August 2002): 44–51.

Soni, Ashok, M. A. Venkataramanan, and Vincent A. Mabert. "Enterprise Resource Planning: Common Myths vs. Evolving Reality." *Business Horizons*, 44(3) (2001): 69–76.

For more information on IT in the supply chain, see *InformationWeek, Line 56,* and *Manufacturing Systems.* In addition, a number of investment banks periodically publish overviews of the enterprise software industry that provide a large amount of useful information on how IT is being used in the supply chain.

CHAPTER 17
COORDINATION IN A SUPPLY CHAIN

Learning Objectives

After reading this chapter, you will be able to:

1. Describe supply chain coordination, the bullwhip effect, and their impact on performance.
2. Identify causes of the bullwhip effect and obstacles to coordination in a supply chain.
3. Discuss managerial levers that help achieve coordination in a supply chain.
4. Describe actions that facilitate the building of strategic partnerships and trust within a supply chain.
5. Understand the different forms of CPFR possible in a supply chain.

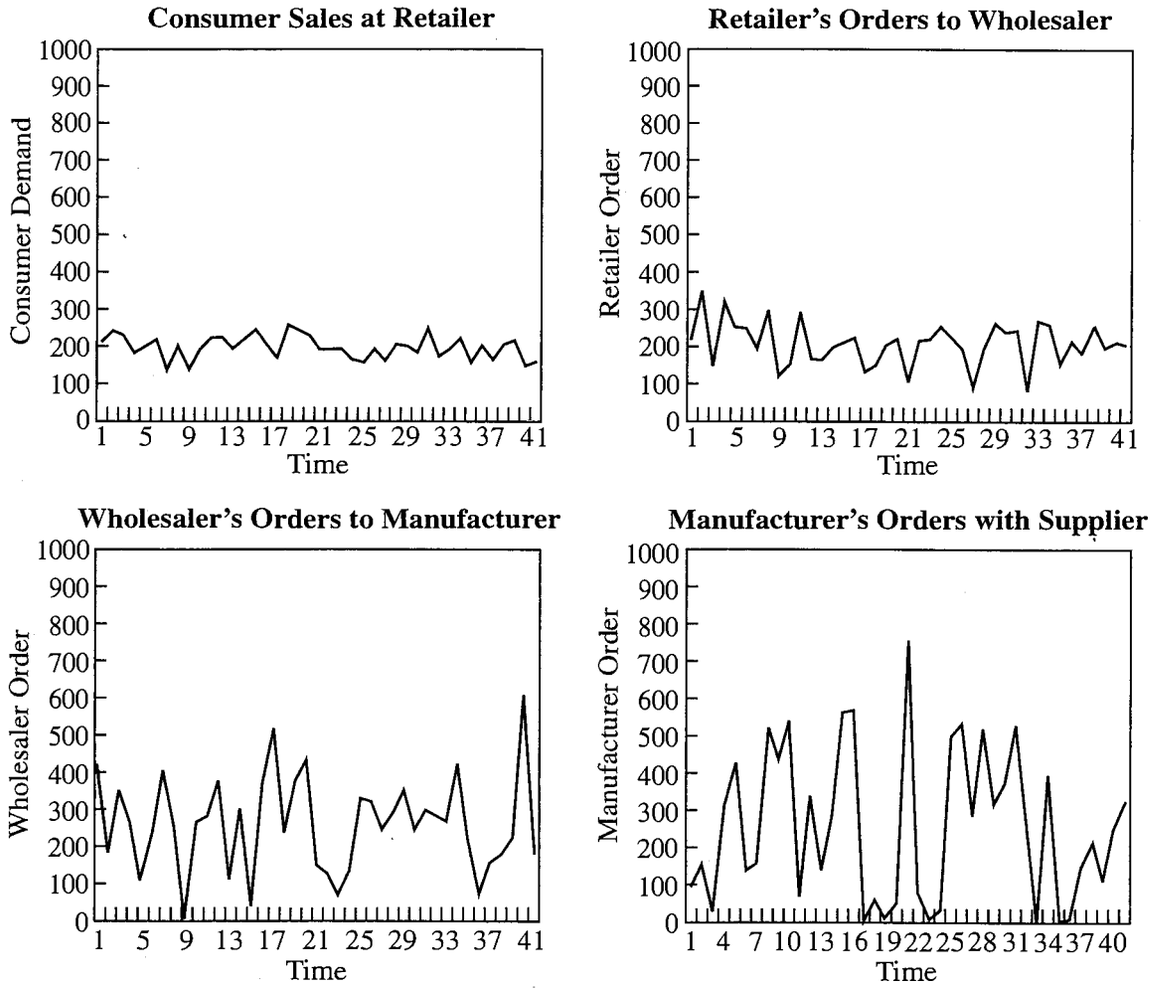
In this chapter, we discuss how lack of coordination leads to a degradation of responsiveness and an increase in cost within a supply chain. We describe various obstacles that lead to this lack of coordination and exacerbate variability through the supply chain. We then identify appropriate managerial levers that can help overcome the obstacles and achieve coordination. In this context, we also discuss actions that facilitate strategic partnerships and the building of trust within a supply chain.

17.1 LACK OF SUPPLY CHAIN COORDINATION AND THE BULLWHIP EFFECT

Supply chain coordination improves if all stages of the chain take actions that together increase total supply chain profits. Supply chain coordination requires each stage of the supply chain to take into account the impact its actions have on other stages.

A lack of coordination occurs either because different stages of the supply chain have objectives that conflict or because information moving between stages is delayed and distorted. Different stages of a supply chain may have conflicting objectives if each stage has a different owner. As a result, each stage tries to maximize its own profits, resulting in actions that often diminish total supply chain profits (see Chapters 10 and 12). Today, supply chains consist of stages with many different owners. For example, Ford Motor Company has thousands of suppliers from Goodyear to Motorola, and each of these suppliers has many suppliers in turn. Information is distorted as it moves across the supply chain because complete information is not shared between stages. This distortion is exaggerated by the fact that supply chains today produce a large amount of product variety. For example, Ford produces many different models with several options for each model. The increased variety makes it difficult for Ford to coordinate information exchange with thousands of suppliers and dealers. The

FIGURE 17-1 Demand Fluctuations at Different Stages of a Supply Chain



fundamental challenge today is for supply chains to achieve coordination in spite of multiple ownership and increased product variety.

Many firms have observed the *bullwhip effect,* in which fluctuations in orders increase as they move up the supply chain from retailers to wholesalers to manufacturers to suppliers, as shown in Figure 17-1.

The bullwhip effect distorts demand information within the supply chain, with each stage having a different estimate of what demand looks like. The result is a loss of supply chain coordination.

Proctor & Gamble (P&G) has observed the bullwhip effect in the supply chain for Pampers diapers.[1] The company found that raw material orders from P&G to its suppliers fluctuated significantly over time. Farther down the chain, when sales at retail stores were studied, it was found that the fluctuations, while present, were small. It is reasonable to assume that the consumers of diapers (babies) at the last stage of the supply chain used them at a steady rate. Although consumption of the end product was stable, orders for raw material were highly variable, increasing costs and making it difficult for supply to match demand.

[1]Lee, Padmanabhan, and Whang (1997).

HP also found that the fluctuation in orders increased significantly as they moved from the resellers up the supply chain to the printer division to the integrated circuit division.[2] Once again, while product demand showed some variability, orders placed with the integrated circuit division were much more variable. This made it difficult for HP to fill orders on time and increased the cost of doing so.

Studies of the apparel and grocery industry have shown a similar phenomenon; the fluctuation in orders increases as we move upstream in the supply chain from retail to manufacturing. Barilla, an Italian manufacturer of pasta, observed that weekly orders placed by a local distribution center fluctuated by up to a factor of 70 in the course of the year, whereas weekly sales at the distribution center (representing orders placed by supermarkets) fluctuated by a factor of less than three.[3] Barilla was thus facing demand that was much more variable than customer demand. This led to increased inventories, poorer product availability, and a drop in profits.

A similar phenomenon, over a longer time frame, has been observed in several industries that are quite prone to "boom and bust" cycles. A good example is the production of memory chips for personal computers. Between 1985 and 1998 there were at least two cycles during which prices of memory chips fluctuated by a factor of more than three. These large fluctuations in price were driven by either large shortages or surpluses in capacity. The shortages were exacerbated by panic buying and overordering that was followed by a sudden drop in demand.

In the next section we consider how lack of coordination affects supply chain performance.

17.2 THE EFFECT ON PERFORMANCE OF LACK OF COORDINATION

A supply chain lacks coordination if each stage optimizes only its local objective, without considering the impact on the complete chain. Total supply chain profits are thus less than what could be achieved through coordination (see Chapters 10 and 12). Each stage of the supply chain, in trying to optimize its local objective, takes actions that end up hurting the performance of the entire supply chain.

Lack of coordination also results if information distortion occurs within the supply chain. Consider the bullwhip effect P&G observed in the diaper supply chain. As a result of the bullwhip effect, orders P&G receives from its distributors are much more variable than demand for diapers at retailers. We discuss the impact of this increase in variability on various measures of performance in the diaper supply chain.

MANUFACTURING COST

The bullwhip effect increases manufacturing cost in the supply chain. As a result of the bullwhip effect, P&G and its suppliers must satisfy a stream of orders that is much more variable than customer demand. P&G can respond to the increased variability by either building excess capacity or holding excess inventory (see Chapter 11), both of which increase the manufacturing cost per unit produced.

[2]Ibid.

[3]Hammond (1994).

INVENTORY COST

The bullwhip effect increases inventory cost in the supply chain. To handle the increased variability in demand, P&G has to carry a higher level of inventory than would be required in the absence of the bullwhip effect. As a result, inventory costs in the supply chain increase. The high levels of inventory also increase the warehousing space required and thus the warehousing cost incurred.

REPLENISHMENT LEAD TIME

The bullwhip effect increases replenishment lead times in the supply chain. The increased variability as a result of the bullwhip effect makes scheduling at P&G and supplier plants much more difficult compared to a situation with level demand. There are times when the available capacity and inventory cannot supply the orders coming in. This results in higher replenishment lead times in the supply chain from both P&G and its suppliers.

TRANSPORTATION COST

The bullwhip effect increases transportation cost in the supply chain. The transportation requirements over time at P&G and its suppliers are correlated with the orders being filled. As a result of the bullwhip effect, transportation requirements fluctuate significantly over time. This raises transportation cost because surplus transportation capacity needs to be maintained to cover high-demand periods.

LABOR COST FOR SHIPPING AND RECEIVING

The bullwhip effect increases labor costs associated with shipping and receiving in the supply chain. Labor requirements for shipping at P&G and its suppliers fluctuate with orders. A similar fluctuation occurs for the labor requirements for receiving at distributors and retailers. The various stages have the option of carrying excess labor capacity or varying labor capacity in response to the fluctuation in orders. Either option increases total labor cost.

