Introduction to the Four Cs of Supply Chain Management

Chain Structure, Competition, Capacity and Coordination

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This book is dedicated to my family—Rani, Apsara, and Vidhya—
and to the memory of my parents.

—Ananth Iyer

Introduction

This Introductory volume presents an overview of Supply Chain Management within the Four Cs framework along with a survey on the information feedback systems that are used to support supply chain operations. Similar to the 4 P's of marketing, these Four Cs combined encompass the key managerial and strategic issues facing managers and companies must deal with in order to set up, manage, and improve their supply chain systems upstream and downstream. This volume is a derivative of the complete text, Managing Supply Chains, which also includes teaching and learning support by way of homework problems and case assignments. The related companion volume, Supply Chain Logistics and Applications is also derived from the original Managing Supply Chains text.

Preface

Why are there pictures of coffee, chocolate, cake, and coupons on the cover of this book? They were gifts from German students who had just finished my class on supply chain management and were intended to represent the Four C framework that underlies this book's content. In this book, however, the Four Cs are *Chain structure and ownership, Capacity, Coordination,* and *Competitiveness.* If you visualize the set of ordinary items on the cover of this book, you can use them as a mnemonic to remember the Four Cs of supply chain management—and we have accomplished a key goal of this book in this very first paragraph.

This book has been several years in the making. My goal is to bridge the gap between applications, tools, and concepts, linking ideas generated by researchers, practices described in the press, and tools that can be used to generate insights. Connecting these worlds, each of which has been developed by people passionate about supply chain management, will make for a smoother transition between theory and practice. This textbook is a static object that can serve as the start of conversations between you, your professor, your fellow students, your current or future work colleagues, and me, albeit remotely, engaging your heart and mind in understanding, managing, and enabling supply chain systems—leading to growth and commerce, while promoting sustainability. In order to support those conversations, I write a daily blog (http://aviyer2010.wordpress.com/) to cover current ideas linked to global supply chain management.

Supply chain management is primarily about a collection or a chain of companies that coordinate their activities and choose the appropriate capacities and some metric of competition to deliver a valuable product or service to customers. This activity is inherently global in many industries and is thus subject to the vagaries of economic shocks, political upheavals, weather-related disruptions, and many other factors. Ensuring that the supply chain keeps its commitment to customers requires planning, contracting to share risk, and adapting to changes in all functions and transactions. Ensuring that transportation capacity is available and deliveries take place as scheduled, suppliers invest effort, people, and resources to keep component designs competitive, and warehouses and associated inventories are deployed to optimize performance. These are a few examples of topics we will discuss in detail.

Information systems now have a ubiquitous presence, enabling customers to access data regarding products and schedules from product genesis to final delivery, and judge whether they approve. Virtually, the supply chain sits in a glass box, with every decision or choice documented and rated, thus impacting customer purchase decisions, the top-line revenue of the firm, and, finally, the bottom-line profits. Customers care about sustainable choices, and firms who recycle and reuse both reduce costs and attract customers. Matching information and material flows is key to effective supply chain management and sustainability.

This book is written to make you aware of the choices made by existing supply chain managers and to provide you with suggestions for alternate solutions as well as the tools to analyze their impacts. Vigilance about the competitiveness of current choices ensures that managerial interventions can be made when necessary to make course corrections.

Circumstances may require a shift to outsourcing from local sourcing, which may involve higher costs but also higher profits, if the resulting decisions are made quickly and adapt to current trends. For example, moving from a promotion-intensive retail environment to an every-day-low-price format may improve or decrease profits, depending on the context. The models and tools we will discuss will enable these decisions.

The concepts in this book have been tested on over a thousand students, and the book includes new cases developed to illustrate contexts based on my consulting and research experience. Several of the chapters are motivated by the content of research papers, which I have adapted to be accessible to students in a business school or an industrial engineering course. The problem sets provide many contexts to test your ability to apply the tools we will learn. The applications are highlighted with specific case studies, references to websites that provide updated content, and trade and government publications to let you gauge the financial impact of choices. Through this work, I hope you will be convinced and understand that supply chains can and do have a significant impact.

This book is built on the shoulders of insight generated by practitioners in industry, as well as by researchers and students in universities. But it would not have been possible without the support of my family, to whom I am eternally grateful. I am also grateful for the environment in the operations management group, and all the faculty colleagues and graduate and doctoral students at the Krannert School of Management here at Purdue, where I have been fortunate to try out many of these concepts on students. I take responsibility for any errors and have endeavored to acknowledge all sources for their input.

I would like to acknowledge the many coauthors and students over the years who have made the journey to write this book memorable. My students and now faculty include professors Apurva Jain at the University of Washington at Seattle; Jinghua Wu at Renmin University; Zhengping Wu at Singapore Management University; Mohammad Saoud at Kuwait University; Hung Do Tuan at the University of Vermont; Asima Mishra at Intel Labs; and Kyoungsun Lee, now in South Korea. Other collaborating faculty whose insights and research influenced and are represented in this book include Professors Sridhar Seshadri at the University of Texas at Austin, Arnd Huchzermeier at WHU-Koblenz, Vinayak Deshpande at the University of Texas at Austin, Svenja Sommer at HEC Paris, and Lee Schwarz at Purdue University. I deeply appreciate the opportunity to work with each of them.

The following colleagues provided detailed reviews and hundreds of very thoughtful and valuable suggestions for improvement to this text. I am very grateful to each and hope each will be pleased with how it has turned out.

Sridhar Seshadri, University of Texas, Austin
Apurva Jain, University of Washington, Seattle
Mark Ferguson, Clemson University
Vijay Kannan, Utah State University
Corrington Hwong, Baruch College, The City University of New York
Adam Rapp, Kent State University
Howard Kreye, University of New Mexico
Paul Hong, University of Toledo

My publisher, Dick Hercher, has been a staunch advocate of this book through its many manifestations—I hope you enjoy his efforts and enable his fledgling company to soar. Jennifer Murtoff, the copyeditor, has been a diligent and effective advisor, turning notes into precise text and reminding me time and again of the reader's perspective. My daughters Apsara and Rani have suffered through many years of hearing about the Four Cs (which I tried out on them during their elementary school years), and my wife Vidhya has endured the long journey of this book from start to finish—I thank them for their patience and support on this journey.

So please enjoy this book, and, if you can, drop me an email so that I can learn of your experience with it. If you decide to make a career in managing supply chains, you will find a large global community ready to welcome your ideas. Enjoy the ride and remember the Four Cs described in this book.

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CHAPTER 1

Introduction to Supply Chains

The supply chain of a firm consists of the business entities from customer. The supply chain is the firm's lifeblood—delivering product to revenue, procuring components or services at globally competitive new ideas from design to delivery to enable sustained competitiveness. concepts, tools, and applications to understand how to manage supply chains standing supply chains is important because of their large economic footprint Second Annual State of Logistics report ([12]), published in June 2011, estimated chain costs were 8.3% of the overall US gross domestic product: an estimated $1.25 This supply chain cost estimate was based on $2.1 trillion of US inventory carried across the economy.

But how is supply chain management (SCM) defined by professional organizations? The Council of Supply Chain Management Professionals (CSCMP), a professional society, states on its website ([22]) that

> Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.

In this book, we will use a Four C framework focused on chain structure, capacity, coordination, and competitiveness to understand effective management of these steps.

1.1 Supply Chain Architecture

To present the different perspectives of this book, imagine the choices made by the architect of a building. If you step far enough away from the building, you observe the architect's choices of shape of the building and how it fits in with its neighbors: its curb appeal, its contribution to the skyline, the type of architectural style, and so on. As you step closer to the building, you observe more details: layouts of various functional components such as access, elevators, information desks, and lobby; the number of different companies that share the building and their distribution; and so on. Finally, if you are one of the people using the building, you observe how traffic flows through the building: congestion and delays for elevators, flows of freight and postal deliveries, how special visitors are handled, how security is managed, the heating and cooling, building noise, and so on. Now transfer the same set of choices and vantage points to a supply chain. This book is about understanding and improving choices made in the operation of a supply chain, at all of these viewing distances.

The first goal of this book is to focus on supply chain architecture by focusing on four specific concepts, i.e., the **Four Cs of supply chain management**. These four Cs are **chain** structure and ownership, **capacity**—its type and location across the supply chain, **coordination** mechanisms, and **competitiveness**—the metrics of competition and the competitive pressures faced by the supply chain. Choices made regarding each of these Four Cs generate possible supply chain architectures.

The next goal of this book is to focus on **applications** of these concepts to manage transactions within the supply chain architecture. Consider the functional transactions within a supply chain. Functional transactions refer to flows due to transportation, purchasing, warehousing, spare-parts management, recycling flows, and so on. Sector-specific applications will focus on details of transactions for industry-specific supply chains such as the grocery, apparel industry, humanitarian logistics, and developing country supply chains. For each of these flows, use of the Four C concept will enable us to understand how these transactions can be managed and performance improved or optimized.

The third and final goal of the book is to provide **tools** that can be used to manage and improve performance of a supply chain. These tools include simulation models, linear programming models, and calculus-based models. By permitting a quantitative estimate of the impact of improvements to the supply chain, these tools will enable management to get a forecast of the relative quantitative impact of alternate choices in managing the supply chain.

Thus there are three goals for this book: (1) an emphasis on concepts embodied by the Four Cs, (2) a focus on applications through consideration of transactions, and (3) a use of tools to estimate the impact of changes. Our pedagogical device will thus be a focus on concepts, applications, and tools to develop your capability in the field of supply chain management.

1.1.1 Chain Structure

The chain structure of a supply chain for a product or service is the collection of entities and paths through which material and information flow. Its description includes the ownership of the associated entities. Both information and material flows affect costs in a supply chain, so altering either of these can impact performance. Intuitively, longer chains might suffer from longer lead times and thus higher variability as one moves upstream. Similarly, chain structures that combine several parts into an assembled kit will suffer if their performance is constrained by a weak supplier. The inventory policies and capacities of a warehouse affect the retail outlets that share the space. In more general contexts, the network that governs the chain of flows may have systematic effects on performance through its ability to redeploy flows as conditions change. Country boundaries that a chain crosses are also of concern because they affect duties, taxation, and so on. In short, supply chain structure, the first C, affects supply chain performance.

1.1.2 Capacity

Capacity at any given stage in a supply chain is defined as the designed quantity of resources available to handle transactions that flow through that stage. Capacity decisions may require both long- and short-term considerations. Long-term contracts relate to plant sizing, infrastructure investments, and so on. Tactical decisions regarding capacity include short-term adjustments in workforce, scheduling considerations, and other factors. Capacity decisions often require a forecast of possible transaction flows. For example, given the long lead times for start-up of a supply chain, capacity decisions require demand forecasts with the possible consequence of large errors. This necessitates capacity buffers or contingency arrangements to deal with demand surges. Aligning capacity to impending demand is thus a key factor in determining supply chain performance, hence the importance of the second C, capacity.

1.1.3 Coordination

Coordination deals with the rules of engagement or contracts between separate entities in the supply chain. Many supply chains involve different owners, both locally and globally. As ownership of a supply chain gets fragmented, coordination becomes essential to guarantee performance. In addition, legally acceptable rules of engagement may change with country boundaries and must be observed. These rules of operation may impact the amount that can be ordered during a period, the prices that will be charged, the committed quantities over a period of time, the guaranteed delivery time, the agreed-upon efforts and rewards, and so on. In this book we will provide a number of possible coordination mechanisms, discuss their impact on supply chain performance, and provide applications to practice. Thus, coordination represents the third C in our list of concepts.

1.1.4 Competitiveness

Competitiveness is the fourth C in our list of concepts. Managing the competitiveness of a supply chain requires two sets of choices—the choice of the metrics of competition as well as responses to competitors' choices. Typical metrics used include lead time, cost, profit, product variety, consistency, service level, fill rate, and others. For a monopolist, it is important to identify appropriate metrics to coordinate optimal choices across the supply chain. However, competition has an impact on the feasible choices for a supply chain manager. In general, competition forces the supply chain manager to think about how best to compete, given other competitors' actions, also known as an *equilibrium view* (Nash equilibrium) of required performance. In some cases, intense competition may force choices that significantly decrease profits but that are a necessary component to participate. Thus both the choice of metrics of competition as well as the level of competitive intensity affect supply chain choices and performance.

The next section will provide examples from sector-specific supply chains to illustrate the Four C concepts.

1.2 The Book Supply Chain

The printing industry has annual revenues of over $210 billion. In the book supply chain, book printing is a $5 billion industry. The typical book supply chain operates as follows ([76]): Authors work with publishers to create content, who in turn place orders with printers. Printers print the physical books and ship them to wholesalers in full truckload quantities. These larger loads received at wholesalers undergo break bulk (i.e., they are broken down into smaller shipments) at their fulfillment centers. Bookstores order books from the wholesalers and then manage retail sales. As an example, Ingram Book Company, a wholesaler, processed over 115 million books through eleven fulfillment centers to serve 32,000 outlets and accounts for one-third of all units shipped through wholesalers ([76]).

The top five printers constitute over 40% of the printing market volume. Printing economics dictate the use of large presses that can print 10,000 copies of a 250-page book in two hours with about one hour to set up the press. An average of 1 billion trade books is purchased in the United States. Of these, 50% are backlist books (i.e., published in previous years). The other 50% of the demand consists of orders for the 51,000 current titles, i.e., released that year. The average new title sells fewer than 10,000 copies over its lifetime. With 25,000 publishers and 51,000 new titles per year, the average publisher releases two titles a year. The largest, Random House, released 11,000 titles in 2011. The top ten publishers account for 20% of new titles. The largest publishers have a backlist of 30,000 titles. (For details see [76].)

In the retail environment, bestsellers account for only 3% of sales. The number of bookstores, or retail outlets, went up from 6,500 in 1991 to 10,600 in 2007. In 2008, retail returns of books to the publisher were estimated to be 25% ([91]). An efficient supply network could save over $2 billion—the profit from sale of 1 billion trade books is about $4 billion.