LEVEL OF PRODUCT AVAILABILITY

The bullwhip effect hurts the level of product availability and results in more stockouts in the supply chain. The large fluctuations in orders make it harder for P&G to supply all distributor and retailer orders on time. This increases the likelihood that retailers will run out of stock, resulting in lost sales for the supply chain.

RELATIONSHIPS ACROSS THE SUPPLY CHAIN

The bullwhip effect has a negative effect on performance at every stage and thus hurts the relationships between different stages of the supply chain. There is a tendency to assign blame to other stages of the supply chain because each stage feels it is doing the best it can. The bullwhip effect thus leads to a loss of trust between different stages of the supply chain and makes any potential coordination efforts more difficult.

From the earlier discussion, it follows that the bullwhip effect and the resulting lack of coordination have a significant negative impact on the supply chain's performance. The bullwhip effect moves a supply chain away from the efficient frontier by increasing cost and decreasing responsiveness. The impact of the bullwhip effect on different performance measures is summarized in Table 17-1.

TABLE 17-1 Impact of Bullwhip Effect on Supply Chain Performance

Performance Measure	*Impact of Bullwhip Effect*
Manufacturing cost	Increases
Inventory cost	Increases
Replenishment lead time	Increases
Transportation cost	Increases
Shipping and receiving cost	Increases
Level of product availability	Decreases
Profitability	Decreases

KEY POINT The bullwhip effect reduces the profitability of a supply chain by making it more expensive to provide a given level of product availability.

In the next section we discuss various obstacles to achieving coordination in the supply chain.

17.3 OBSTACLES TO COORDINATION IN A SUPPLY CHAIN

Any factor that leads to either local optimization by different stages of the supply chain, or an increase in information delay, distortion, and variability within the supply chain, is an obstacle to coordination. If managers in a supply chain are able to identify the key obstacles, they can then take suitable actions to help achieve coordination. We divide the major obstacles into five categories:

- Incentive obstacles
- Information-processing obstacles
- Operational obstacles
- Pricing obstacles
- Behavioral obstacles

INCENTIVE OBSTACLES

Incentive obstacles occur in situations when incentives offered to different stages or participants in a supply chain lead to actions that increase variability and reduce total supply chain profits.

LOCAL OPTIMIZATION WITHIN FUNCTIONS OR STAGES OF A SUPPLY CHAIN

Incentives that focus only on the local impact of an action result in decisions that do not maximize total supply chain profits. For example, if the compensation of a transportation manager at a firm is linked to the average transportation cost per unit, the manager is likely to take actions that lower transportation costs even if they increase inventory costs or hurt customer service. It is natural for any participant in the supply chain to take actions that optimize performance measures along which they are evaluated. For example, managers at a retailer such as K-Mart make all their purchasing and inventory decisions to maximize K-Mart profits, not total supply chain profits. Buying decisions

based on maximizing profits at a single stage of the supply chain lead to ordering policies that do not maximize supply chain profits (see Chapters 10 and 12).

Sales Force Incentives

Improperly structured sales force incentives are a significant obstacle to coordination in a supply chain. In many firms, sales force incentives are based on the amount the sales force sells during an evaluation period of a month or quarter. The sales typically measured by a manufacturer are the quantity sold to distributors or retailers (sell-in), not the quantity sold to final customers (sell-through). Measuring performance based on sell-in is often justified on the grounds that the manufacturer's sales force does not control sell-through. For example, Barilla offered its sales force incentives based on the quantity sold to distributors during a four- to six-week promotion period. To maximize their bonuses, the Barilla sales force urged distributors to buy more pasta toward the end of the evaluation period, even if distributors were not selling as much to retailers. The sales force offered discounts they controlled to spur end-of-period sales. This increased variability in the order pattern, with a jump in orders toward the end of the evaluation period followed by very few orders at the beginning of the next evaluation period. Order sizes from distributors to Barilla fluctuated by a factor of up to 70 from one week to the next. A sales force incentive based on sell-in thus results in order variability being larger than customer demand variability.

INFORMATION-PROCESSING OBSTACLES

Information-processing obstacles occur in situations when demand information is distorted as it moves between different stages of the supply chain, leading to increased variability in orders within the supply chain.

Forecasting Based on Orders and Not Customer Demand

When stages within a supply chain make forecasts that are based on orders they receive, any variability in customer demand is magnified as orders move up the supply chain to manufacturers and suppliers. In supply chains that exhibit the bullwhip effect, the fundamental means of communication between different stages are the orders that are placed. Each stage views its primary role within the supply chain as one of filling orders placed by its downstream partner. Thus, each stage views its demand as the stream of orders received and produces a forecast based on this information.

In such a scenario, a small change in customer demand becomes magnified as it moves up the supply chain in the form of customer orders. Consider the impact of a random increase in customer demand at a retailer. The retailer may interpret part of this random increase as a growth trend. This interpretation will lead the retailer to order more than the observed increase in demand because the retailer expects growth to continue into the future and thus orders to cover for future anticipated growth. The increase in the order placed with the wholesaler is thus larger than the observed increase in demand at the retailer. Part of the increase is a one-time increase. The wholesaler, however, has no way to interpret the order increase correctly. The wholesaler simply observes a jump in the order size and infers a growth trend. The growth trend inferred by the wholesaler will be larger than that inferred by the retailer (recall that the retailer increased the order size to account for future growth). The wholesaler will thus place an even larger order with the manufacturer. As we go further up the supply chain, the order size will be magnified.

Now assume that periods of random increase are followed by periods of random decrease in demand. Using the same forecasting logic as earlier, the retailer will now anticipate a declining trend and reduce order size. This reduction will also become magnified as we move up the supply chain.

KEY POINT The fact that each stage in a supply chain forecasts demand based on the stream of orders received from the downstream stage results in a magnification of fluctuations in demand as we move up the supply chain from the retailer to the manufacturer.

Lack of Information Sharing

The lack of information sharing between stages of the supply chain magnifies the bullwhip effect. For example, a retailer such as Wal-Mart may increase the size of a particular order because of a planned promotion. If the manufacturer is not aware of the planned promotion, it may interpret the larger order as a permanent increase in demand and place orders with suppliers accordingly. The manufacturer and suppliers thus have a lot of inventory right after Wal-Mart finishes its promotion. Given the excess inventory, as future Wal-Mart orders return to normal, manufacturer orders will be smaller than before. The lack of information sharing between the retailer and manufacturer thus leads to a large fluctuation in manufacturer orders.

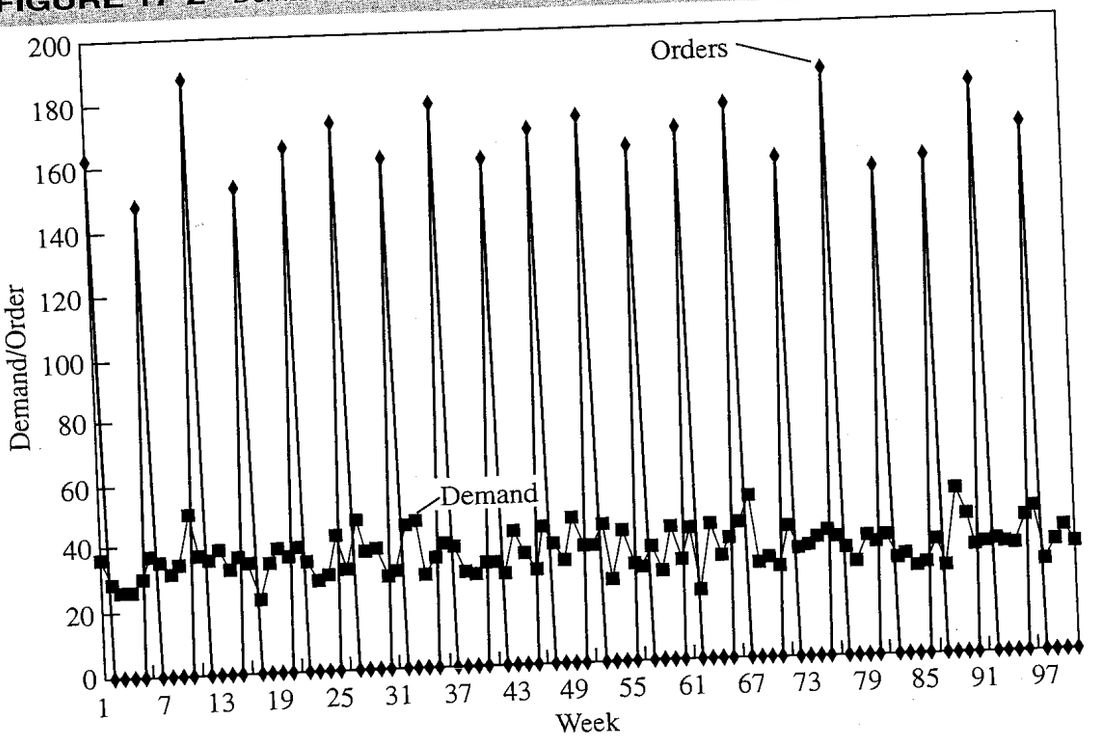
OPERATIONAL OBSTACLES

Operational obstacles occur when actions taken in the course of placing and filling orders lead to an increase in variability.

Ordering in Large Lots

When a firm places orders in lot sizes that are much larger than the lot sizes in which demand arises, variability of orders is magnified up the supply chain. Firms may order in large lots because there is a significant fixed cost associated with placing, receiving, or transporting an order (see Chapter 10). Large lots may also occur if the supplier offers quantity discounts based on lot size (see Chapter 10). Figure 17-2 shows both the

FIGURE 17-2 Demand and Order Stream with Orders Every Five Weeks



demand and the order stream for a firm that places an order every five weeks. Observe that the order stream is far more erratic than the demand stream.

Because orders are batched and placed every five weeks, the order stream has four weeks without orders followed by a large order that equals five weeks of demand. A manufacturer supplying several retailers who batch their orders faces an order stream that is much more variable than the demand the retailers experience. If the manufacturer further batches its orders to suppliers, the effect is further magnified. In many instances there are certain focal-point periods, such as the first or the last week of a month, when a majority of the orders arrive. This concentration of orders further exacerbates the impact of batching.

Large Replenishment Lead Times

The bullwhip effect is magnified if replenishment lead times between stages are long. Consider a situation in which a retailer has misinterpreted a random increase in demand as a growth trend. If the retailer faces a lead time of two weeks, it will incorporate the anticipated growth over two weeks when placing the order. In contrast, if the retailer faces a lead time of two months, it will incorporate into its order the anticipated growth over two months (which will be much larger). The same applies when a random decrease in demand is interpreted as a declining trend.

Rationing and Shortage Gaming

Rationing schemes that allocate limited production in proportion to the orders placed by retailers lead to a magnification of the bullwhip effect. This can occur when a high-demand product is in short supply. HP, for example, has faced many situations in which a new product has demand that far exceeds supply. In such a situation, manufacturers come up with a variety of mechanisms to ration the scarce supply of product among various distributors or retailers. One commonly used rationing scheme is to allocate the available supply of product based on orders placed. Under this rationing scheme, if the supply available is 75 percent of the total orders received, each retailer receives 75 percent of its order.

This rationing scheme results in a game in which retailers try to increase the size of their orders to increase the amount supplied to them. A retailer needing 75 units orders 100 units in the hope of getting 75. The net impact of this rationing scheme is to artificially inflate orders for the product. In addition, a retailer ordering based on what it expects to sell gets less and as a result loses sales, whereas a retailer that inflates its order is rewarded.

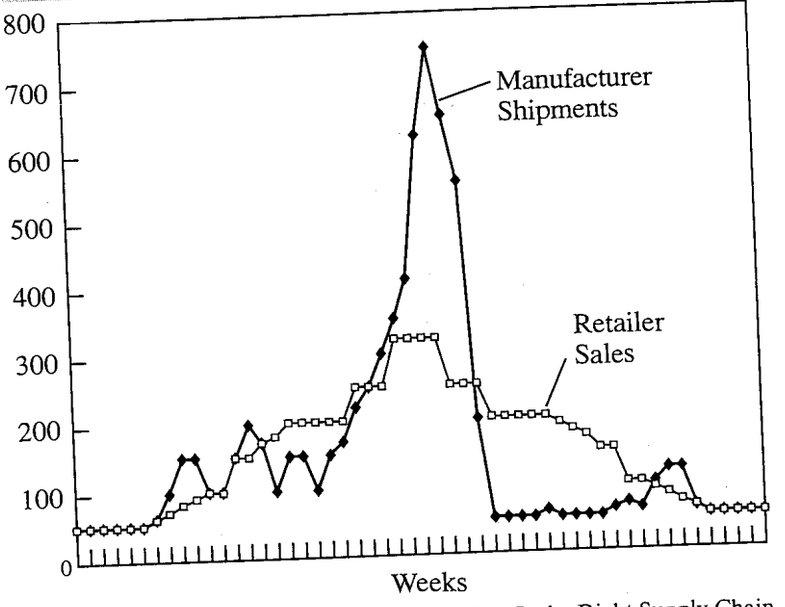
If the manufacturer is using orders to forecast future demand, it will interpret the increase in orders as an increase in demand even though customer demand is unchanged. The manufacturer may respond by building enough capacity to be able to fill all orders received. Once sufficient capacity becomes available, orders return to their normal level because they were inflated in response to the rationing scheme. The manufacturer is now left with a surplus of product and capacity. These boom-and-bust cycles then tend to alternate.

This phenomenon is fairly common in the computer industry, in which alternating periods of component shortages followed by a component surplus are often observed. In particular, memory chip manufacturing has experienced a couple of such cycles over the last decade.

PRICING OBSTACLES

Pricing obstacles arise when the pricing policies for a product lead to an increase in variability of orders placed.

FIGURE 17-3 Retailer Sales and Manufacturer Shipments of Soup



Source: Adapted from Marshall L. Fisher, "What Is the Right Supply Chain for Your Product?" *Harvard Business Review* (March–April 1997): 83–93.

Lot Size–Based Quantity Discounts

Lot size–based quantity discounts increase the lot size of orders placed within the supply chain (see Chapter 10). As discussed earlier, the resulting large lots magnify the bullwhip effect within the supply chain.

Price Fluctuations

Trade promotions and other short-term discounts offered by a manufacturer result in forward buying, by which a wholesaler or retailer purchases large lots during the discounting period to cover demand during future periods. Forward buying results in large orders during the promotion period followed by very small orders after that (see Chapter 10), as shown in Figure 17-3 for chicken noodle soup.

Observe that the shipments during the peak period are higher than the sales during the peak period because of a promotion offered during this period. The peak shipment period is followed by a period of very low shipments from the manufacturer, indicating significant forward buying by distributors. The promotion thus results in a variability in manufacturer shipments that is significantly higher than the variability in retailer sales.

BEHAVIORAL OBSTACLES

Behavioral obstacles are problems in learning within organizations that contribute to the bullwhip effect. These problems are often related to the way the supply chain is structured and the communications between different stages. Some of the behavioral obstacles are as follows.

1. Each stage of the supply chain views its actions locally and is unable to see the impact of its actions on other stages.

2. Different stages of the supply chain react to the current local situation rather than trying to identify the root causes.
3. Based on local analysis, different stages of the supply chain blame each other for the fluctuations, with successive stages in the supply chain becoming enemies rather than partners.
4. No stage of the supply chain learns from its actions over time because the most significant consequences of the actions any one stage takes occur elsewhere. The result is a vicious cycle in which actions taken by a stage create the very problems that the stage blames on others.
5. A lack of trust among supply chain partners causes them to be opportunistic at the expense of overall supply chain performance. The lack of trust also results in significant duplication of effort. More important, information available at different stages is either not shared or is ignored because it is not trusted.

17.4 MANAGERIAL LEVERS TO ACHIEVE COORDINATION

Having identified obstacles to coordination, we now focus on actions a manager can take to help overcome the obstacles and achieve coordination in the supply chain. The following managerial actions increase total supply chain profits and moderate the bullwhip effect.

- Aligning of goals and incentives
- Improving information accuracy
- Improving operational performance
- Designing pricing strategies to stabilize orders
- Building partnerships and trust

ALIGNING OF GOALS AND INCENTIVES

Managers can improve coordination within the supply chain by aligning goals and incentives so that every participant in supply chain activities works to maximize total supply chain profits.

Aligning Incentives Across Functions

One key to coordinated decisions within a firm is to ensure that the objective any function uses to evaluate a decision is aligned with the firm's overall objective. All facility, transportation, and inventory decisions should be evaluated based on their effect on profitability, not total costs, or even worse, just local costs. This helps avoid situations such as a transportation manager making decisions that lower transportation cost but increase overall supply chain costs (see Chapter 13).

Pricing for Coordination

A manufacturer can use lot size–based quantity discounts to achieve coordination for commodity products if the manufacturer has large fixed costs associated with each lot (see Chapter 10). For products for which a firm has market power, a manager can use two-part tariffs and volume discounts to help achieve coordination (see Chapter 10). Given demand uncertainty, manufacturers can use buy-back, revenue-sharing, and quantity flexibility contracts to spur retailers to provide levels of product availability that maximize supply chain profits. Buy-back contracts have been used in the publishing industry to increase total supply chain profits. Quantity flexibility contracts have helped Benetton increase supply chain profits.

Altering Sales Force Incentives from Sell-In to Sell-Through

Any change that reduces the incentive for a salesperson to push product to the retailer reduces the bullwhip effect. If sales force incentives are based on sales over a rolling horizon, the incentive to push product is reduced. This helps reduce forward buying and the resulting fluctuation in orders. Managers can also link incentives for the sales staff to sell-through by the retailer rather than sell-in to the retailer. This action eliminates any motivation the sales staff may have to encourage forward buying. Elimination of forward buying helps reduce fluctuations in the order stream.

IMPROVING INFORMATION ACCURACY

Managers can achieve coordination by improving the accuracy of information available to different stages in the supply chain.

Sharing Point-of-Sale Data

Sharing point-of-sale (POS) data across the supply chain can help reduce the bullwhip effect. A primary cause for the bullwhip effect is the fact that each stage of the supply chain uses orders to forecast future demand. Given that orders received by different stages vary, forecasts at different stages also vary. In reality, the only demand that the supply chain needs to satisfy is from the final customer. If retailers share POS data with other supply chain stages, all supply chain stages can forecast future demand based on customer demand. Sharing of POS data helps reduce the bullwhip effect because all stages now respond to the same change in customer demand. Observe that sharing aggregate POS data is sufficient to dampen the bullwhip effect. We do not necessarily need to share detailed POS data. Use of appropriate information systems facilitates the sharing of such data (see Chapter 16).

Companies can also use the Internet to share data with suppliers. For direct-sales companies such as Dell, and companies involved in e-commerce, POS data are available in a form that can easily be shared. Dell shares demand data as well as current inventory positions of components with many of its suppliers via the Internet, thereby helping to avoid unnecessary fluctuations in supply and orders placed. P&G has convinced many retailers to share demand data. P&G in turn shares the data with its suppliers, improving coordination in the supply chain.

Implementing Collaborative Forecasting and Planning

Once point-of-sale data are shared, different stages of the supply chain must forecast and plan jointly if complete coordination is to be achieved. Without collaborative planning, sharing of POS data does not guarantee coordination. A retailer may have observed large demand in the month of January because it ran a promotion. If no promotion is planned in the upcoming January, the retailer's forecast will differ from the manufacturer's forecast even if both have past POS data. The manufacturer must be aware of the retailer's promotion plans to achieve coordination. The key is to ensure that the entire supply chain is operating with a common forecast. To facilitate this type of coordination in the supply chain environment, the Voluntary Interindustry Commerce Standards (VICS) Association has set up a Collaborative Planning, Forecasting, and Replenishment (CPFR) committee to identify best practices and design guidelines for collaborative planning and forecasting. These practices are detailed later in the chapter.

Designing Single-Stage Control of Replenishment

Designing a supply chain in which a single stage controls replenishment decisions for the entire supply chain can help diminish the bullwhip effect. As we mentioned earlier, a key cause of the bullwhip effect is the fact that each stage of the supply chain uses

orders from the previous stage as its historical demand. As a result, each stage views its role as one of replenishing orders placed by the next stage. In reality, the key replenishment is at the retailer, because that is where the final customer purchases. When a single stage controls replenishment decisions for the entire chain, the problem of multiple forecasts is eliminated and coordination within the supply chain follows.

For a manufacturer such as Dell that sells directly to customers, single control of replenishment is automatic because there is no intermediary between the manufacturer and the customer. The manufacturer automatically becomes the single point of control for replenishment decisions. When sales occur through retailers, there are several industry practices such as continuous replenishment programs (CRP) and vendor-managed inventories (VMI) that are detailed later in the chapter.

IMPROVING OPERATIONAL PERFORMANCE

Managers can help dampen the bullwhip effect by improving operational performance and designing appropriate product rationing schemes in case of shortages.

Reducing Replenishment Lead Time

By reducing the replenishment lead time, managers can decrease the uncertainty of demand during the lead time (see Chapter 11). A reduction in lead time is especially beneficial for seasonal items because it allows for multiple orders to be placed in the season with a significant increase in the accuracy of the forecast (see Chapter 12). Thus, a reduction in replenishment lead time helps dampen the bullwhip effect by reducing the underlying uncertainty of demand.

Managers can take a variety of actions at different stages of the supply chain to help reduce replenishment lead times. Ordering electronically, either through e-commerce on the Internet or through older methods such as electronic data interchange (EDI), can significantly cut the lead time associated with order placement and information transfer. At manufacturing plants, increased flexibility and cellular manufacturing can be used to achieve a significant reduction in lead times. A dampening of the bullwhip effect further reduces lead times because of stabilized demand and, as a result, improved scheduling. This is particularly true when manufacturing produces a large variety of products. ASNs can be used to reduce the lead time as well as effort associated with receiving. Cross-docking can be used to reduce the lead time associated with moving the product between stages in the supply chain. Wal-Mart has used many of the aforementioned approaches to significantly reduce lead time within its supply chain.