1.2.1 The Book Supply Chain Architecture

The book supply chain involves the printer, the wholesaler, the retail store, and the customer. Ownership of this supply chain is fragmented, with each entity's success based on different metrics. For printers to be competitive, they must have large-volume press runs that economize printing costs. Capacity decisions are made by retailer and wholesaler and determine the level of inventory and lead time to satisfy demand. Coordination between wholesaler and retailer depends on the flexibility offered for books to be returned from the retailer to the wholesaler. At the store level, competitiveness requires a large variety of books to be in stock, the flexibility for the customer to browse books before purchase, accessible locations, and other factors. The wholesaler has to be flexible to accommodate bookstore returns. The flexibility to return books provides the incentive for the bookstore to order efficient quantities from the supply chain.

1.3 The Diaper Supply Chain

Diapers are a steady-selling item at the retail store. Yet, in the past, Procter and Gamble (P&G) faced large demand swings that percolated through the supply chain. These demand swings, termed the *bullwhip effect,* caused increased order volatility to suppliers and plants. One reason for such volatility was the different price brackets that were offered to retailers every day. Every retailer adjusted orders to attain the lowest cost procurement price for products. In addition, they offered products with volume discounts, discounts for joint purchases, customer backhaul discounts, and so on. The net effect was that the orders, i.e., demand seen by P&G, was unpredictable, even if retail demands were reasonably stable. The impact of these demand fluctuations was substantial. Additional plant capacity, premium transportation payments, large finished goods inventories, warehouse space, raw material inventories—all added to the total cost to produce and distribute products ([38],[49]). Choices across supply chain participants were thus impacting performance.

The stimulus for change came from the increasing brand premium that customers were being forced to pay. P&G customers paid a brand premium of over $105 compared to a basket of generic products (a consumer's typical mix of product purchased over a year). But the quality of generics was improving, and more and more customers seemed unwilling to pay the brand premium. Demand was declining, and P&G had to make significant changes to lower supply costs.

P&G evolved a new supply chain strategy. A new pricing plan was offered with a clearly stated, stable price that would remain in place except for known price adjustments due to backhaul, annual volume discounts, and so on. The new pricing scheme resulted in a dramatically lower order variability and correspondingly lower asset requirements. P&G closed over thirty plants and reduced supply chain assets such as warehouses and associated material handling equipment. Inventory turns increased significantly from sixteen to twenty-seven per year and in some cases up to seventy turns. But significant management attention was required: sales had new roles, customers had to get used to fewer price changes and hence lower order volatility, merchandising and product variety had to be tended to garner sales growth. Would such a system last? Would it be appropriate for new products? How would it affect P&G's competitiveness in the industry?

1.3.1 P&G's Supply Chain Architecture

The diaper supply chain consists of flow from manufacturer to distributor to retail store to customer. The supply chain for diapers generated large volume fluctuations at the manufacturer. Coordination with wholesalers was based on pricing. But the price variation used to attract retail purchases generated volume fluctuations for the manufacturing plants. Retailer competitiveness demanded that their buyers minimize the cost of goods sold, thus generating large order fluctuations. Manufacturer plant capacity, warehouse capacity at manufacturers and retailers, and transport capacity are all affected by the demand fluctuations. Coordination agreements in this industry include vendor-managed inventory

(P&G manages the inventory at the Walmart warehouses), scanner-based promotions (where the manufacturer pays the retailer based on units sold during a particular period). Changes in the coordination agreements impact the entire supply chain.

1.4 Cemex: A New Approach to Distributing Cement

Cemex is a Mexican cement manufacturer with worldwide operations ([10],[98]). One of the company's main operations focuses on delivering mixed cement (i.e., concrete) to builders. Once mixed, concrete has to be used within a few hours. However, it is common for contractors to order the cement and try to cancel at the last minute to accommodate schedule delays in other steps. The industry service level was poor and flexibility to reschedule shipments in transit was minimal.

Cemex decided to leverage technology for concrete delivery the way Federal Express uses global positioning system (GPS) technology to track packages. Cemex invested over $200 million in a state-of-the-art information system that permitted GPS tracking of all of its delivery trucks ([10]). This close link between customer information, truck locations, and mixing centers enabled deliveries to be committed within a fifteen-minute window while permitting reschedules up to thirty minutes before delivery at no extra charge. Such flexibility has resulted in rapid growth in a mature industry.

But the next step was for Cemex to target the poorest segment of the population in Mexico. This segment was large and required special distribution and credit management capabilities. A key feature was the management of savings in poor households that could lead to tangible improvements in the housing, such as the addition of a room. Cemex created a savings plan whereby groups of families jointly worked to save to finance home improvements. The initiative, termed *Patrimonio Hoy* ([108]), rewarded families who saved consistently with construction material provided in advance by Cemex. Customers also had the flexibility to store material at Cemex or store it themselves. A new feature allowed US- based family members to deposit funds with Cemex's financial representative in the United States, in return for either funds provision or material provision to their family in Mexico. The impact of these customer commitments increased the participation of Cemex further downstream and the complexity of the associated logistics system but potentially generated a more stable source of demand.

1.4.1 The Cemex Supply Chain Architecture

The supply chain involves flows from the cement manufacturer to the concrete mixer to the construction site. Cemex modified these flows through the intensive use of technology. Dynamic routing enabled last-minute cancellations to be accommodated. This coordination between Cemex and the user provided significant value for the user but depended on Cemex's ability to accommodate such requests efficiently. The result was a more competitive supply chain that was responsive to customer demand and thus enabled significant market share growth. Having the right level of ability to accommodate change requests played a key role in this system. Coordinating incentives also included having visibility regarding future demands through the use of credit terms to enable management of the financing of construction materials, further increasing the success of the supply chain.

1.5 Zara and the Apparel Supply Chain

Zara is a multibillion dollar Spanish company with stores all over the world. Zara owns large sections of the apparel supply chain and manages the entire chain to speed up innovation and product availability. One secret to Zara's success is the constant flow of customer requests and information from stores to the design studios. In turn, Zara generates a constant flow of product from plants to stores, even at the expense of retiring products for which there is demand.

Zara represents a new generation of supply chains in the apparel industry. The following anecdote regarding Zara says it all:

> When Madonna went on tour in Spain in early 2001, she started in Madrid and ended in Barcelona ten days later. The fashion that teenagers picked up from Madonna's outfits was developed, manufactured, and available in stores in Barcelona by the time

> the tour ended. A remarkable ten days from design, development, manufacturing to store availability ([10],[74]).

Zara sources the fabric from all over the world (Italy, China, Japan, India). Zara owns its own cutting machines that cut the fabric in batches, using laser-cutting devices, and optimize layouts within each roll to minimize scrap. Independent sewing shops in Europe do all of the stitching. The apparel comes back to Zara, where it is ironed, packaged, and grouped by store. Zara contracts with independent trucking companies to distribute the products to stores that are solely owned by Zara.

Customers expect fresh assortments every time they visit the store and do not expect products to be in stock for a long time. By controlling most steps in the supply chain, Zara is able to respond faster to market trends. This also decreases the cost of errors in the forecast. But Zara may also have identified that having a fast supply chain enables it to charge a price premium for the market segment it targets. Is such a high degree of supply chain ownership necessary for Zara? How can competitors respond in the apparel market?

1.5.1 Zara's Supply Chain Architecture

Zara has a vertically integrated supply chain with intense coordination between levels. Store managers pass along customer requests to designers, who then incorporate customer suggestions into new designs that are manufactured and delivered frequently to stores. This coordination enables faster cycle times, under two weeks from start to finish. Capacity for cutting, packing, delivery, and so on are owned and deployed by Zara to maximize flexibility. The sewing capacity is subcontracted but managed by Zara. Is the Zara supply chain competitive? The company has a market value that is significantly larger than most firms in the apparel industry. Success has come from significant control of assets as well as an intense coordination of information flows throughout the supply chain.

1.6 Global Apparel Supply Chain Management

Li & Fung is a Hong Kong–based company that specializes in supply chain management ([82]). The origins of the firm can be traced to Victor

Fung's grandfather, who worked as a translator of business documents from Chinese to English. The firm had a fee of 15% of sales, which rapidly reduced to under 1% of sales and became nonexistent. The company then moved to serve as a broker or agent for manufacturers in Taiwan and China, thus providing regional sourcing capability. The next step was a move to assortment packing: an order for a product might involve making components in different places, creating a kit sent for assembly, and then packaging the finished product.

The company then moved to the management of outsourced production. Companies provided design details and Li & Fung managed the manufacturing and delivery. For example, companies like The Limited would approach Li & Fung and discuss design plans for the upcoming season. Li & Fung would provide a sourcing plan and develop a regional sourcing capability that covered manufacturing in China, Taiwan, and Hong Kong.

The next step involved managing dispersed manufacturing. For example, an order placed for apparel manufacturing may involve sourcing fabric in Taiwan, cutting in Hong Kong, stitching in Thailand, and sourcing zippers and buttons from Japan and fabric shell from Germany. This garment might have to match with other garments sourced in other parts of the world and be delivered on time to a specified location. All of these shipments would have to fall within the specified import quotas into the United States or Europe.

Li & Fung takes no business risk but has access to over 1 million employees. The employees work for their independent owners but reserve about 30% of the capacity for access by Li & Fung. Li & Fung knows their capabilities and allocates work after demand unfolds. The ability to adjust capacity use to demand realizations permits faster turnaround of orders within the quotas. Also, since Li & Fung approaches the particular supplier with the expertise independent of location, they effectively manage dispersed production.

Victor Fung refers to the firm's capability as the "soft \$3" of the supply chain. He explains that if a product that leaves a plant costing \$1 ends up at retail for \$4, the \$3 represents the cost of inventory, forecast error, exchange rates, retail markup, and other factors. There is a much better chance at reducing the \$3 than the \$1. Li & Fung focuses on "creating a customized value chain for each order" ([82]). This represents a classic example of a pure supply chain company.

1.6.1 Li & Fung's Supply Chain Architecture

The Li & Fung supply chain consists of dispersed manufacturing capacity owned by independent apparel suppliers that provide flexible access to their capacity in return for lower selling costs. The customized supply chains created by Li & Fung for a manufacturer requires understanding the price vs. lead time trade-offs. Capacity is reserved by the supplier to accommodate demand as it unfolds. Trust between the supplier and Li & Fung and several years of continued growth enable this capacity to be reserved at no explicit cost. The ability to mediate between the information-technology-savvy Western retailers and the Eastern suppliers, operating at lower technology but at competitive price and quality levels, provides Li & Fung with its competitive advantage. Li & Fung enables supply chain efficiency, enabling improved forecasts, lower lead times, higher in-stock levels, and the ability to curtail orders for lower-demand volume products.

1.7 Understanding Supply Chain Architecture and its Impact—A Case*

Industrial Chemicals faced a dilemma. The vice president of sales had a consultant's report that showed a significant sales opportunity as the North American Free Trade Agreement (NAFTA) became a reality. While the forecasts were known in the past to be a poor predictor of actual sales, sales had always managed to deliver long-term growth. Industrial needed to prepare for this expansion, and the lead time for plant and warehouse expansion was two years.

Industrial sold mainly through distributors, large and small. Orders from distributors generated a volatile demand at Industrial's warehouse (Figure 1.1). To optimize manufacturing, Industrial's plants produced in large lots periodically (Figure 1.2). To ensure a high in-stock availability, Industrial's warehouses carried a high level of inventory (Figure 1.3). All of this resulted in large levels of finished goods inventory at Industrial

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*This case is based on a description in Byrnes and Shapiro [13]. It is adapted here to fit the models and description of this text. Please refer to the article for a broader view to the organization.

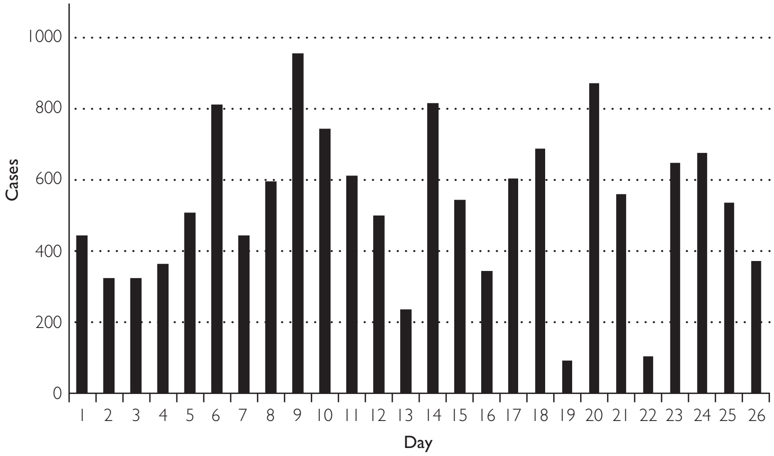


Figure 1.1 Orders received by the warehouse before agreements

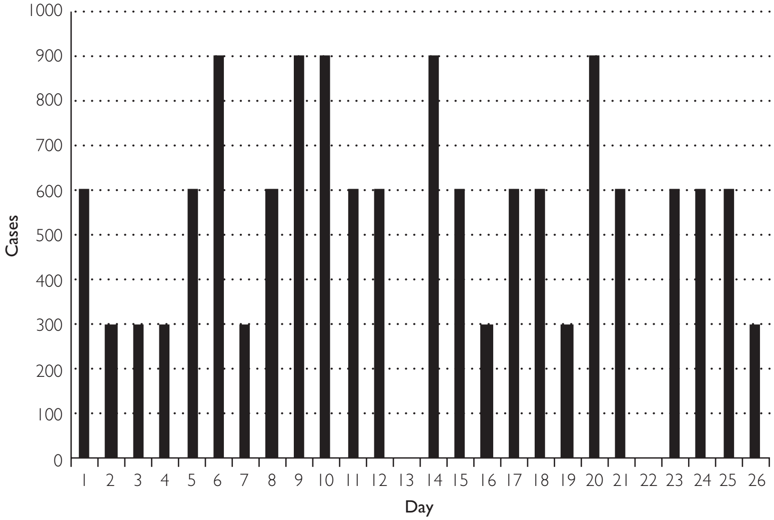


Figure 1.2 Production at the manufacturing plant before agreements

and thus demanded high levels of working capital. The demands for additional capacity would strain an already precarious business situation.