Reducing Lot Sizes

Managers can dampen the bullwhip effect by implementing operational improvements that reduce lot sizes. A reduction of lot sizes decreases the amount of fluctuation that can accumulate between any pair of stages of a supply chain, thus decreasing the bullwhip effect. To reduce lot sizes, managers must take actions that help reduce the fixed costs associated with ordering, transporting, and receiving each lot (see Chapter 10). Wal-Mart and Seven-Eleven Japan have been very successful at reducing replenishment lot sizes by aggregating deliveries across many products and suppliers.

Computer-assisted ordering (CAO) refers to the substitution through technology of the functions of a retail order clerk in preparing an order through the use of computers that integrate information about product sales, market factors affecting demand, inventory levels, product receipts, and desired service levels. CAO and EDI help reduce the fixed costs associated with placing each order. Today, the growing use of Web-based ordering by companies such as W.W. Grainger and McMaster-Carr has

facilitated ordering in small lots because of reduced ordering costs for customers and reduced fulfillment costs for companies themselves. The growth of B2B e-commerce is also reducing ordering costs. For example, General Motors and Ford will require many of their suppliers to be equipped to receive orders on the Web in an attempt to make ordering more efficient. More discussion of this idea is included in Chapter 16.

In some cases, managers can simplify ordering by eliminating the use of purchase orders. In the auto industry, some suppliers are paid based on the number of cars produced, eliminating the need for individual purchase orders. This eliminates the order processing cost associated with each replenishment order. Information systems also facilitate the settlement of financial transactions, eliminating the cost associated with individual purchase orders.

The large gap in the prices of TL and LTL shipping encourages shipment in TL quantities. In fact, with the efforts to reduce order processing costs, transportation costs are now the major barrier to smaller lots in most supply chains. Managers can reduce lot sizes without increasing transportation costs by filling a truck using smaller lots from a variety of products (see Chapter 10). P&G, for example, requires all orders from retailers to be a full TL. The TL, however, may be built from any combination of products. A retailer can thus order small lots of each product as long as a sufficiently large variety of products is included on each truck. Seven-Eleven Japan has used this strategy with combined trucks, where the separation is by the temperature at which the truck is maintained. All products to be shipped at a particular temperature are on the same truck. This has allowed Seven-Eleven Japan to reduce the number of trucks sent to retail outlets while keeping product variety high. Some firms in the grocery industry use trucks with different compartments, each at a different temperature and carrying a variety of products, to help reduce lot sizes.

Managers can also reduce lot sizes by using milk runs that combine shipments for several retailers on a single truck, as we saw in Chapter 13. In many cases third-party transporters combine shipments to competing retail outlets on a single truck. This reduces the fixed transportation cost per retailer and allows each retailer to order in smaller lots. In Japan, Toyota uses a single truck from a supplier to supply multiple assembly plants, which enables managers to reduce the lot size received by any one plant. Managers can also reduce lot sizes by combining shipments from multiple suppliers on a single truck. In the United States, Toyota uses this approach to reduce the lot size it receives from any one supplier.

As smaller lots are ordered and delivered, both the pressure on and the cost of receiving can grow significantly. Thus, managers must implement technologies that simplify the receiving process and reduce the cost associated with receiving. For example, ASNs identify shipment content, count, and time of delivery electronically and help reduce unloading time and increase cross-dock efficiency. ASNs can be used to update inventory records electronically, thus reducing the cost of receiving. Bar coding of pallets also facilitates receiving and delivery. DEX and NEX are two receiving technologies that allow the direct updating of inventory records once the item count has been verified.

Each of these technologies works to simplify the task of shipping, transporting, and receiving complex orders with small lots of many products. This facilitates the reduction of lot size, counteracting the bullwhip effect.

Another simple way to minimize the impact of batching is to encourage different customers to order in such a way that demand is evenly distributed over time. Frequently, customers that order once a week tend to do so on either a Monday or Friday. Customers that order once a month tend to do so either at the beginning or the end of the month. In such situations it is better to evenly distribute customers ordering once a week across all days of the week, and customers ordering once a month across

all days of the month. In fact, regular ordering days may be scheduled in advance for each customer. This generally does not affect retailers, but it does level out the order stream arriving at the manufacturer, thus dampening the bullwhip effect.

Rationing Based on Past Sales and Sharing Information to Limit Gaming

To diminish the bullwhip effect, managers can design rationing schemes that discourage retailers from artificially inflating their orders in the case of a shortage. One approach, referred to as *turn-and-earn,* is to allocate the available supply based on past retailer sales rather than current retailer orders. Tying allocation to past sales removes any incentive a retailer may have to inflate orders, as a result dampening the bullwhip effect. In fact, during low-demand periods, the turn-and-earn approach pushes retailers to try and sell more to increase the allocation they receive during periods of shortage. Several firms, including General Motors, have historically used the turn-and-earn mechanism to ration available product in case of a shortage. Others, such as HP, have historically allocated based on retailer orders but are now switching to using past sales.

Other firms have tried to share information across the supply chain to minimize shortage situations. Firms such as Sport Obermeyer offer incentives to their large customers to preorder at least a part of their annual order. This information allows Sport Obermeyer to improve the accuracy of its own forecast and allocate production capacity accordingly. Once capacity has been allocated appropriately across different products, it is less likely that shortage situations will arise, thus dampening the bullwhip effect. The availability of flexible capacity can also help in this regard, because flexible capacity can easily be shifted from a product whose demand is lower than expected to one whose demand is higher than expected.

DESIGNING PRICING STRATEGIES TO STABILIZE ORDERS

Managers can diminish the bullwhip effect by devising pricing strategies that encourage retailers to order in smaller lots and reduce forward buying.

Moving from Lot Size–Based to Volume-Based Quantity Discounts

As a result of lot size–based quantity discounts, retailers increase their lot size to take full advantage of the discount. Offering volume-based quantity discounts eliminates the incentive to increase the size of a single lot because volume-based discounts consider the total purchases during a specified period (say, a year) rather than purchases in a single lot (see Chapter 10). Volume-based quantity discounts result in smaller lot sizes, thus reducing order variability in the supply chain. Volume-based discounts with a fixed end date at which discounts will be evaluated may lead to large lots close to the end date. Offering the discounts over a rolling time horizon helps dampen this effect. HP is experimenting with a move away from lot size–based discounts to volume-based discounts.

Stabilizing Pricing

Managers can dampen the bullwhip effect by eliminating promotions and charging an EDLP. The elimination of promotions removes forward buying by retailers and results in orders that match customer demand. P&G, Campbell Soup, and several other manufacturers have implemented EDLP to dampen the bullwhip effect.

Managers can place limits on the quantity that may be purchased during a promotion to decrease forward buying. This limit should be retailer specific and linked to historical sales by the retailer. Another approach is to tie the promotion dollars paid to the retailer to the amount of sell-through rather than the amount purchased by the retailer. As a result, retailers obtain no benefit from forward buying and purchase more only if they can sell more. Promotions based on sell-through significantly dampen the bullwhip

effect. The presence of specific information systems facilitates the tying of promotions directly to customer sales.

BUILDING STRATEGIC PARTNERSHIPS AND TRUST

Managers find it easier to use the levers discussed earlier to diminish the bullwhip effect and achieve coordination if trust and strategic partnerships are built within the supply chain. Sharing of accurate information that is trusted by every stage results in a better matching of supply and demand throughout the supply chain and a lower cost. A better relationship also tends to lower the transaction cost between supply chain stages. For example, a supplier can eliminate its forecasting effort if it trusts orders and forecast information received from the retailer. Similarly, the retailer can lessen the receiving effort by decreasing counting and inspections if it trusts the supplier's quality and delivery. In general, stages in a supply chain can eliminate duplicated effort on the basis of improved trust and a better relationship. This lowering of transaction cost along with accurate shared information helps mitigate the bullwhip effect. Wal-Mart and P&G have been trying to build a strategic partnership that will be mutually beneficial and help reduce the bullwhip effect.

Managerial levers that help a supply chain achieve better coordination fall into two broad categories. *Action-oriented levers* include information sharing, changing of incentives, operational improvements, and stabilization of pricing. *Relationship-oriented levers* involve the building of cooperation and trust within the supply chain. In the next section we discuss relationship-oriented levers in greater detail.

17.5 BUILDING STRATEGIC PARTNERSHIPS AND TRUST WITHIN A SUPPLY CHAIN

A *trust-based relationship* between two stages of a supply chain includes *dependability* of the two stages, and the ability of each stage to make a *leap of faith*.[4] Trust involves a belief that each stage is interested in the others' welfare and will not take actions without considering their impact on the other stages. Cooperation and trust within the supply chain help improve performance for the following reasons.

1. When stages trust each other, they are more likely to take the other party's objectives into consideration when making decisions.
2. Action-oriented managerial levers to achieve coordination become easier to implement. Sharing of information is natural between parties that trust each other. Similarly, operational improvements are easier to implement and appropriate pricing schemes are easier to design if both parties are aiming for the common good.
3. An increase in supply chain productivity results, either by elimination of duplicated effort or by allocating effort to the appropriate stage. For example, a manufacturer receives material from a supplier without inspecting it if the supplier shares process control charts. Another example might be a situation in which a distributor aids the postponement strategy of a manufacturer by performing customization just before the point of sale.
4. A greater sharing of detailed sales and production information results. This sharing allows the supply chain to coordinate production and distribution decisions. As a result, the supply chain is better able to match supply and demand, resulting in better coordination.

[4]See Kumar (1996).

TABLE 17-2 Comparison of Retailers by Level of Trust

Measure of Comparison	*Low Trust*	*High Trust*
Retailers' development of alternative supply sources	100	78
Retailers' commitment to the manufacturer	100	112
Retailers' sales of manufacturer product line	100	178
Retailers' performance as rated by manufacturer	100	111

Source: Adapted from N. Kumar, "The Power of Trust in Manufacturer-Retailer Relationships," *Harvard Business Review* (November–December 1996): 92–106.

The benefits of trust are highlighted in Table 17-2 in the context of a replacement automotive parts supply chain. The table contains average ratings of over 400 retailers classified into low or high categories (and scaled relative to the level of low-trust respondents) based on their trust in the manufacturer. For example, the average retailer with high trust toward its manufacturers developed fewer alternative supply sources, was more committed to the manufacturer, sold more of the manufacturer's products, and was rated higher by the manufacturer. It also highlights that the retailers themselves were likely happier when they had greater trust in the manufacturer because they were less likely to search for alternative supply sources.