But before approving the expansion, Industrial's management wanted a supply chain audit of the entire system. This meant an analysis of all physical and informational flows throughout the system. Industrial wanted a complete analysis of every step in the supply chain, inside and

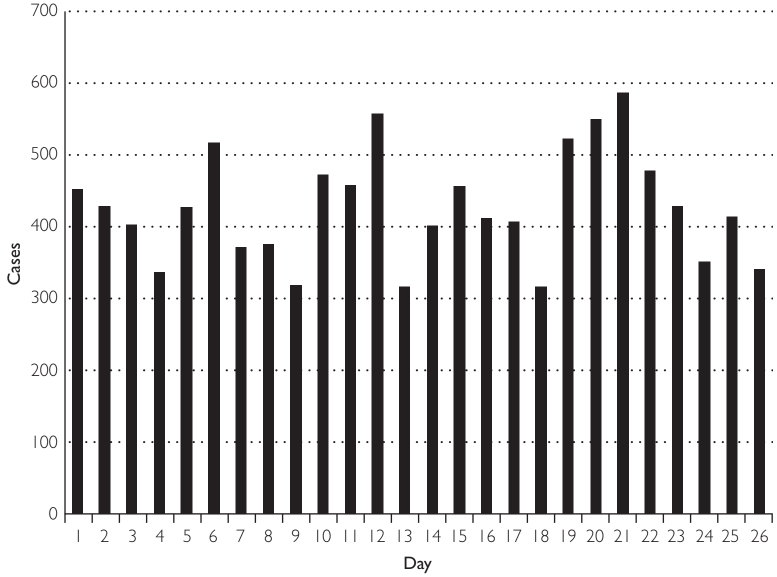


Figure 1.3 Warehouse inventory levels before agreements

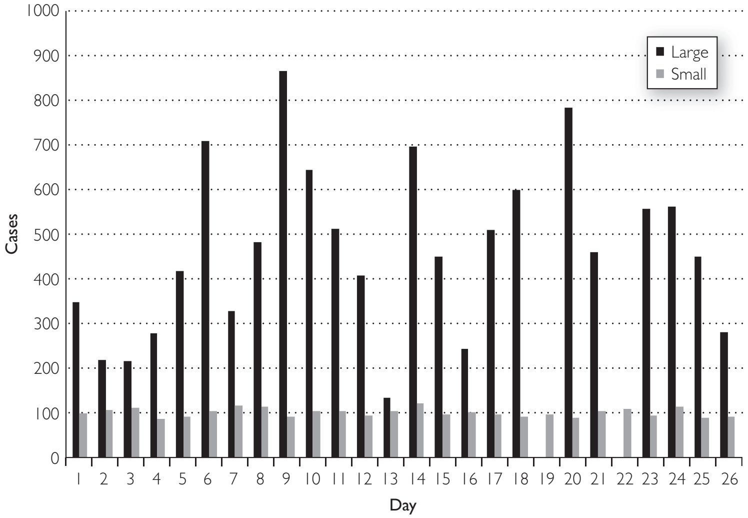


Figure 1.4 Orders split into large and small distributors before agreements

outside the company, to identify performance improvement opportunities. This included new contracts, accounting allocations, and new responsibilities. Suggestions for improvement could cut across the supply chain and across functional areas.

A first step was to understand the link between orders received by Industrial and demand faced by Industrial's customers. Ten key distributors comprised over 80% of Industrial's sales. Separating the order streams indicated that these ten distributors generated the bulk of the order volatility faced by Industrial. The remaining 20% of the demand volume observed by Industrial was a quite steady (Figure 1.4).

If orders to Industrial were volatile, could the demand faced by these distributors in turn be the cause of volatility? Meetings with these distributors indicated that their sales to small retail stores generated a reasonably steady demand to these large distributors. But Industrial had to identify why the distributors were ordering in such large quantities when their demand was steady. The secret turned out to be the transport cost that distributors were concerned with. Since Industrial offered large discounts for customer pickup, all distributors tried to create backhaul loads with their retail accounts and other product demands. In addition, sales offered discounts for large-volume purchases, which incented distributors to order large volumes to reduce their cost of goods sold and improve margins. Finally, Industrial offered generous return terms so that leftover product could be returned. This decreased distributors' need for careful planning. It was clear that choices made regarding the accounting and charging for customer services, sales incentives, and marketing programs all affected the demand volatility faced by Industrial.

How could Industrial get the same steady order that reflected the demand faced by distributors? Perhaps vendor-managed inventory (VMI) offered such a solution. The supply chain community had been reporting the benefits of such agreements for some time. Industrial decided to set up such agreements with the ten key accounts to stabilize demand through its supply chain. The process would essentially work by replenishing the volume that distributors shipped. But this also implied that there would be additional significant changes at Industrial's end to stabilize the supply chain. Long-term price agreements, taking over transport responsibility and establishing a coordinated transport system and eliminating specific programs for large buys were all part of this scheme. Industrial's management was committed to smoothing demand and implemented these programs. The results are shown in Figure 1.5 and Figure 1.6.

The result was a smooth order pattern Industrial that reflected the steady demand faced by the distributors (Figure 1.8). The stabilization of demand by the large distributors in turn meant that Industrial's total demand became smoother (Figure 1.5). As a result, the plant could reliably commit a portion of its capacity for steady production (Figure 1.6). As safety stock decreased, the warehouse inventory decreased by 70% (Figure 1.7). The result was that operating costs fell by 30%, and Industrial could reliably commit to supporting new sales zones with no need for new capital campaigns while maintaining its legendary service.

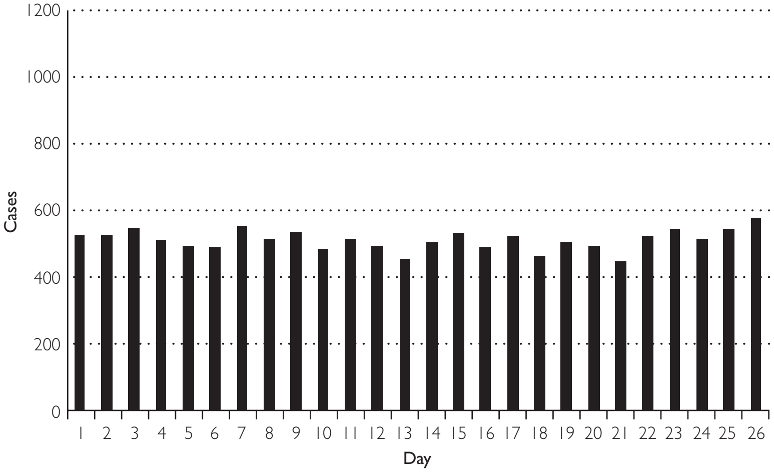


Figure 1.5 Warehouse orders after agreements

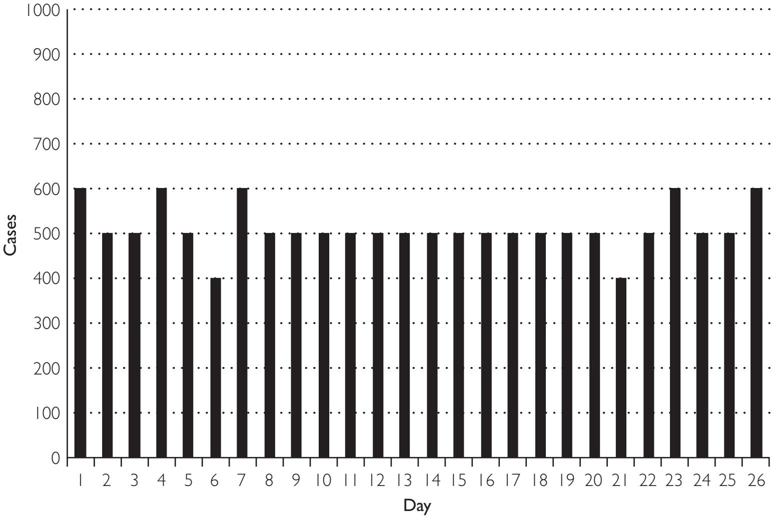


Figure 1.6 Production batches after agreements

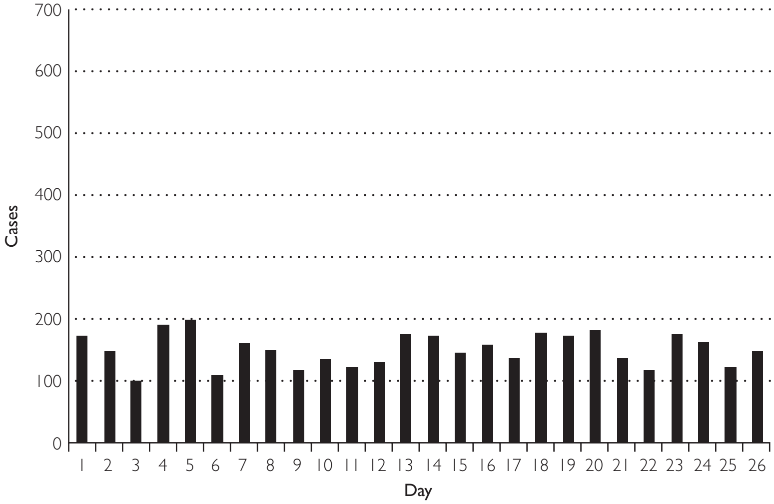


Figure 1.7 Warehouse inventory after agreements

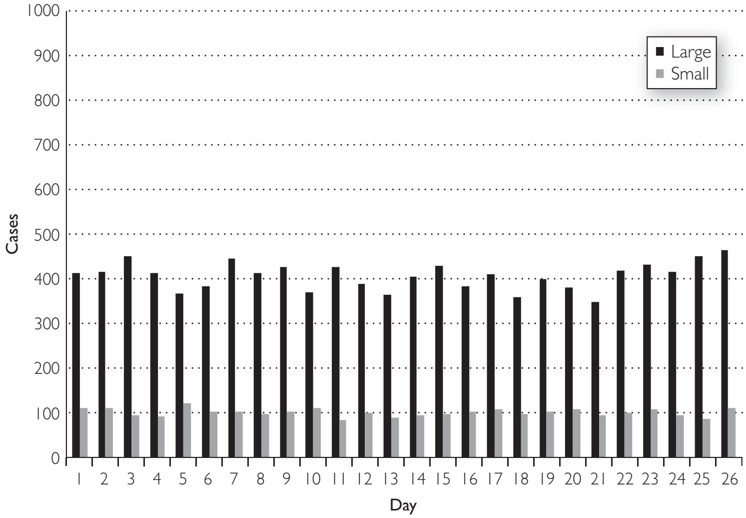


Figure 1.8 Split of orders after agreements

This example illustrates the benefit of thinking outside the box as defined by Industrial Chemicals and examining the root causes for order variation, i.e., the supply chain structure. But it also means moving to a bigger box, i.e., including more entities in the supply chain. The new perspective considers the link between demand variation and truck capacity driven by existing coordination agreements (backhaul discounts). The case shows the benefit of developing a coordination agreement between Industrial Chemicals and its customers, and the impact of the agreement on orders from distributors. Consequently, we see the ripple effect of such a change on the overall supply chain. This case provides a quick glimpse of the power of supply chain management to influence costs across functional areas of a company. The changes at Industrial impacted manufacturing, sales, logistics, and, by avoiding additional investments, the finance functions of the company. In short, integration across functional areas, both within and across company boundaries, provides supply chain opportunities. A Four C framework, which focuses on competitiveness, chain structure, capacity, and coordination choices across a supply chain, thus provides a succinct approach to understand the existing supply chain choices and to develop innovative alternatives.

1.7.1 Supply Chain Architecture at Industrial Chemicals

Industrial Chemicals has a supply chain that includes manufacturing plants, plant warehouse, distributor, and customers. Without changes in the existing supply chain architecture, expansion into a new market required new plants and warehouses. But a change in the supply chain architecture, through increased coordination with distributors, the introduction of vendor-managed inventory, and increased distributor demand information sharing, changed the product and information flows through the supply chain. Capacity was now freed up for expansion, and competitive costs were maintained. Solving the supply chain management problem for Industrial required dealing with coordination issues, adjusting capacity, and adjusting the competitive metrics of performance, thus influencing information and material flows throughout the supply chain. The changes in the supply chain architecture (i.e., the Four Cs) touched all functional areas of the company.

1.8 A Supply Chain Audit

We will now focus on steps involved in completing an audit of a supply chain ([59]). The goals of this supply chain audit are to (1) understand the architecture of the current supply chain and (2) identify potential sources for improvement.

1.8.1 *Mapping Chain Structure*

The first step in a supply chain audit is to map chain structure and ownership as well as associated flows of physical products and information (orders) between members of the supply chain. The role of a supply chain map is to get a picture of the overall supply process and where the particular retail store fits. It reminds the manager that the current supply sources may need to evolve as the product characteristics change.

Key decisions at this stage involve the level of detail to include, e.g., a cross-product analysis rather than a focused analysis of an individual stock-keeping unit (SKU), the granularity of the data that will be considered (annual vs. monthly vs. daily flows), use of a finished goods inventory or work-in-process inventory, or whether the raw material and its sources will be included. These critical choices impact the Four C analysis.