Historically, supply chain relationships have been based on either power or trust. In a power-based relationship, the stronger party dictates its view. Although exploiting power may be advantageous in the short term, its negative consequences are felt in the long term for three main reasons:

1. Exploiting power often results in one stage of the supply chain maximizing its profits, often at the expense of other stages. This decreases total supply chain profits.
2. Exploiting power to extract unfair concessions can hurt a company once the balance of power changes. This reversal of power has occurred over the last two decades, with retailers in Europe and the United States becoming more powerful than manufacturers in many supply chains.
3. When a stage of a supply chain systematically exploits its power advantage, the other stages seek ways to resist. In many instances in which retailers have tried to exploit their power, manufacturers have sought ways to access the consumer directly. These include selling over the Internet and setting up company stores. The result can be a decrease in supply chain profits because different stages are competing rather than cooperating.

Although everybody agrees that cooperation and trust in a supply chain are valuable, these qualities are very hard to initiate and sustain. There are two views regarding how cooperation and trust can be built into any supply chain relationship:

- ***Deterrence-based view.*** In this view the parties involved use a variety of formal contracts to ensure cooperation. With the contracts in place, parties are assumed to behave in a trusting manner purely for reasons of self-interest.
- ***Process-based view.*** With this view, trust and cooperation are built over time as a result of a series of interactions between the parties involved. Positive interactions strengthen the belief in the cooperation of the other party.

In most practical situations, neither view holds exclusively. It is impossible to design a contract that will take into account every contingency that may arise in the future. Thus, parties that may not yet trust each other have to rely on the building of trust to resolve issues that are not included in the contract. Conversely, parties that

trust each other and have a long relationship still rely on contracts. In most effective partnerships, a combination of the two approaches is used. An example is the situation in which suppliers sign an initial contract containing contingencies with manufacturers and then the manufacturers never want to refer to the contract again. Their hope is that all contingencies can be resolved through negotiation in a way that is best for the supply chain.

In most strong supply chain relationships, the initial period often relies more on the deterrence-based view. Over time, the relationship evolves toward a greater reliance on the process-based view. From the supply chain perspective, the ideal goal is *co-identification,* in which each party considers the other party's objective as its own. Co-identification ensures that each stage accounts for total supply chain profits when making decisions.

There are two phases to any long-term supply chain relationship. In the *design phase,* ground rules are established and the relationship is initiated. In the *management phase,* interactions based on the ground rules occur and the relationship as well as the ground rules evolve. A manager seeking to build a supply chain relationship must consider how cooperation and trust can be encouraged during both phases of the relationship. Careful consideration is very important, because in most supply chains, power tends to be concentrated in relatively few hands. The concentration of power often leads managers to ignore the effort required to build trust and cooperation, hurting supply chain performance in the long term.

Next we discuss how a manager can design a supply chain relationship to encourage cooperation and trust.

DESIGNING A RELATIONSHIP WITH COOPERATION AND TRUST

The key steps in designing effective supply chain partnerships are as follows:

1. Assessing the value of the relationship
2. Identifying operational roles and decision rights for each party
3. Creating effective contracts
4. Designing effective conflict resolution mechanisms

Assessing the Value of the Relationship

The first step in designing a supply chain relationship is to clearly identify the mutual benefit that the relationship provides. In most supply chains, each member of the partnership brings distinct skills, all of which are needed to supply a customer order. For example, a manufacturer produces the product, a carrier transports it between stages, and a retailer makes the product available to the final customer. The next step is to identify the criteria used for evaluating the relationship as well as the contribution of each party. A common criterion is the increase in total profits as a result of the relationship. *Equity,* defined here as "fair dealing," should be another important criterion when evaluating and designing a relationship.[5] Equity measures the fairness of the division of the total profits among the parties involved.

Stages of the supply chain are unlikely to work at utilizing the various managerial levers that achieve coordination unless they are confident that the resulting increase in profits will be shared equitably. For example, when suppliers work hard to reduce replenishment lead times, the supply chain benefits because of reduced safety inventories at manufacturers and retailers. Suppliers are unlikely to put in the effort if

[5]Ring and Van de Ven (1994).

the manufacturers and retailers are not willing to share the increase in profits with them. Thus, a supply chain relationship is likely to be sustainable only if it increases total profits and this increase is shared equitably among the parties involved.

The next step is to clarify the contribution of each party as well as the benefits that will accrue to each. For example, if a manufacturer and distributor are to implement postponement together, it is important to clarify the role of each party in implementing postponement, the value of this strategy to the supply chain, and how the increased profits are to be shared between the parties. Flexible mechanisms should be designed that allow the partners to monitor the relationship periodically and adjust both contributions and the allocation of resulting benefits. For example, DiamlerChrysler negotiates a certain level of improvement per year with each supplier. It does not, however, specify areas within which the improvement must be achieved. This flexibility allows suppliers to identify areas where the largest improvement can result with the minimum effort and creates a win–win situation for both sides.

Identifying Operational Roles and Decision Rights for Each Party

When identifying operational roles and decision rights for different parties in a supply chain relationship, managers must consider the resulting interdependence between the parties. A source of conflict may arise if the tasks are divided in a way that makes one party more dependent on the other. In many partnerships, an inefficient allocation of tasks results simply because neither party is willing to give the other a perceived upper hand based on the tasks assigned.

The allocation of tasks results in a *sequential interdependence* if the activities of one partner precede the other. Traditionally, supply chain relationships have been sequential, with one stage completing all its tasks and then handing off to the next stage. In *reciprocal interdependence,* parties come together and exchange information and inputs in both directions. P&G and Wal-Mart are attempting to create reciprocal interdependence through collaborative forecasting and replenishment teams. The teams contain people from both Wal-Mart and P&G. Wal-Mart brings in demand information and P&G brings in information on available capacity. The teams then decide on the production and replenishment policy that is best for the supply chain.

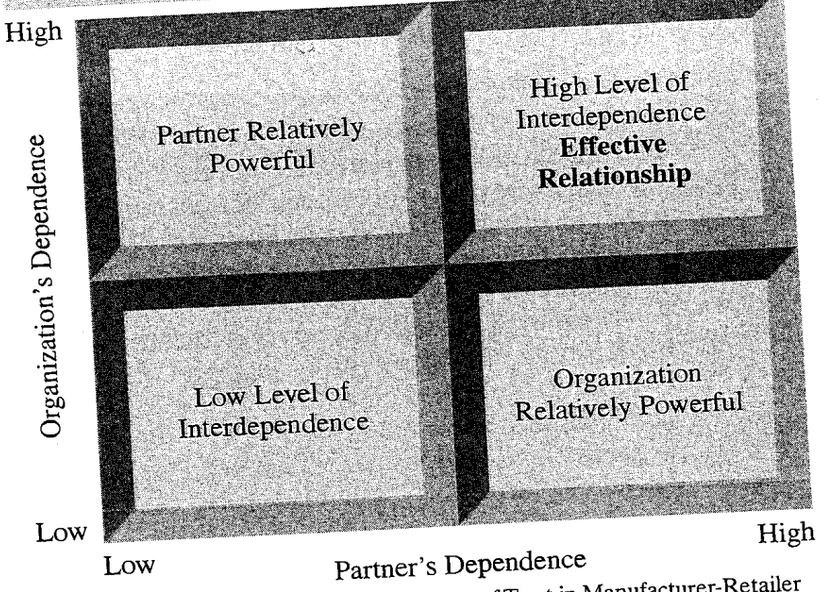
Reciprocal interdependence requires a significant effort to manage and can increase transaction costs if not managed properly. However, reciprocal interdependence is more likely to result in decisions that maximize supply chain profitability because all decisions must take the objectives of both parties into account. Thus, greater reciprocal interdependence in the allocation of operational roles and decision rights increases the chances of an effective relationship, as shown in Figure 17-4.

Managers must ensure that tasks that are required from each party for a successful handoff of the product from one to the other are well defined. Consider the relationship among Dell, Sony, and Airborne. Dell takes orders for computers it assembles and monitors that Sony manufactures. Airborne picks up computers from the Dell warehouse in Texas and monitors from the Sony warehouse in Mexico. It then merges the two and sends a combined order to the customer. For an order to be filled on time, all three parties must coordinate and complete their tasks. To achieve cooperation, managers must also put in place some mechanism, such as appropriate information systems, that helps accurately track all failures to their source.

Creating Effective Contracts

Managers can help promote trust by creating contracts that encourage negotiation as unplanned contingencies arise. Contracts are most effective for governance when *complete information* is available and all future contingencies can be accounted for. In

FIGURE 17-4 Effect of Interdependence on Supply Chain Relationships



Source: Adapted from N. Kumar, "The Power of Trust in Manufacturer-Retailer Relationships," *Harvard Business Review* (November–December 1996): 92–106.

practice, uncertainty with respect to the future makes it impossible to design a contract with all contingencies included. Thus, it is essential that the supplier and the retailer develop a relationship that allows trust to compensate for gaps in the contract.

The relationship often develops initially between individuals that have been assigned from each side. Over time, the informal understandings and commitments between the individuals tend to be formalized when new contracts are drawn up. When designing the partnership and initial contract, it should be understood that informal understandings will operate side by side and these will contribute to the development of the formal contract over time. Thus, contracts that evolve over time are likely to be much more effective than contracts that are completely defined at the beginning of the partnership.

Over the long term, contracts can only play a partial role in maintaining effective partnerships in a supply chain. A good example is the relationship between Caterpillar and its dealerships, in which either the dealer or Caterpillar can terminate agreements without cause with 90 days' notice. Clearly it is not the contract alone that keeps the relationship effective. A combination of a contract, the mutual benefit of the relationship, along with trust that compensates for gaps in the contract, results in effective supply chain partnerships.

Designing Effective Conflict-Resolution Mechanisms

Effective conflict-resolution mechanisms can significantly strengthen any supply chain relationship. Conflicts are bound to arise in any relationship. Unsatisfactory resolutions cause the partnership to worsen, whereas satisfactory resolutions strengthen the partnership. A good conflict-resolution mechanism should give the parties an opportunity to communicate and work through their differences, in the process building greater trust.

An initial formal specification of rules and guidelines for financial procedures and technological transactions can help build trust between partners. The specification of

rules and guidelines facilitates the sharing of information among the partners in the supply chain. The sharing of information over time helps move the relationship from deterrence-based trust to process-based trust. Once process-based trust is built between the parties, it facilitates conflict resolution.

To facilitate communication, frequent meetings should be held between managers and staff assigned to the partnership. These meetings allow issues to be raised and discussed before they turn into major conflicts. They also provide a basis for resolution at a higher level, should resolution not take place at the lower level. An important goal of meetings and other formal conflict-resolution mechanisms is to ensure that disputes about financial or technological issues do not turn into interpersonal squabbles.

When designing conflict-resolution mechanisms, it is important to be sensitive to the context of the partnership. In the United States, parties are sometimes comfortable returning to the detailed contract to resolve a dispute. The help of a court or an intermediary can also be sought to interpret the contract. Thus, detailed contracts can be quite effective in the United States. In Asia, in contrast, conflict-resolution mechanisms involving courts are unlikely to be very effective. Parties are much more comfortable negotiating resolutions to every conflict directly. Flexible contracts that allow for such negotiation are effective in building trust in that context.