As an example, imagine that you are inside a grocery store and want to understand the supply chain of finished goods upstream of this store. The supply chain map (Figure 1.9) starts at the store and works its way upstream. The store carries inventory, which is picked up and purchased by retail customers. The goal of the store is to make things convenient for customers by enabling them to get their demand satisfied immediately

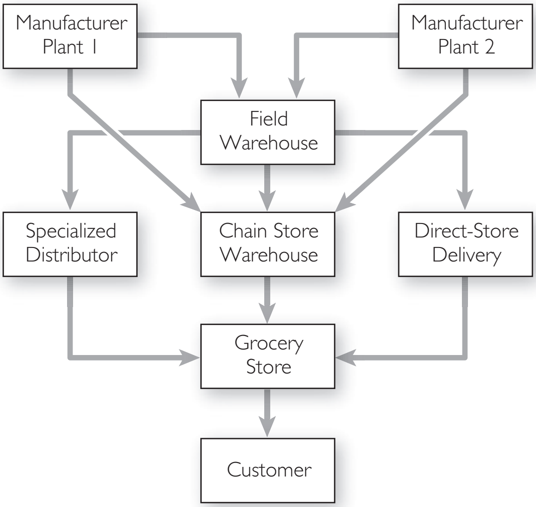


Figure 1.9 Flows in a grocery supply chain

from store inventory (thus making their lead time zero). The store inventory ensures that customers do not have to worry about how the product got there, the associated Four Cs involved in making the product, moving it, and managing availability.

Upstream of the store, i.e., moving towards the manufacturer, there are numerous possible supply sources. The store can get its product from the chain store warehouse, which may have regular deliveries to the store. But the store can also get deliveries from wholesalers who support a particular manufacturer and deliver in bulk. The store can also receive deliveries from specialized distributors who may focus on a niche market, e.g., organics or special ethnic foods. Each of these sources in turn gets product from the plant warehouses or other sources. The plant in turn gets supplies from suppliers.

How does a store manager benefit by knowing where he fits into the grocery supply chain? Clearly it makes sense that for large-volume products, the store might try to get direct delivery from the plant warehouse. This reduces the lead time and handling and transport costs and generates a more efficient supply. But for small-volume products, with varying demand, it may be best to consider using specialized distributors who can deliver the required small volumes. Some manufacturers may be willing to manage the store shelves directly, as in the case of Coke, Pepsi, and Frito Lay. At the same time, some customers may be willing to take larger case sizes, thus reducing costs related to breaking bulk. Clearly, it might be to the store's advantage to match the product supply to its demand characteristics.

1.8.2 Capacity Audit

The next step in a supply chain audit is to examine how capacity is deployed by understanding its product-based allocation, which is related to design choices across locations and product types and across locations. Thus, we will first consider how products can be separated based on their demand volumes and consequent impact on capacity requirements. The next step will be to consider if product design specifications can be standardized to improve supply chain performance. Finally, the impact of a consolidation warehouse on required capacity will be considered.

Capacity and Product Characteristics

Next, focus on products handled by the supply chain and verify if the supply process matches product characteristics. If all SKUs are sorted in order of decreasing sales (i.e., from the highest to lowest sales levels) and the cumulative sales are plotted vs. the corresponding ranking of products, the data usually generates a Pareto distribution. Products can thus be divided into three categories: **A** products that represent 20% of the products but 80% of the sales volume, **B** products that represent 30% of the products and 15% of the sales volume, **C** products that represent 50% of the products and 5% of the sales volume.

How can the capacity associated with supply of products be adjusted to demand characteristics? Suppose the A products have high mean demand and low demand standard deviation (thus a low demand forecast error) while C products have low mean demand and high standard deviation of demand (thus a high demand forecast error). Suppose there is a choice between supplier 1, who operates with a high capacity utilization and thus has a four-week lead time but a price per unit of $10, and supplier 2, who has a high buffer capacity, low capacity utilization, and a one-week lead time but a price of $11 per unit. Given the low demand standard deviation, it might be optimal to avail of the efficiency of capacity utilization and its consequent lower costs by using supplier 1 for A products. Given the high forecast error for C products, it might correspondingly be optimal to use supplier 2 if the higher price and faster delivery is a better cost option to carrying safety stock.

This example suggests that supply chain costs can be decreased by adjusting the supply process to match product characteristics. Thus, in this step of a supply chain audit, the question is **Are the supply chain capacity and its deployment tailored to product characteristics? If not, how can supply chain costs be reduced by such adjustments?**

Capacity and the Role of Standardization

In many supply chains, products with similar form and function may end up having different specifications (e.g., consider the number of different power cords for cell phones). Such SKU proliferation can generate significant supply chain costs because each of these product variants has to be ordered, inventoried, accounted for, transported, and replenished. One reason for such proliferation across product selling segments may be the different design and procurement teams for each division that manages that segment. Standardization of components or product is an approach to manage capacity requirements to satisfy demand.

This is particularly true for a category of goods termed *maintenance, repair, and operating (MRO) supplies.* MRO refers to items that never end up in the product sold to the customer but that enable the manufacturing and distribution of the product. Examples include machine coolants, electrical fixtures, plumbing fixtures, paper, office supplies, supplies for environmental compliance of the plant and packaging material. In many cases, there is no engineering control of these product specifications, thus resulting in maverick buying or local decision making regarding specifications. The net result is a multitude of different specifications that can vary by location or even within a plant.

Standardization refers to identifying basic product specifications to gain the benefit of economies of scale as well as to increase supplier incentives for service. In many instances, standardizing parts permits vendors to reduce costs because it enables the vendor to use peddling routes (milk runs) to deliver products efficiently across locations. As a result, standardizing product specifications can reduce inventory by decreasing associated ordering costs, safety stocks associated with product forecast errors, as well as supplier lead time associated with eliminating supplier setups, which all lead to decreased supply chain costs. So the question is **Has the supply chain taken advantage of product design standardization to decrease costs?**

Capacity and the Role of Consolidation

Consolidation in a supply chain refers to the accumulation of product in a central location in order to take advantage of economies of scale in manufacturing, warehousing, and transportation. The basic economic reason for consolidation is to increase utilization of fixed capacity and thus gain the associated cost reduction. When many products share capacity, there is the opportunity to decrease delivery sizes across products, thus also decreasing inventory costs. Consolidation of orders also permits shipments to be potentially *cross-docked* (moved directly from inbound to outbound trucks) through careful coordination, also decreasing costs.

To evaluate if consolidation warehouses reduce overall supply chain costs, one has to balance the coordination costs associated with managing the timing of availability of products with the gains from sharing transport and providing deliveries to individual demand points that reflect their demand mix over time. So the question is **Has the supply chain taken advantage of product consolidation across locations to decrease supply chain costs?**

1.8.3 Coordination Audit

The next step is to consider a few standard opportunities to coordinate product flows and thus enable supply chain improvement. Assembly postponement is an approach to coordinate demand across products by creating a standardized design that is customized after demand for a specific product is realized. It permits better coordination of demand and supply by decreasing supply chain costs while enabling requisite variety. Geographic postponement is a similar strategy that stores product in a central location and moves it after demand is realized. Each of these strategies enables a closer link between demands realized and product creation or movement, thus leading to performance improvement.

Coordination Using Assembly Postponement

Assembly postponement refers to maintaining a product in a given state for as long as possible and customizing it after demand is realized. Thus, a set of products is replaced by a common platform product that is manufactured and customized only after demand is realized. Such an approach is also called *design for logistics.* This approach involves designing the product to reduce supply chain costs.

Consider the impact of redesign of the Hewlett-Packard (HP) Deskjet printer sold in Europe ([39],[79]). Before the project started, HP produced a separate model for each market in Europe and sent the manufactured product to its warehouse in Amsterdam for distribution to the retail segment. The warehouse satisfied retail demand from finished goods inventory. But given that product was shipped from the US plant to Europe by sea, the long lead time, coupled with demand variability, implied that high levels of safety stock had to be held in the Amsterdam warehouse.

HP's engineers developed a new printer design that permitted a generic printer to be made at the manufacturing plant. The generic printer was sent shrink wrapped in a pallet to the warehouse in Amsterdam where the customization and packaging would be done by loading the appropriate software and accessories. This design change resulted in lower transport costs, fresher and more recent packaging, lower inventories in Amsterdam, lower manufacturing costs at the plant, and higher in-stock levels. In addition, the lower inventory levels enabled faster introductions of new product and lower obsolescence costs. See Figure 1.10 for a representation of the concept.

But this change required that the designs maintain the product performance and reliability as well as result in reliable operation of the warehouse, whose new role included both light manufacturing as well as distribution.

There are many other examples of assembly postponement. The salad bar at a restaurant is a classic example of making the customer assemble their desired salad on demand. Hardware stores claim to carry over 30,000 colors of paint. But in most cases they carry only a small number of primary colors and additives and create the color on demand with the aid of software. Such assembly postponement permits lowering of supply chain costs while maintaining customer choice.

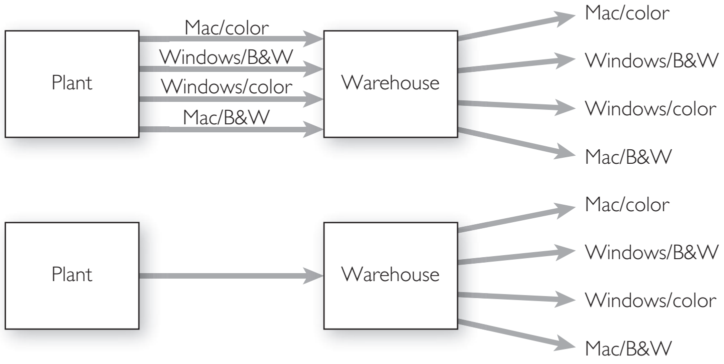


Figure 1.10 Assembly postponement of Deskjet printers

Thus, an important question for an existing supply chain is **Can assembly postponement, through product design changes, enable supply chain improvement?**

Coordination Using Geographic Postponement

Geographic postponement refers to delaying the movement of product to the demand location until after demand has occurred. If the customer lead time for delivery is short, this might require premium transportation. If not, the product may be moved to the customer demand point by normal transport modes.

A classic example is the supply chain for appliances sold by Sears in its retail stores ([116]). Customers went to a Sears retail store, selected an appliance, and then scheduled delivery using Sears delivery service. This meant that after purchase, lead time for delivery to the customer was about one week. Sears supply chain managers realized that retail stores did not need to carry as much store inventory, given the customer delivery lead time. Orders could be placed to a central location after retail orders for appliances were received. The products could, in some cases, be manufactured after demands were realized. Appliances would then be transported to the region and coordinated with retail deliveries. Retail customers received deliveries without ever knowing where the inventory was located. Geographic postponement thus enabled lower inventories, higher service level, and smoother new product introductions (and therefore easier handling of product recalls).

Such approaches to improving supply chain performance are common in the computer industry, where expensive parts required to fix computer systems are stored in a central location and shipped either overnight or on the next flight out to deal with mainframe failures for critical applications. For example, Federal Express (FedEx) has a division called Critical Parts Supply that permits manufacturers to warehouse product in Memphis with immediate automatic shipment by FedEx on customer demand.

The supply chain audit question is **Can geographic postponement be used in this supply chain to improve performance?**

Coordination using Speculative Capacity

Speculation refers to decisions (regarding inventory or capacity) made in advance of demand realization. Price variation may suggest use of speculation as a strategy, with purchases during low price points in anticipation of price increases. Long lead times for supply may suggest buffer safety stock and thus speculative inventory. Uncertain demands may require capacity buffers or speculative capacity. Product supply disruptions may imply stocks to be purchased whenever product is available. Seasonal demand or supply may demand that products are purchased and inventoried when "in season." Inventories may also have to be held to smooth production.

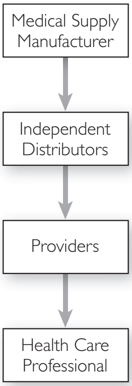
Consumer examples of speculative inventory include decisions to stock up on grocery products during a sale. Similarly, Chapter 9 on grocery supply chains highlights optimal retail warehouse purchases during trade promotions, with large increases in inventory and thus additional required warehouse capacity. Firms that build up inventory in anticipation of a strike or production disruptions during changeover use speculative capacity to buffer the impact.

Thus, the supply chain audit question is **Can speculative capacity or inventory be used to improve supply chain performance?**

1.8.4 Competitiveness Metric of the Supply Chain

What is the basis of competition for the supply chain? For purposes of illustration, we will use cost as a metric of performance, but many other possible choices (e.g., time, days of inventory) could also be the relevant metric. Consider the cost impact on the product as it moves through the supply chain. Examine how costs are added as each of the entities in the supply chain impact the product.

We provide an example for a medical supply manufacturer in Japan. This manufacturer first mapped the supply chain (Figure 1.11). The supply chain (on the left side of the figure) showed that the manufacturer produced the product and sold it to distributors. The distributors carried products made by this supplier as well as products made by many other suppliers. By providing one-stop shopping for all products, the



Channel Costs (Millions)

	Manufacturer	Distributors	Providers	Total
Warehousing	$10.3	$7.1	+	$17.4+
Transportation	21.2	8.3	–	29.5
Inventory	9.2	12.2	9.3	30.7
Administration	6.3	4.0	+	10.3
	$47.0	$31.6	$9.3+	$87.9+

Figure 1.11 Medical supply system before changes

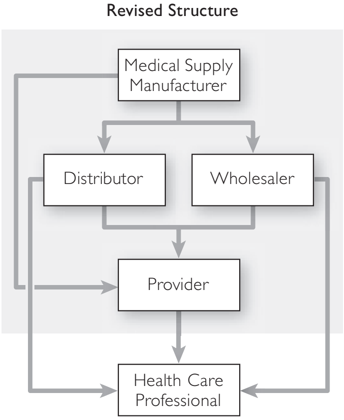
distributors made procurement easy for the health care providers. The health care providers sold products to health care professionals, who in turn used them to treat patients.

The medical supply manufacturer asked a consulting firm to identify the total costs as the product moved through the supply chain. The right side of Figure 1.11 shows the costs added due to warehousing, transportation, inventory, and administration as the product moves through the supply chain. The data showed that about 45% of the costs were added after the product left the manufacturer.

The question now is **Which of the supply chain entities is affected by these added costs?** For the manufacturer, these added costs meant lower margins as well as greater potential for competitors to enter the market. The end customers (patients) cared because the supply chain inefficiencies meant higher costs.

But what could be done to improve the supply chain? The manufacturer studied the source of the costs and decided that the problem was the *one-size-fits-all* approach implied by the original supply chain. Because all products followed the same path in going from the manufacturer to the customer, the associated supply was not matched to demand patterns.