MANAGING SUPPLY CHAIN RELATIONSHIPS FOR COOPERATION AND TRUST

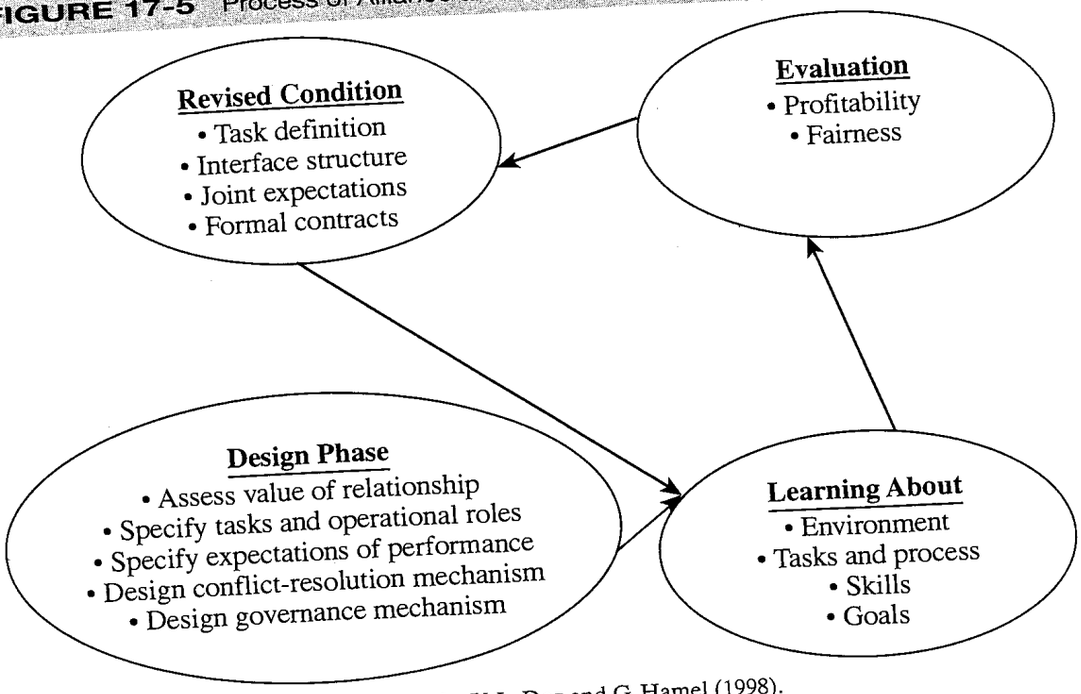
Effectively managed supply chain relationships foster cooperation and trust, thus increasing supply chain coordination. In contrast, poorly managed relationships lead to each party being opportunistic, resulting in a loss of total supply chain profits. The management of a relationship is often seen as a tedious and routine task. Top management, in particular, is often very involved in the design of a new partnership but rarely involved in its management. This has led to a mixed record in running successful supply chain alliances and partnerships.

Figure 17-5 shows the basic process by which any supply chain partnership or alliance evolves. Once the partnership has been designed and established, both partners learn about the environment in which the partnership will operate, the tasks and processes to be performed by each partner, the skills required and available on each side, and the emerging goals of each side. The performance of each side is evaluated based on the improvement in profitability and on equity or fairness. At this stage, a better evaluation of the value of the partnership becomes available, which provides both parties in the supply chain partnership an opportunity to revise the conditions of the partnership to improve profitability and fairness. It is important that the initial contracts be designed with sufficient flexibility to facilitate such alterations. Formal contracts may be restructured to reflect the changes. As the business environment and company goals change, the cycle repeats itself and the relationship evolves. Any successful supply chain partnership will go through many such cycles.

A supply chain partnership falters if the perceived benefit from the relationship diminishes or one party is seen as being opportunistic. Problems arise when communication between the two parties is weak and the mutual benefit of the relationship is not reiterated regularly. When managing a supply chain relationship, managers should focus on the following factors to improve the chances of success of a supply chain partnership:

1. The presence of flexibility, trust, and commitment in both parties helps a supply chain relationship succeed. In particular, commitment of top management on both sides is crucial for success.

FIGURE 17-5 Process of Alliance and Partnership Evolution



Source: Adapted from *Alliance Advantage* by Y. L. Doz and G. Hamel (1998).

2. Good organizational arrangements, especially for information sharing and conflict resolution, improve chances of success. Lack of information sharing and the inability to resolve conflicts are the two major factors that lead to the breakdown of supply chain partnerships.
3. Mechanisms that make the actions of each party and resulting outcomes visible help avoid conflicts and resolve disputes. Such mechanisms make it harder for either party to be opportunistic and help identify defective processes, increasing the value of the relationship for both parties.
4. The more fairly the stronger partner treats the weaker, vulnerable partner, the stronger the supply chain relationship tends to be.

The issue of fairness is extremely important in the supply chain context because most relationships involve parties with unequal power. Unanticipated situations that hurt one party more than the other often arise. The more powerful party often has greater control over how the resolution occurs. The fairness of the resolution influences the strength of the relationship in the future.

The relationship between Marks & Spencer and a manufacturer of a kitchen product provides an excellent example of a fair sharing of benefits.[6] A few months after the product's introduction, the manufacturer realized that costs had been miscalculated and exceeded the price at which the product was being sold to Marks & Spencer. Meanwhile, given its low retail price, customers found the product an outstanding value and made it a big hit. When the manufacturer brought the problem to the attention of Marks & Spencer, its managers helped the manufacturer reengineer both the product and the process to lower cost. Marks & Spencer also lowered its margin to provide a sufficient profit for the manufacturer. The outcome was one in which the

[6]Kumar (1996).

relationship was strengthened between the two partners because Marks & Spencer's fairness allowed a resolution that recognized the manufacturer's needs. In the long run, both partners benefited and a higher level of trust developed.

Procedures and policies govern the interaction between parties in a supply chain relationship. It is thus important that the weaker party perceive the fairness of the stronger party's procedures and policies for dealing with its partners. The stronger party is in control of its policies and procedures and should not bias the policies in a way that is opportunistic and does not benefit the entire supply chain. Fair procedures should encourage two-way communication between the partners. The procedures should be impartial and should allow the weaker party an opportunity to appeal the stronger party's decisions. Finally, the stronger party should be willing to explain all its decisions.

17.6 CONTINUOUS REPLENISHMENT AND VENDOR-MANAGED INVENTORIES

The bullwhip effect can be dampened by practices that assign replenishment responsibility across the supply chain to a single entity. A single point of replenishment decisions ensures visibility and a common forecast that drives orders across the supply chain. Two common industry practices that assign a single point of responsibility are continuous replenishment programs and vendor-managed inventories.

In *continuous replenishment programs* (CRP), the wholesaler or manufacturer replenishes a retailer regularly based on POS data. CRP may be supplier, distributor, or third-party managed. In most instances CRP systems are driven by actual withdrawals of inventory from retailer warehouses rather than POS data at the retailer level. Tying CRP systems to warehouse withdrawals is easier to implement and retailers are often more comfortable sharing data at this level. IT systems that are linked across the supply chain provide a good information infrastructure on which a continuous replenishment program may be based. In CRP, inventory at the retailer is owned by the retailer.

With vendor-managed inventory (VMI), the manufacturer or supplier is responsible for all decisions regarding product inventories at the retailer. As a result, the control of the replenishment decision moves to the manufacturer instead of the retailer. In many instances of VMI, the inventory is owned by the supplier until it is sold by the retailer. VMI requires the retailer to share demand information with the manufacturer to allow it to make inventory replenishment decisions. VMI can allow a manufacturer to increase its profits as well as profits for the entire supply chain if both retailer and manufacturer margins are considered when making inventory decisions. VMI also helps by conveying customer demand data to the manufacturer, which can then plan production accordingly. This helps improve manufacturer forecasts and better match manufacturer production with customer demand.

VMI has been implemented with significant success by, among others, K-Mart (with about 50 suppliers) and Fred Meyer. K-Mart has seen inventory turns on seasonal items increase from 3 to between 9 and 11, and for nonseasonal items from 12–15 to 17–20. Fred Meyer has seen inventories drop by 30 to 40 percent while fill rates have increased to 98 percent. Other firms with successful implementations include Campbell Soup, Frito-Lay, and Proctor & Gamble.

One drawback of VMI arises because retailers often sell products from competing manufacturers that are substitutes in the customer's mind. For example, a customer may substitute detergent manufactured by Proctor & Gamble with detergent manufactured

by Lever Brothers. If the retailer has a VMI agreement with both manufacturers, each manufacturer will ignore the impact of substitution when making their inventory decisions. As a result, inventories at the retailer will be higher than optimal. In such a setting, the retailer may be better positioned to decide on the replenishment policy. Another possibility is for the retailer to define a category leader from among the supplier and have the category leader manage replenishment decisions for all suppliers in the category. Wal-Mart follows such a practice and assigns a category leader for most of its products. For example, HP was its category leader for printers and managed all printer replenishment.

17.7 COLLABORATIVE PLANNING, FORECASTING, AND REPLENISHMENT (CPFR)

The Voluntary Interindustry Commerce Standards Association (VICS) has defined CPFR as "a business practice that combines the intelligence of multiple partners in the planning and fulfillment of customer demand." According to VICS, since 1998, "over 300 companies have implemented the process." In this section we describe CPFR and some successful implementations. It is important to understand that successful CPFR can only be built on a foundation in which the two parties have synchronized their data and established standards for exchanging information. Much of the material in this section is an adaptation of material from the VICS Web site, www.vics.org/committees/cpfr.

Sellers and buyers in a supply chain may collaborate along any or all of the following four supply chain activities.

1. ***Strategy and planning.*** The partners determine the scope of the collaboration and assign roles, responsibilities, and clear checkpoints. In a joint business plan they then identify significant events such as promotions, new product introductions, store openings/closings, and changes in inventory policy that affect demand and supply.
2. ***Demand and supply management.*** A collaborative sales forecast projects the partners' best estimate of consumer demand at the point of sale. This is then converted to a collaborative order plan that determines future orders and delivery requirements based on sales forecasts, inventory positions, and replenishment lead times.
3. ***Execution.*** As forecasts become firm, they are converted to actual orders. The fulfillment of these orders then involves production, shipping, receiving, and stocking of products.
4. ***Analysis.*** The key analysis tasks focus on identifying exceptions and evaluating metrics that are used to assess performance or identify trends.

A fundamental aspect of successful collaboration is the identification and resolution of exceptions. Exceptions refer to a gap between forecasts made by the two sides or some other performance metric that is falling or is likely to fall outside acceptable bounds. These metrics may include inventories that exceed targets or product availability that falls below targets. For successful CPFR, it is very important to have a process in place that allows the two parties to resolve exceptions. Detailed processes for identifying and resolving exceptions are discussed in the VICS CPFR Voluntary Guidelines V 2.0 (2002).