An alternative approach (Figure 1.12) was to permit multiple approaches to get the product to downstream customers, relative to the nature of the demands. Thus, a wholesaler who ships large volumes of product to a large health care provider could get product directly without going through



Channel Costs (Millions)

	Old System	Integration	Reduction
Warehousing	$17.4 →	$15.0	$2.4
Transportation	29.5 →	26.9	2.6
Inventory	30.7 →	22.6	8.1
Administration	10.3 →	9.2	1.1
	$87.9	$73.7	$14.2

Figure 1.12 Medical supply system after changes

a distributor. In some cases the product could be shipped directly to the health care professional, thus eliminating some steps in the process.

The net effect of the changes in the supply chain was to provide a more finely tuned link between supply and demand by product type. The impact on the supply chain was projected to be $14 million (out of $87.9 million spent). The impacts on individual steps in the supply chain are as shown in Figure 1.12. This example shows how supply chain structure and its adjustment can impact cost competitiveness.

1.8.5 Impact of Competitors on the Supply Chain

Consider how competitors impact a supply chain ([59]). Use the following questions to check performance relative to competitors.

1. How do our product attributes match customer requirements? How do our competitors' product attributes match customer requirements? The goal of this question is to understand whether there are differences in the extent to which our offerings and the offerings of the competition match the attributes demanded by our customers. The relevant attributes could include the extent of product customization to buyer requirements, the buyer-delivery flexibility vs. the delivery offered, and buyer preferences for the level of involvement in the supply chain vs. the level currently offered across the industry.

2. How do our competitors offer the service they do or how do the customers perceive they offer it?
   The goal of this question is to compare customer perceptions of service offered by our competitors to the service we offer. Can differences in perceived service be traced to strategic choices in product attributes we make vs. those made by our competitors? As an example, if we offer customized products while our competitors offer off-the-shelf solutions, then we should expect customers to face higher lead times for our products vs. our competitors' products. After analyzing the response to this question, one should decide whether to maintain or adjust product characteristics to match the competition.
3. Where in the product life cycle do our products sit, and how have we adjusted our supply chain strategy to match? Where are the competitors' products located in their life cycle?
   It is clear that the operation of a supply chain during product introduction and ramp-up is quite different from the operation during product phase-out. As the product reaches the end of its life cycle, it may be appropriate to reduce inventories throughout the chain at the expense of slightly higher lead times (through, for example, geographic postponement). At the same time, pricing of new and old products may have to be managed to permit new product demand to grow without being cannibalized by old products. All of this requires a planned supply chain strategy for product phase-in and phase-out. This step checks if these strategies are in place in the supply chain. By considering the life cycle position of our products and comparing it to our competitors' products, we ensure that our supply chain is competitive through time.
4. How coordinated are the supply chain choices with the company strategy? How does this differ from our competitors? If our competitors have a coordinated supply chain and we do not, then the relative efficiency of competitors may require coordination of our supply chain. Note that the coordination of all competing supply chains does not guarantee improved profits, but only suggests a competitive necessity. The decision then is whether to continue to engage as needed or to change market focus.

1.9 Chapter Summary

This chapter focused on examples of supply chains and their underlying supply chain architecture, using a Four C conceptual framework. The Four Cs refer to chain structure and ownership, capacity, coordination, and competitiveness. The supply chain audit permits an understanding of current choices and an approach to evaluate alternate choices for supply chain architecture. The goal of this chapter was to explain the Four C choices made in different successful supply chain contexts.

CHAPTER 2

Chain Structure

This chapter focuses on supply chain structure and ownership, one of the Cs in the supply chain framework. The chain structure is the backbone or the pipeline through which information and material flow in the supply chain. It is the process map of a supply chain that typically crosses many independent company boundaries. Once a supply chain map is generated, the location of entities, as well as ownership, and the connections to the rest of the supply chain architecture influence the observed lead times, costs, incentives, and thus performance, of the supply chain.

Our goal in this chapter is to understand commonly observed supply chain structures and discuss their potential impact on performance. Key supply chain features include the number of links in the chain, the locations where capacity is shared, the level of flexibility of the entities and their impact, the impact of chain structure and capacity, the impact of uncertainty on performance of the network and finally, how country boundaries interact with flows across the chain.

2.1 Chain Structures

The following are commonly used supply chain structures.

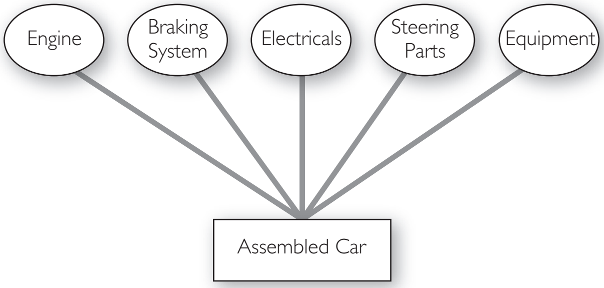
2.1.1 Serial Supply Chain

A serial supply chain consists of a number of entities that work sequentially to deliver product. In a serial supply chain, any given node's supply is affected by the decisions of upstream entities, and that node's demand is generated by downstream entities. Serial supply chains provide a simple supply chain structure, but it often implies use of a one-size- fits-all strategy that can generate significant costs if products and customer segments can be differentiated. Thus, it is clear that managing a given node, even in a serial supply chain, is complex due to the need to anticipate how information and incentives are incorporated into actions by other participating entities.

The example provided earlier in the book (Figure 1.11) described the supply chain for a medical device manufacturer. In that example, products flow from the manufacturer to a distributor to a health care provider to a health care professional and finally to the patient. This is a serial supply chain: the product flows through a series of steps to reach the patient.

2.1.2 Assembly Structure

An assembly structure is one in which products from separate suppliers or plants are combined to form subassemblies, which in turn are combined to form the final assembly. Figure 2.1 shows a sample assembly supply chain. Automobile industry manufacturers, such as Toyota, Honda, and Ford, all use tiered purchasing arrangements, in which subassemblies from one set of suppliers are combined at the next level until the final car assembly, thus generating an assembly structure of suppliers. In such structures, the complete "kit" of parts from all suppliers is necessary to complete assembly. Thus, a key task for the operation of an assembly structure is coordinating the deliveries from all suppliers to produce a unit of a finished product.



A Car Assembly Structure

Figure 2.1 An assembly supply chain

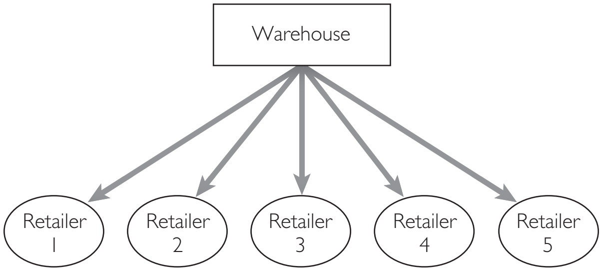


Figure 2.2 A distribution supply chain

2.1.3. Distribution Structure

In a distribution supply chain, products flow out in a fan-shaped structure to the retailers. Consider the example of a warehouse and retailers in Figure 2.2. Even if the retailers serve independent markets, the retail supplies are linked because the warehouse inventory policy affects the supply to otherwise independent retailers. But the presence of the warehouse may generate significant benefits to the supply chain by enabling bulk commitments by the wholesaler or plant, which can deliver to the warehouse, followed by a distribution to retailers as their demands unfold. The warehouse thus offers the benefits of "demand risk pooling" and enables geographic postponement of the deliveries to retailers. We will analyze the impact of such risk pooling in Section 2.3.

2.1.4 Assembly Followed by Distribution

Many supply chains have an assembly structure for product manufacturing followed by a distribution structure for product distribution. The assembly structures enable economies of scale in transportation and assembly, while the distribution structure enables efficiencies in matching finished goods inventories with product demand across retail locations.

2.1.5 Network Structure

In more general contexts, the components and products flow through a network. Figure 2.3 shows component suppliers (S), intermediate subassembly plants (I), assembly plants (A), distribution centers (W), and customer zones (C). The locations of these entities may be spread across

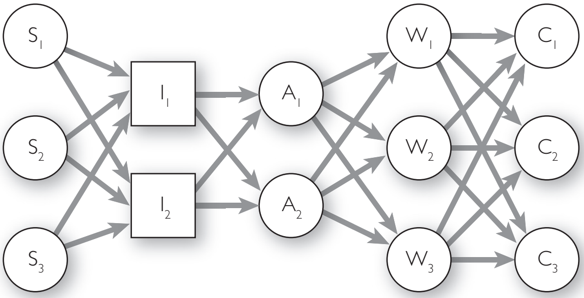


Figure 2.3 A supply network

the world. The main benefit from such a network structure is the flexibility to adjust flows to reflect demand, cost, and competitiveness. If the network flows cross country boundaries, then decisions made by each country location regarding exchange rates, duties, and tax structures impact the profitability implied by the supply chain.

2.2 Order Variability in a Serial Supply Chain: The Bullwhip Effect

Consider a set of n independent entities (nodes) in a serial supply chain, shown in Figure 2.4. Node 1 is closest to the customer, and Node 1 is supplied by Node 2, Node 2 is supplied by Node 3, and so on. Now suppose that Node 1 faces a demand of μ every period. Suppose each node faces a lead time L to get product from its supplier immediately upstream. Finally, suppose that each node carries a pipeline inventory (sum of all physical inventory, plus orders or material in transit) of $(L + S) \times$ DemandForecast, where S is the safety stock factor at that location. Thus, if every node passed along the demand forecast it faced, each node would have a pipeline inventory of $(L + S) \times$ DemandForecast.

But suppose customer demand were to increase suddenly by K units. For simplicity, suppose Node 1 changes its demand forecast to $\mu + K$. It would immediately order to satisfy the current demand and to fill the

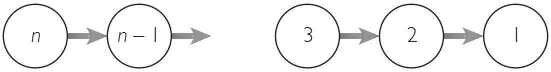


Figure 2.4 Chain for the bullwhip effect

pipeline; thus the order placed to Node 2 would be $\mu + K + ((L + S)K)$, which can be written as $\mu + K(L + S + 1)$. In turn, the order placed by Node 2, following the same logic, would be $\mu + K(L + S + 1)^2$. The order placed by the nth node is, in turn, $\mu + K(L + S + 1)^n$. Notice the polynomial growth as we move upstream. This growth in orders is called the *bullwhip effect* and occurs because every node faces a demand that is partly in response to the current order and partly an attempt to fill up the pipeline.

What would happen if all nodes shared the downstream demand information? In such a case, every node would see the underlying demand. Thus, the order adjustment would cover the demand faced and would not be confused with the pipeline inventory increase. Thus, the order faced by node n would be $\mu + K((L + S)n + 1)$. The increase in order due to lack of demand information can thus be described as

$$\frac{(L + S + 1)^n}{((L + S)n + 1)}$$

This increase reflects the exponential growth in orders in response to lack of information in a fragmented supply chain. As mentioned in Chapter 1, this is called the bullwhip effect. Thus, even in a serial supply chain, lack of transparency can create undesirable volatility even when each entity behaves optimally, thus generating the bullwhip effect. The consequences of such volatility are increased capacity, inventory, delivery lead time, and costs.

2.3 Distribution Supply Chains: Risk Pooling and Inventory Impact

Consider a distribution supply chain consisting of a set of n downstream retailers linked to a common source warehouse. There is a common inventory pool at the warehouse shared by all downstream locations. Suppose the supplier lead time is L. If every retailer faced a demand with a mean of μ and a variance of σ^2, then the common pool of inventory at the warehouse would be $(nL\mu) + (Z\sigma\sqrt{Ln})$, where the Z refers to the standard normal value whose cumulative probability is the service level offered to retailers, and L is the supply lead time.

If each individual retailer carried its own inventory, it would maintain an inventory level of $L\mu + (Z\sigma\sqrt{L})$. Thus the total system inventory would be $n(L\mu + (Z\sigma\sqrt{L}))$. The pooled inventory includes a safety stock of $Z\sigma\sqrt{nL}$ while the individual locations would generate a safety stock of $Z\sigma n\sqrt{L}$. Thus, the role of the warehouse in a distribution supply chain is to decrease the buffer capacity by a factor of $\sqrt{n}$. This $\sqrt{n}$ effect is a rule of thumb to estimate the benefit of consolidating inventory in a supply chain.

2.4 Optimizing the Supply Chain Network

A typical supply chain network is shown in Figure 2.3. Designing a supply chain involves choosing facilities, capacity, and deployment to maximize competitiveness. Steps to optimize a supply chain are described below.

2.4.1 Collect Supply Chain Network Data

The first step is to collect the relevant data regarding costs and demands faced by the supply chain. For a typical supply network, such as the one shown in Figure 2.3, some of the data that will affect performance of the chain are:

1. Products and their production requirements
2. Cost to get raw material to each producing plant
3. Component production costs
4. Inter-plant transport costs
5. Assembly costs at each plant
6. Cost of transporting finished goods to warehouses
7. Warehousing costs at each distribution center
8. Customer zone demands by product

Note that there are important managerial accounting decisions that precede this data collection. These include decisions regarding appropriate average costs and flows. How should these average costs per unit be chosen, given data regarding the past history of transactions and associated costs? What values will convince current managers that these costs are truly those associated with their transactions? The typical validation check is to evaluate the costs generated by the model for the current history of flows and compare it with the current costs to see if it provides an acceptable representation.

2.5 PURPOSE OF THE MODEL

The role of the supply chain design model is to answer the following questions:

1. Where should intermediate and final products be produced?
2. What interplant shipments of intermediate products should occur?
3. How many distribution centers (DCs) should be included?
4. Where should these DCs be located, and what should be the planned capacity?
5. Which plants should supply each of the DCs?
6. Which DC should supply a specific customer zone?

Describing the chain structure, a network in this case, along with all the associated data that capture the performance impact of flows, enables an understanding of the impact of interactions between flows in the system and their effects on costs and capacity.

2.6 A NETWORK FLOW EXAMPLE

Consider the example network shown in Figure 2.5. This example is from a presentation by Jeffrey Karrenbauer from Insight Consulting, distributed

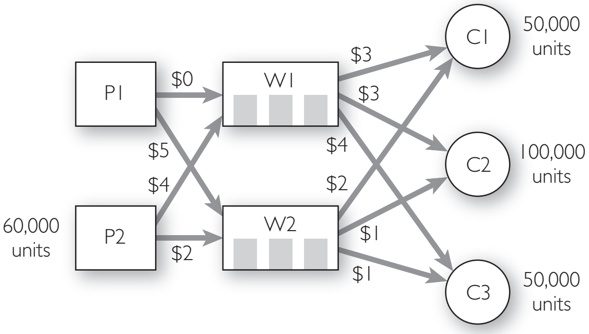


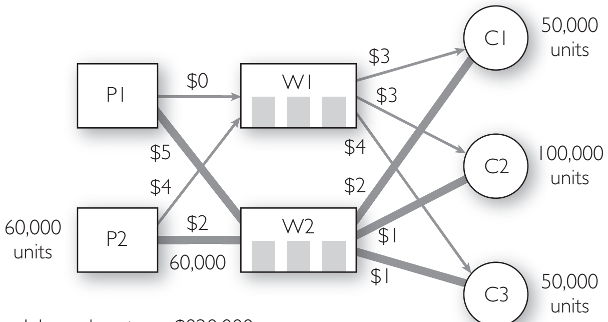
Figure 2.5 A sample network with data

in one of my classes. The supply chain consists of two plants, P1 and P2, that can each supply the demands at warehouses W1 and W2, which in turn can supply each of three customer zones, C1, C2, and C3. Demands at C1, C2, and C3 are 50,000, 100,000, and 50,000 units respectively. Warehouses W1 and W2 have no capacity constraint. The capacity at plant P2 is 60,000 units. The costs per unit are provided for each link between plants and warehouses and between warehouses and customer zones.

2.6.1 A Least-Cost-per-Lane Solution

A least-cost-per-lane solution ignores the network structure and chooses the minimum- cost warehouse to supply each customer zone, i.e., each customer zone gets delivery from the closest warehouse. In turn, the warehouses are supplied from the closest plant subject to capacity constraints. For the network shown in Figure 2.5, the corresponding decisions regarding how much each plant produces, the quantities shipped to each warehouse, and the quantities shipped by each warehouse to customer zones are shown in the Figure 2.6.

The cost associated with these decisions is obtained by multiplying the decisions with the corresponding costs on each lane to obtain a total cost of $1,070,000. But notice that when the first set of decisions was made by the customer zones, the zones did not consider which plants supply the warehouses. In addition, when the customer zones chose their closest warehouse, the deployment of the capacity of plant P2 is not accounted for.



Inbound cost	$820,000
Outbound cost	$250,000
Total	$1,070,000

Figure 2.6 Results using a least-cost-per-lane solution

Thus, the resulting decision may not generate the lowest-cost decision for the supply chain. The key takeaway from this example is that myopic, single-stage optimal decisions may not generate the best result throughout the entire supply chain. But how much can the solution be improved?

2.6.2 A Least-Cost-Path Solution

A first step to improving the solution is to consider the total cost per unit along the chain from the plant through the warehouse to the customer zone. There are twelve possible chains:

> (P1, W1, C1), (P1, W1, C2), (P1, W1, C3), (P1, W2, C1),
> (P1, W2, C2), (P1, W2, C3), (P2, W1, C1), (P2, W1, C2),
> (P2, W1, C3), (P2, W2, C1), (P2, W2, C2), (P2, W2, C3).

The cost per unit associated with each of the paths is, in dollars, 3, 3, 4, 7, 6, 6, 7, 7, 8, 4, 3, and 3, respectively.

Given the costs of these paths, the optimal decision for each customer zone would be for C1 to pick W1, C2 to pick W2, and C3 to pick W2. In turn, warehouse W1 is supplied 50,000 units by plant P1, and warehouse W2 is supplied 60,000 units by P2 and 90,000 units by P1. Given these flows, the associated cost can be verified to be 870,000, which is lower than the earlier solution.

Note that unlike the solution in the earlier section, this approach takes account of the cost along the entire path from the plant to the warehouse to the customer zone. However, it still does not account for plant P2's capacity when making the customer zone sourcing decision. Thus, a possible reason for the absence of a lowest-cost solution for the supply chain is that we may not have allocated plant P2's capacity optimally across the warehouses.

2.7 Solving the Model Using Linear Programming

In this section, we describe the optimal solution to the problem using linear programming as a solution tool. The linear programming model takes a "global" look at the problem and incorporates the path of flows,

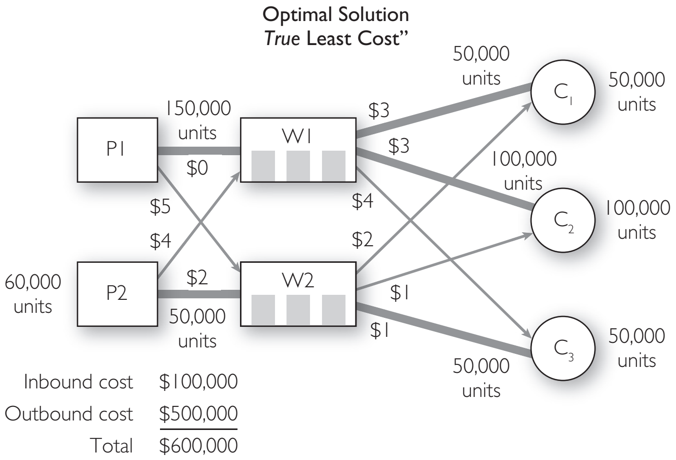


Figure 2.7 Optimal solution for the network

the capacity impact, and the benefit to taking multiple paths of flows to balance use of capacity and satisfying demand.

The results of using Microsoft Excel Solver (one of many possible analytical tools) on the optimal solution are shown in Figure 2.7. The results show that the optimal cost to satisfy demands can be decreased to $600,000. The key to achieving this solution is to choose which warehouse supplies customer zone C2 and thus how the plant capacity will be used.

The linear programming tool is a first step in uncovering possible choices to operate a supply chain that may differ from the usual heuristics that do not account for the chain structure. Often the solution generated exposes opportunities that may not have been considered. At other times, the solution enables an understanding of the value of changes to a supply chain, such as addition of new supply sources or warehouses, that may further improve performance.

In addition, the optimization model also provides sensitivity analysis that can be used to understand the impact of capacity or demand changes.

2.8 Evaluating the Effect of Fixed Costs in the Supply Chain Example

Consider the earlier example, but include the possibility of closing plants and warehouses given fixed costs associated with each facility. During supply chain network design, such facility decisions will have to be made to optimize supply chain costs. Suppose the following capacities and fixed costs are associated with each of the plants and warehouses (Table 2.1).

There are three possible decisions regarding plant capacity: (1) keep both plants open, (2) keep plant 1 only open, or (3) keep plant 2 only open. Similarly we have three possibilities for the two warehouses: (1) keep both warehouses open, (2) keep warehouse 1 only open or (3) keep warehouse 2 only open. Closing plants or warehouses gives us fixed cost reductions but potentially decreases the flexibility to respond to changing cost or demand situations.

How would we evaluate the effect of potentially closing plants or warehouses and the impact on flexibility to respond to changing circumstances? The results obtained are summarized in Table 2.2.

Note that the optimal decision is to close plants P1 and W1, leaving plant P2 and warehouse W2 open. But this decision assumes that all costs, demands, and capacities are known. What if some of the parameters are not known with certainty?

Table 2.1 Capacities and fixed costs for the example network

Facility	Capacity (Units)	Fixed Cost
P1	250,000	300,000
P2	220,000	280,000
W1	250,000	100,000
W2	200,000	90,000

Table 2.2 Results of plant and warehouse closings

Facilities Open	Cost ($)
(P1,P2, W1,W2)	1,370,000
(P1,W1,W2)	1,140,000
(P2,W1,W2)	1,120,000
(P1, P2, W1)	1,330,000
(P1, P2, W2)	1,320,000
(P1,W1)	1,050,000
(P1,W2)	1,640,000
(P2,W1)	1,830,000
(P2,W2)	1,020,000

2.9 The Impact of Possible Cost Scenarios

When decisions are made regarding long-term capacity and network structure, it may be useful to consider possible future changes in the demand or cost scenarios when making choices. Assuming that once capacity is eliminated, it cannot be recovered easily (except after a long lead time), the reduced capacity levels may prevent access to the benefits that could accrue from having the flexibility to adapt product flows to match cost or demand levels at a future point in time.

To illustrate this idea, consider an alternative to the problem described earlier: a new transport company decreases costs from P2 to W1 to \$1/unit from W1 to C1, C2 and C3 decrease to \$1/unit, \$0.5/unit and \$0.5/unit respectively. Such a cost decrease may occur because of an arrangement with a trucking company that does extensive backhaul along these routes. Note that if we had closed P1 and W1 based on costs in the previous section, then we would operate only with P2 and W2, and our costs would have continued to be \$1,020,000.

However, if all plants and warehouse capacities remain, then the model can be optimized with the new cost parameters. The new optimal solution is to operate only P1 and W1 and thus have a cost of \$895,000. If there was an 80% chance of such a cost change, then the expected cost with all plants open would be $(0.2 \times 1{,}370{,}000) + (0.8 \times 895{,}000) = 990{,}000$. Thus, the slack capacity offers the flexibility to respond to such cost-reducing opportunities and decreases expected cost.

This example suggests that excess capacity in a network can provide the flexibility to react to changing cost or demand conditions. As we shall see later, when demands and costs are generated by scenarios and thus lack certainty, building in slack capacity throughout the network may preserve the flexibility to deal with parameter changes.

2.10 Choosing Supply Chain Structure Under Uncertain Future Scenarios

Decisions regarding capacity and flexibility of plants in an automobile supply chain have to anticipate parameters several years out into the future. This is true for large assembly plants that take several years to construct and involve commitments to local governments to remain open for several years.

The article “A Scenario-Based Approach to Capacity Planning” ([36]) is motivated by capacity configuration decisions at General Motors (GM). The decisions involved choosing the appropriate type and level of production capacity at each of several locations, termed *capacity configuration.* But future demands for specific car types (large vs. small, fuel efficient vs. comfortable, etc.) are affected by several fundamental parameters such as oil prices, federally mandated miles per gallon laws, the state of the economy, and so on. Thus future demands can be described as being generated by demand scenarios unfolding over time.

Given an existing type and level of capacity at each plant, changing the configuration involves changeover costs. The resulting configuration can then produce a number of different product types, with associated fixed and variable costs, as the specific product demands unfold. Because the capacity decisions affect not just expected profits but also their variability, GM chose the decision that best maximized expected profit, subject to a limit on downside risk (which controlled the variability of profits). Downside risk is a prescribed target profit that has to be generated with large linear penalties for falling short of the target, but that gives no benefits to beating the target.

The paper [36] suggests that balancing expected profit with downside risk causes capacity choices to value the benefit of flexible resources in the supply network.

2.11 Estimating Synergy Across Merged Supply Chains

This section focuses on identifying synergies across merged supply chains. Our example involves a major US drug manufacturer and distributor that decided to form an alliance with a European counterpart. The alliance was expected to generate significant cost reductions and efficiency improvements as products were rationalized, production locations, and warehouses consolidated, and so on. But how much value could be realized by such actions, given the details of each company’s supply chain?

The supply chain was complex and involved seven countries, two plants, twenty-one distribution centers, ten candidate distribution centers, 5,700 SKUs, and multiple channels of distribution. There was substantial overlap in plants and warehouse locations across both companies, with the US company having six plants and eight warehouses and the European company having four plants and seven warehouses.

The first step was to pull historical transaction data and recreate the costs associated with every possible flow through the merged supply chain. Validation of these data in the model was accomplished by comparing the costs generated by the model with the current flows and observed costs. The next step was to optimize the model and use it to recommend a configuration for the merged system. The resulting model was subject to several what-if analyses dealing with changes in freight costs, service-level requirements, warehousing costs, regulation outcomes for transport, changes in financing costs, and other factors.

The analysis described above is typically used to estimate the synergy-related savings associated with merging supply chains and is often a key justification for mergers.

2.12 Rationalizing Supply Chain Evolution

Often a company's supply chain is the result of a historical accumulation of assets or expansion in response to growth. In such contexts, revisiting the rationale for the existing network structure reveals opportunities to improve performance.

Consider an example provided by Dr. Jeffrey Karrenbauer in one of my classes. The company, XYZ, was founded in 1930, and started with one plant near New York City and one distribution center on the outskirts of Chicago. The market area covered the states bordering New York and the MidWestern states. In 1930, transportation to customers generated a significant portion of total logistics costs, compared to warehousing and inventory carrying costs. However, by 1980, the company had grown its market to include customers across the continental United States, thus evolving to five plants and seventeen distribution centers. Over 11,000 customers placed more than 100,000 orders per year. The company offered a 98% service level within seven days and had twelve major product categories with two separate production technologies. Supply chain costs as a percent of sales had grown from 5.8% in 1970 to 8% in 1980 and were growing faster than manufacturing costs. Similarly, inventory turns had declined from 7.5% in 1970 to 6% in 1980.

The company had tried many strategies. Edicts to decrease inventory had resulted in arbitrary inventory cuts, which had driven up manufacturing and transport costs while reducing inventory costs and reducing the level of customer service. Next, to solve the service problem while lowering transport costs, additional warehouses were introduced. This step decreased transport costs but increased warehousing and inventory costs. Adjustments of the rail and truck movements decreased transport costs while increasing warehousing costs and inventory costs. Then plant warehouse space was eliminated to add more equipment. This decreased manufacturing costs but increased transport costs due to the need to ship product out as it was manufactured, also increasing field warehousing costs and associated inventory costs.