One successful CPFR implementation has involved Henkel, a German detergent manufacturer, and Eroski, a Spanish food retailer. Prior to CPFR, Eroski saw frequent stockouts of Henkel products, especially during promotions. At the inception of CPFR

TABLE 17-3 Four Common CPFR Scenarios

CPFR Scenario	*Where Applied in Supply Chain*	*Industries Where Applied*
Retail event collaboration	Highly promoted channels or categories	All industries other than those that practice EDLP
DC replenishment collaboration	Retail DC or distributor DC	Drugstores, hardware, grocery
Store replenishment collaboration	Direct store delivery or retail DC-to-store delivery	Mass merchants, club stores
Collaborative assortment planning	Apparel and seasonal goods	Department stores, specialty retail

in December 1999, 70 percent of the sales forecasts had an average error of over 50 percent and only 5 percent of the forecasts had errors under 20 percent. Within four months of the CPFR implementation, however, 70 percent of the sales forecasts had errors under 20 percent and only 5 percent had errors over 50 percent. CPFR resulted in a customer service level of 98 percent and an average inventory of only five days. This was accomplished despite 15 to 20 products being promoted every month. Another successful implementation involved Johnson & Johnson and Superdrug, a chain in the United Kingdom. Over the three-month trial period beginning April 2000, Superdrug saw inventory levels at its DCs drop by 13 percent, while product availability at its DCs increased by 1.6 percent. As reported by Steerman (2003), Sears and Michelin also saw significant benefits from their CPFR initiative in 2001. In-stock levels at Sears improved by 4.3 percent, DCs-to-stores fill rate improved by 10.7 percent, and overall inventory levels fell by 25 percent.

VICS has identified the four scenarios in Table 17-3 as the most common areas where large-scale CPFR deployments have taken place between a retailer and a manufacturer.

Next, we describe each of the four scenarios.

RETAIL EVENT COLLABORATION

In many retail environments, such as supermarkets, promotions and other retail events have a significant impact on demand. Stockouts, excess inventory, and unplanned logistics costs during these events affect financial performance for both the retailer and the manufacturer. In such a setting, collaboration between retailers and suppliers to plan, forecast, and replenish promotions is very effective.

Retail event collaboration requires the two parties to identify brands and specific SKUs that are included in the collaboration. Details of the event such as timing, duration, price point, advertising, and display tactics are shared. It is important for the retailer to update this information as changes occur. Event-specific forecasts are then created and shared. These forecasts are then converted to planned orders and deliveries. As the event unfolds, sales are monitored to identify any changes or exceptions, which are resolved through an iterative process between the two parties.

P&G has implemented some form of retail event collaboration with a variety of partners including Wal-Mart.

DC REPLENISHMENT COLLABORATION

DC replenishment collaboration is perhaps the most common form of collaboration observed in practice and also the simplest to implement. In this scenario the two trading partners collaborate on forecasting DC withdrawals or anticipated demand from the

DC to the manufacturer. These forecasts are converted to a stream of orders from the DC to the manufacturer that are committed or locked over a specified time horizon. This information allows the manufacturer to build anticipated orders into future production plans and build the committed orders on demand. The result is a reduction in production cost at the manufacturer and a reduction of inventory and stockouts at the retailer.

DC replenishment collaboration is relatively easy to implement because it requires collaboration on an aggregate forecast and does not require sharing of detailed point-of-sale data. As a result, it is often the best scenario with which to start collaboration. Over time, this form of collaboration can be extended to include all storage points in the supply chain from retail shelves to raw material warehouses. According to Hammond (1994), Barilla implemented this form of collaboration with its distributors.

STORE REPLENISHMENT COLLABORATION

In store replenishment collaboration, trading partners collaborate on store-level point-of-sale forecasts. These forecasts are then converted to a series of store-level orders, with orders committed over a specified time horizon. This form of collaboration is much harder to implement than a DC-level collaboration, especially if stores are small. Store replenishment collaboration is easier for large stores such as Costco and Home Depot. The benefits of store-level collaboration include greater visibility of sales for the manufacturer, improved replenishment accuracy, improved product availability, and reduced inventories. This form of collaboration is very beneficial for new products and promotions. Manufacturers and their suppliers can use this information to improve operational execution.

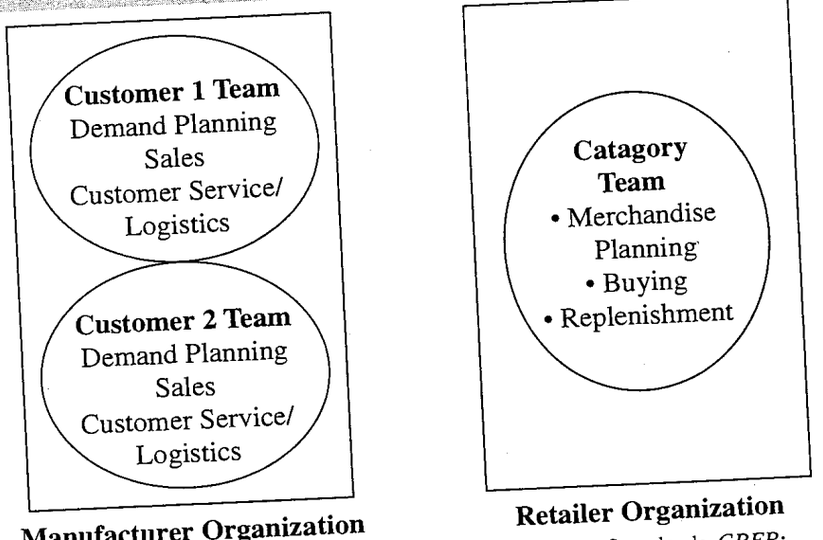
COLLABORATIVE ASSORTMENT PLANNING

Fashion apparel and other seasonal goods follow a seasonal pattern of demand. Thus, collaborative planning in these categories has a horizon of a single season and is performed at seasonal intervals. Given the seasonal nature, forecasts rely less on historical data and more on collaborative interpretation of industry trends, macroeconomic factors, and customer tastes. In this form of collaboration, the trading partners develop an assortment plan jointly. The output is a planned purchase order at the style/color/size level. The planned order is shared electronically in advance of a show, where sample products are viewed and final merchandising decisions are made. The planned orders help the manufacturer purchase long-lead-time raw materials and plan capacity. This form of collaboration is most useful if capacity is flexible enough to accommodate a variety of product mix and raw materials have some commonality across end products.

ORGANIZATIONAL AND TECHNOLOGY REQUIREMENTS FOR SUCCESSFUL CPFR

A successful CPFR implementation requires changes in the organizational structure and, to be scalable, requires the implementation of appropriate technology. Effective collaboration requires manufacturers to set up cross-functional, customer-specific teams that include sales, demand planning, and logistics, at least for large customers. Such a focus has become feasible with the consolidation in retailing. For smaller customers such teams can be focused by geography or sales channel. Retailers should also attempt to organize merchandise planning, buying, and replenishment into teams around suppliers. This can be difficult given the large number of suppliers that consolidated retailers have. They can

FIGURE 17-6 Collaborative Organizational Structure



Source: Adapted from Voluntary Interindustry Commerce Standards, *CPFR: An Overview*, 2004.

then organize the teams by categories that include multiple suppliers. For retailers that have multiple levels of inventory such as DCs and retail stores, it is important to combine the replenishment teams at the two levels. Without collaborative inventory management at the two levels, duplication of inventories is common. The proposed organizational structure is illustrated in Figure 17-6.

The CPFR process is not dependent on technology but requires technology to be scalable. CPFR technologies have been developed to facilitate sharing of forecasts and historical information, evaluating exception conditions, and enabling revisions. These solutions must be integrated with enterprise systems that record all supply chain transactions.

RISKS AND HURDLES FOR A CPFR IMPLEMENTATION

It is important to realize that there are risks and hurdles for a successful CPFR implementation. Given the large-scale sharing of information, there is a risk of information misuse. Often one or both of the CPFR partners has relationships with the partner's competitors. Another risk is that if one of the partners changes its scale or technology, the other partner is forced to follow suit or lose the collaborative relationship. Finally, the implementation of CPFR and the resolution of exceptions require close interactions between two entities whose cultures may be very different. The inability to foster a collaborative culture across the partner organizations can be a major hurdle for the success of CPFR. One of the biggest hurdles to success is often that partners attempt something like store-level collaboration, which requires a higher organizational and technology investment. It is often best to start with something like event- or DC-level collaboration, which is more focused and easier to collaborate on. One of the biggest hurdles for successful CPFR, however, is that demand information shared with partners is often not used within the organization in an integrated manner. It is important to have integrated demand, supply, logistics, and corporate planning within the organization to maximize the benefits of a CPFR effort with a partner.

17.8 THE ROLE OF IT IN COORDINATION

The enablement of coordination can be viewed as the ultimate goal of IT in the supply chain. Much of what we have discussed in the various IT sections so far has elements of coordination—sharing forecasts, visibility of inventory levels, transmitting arrival times—but much of what we have talked about has been internal supply chain operations. In this chapter we are truly focusing on improving interenterprise operations. At the highest level, there are two ways in which IT can help to improve this area.

The first is information availability. Significant benefit from interenterprise coordination arises just from the sharing of information between companies. IT enables this in two ways. The first is the actual physical sharing of this information. Through applications that enable data to be viewed on the Internet to the integration of companies systems, IT provides the "plumbing" to make the actual sharing of information happen. IT also helps in sorting these data and preparing them for viewing. The amount of data available is overwhelming and so just making the data visible to everyone is not necessarily helpful. IT structures the data and allows users to pull the figurative needle out of the haystack of data through intelligent organization and searches.

The second way that IT helps improve coordination is to use the visible information to make decisions. IT enables the use of supply chain information to make many of the inventory, production, transportation, sourcing, and pricing decisions.

There are perhaps more pitfalls in using IT for coordination than in any other area. This is primarily because of the complexity and difficulty of the task at hand. Certainly the technical challenges are significant. One example is the integration of disparate systems so that the information we discussed above is available to multiple enterprises. Another problem is that different companies often have very different operating processes. For coordination to be effective, these processes must somehow interact in a way that makes sense. Overcoming this problem within a company is difficult, and it is even more so when more than one company is involved. However, the biggest hurdle to making these IT systems work is the trust factor that we have discussed at length in this chapter. Companies that do not have a degree of trust in their interactions are very unlikely to get much in the way of benefit from investing in coordination software, regardless of how good the technology is.

The major companies that provide software in this area are the supply chain software providers from the ERP ranks such as SAP and Oracle and the best-of-players such as i2 Technologies and Manugistics. This area is in some sense the youngest of all the software areas we have discussed. Few companies do this well, and most don't do it at all, so there may be the potential for new software companies to make headway in offering products in this area. However, it is likely that the ERP players will firmly occupy this space as it becomes more mature.