Examination of the supply chain network focused on questions such as (1) How should inventory be stratified and positioned in the network?; (2) How many distribution centers should there be, and where should they be located?; (3) Should new plants be added, and if so where?; and (4) Which plants should make which products in order to have the greatest impact on the supply chain? In addition, the analysis was used to evaluate the impact of contingencies such as (1) the effect of trucking deregulation, which happened in the United States in the early 1980s, on full truckload and the consequent impact of less-than- truckload freight costs on XYZ; (2) the impact of increasing delivery lead times; (3) the impact of increases in the cost of financing inventory; and so on.

The main goal of the model was to understand the impact of capacity changes in the system on the supply chain. The model solution recommended changes in the network—a 20% reduction in the number of distribution centers, an 8% increase in the return on assets, and an improvement in the customer service offered, while decreasing inventory. An interesting component of the model was its ability to quantify the impact of managerial choices on the supply chain that were different from the optimal solution.

2.13 The Global Tax Impact of Supply Chains

As global supply chains cross country boundaries, their structure impacts taxes and profitability. Consider the consequences of chain structure as illustrated by the Digital Equipment Corporation ([1]). In 1991, Digital Equipment Corporation served over 250,000 customers worldwide, with $14 billion in revenues coming from eighty-one countries outside the United States. The company had thirty-three plants in thirteen countries, along with thirty distribution and repair centers. The company produced a full range of minicomputers and mainframes but was also vertically integrated to produce chips, memory, disks, power supplies, cabinets, cables, keyboards, and other equipment. However, between 1988 and 1993, Digital had to make significant changes to its supply chain, in response to declining product volumes.

A study done over an eighteen-month period ([1]) recommended a decrease in the number of plants worldwide from thirty-three down to twelve. The recommendation included restructuring and adjusting plant production and associated equipment. The global supply chain model included tradeoffs between product transit time, associated costs, capacity, and, in addition, costs associated with crossing country boundaries, such as duties and taxes.

The study examined three types of duty drawbacks ([1]): (1) duty drawback for "re-export in the same condition," (2) duty drawback for "re-export in a different condition," and (3) duty drawback for "domestic goods returned in a different condition." As an example, see Figure 2.8 below. In the example, printers entering Europe from China had a 4.9% duty. When these printers were re-exported to Brazil, the printers were eligible for a duty drawback for "re-export in the same condition." This applied even if the printers exported were different, as long as they were fungible. Similarly, Europe imported liquid crystal displays (LCDs) from Taiwan but exported laptop computers. The shipments to Taiwan were eligible for duty drawback in Europe because of "re-export in a different condition." The LCDs, when reimported to Taiwan as laptops, were eligible for duty drawback in Taiwan for "domestic goods returned in a different condition." Duties ranged from 0%–200% for specific products, but the typical duty rates were in the range of 5%–10%.

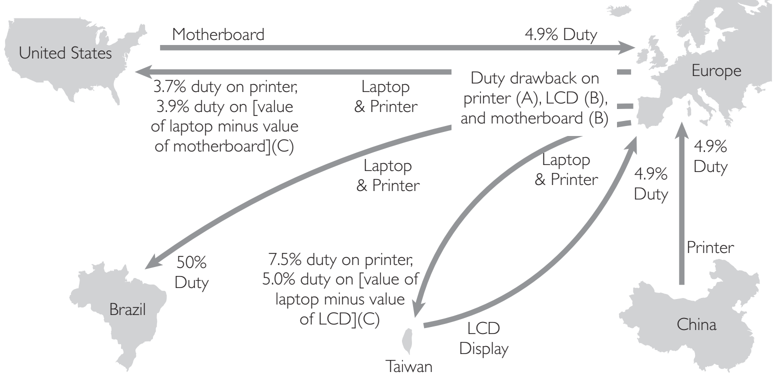


Figure 2.8 Supply chain flows in a global context

Duty drawback and duty avoidance are worth modeling. Shown are three ways to take advantage of import duty relief. When printers imported from China enter Europe, a duty of 4.9% is due. Europe also imports LCD displays from Taiwan and motherboards from the United States to manufacture laptop PCs which it exports to Taiwan and the United States. Laptop PCs with printers are exported from the United States to Brazil. Because the printers from China went through Europe and were ultimately shipped to Brazil, they are eligible for European duty drawback for re-export in the same condition. Usually the same printers imported into Europe from China need not be re-exported to Brazil; they need only be fungible, that is, equivalent. Europe imports LCDs from Taiwan, then re-exports them to Taiwan in laptop computers. It avoids the 4.9% LCD duty due in Europe because of re-export in a different condition. The LCDs reimported into Taiwan also create an opportunity for duty avoidance for domestic goods returned in different condition.

Source: Arntzen, B., Brown, G.G., Harrison, T.P., Trafton, L.L. Global Supply Chain Management at Digital Equipment Corporation. *Interfaces*, 25(1):69–93, January-February 1995.

The study ([1]) reported that implementation of the recommendations reduced the cost of raw materials and purchased components by $225 million and logistics costs by $150 million over eighteen months. By June 1995, annual logistics costs had decreased by $200 million and annual manufacturing costs had decreased by $167 million. This occurred even though the number of units shipped from the remaining locations increased dramatically. Managing the supply chain structure while accounting for tax consequences can thus generate significant financial benefits to a firm.

2.14 Chapter Summary

This chapter focused on the impact of the chain structure on a supply chain's performance. The supply chain links supply locations, intermediaries, and final demand points and thus influences possible adjustments in information and material flow in response to costs or demand shifts. The impact of different supply chain structures were discussed. The bullwhip effect and the risk-pooling effect illustrate the impact of chain structure, visibility, and inventory pooling. The tools presented in this chapter show how supply chain optimization can enable cost reductions. The scenario-based planning approach permits the incorporation of risk in the choice of supply chain structure. Global operations require consideration of duties and duty drawbacks, which can affect the net costs of operation. Finally, mergers or alliances affect the cost structure of the new entity, and rationalization or synergy requires managing the combined supply chains. This chapter thus provides a detailed focus on one of the Cs—supply chain structure.

CHAPTER 3

Competition

3.1 Competitiveness

The focus of a company is to be competitive in the marketplace and thus be profitable. A competitive supply chain has to provide customers with the expected or superior performance. But what does it mean to be competitive? The competitiveness of a supply chain refers to two aspects of the supply chain: (1) the link between a supply chain's choice of its competitive metric and the corresponding choice of its architecture and (2) the impact of competitors on a supply chain's performance. While successful firms in every industry often have unique capabilities, an important question for every firm is to adjust its supply chain architecture to remain competitive in the presence of a changing environment.

The examples in Chapter 1 describe the unique capabilities of Amazon.com, Li & Fung, Cemex, and Zara. In each of these cases, these firms chose specific supply chain architectures to impact their competitiveness. Fine [32] identifies industry clockspeed, i.e., the time between significant product or supply chain shifts, as affecting the choice of the competitive supply chain architecture. His description of the US bicycle industry shows several shifts between vertically integrated and fragmented supply chains between 1890 and 1990. Whenever a dominant player was vertically integrated, pressures to improve components forced disintegration, as assembly of components created competitiveness. At the peak of such fragmentation, a vertically integrated company with unique offerings became the dominant competitor. The lifecycle of a competitive supply chain architecture thus depends on the industry clockspeed.

There are many possible proposed measures of supply chain performance. The Supply Chain Operations Reference (SCOR) [80] model is a consensus view across member companies of how to operate a supply chain. The model focuses on the series of activities in a supply chain, i.e., plan, source, make, deliver, return. The basic approach of the SCOR framework is to document current performance, benchmark comparable companies, and identify approaches to incorporate best-in-class approaches. The associated list of metrics is exhaustive and covers all the transactions in a supply chain. Given that the SCOR metrics are evolving over time, we will focus on generic metrics.

One of the key messages in this chapter is that the choice of performance parameter and the level of competition will have a significant impact on supply chain performance. Similarly, the presence of competitors, whose strategies may be unknown, may cause a supply chain to be operated differently than in the absence of such competitors.

3.2 Supply Chain Metrics of Competition

3.2.1 *Time-Based Competition*

One measure of competition is response time or speed of response. Blackburn [6] and Stalk [86] describe firms that compete on delivery speed. One example is Atlas Door, an industrial door company that coordinated its supply chain to offer custom door delivery (for reactors or furnaces) within two weeks, when the industry standard was over four months. Atlas performed at this level by coordinating order quotation and scheduling production, excess capacity, and tools, synchronizing all components so that a complete kit was delivered to the construction site. Atlas's market share increased rapidly to 80% of the industry volume within five years, with a 15% price premium.

Similarly, quick response programs in the apparel industry focused on decreasing apparel delivery lead time. The competitive benefit of lead-time reduction has been estimated to be equivalent to the profit associated with a 40% demand increase. In short, time can generate money for the supply chain.

3.2.2 *Resilience*

Resilience refers to the ability to restore performance rapidly following an adversity. Sheffi [85] describes how companies can create a resilient supply chain. Nokia's response to the fire in a Phillips semiconductor plant in Albuquerque, NM, a key component supplier, illustrates resilience. Unlike other cell phone manufacturers who also used the same plant, Nokia immediately recognized the criticality of the problem and coordinated with Phillips to allocate components and synchronize the recovery and ramp-up of production. Thus, Nokia's resilience enabled it to minimize the detrimental effects of the disruption. How should supply chains be structured to build in resilience to disruptions? Iyer and Zelikovsky [48] suggest building flexibility, agility, and real options into supply chain facilities as a way to develop resilience in a supply chain.

3.2.3 *Triple A Supply Chains*

Lee [62] describes three specific features of a supply chain: agility, adaptability, and alignment. Agility refers to the ability to adjust to unexpected changes in demand or supply. Adaptability refers to the ability to adjust supply chain structure to deal with shifts in products, technologies, and so on. Alignment deals with adjusting incentives or coordinating to improve supply chain performance. Seven-Eleven Japan is one company that manages its supply chain to develop all three capabilities. Its performance during the Kobe earthquake was testament to this capability. When the transportation infrastructure was destroyed, Seven-Eleven continued to deliver product, even on motorcycles, to keep shelves stocked for customers.

3.2.4 *Environmentally Responsible Supply Chains*

McDonough and Braungart [68] focus on the impact across the entire lifecycle of the product from manufacture to reuse. They provide several examples in which the choice of chemicals, technology, installation, and other factors affect the environmental impact of the supply chain. Their goal is to minimize the supply chain's detrimental impact on the environment. McDonough suggests that building supply chains behave like biological systems, such that one entity's waste is another entity's input. Realizing such a goal will require closed-loop supply chains that recycle product across generations and thus reduce waste generated.

3.2.5 *Balanced Variety*

In a study of Toyota's Supply Chain Management systems, Iyer, Seshadri, and Vasher [49] describe a v4L framework, which comprises velocity, variability, visibility, and variety along with leadership. They describe Toyota's supply chain choices as a balance of these four Vs, this requires involvement across the employee base as well as coordination across entities in their supply chain, from dealers to manufacturing to transportation to suppliers. As an example, Toyota's careful mix planning, which selects the variety of products that will be offered in each region, enables decreased variability and increased velocity while providing a high level of quality. This framework permits an understanding of supply chain differences across products offered, i.e., Scion, Lexus, and Toyota, and how it varies by geographic location (United States, Europe, and Japan).

3.3 The Impact of Alternate Performance Metrics

To understand how choosing different performance metrics will impact a supply chain, consider a supply chain with a single manufacturer that supplies a retailer. The manufacturer produces and sells the product at a per-unit price of c and a production lead time of L_m. It costs c_1^t to transport the product to the retailer with a lead time of L_m^t. The result is total lead time of $L_m + L_m^t$ (manufacturing time and transport time) and a cost of $c + c_m^t$ to a single retailer, who in turn adds a markup α. The retailer incurs a holding cost h per unit of product and per unit time. The customer incurs a cost of c_c^t and lead time L^c to get the product to his or her location. In the absence of any inventory in the system, the cost per unit product for the customer is $\alpha(c + c_m^t) + c_c^t$, and the lead time for delivery to the customer is $L_m + L_m^t$. The customer will then have to hold inventory at his or her location to cover demands over $L_m + L_m^t + L_c^t$, or wait for the product.

3.3.1 *Minimum Purchase Cost*

If the manufacturer and retailer were to carry no inventory and all production and orders followed customer order placement, the product purchase price paid by the customer would be minimized. Notice that this corresponds to a make-to-order system at the manufacturer and assumes that the lead time $L_m + L_m^t$ permits the manufacturer to produce and deliver to the retailer at minimum cost. Similarly, we assume that receiving and shipping to the customer enables the retailer to manage his or her operation at the lowest cost. Finally we assume that the markup charged by the retailer, α, is competitive.

If the goal of the supply chain is to minimize purchase cost, then this approach offers a supply chain structure that enables that performance metric to be minimized. But will the customer wait for delivery in such a system? If not, alternate configurations will be appropriate.

3.3.2 *Reducing Supply Lead Time*

If competitive conditions require that the customer be provided product immediately, without any lead time, then the retailer has to carry inventory. The magnitude of the retailer's inventory will depend on the manufacturer's process lead time as well as transportation lead time. The customer's inventories can thus be reduced if the customer can acquire inventory from the retailer after his or her demands are realized. An interesting tradeoff is to choose the best location to hold inventory. Clearly this will depend on the relative costs associated with carrying inventory at different locations.

If the manufacturer carries finished goods inventory, the retailer can place orders with the manufacturer in accordance with customer demands, thus satisfying customer demand with a lower retail inventory than if he were to buffer the entire upstream lead time. If the manufacturer were to carry inventory to hedge against manufacturing lead time L_m, then the only lead time that the retailer has to cover is the transport lead time L_m^t from the manufacturer to the retailer.

On the other hand, if the manufacturer operates in a make-to-order manner, the retailer has to carry inventory to cover the lead time of $L_m + L_m^t$, and the customer will only need to carry inventory to cover his transport lead time of L_c^t.

3.3.3 *Total Delivered Cost*

The earlier section focused on reducing lead time, but an ideal supply chain choice could locate inventories to optimize supply chain costs.