17.9 ACHIEVING COORDINATION IN PRACTICE

1. ***Quantify the bullwhip effect.*** Companies often have no idea that the bullwhip effect plays a significant role in their supply chain. Managers should start by comparing the variability in the orders they receive from their customers with the variability in orders they place with their suppliers. This helps a firm quantify its own contribution to the bullwhip effect. Once its contribution is visible, it becomes easier for a firm to accept the fact that all stages in the supply chain contribute to the bullwhip effect, leading to a significant loss in profits. In the absence of this concrete information, companies try to

react better to the variability rather than eliminate the variability itself. This leads companies to invest significant amounts in inventory management and scheduling systems, only to see little improvement in performance or profits. Evidence of the size of the bullwhip effect is very effective in getting different stages of the supply chain to focus on efforts to achieve coordination and eliminate the variability created within the supply chain.

2. ***Get top management commitment for coordination.*** More than any other aspect of supply chain management, coordination can succeed only with top management's commitment. Coordination requires managers at all stages of the supply chain to subordinate their local interests to the greater interest of the firm and even the supply chain. Coordination often requires the resolution of trade-offs in a way that requires many functions in the supply chain to change their traditional practices. These changes often run counter to approaches that were put in place when each function focused only on its local objective. Such changes within a supply chain cannot be implemented without strong top management commitment. Top management commitment was a key factor in helping Wal-Mart and P&G set up collaborative forecasting and replenishment teams.

3. ***Devote resources to coordination.*** Coordination cannot be achieved without all parties involved devoting significant managerial resources to this effort. Companies often do not devote resources to coordination because they either assume that lack of coordination is something they have to live with or they hope that coordination will occur on its own. The problem with this approach is that it leaves all managers involved with only the separate areas that they control, while no one is responsible for highlighting the impact one manager's actions have on other parts of the supply chain. One of the best ways to solve coordination problems is through teams made up of members from different companies throughout the supply chain. These teams should be made responsible for coordination and given the power to implement the changes required. Setting up a coordination team is fruitless unless the team has the power to act, because the team will run into conflict with functional managers who are currently maximizing local objectives. Coordination teams can be effective only once a sufficient level of trust builds between members from different firms. If they are used properly, coordination teams can provide significant benefit, as has happened with the collaborative forecasting and replenishment teams set up by Wal-Mart and P&G.

4. ***Focus on communication with other stages.*** Good communication with other stages of a supply chain often creates situations that highlight the value of coordination for both sides. Companies often do not communicate with other stages of the supply chain and are unwilling to share information. However, often all companies in the supply chain are frustrated by the lack of coordination and would be happy to share information if it helped the supply chain operate in a more effective manner. Regular communication among the parties involved facilitates change in such a setting. For instance, a major PC company had been ordering its microprocessors in batches of several weeks of production. It was trying to move to a build-to-order environment in which it would place microprocessor orders on a daily basis. The PC company assumed that the microprocessor supplier would be reluctant to go along with this approach. However, once communication was opened up with the supplier, the opposite turned out to be true. The supplier also wanted to reduce lot sizes and increase the frequency of orders. It had just assumed that the PC manufacturer wanted large lots and thus never requested a change. Regular communication helps different stages of the supply chain share their goals and identify common goals and mutually beneficial actions that improve coordination.

5. ***Try to achieve coordination in the entire supply chain network.*** The full benefit of coordination is achieved only when the entire supply chain network is coordinated. It

is not enough for two stages in a supply chain to coordinate. The most powerful party in a supply chain should make an effort to achieve coordination in the entire network. Toyota has been very effective in achieving knowledge sharing and coordination in its entire network.

6. ***Use technology to improve connectivity in the supply chain.*** The Internet and a variety of different types of software systems can be used to increase the visibility of information throughout the supply chain. Until now, most IT implementations have achieved visibility of information only within a firm. Visibility across the supply chain still requires additional effort in most cases. From the discussion in this chapter, it should be clear that the major benefits of IT systems can be realized only if the systems help increase visibility across the supply chain and facilitate coordination. If firms are to realize the full benefit of the huge investments they make in current IT systems, particularly ERP systems, it is crucial that they make the extra effort required to use these systems to facilitate collaborative forecasting and planning across the supply chain. The Internet should be used to share information and increase connectivity in the supply chain. The growth of Internet exchanges can be very effective in this regard.

7. ***Share the benefits of coordination equitably.*** The greatest hurdle to coordination in the supply chain is the feeling on the part of any stage that the benefits of coordination are not being shared equitably. Managers from the stronger party in the supply chain relationship must be sensitive to this fact and ensure that all parties perceive that the way benefits are shared is fair.

17.10 SUMMARY OF LEARNING OBJECTIVES

1. Describe supply chain coordination and the bullwhip effect and their impact on supply chain performance.

   Supply chain coordination requires all stages to take actions that maximize total supply chain profits. A lack of coordination results if different stages focus on optimizing their local objectives or if information is distorted as it moves across the supply chain. The phenomenon that fluctuation in orders increases as one moves up the supply chain from retailers to wholesalers to manufacturers to suppliers is referred to as the bullwhip effect. The bullwhip effect results in an increase in all costs in the supply chain and a decrease in customer service levels. The bullwhip effect moves all parties in the supply chain away from the efficient frontier and results in a decrease of both customer satisfaction and profitability within the supply chain.

2. Identify causes of the bullwhip effect and obstacles to coordination in a supply chain.

   A key obstacle to coordination in the supply chain is misaligned incentives that result in different stages optimizing local objectives instead of total supply chain profits. Other obstacles include lack of information sharing, operational inefficiencies leading to large replenishment lead times and large lots, sales force incentives that encourage forward buying, rationing schemes that encourage inflation of orders, promotions that encourage forward buying, and a lack of trust that makes any effort toward coordination difficult.

3. Discuss managerial levers that help achieve coordination in a supply chain.

   Managers can help achieve coordination in the supply chain by aligning goals and incentives across different functions and stages of the supply chain. Other actions that managers can take to achieve coordination include sharing of sales information and collaborative forecasting and planning, implementation of single-point control of replenishment, improving operations to reduce lead times and lot sizes, EDLP and other strategies that limit forward buying, and the building of trust and strategic partnerships within the supply chain.

4. Describe actions that facilitate the building of strategic partnerships and trust within a supply chain.

   A manager can help build trust and strategic partnerships by designing a relationship in which the mutual benefit to both sides is clear, both parties are mutually interdependent, contracts are allowed to evolve over time, and conflicts are resolved effectively. When managing the relationship, flexibility, information sharing, visibility of effort and performance of each party, and fairness from the stronger party when distributing costs and benefits help foster trust and facilitate coordination in the supply chain.

5. Understand the different forms of CPFR possible in a supply chain.

   Partners may set CPFR relationships to collaborate on store events, DC replenishment, store replenishment, or assortment planning. DC replenishment collaboration is often the easiest to implement because it requires aggregate-level data. Store replenishment collaboration requires a higher level of investment in technology and data sharing to be successful.

Discussion Questions

1. What is the bullwhip effect and how does it relate to lack of coordination in a supply chain?
2. What is the impact of lack of coordination on the performance of a supply chain?
3. In what way can improper incentives lead to a lack of coordination in a supply chain? What countermeasures can be used to offset this effect?
4. What problems result if each stage of a supply chain views its demand as the orders placed by the downstream stage? How should firms within a supply chain communicate to facilitate coordination?
5. What factors lead to a batching of orders within a supply chain? How does this affect coordination? What actions can minimize large batches and improve coordination?
6. How do trade promotions and price fluctuations affect coordination in a supply chain? What pricing and promotion policies can facilitate coordination?
7. How is the building of strategic partnerships and trust valuable within a supply chain?
8. What issues must be considered when designing a supply chain relationship to improve the chances of developing cooperation and trust?
9. What issues must be considered when managing a supply chain relationship to improve the chances of developing cooperation and trust?
10. What are the different CPFR scenarios and how do they benefit supply chain partners?

Bibliography

Bowersox, Donald J., David J. Closs, and Theodore P. Stank. "21st Century Logistics: Making Supply Chain Integration a Reality." *Supply Chain Management Review* (Fall 1999): 44–9.

Brunell, Tom. "Managing a Multicompany Supply Chain." *Supply Chain Management Review* (Spring 1999): 45–52.

Child, John, and David Faulkner. *Strategies of Cooperation.* Oxford, England: Oxford University Press, 1998.

Crum, Colleen, and George E. Palmatier. "Demand Collaboration: What's Holding Us Back?" *Supply Chain Management Review* (January–February 2004): 54–61.

Doz, Yves L. "The Evolution of Cooperation in Strategic Alliances: Initial Conditions or Learning Process?" *Strategic Management Journal* 17 (1997): 55–83.

Doz, Yves L., and Gary Hamel. *Alliance Advantage.* Boston: Harvard Business School Press, 1998.

Dyer, Jeffrey H., and Kentaro Nobeoka. "Creating and Managing a High-Performance Knowledge-Sharing Network: The Toyota Case." *Strategic Management Journal* 21 (March 2000): 345–67.

Gulati, Ranjay, and Harbir Singh. "The Architecture of Cooperation: Managing Coordination Costs and Appropriation Concerns in Strategic Alliances." *Administrative Science Quarterly* 43 (1998): 781–814.

Hammond, Janice H. 1994. *Barilla Spa (A–D)*. Harvard Business School Case 9–694–046.

Continuous Replenishment: An ECR Best Practices Report. Washington, D. C.: Grocery Manufacturer's Association, 1994.

Computer Assisted Ordering: Practices and Benefits Report. Washington, D. C.: Grocery Manufacturer's Association, 1994.

Kumar, Nirmalya. "The Power of Trust in Manufacturer–Retailer Relationships." *Harvard Business Review* (November–December 1996): 92–106.

Lee, Hau L., V. Padmanabhan, and Seungjin Whang. "The Bullwhip Effect in Supply Chains," *Sloan Management Review* (Spring 1997): 93–102.

Mariotti, John L. "The Trust Factor in Supply Chain Management." *Supply Chain Management Review* (Spring 1999): 70–7.

Ring, P. S., and A. H. Van de Ven. "Developmental Processes of Cooperative Interorganizational Relationships." *Academy of Management Review* 19 (1994): 90–118.

Sabath, Robert E., and John Fontanella. "The Unfulfilled Promise of Supply Chain Collaboration." *Supply Chain Management Review* (July–August 2002): 24–9.

Senge, Peter M. *The Fifth Discipline*. New York: Currency and Doubleday, 1990.

Smeltzer, Larry R. "Integration Means Everybody—Big and Small." *Supply Chain Management Review* (September–October 2001): 36–44.

Steerman, Hank. "A Practical Look at CPFR: The Sears-Michelin Experience." *Supply Chain Management Review* (July–August 2003): 46–53.

Voluntary Interindustry Commerce Standards. *CPFR: An Overview*, 2004.

Voluntary Interindustry Commerce Standards. *Collaborative Planning, Forecasting, and Replenishment*, Version 2.0, 2002.

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