Thus, if the manufacturer could pool demands from many retailers and thus smooth inventories, it may be optimal for inventory to be held at that manufacturer. However, if the manufacturer does not see much demand pooling benefits, possibly due to differing requirements for each retailer, then the retailer may be the pooling location to smooth demands from multiple customers, which will improve supply chain performance.

Finally, there may be a benefit to providing a scheme that permits differentiation across customer sizes. Large-demand customers could absorb a larger lead time in return for a discount and thus be willing to carry their own inventory. Smaller customers may prefer to pay for fast delivery and let the retailer carry the inventory. Thus an appropriately designed retail pricing scheme may permit demand service segmentation. The main message is that when inventory locations are chosen to optimize costs, they may generate different supply chain inventory locations depending on the preferences of entities across the supply chain and associated competitiveness.

3.3.4 Optimal Variety

When products are delivered to customers, there are often consequent customer costs required to adjust the product to the desired customer requirements. The customer may have to either incur costs to adjust other components to fit within these specifications, or there may be a change in the overall design to work effectively with the delivered product. In both cases, lack of flexibility in the manufacturer specifications creates costs, explicit or implicit, for the customer. Studies by Rolls Royce and General Motors suggest that 80% of the manufacturing costs are decided at the design stage. Thus, a higher upstream cost that may be lower than the savings in downstream adjustment cost may be appropriate to optimize the cost of variety.

In the grocery environment, many retailers compete based on variety of products offered. Thus the retailer satisfies the demands of different customer segments, with individual segments not being required to compromise their needs. The same approach is used by some book retailers, in that the increased cost of variety is compensated by a higher revenue if demand is enhanced and associated margins improve. The ability of ecommerce retailers, like Amazon.com, to offer books with low demand volumes (referred to as the long-tail demand) quickly enabled competitive margins to be generated from such competitiveness, thus justifying the variety.

3.3.5 *Availability*

Consider the in-stock availability offered to the customer (with a nearly zero lead time) by the retailer if the retailer and manufacturer were to carry inventory. It is clear that the retailer's choice of inventory would reflect retailer margins and costs associated with excess inventory. Such a choice of customer service level may not reflect what is best for the overall supply chain, something that is discussed in the chapter on coordination. Thus, a focus on availability will encourage the manufacturer and retailer to establish coordination agreements that can increase the delivered service level to the customer.

An alternate approach to increase customer service level is to decrease manufacturer and retailer lead times by adjusting choice of the warehouse location such that the retailer can pick up product during backhaul trips. Such an adjustment of location may represent an optimal approach to improve overall performance.

3.3.6 *Managing Environmental Impact*

What happens to the product after a customer has consumed it? In many product contexts, the customer or society may have to incur costs to dispose of the used product. This is illustrated by the disposal charge at tire repair shops to get rid of worn-out tires, in many cases $10 per tire. These charges increase if the products use hazardous chemicals or toxic materials. In other cases, a carefully designed product and recycling loop may improve overall lifecycle costs of the product.

If the cost of the product over its cradle-to-grave existence is charged to the consumer, it will result in different choices and thus different associated costs. Using renewable inputs at the source may increase costs but may decrease lifecycle costs, e.g., using corn-based bottles for beverages, thus making them competitive. Kodak's disposable camera, cited extensively in the sustainability literature, contains main components that are used in ten generations of the product, in effect amortizing the cost of the product over ten units, making the camera competitive across its lifecycle. Competition based on minimizing environmental impact through zero landfill contribution policies across the supply chain is becoming a supply chain imperative.

3.3.7 *Supply Chain Leadership*

In modern supply chains, new leadership tasks such as the role of category captains or supply chain champions have emerged. Category captains make decisions across products in a category on behalf of the retailers—both for their products as well as their competitors' products. The section on category captains in the grocery supply chain and the description of the role of the brake lining supplier in solving an overall supply chain problem (in another chapter) provide contexts where supply chain leadership is a key expectation of a supplier.

The corresponding questions for supply chain design and for the supplier is, **How should the supply chain be structured so that such supply chain leadership roles can be realized? What are the implications of such supplier roles regarding margins, service levels, variety, and so on? Does the supply chain leader enjoy significant profits or do those gains flow to the customer due to of competition to be the supply chain leader?**

3.3.8 *Global Supply Chains*

In today's global operations environment, competitive suppliers are expected to follow manufacturers to different locations around the globe and provide product with consistent quality and delivery metrics. How should a supplier position a supply chain structure to succeed in such an environment? Should operations be established in all of the locations where the manufacturer plans to operate? Should alliances be established with local suppliers to supply this manufacturer? Or should logistics companies be used to supply locally but from central manufacturing locations? Each of these questions provides interesting alternatives to be competitive on the global access dimension. Given the need to coordinate supplies and manufacturing, such global supply chains may involve joint capital investments, risk sharing agreements, and so on.

In summary, an important decision for a supply chain is the metric of competition. We have identified several different metrics that have significant impacts on the supply chain structure. The key takeaway is that the metric of competition will affect the supply chain structure chosen. This suggests that prior to evaluating supply chain structures, it is important to understand the metric of competition.

3.4 Impact of Competing Supply Chains

Thus far, we have focused on alternate performance metrics and associated supply chain architecture. Now we will consider the impact of competitors who independently make decisions to maximize their performance. The presence of competitors may often benefit individual customers but may also decrease the profitability of supply chain entities. A key concept is that competing supply chains generate "equilibrium" results, in which each supply chain makes decisions independently, anticipating but not knowing decisions by competitors. There are several ways that supply chains affect the competing choices and performance of a given supply chain.

For example, the presence of competing retailers offers a customer the choice of visiting the competition if one retailer is out of stock. In anticipation of such "spillover" customers, as well as the increased options for their own customers, retailers can adjust their inventory. An individual retailer's supply chain choice is an equilibrium response to competing retailer's choices.

In other words, competing retailers offer the customer the option to take advantage of many possible pools of capacity, as we will discuss in Chapter 4 on capacity. We described competitive effects on service level in this section, but the same idea can be considered for any metric in the supply chain.

3.5 Inventory Levels in the Presence of Competitors

To develop intuition regarding the optimal inventory levels carried by retailers in the presence of competitor, consider a retailer's inventory decision when faced with uncertain demand. Because the general model is

Table 3.1 Sample demand distributions

Demand	Probability	Cumulative Probability
10	0.20	0.20
20	0.20	0.40
30	0.20	0.60
40	0.10	0.70
50	0.15	0.85
60	0.15	1.00

complicated, we will develop our intuition using a numerical example. Consider a single retailer who faces a single period of uncertain demand, as illustrated in Table 3.1.

Assume that Retailer 1 buys the product from a supplier for \$1 per unit and has a retail price of \$3.80 per unit. Assume that holding cost for leftover inventory is \$0.2 per unit. If this were a profit-maximizing retailer, the marginal cost per unit short (C_s) is \$2.80 and the marginal cost of excess inventory (C_e) is \$1.2. Thus the critical fractile $\frac{C_s}{C_s + C_e}$ is 0.70, suggesting an inventory level of 40 units. The associated expected profit is \$64, with the following calculation:

$$\begin{gathered}(-1 \times 40) + (0.2 \times 3.8 \times 10) + (0.2 \times 3.8 \times 20) + (0.2 \times 3.8 \times 30) \\ + (0.1 \times 3.8 \times 40) + (0.15 \times 3.8 \times 40) + (0.15 \times 3.8 \times 40) \\ + (-0.2 \times 30 \times 0.2) + (-0.2 \times 20 \times 0.2) + (-0.2 \times 10 \times 0.2)\end{gathered}$$

Retailer 2, in the same market region, has a similar demand distribution from a separate primary market. Assume that customers who face a stockout at Retailer 1 go to Retailer 2 and vice versa. Thus, the demand faced by Retailer 1 for a given inventory level held by Retailer 2 is obtained as the sum of Retailer I's primary demand plus spillover demand from Retailer 2. Given an inventory $Q = 40$ held by Retailer 2, the spillover demand received by Retailer 2 has the distribution shown in Table 3.2.

The total demand faced by Retailer 2 is the sum of primary demand and spillover demand from Retailer 1. If the rows represent the level of

Table 3.2 Spillover demand distributions

Spillover Demand	Probability
0	Demand for retailer 2 is ≤ 40 i.e., 0.7
10	Demand for retailer 2 = 50 i.e., 0.15
20	Demand for retailer 2 = 60 i.e., 0.15

Table 3.3 Primary and spillover demands

Primary Demand		Spillover Demand		
		0	10	20
	Probability	0.7	0.15	0.15
10	0.20	10	20	30
20	0.20	20	30	40
30	0.20	30	40	50
40	0.10	40	50	60
50	0.15	50	60	70
60	0.15	60	70	80

Table 3.4 Joint probability of demand outcomes

Primary Demand		Spillover Demand		
		0	10	20
	Probability	0.7	0.15	0.15
10	0.20	0.14	0.03	0.03
20	0.20	0.14	0.03	0.03
30	0.20	0.14	0.03	0.03
40	0.10	0.07	0.015	0.015
50	0.15	0.105	0.0225	0.0225
60	0.15	0.105	0.0225	0.0225

primary demand and the column the spillover demand, then the following matrices provide the different possible values of total demand and the associated probability of occurrence of each of these events (see Table 3.3).

The corresponding probability of each total demand occurrence, given that Retailer 2 carries an inventory of 40 units, is shown in Table 3.4.

Table 3.5 Total probability of demand outcomes

Total Demand	Probability	Cumulative Probability
10	0.14	0.14
20	0.17	0.31
30	0.20	0.51
40	0.13	0.64
50	0.15	0.79
60	0.14	0.9325
70	0.05	0.9775
80	0.02	1
90	0.00	1
100	0.00	1
110	0.00	1
120	0.00	1

Given the two matrices above, the demand distribution faced by one of the retailers given the other retailer's inventory of 40 units, can be summarized as shown in Table 3.5.

Since Retailer 1 will now choose an inventory level to optimize profits, i.e., one that attains the service level of 0.7, the optimal inventory choice is an inventory of 50 units. The associated expected profit for Retailer 1 is thus $76 (repeat the same calculations as before but with the probability distribution from above and an inventory of 50 units). Using Retailer 1's inventory of 50 units, we can go back and calculate the profits for Retailer 2 as $67.6, taking into account the spillovers from Retailer 1 to the Retailer 2.

We can now repeat this process for different levels of inventory chosen by Retailer 2 and the optimal decision by Retailer 1. Let Q_2 be the inventory chosen by Retailer 2, and Q_1^* be the optimal response of Retailer 1. Recall that we just calculated that when $Q_2 = 40$, we get $Q_1^* = 50$ and the profit for Retailer 1 as 76; correspondingly for Retailer 2, the profit was 67.6. Table 3.6 shows the optimal response of Retailer 1 to every choice by Retailer 2 and the associated profits for each retailer.

Table 3.6 Expected responses and profits for retailers 1 and 2

Fix Q_2	Optimize Q_1^*	EP(Q_1^*)	EP(Q_2)
10	70	119.2	28
20	60	99.2	48
30	50	84.8	62.4
40	50	76	67.6
50	50	68.2	68.2
60	40	64	72.4

Given that both retailers would keep adjusting their inventories in response to each other, what is the equilibrium inventory? It is the point at which, given Retailer 1's decision, the decision made by Retailer 2, fed back to Retailer 1, generates the same decision. Such an equilibrium is called a *Nash Equilibrium,* in honor of economist John Nash.

Note that from the table above, this equilibrium level is 50 units. When Retailer 2 chooses an inventory of 50 units, so does Retailer 1, and thus the decision for Retailer 2 remains the same in response. We can identify an equilibrium level of inventory for both retailers to be 50 units. Note that this inventory level is higher than the level in the independent retailer system, but with a higher level of expected profit. Thus, for this example, competition to satisfy demand from one's own customer base and spillover demand from other retailers leads to higher profits and higher inventory levels for all retailers.

This suggests that a higher inventory level and the higher associated effective service level is the outcome in a competitive environment. This happens because of the opportunity to both sell leftover product to satisfy the spillover demand from the other retailer and gain the higher revenue from satisfying its primary demand. Thus, in this case, competition provides benefits to the customer in the form of improved service and manifests itself in the form of higher retailer profits.

This also means that in a competitive environment, efforts to implement schemes such as inventory pooling among retailers may have limited success.

3.6 Competition Across Product Attributes

How do products with different attributes impact demand? Given customer responses to different attributes, how should a manufacturer position products in the attribute space? What is the impact of promised lead time on capacity required?

To examine this question, we provide an example context and then provide details of a model. The example is based on work done by Iyer and Sommer [47] for the Indiana Department of Transportation. The goal of the study was to understand the effect of improving transportation infrastructure in southern Indiana on competitiveness of the local industry. Southern Indiana's Dubois County is home to a thriving commercial furniture industry. In the furniture supply chain, product flows from forest owners who grow the trees to lumber distributors to veneer manufacturers to component suppliers to furniture manufacturers to — retailers and to the final customers.

Each of these steps of the supply chain was governed by an independent association that focused on maximizing its performance. Data analysis showed that logistics costs (primarily transport costs) were between 5% and 20% of cost at each step of the supply chain. In addition, most companies had suppliers deliver inbound product; thus the cost of product included the inbound transport costs. This suggested that if there were five stages in the supply chain and a 10% reduction in logistics cost at a stage, the supply chain as a whole might save 5% of cost—a significant improvement in competitiveness.

A model developed by Boyaci and Ray [10] was used to develop insights for this project. The model describes a context where a retailer sells two different products to a market characterized by price and delivery lead time. Suppose that, for Customer Product 1, the retailer chooses a lead time L_1 and price p_1, while for Product 2 there is a fixed, long lead time L_2 but a choice of price p_2. Given these parameters, customers adjust their choices and thus generate demand rates for each of the two products, as follows:

$$\lambda_1 = a - \beta_p p_1 + \theta_p(p_2 - p_1) - \beta_L L_1 + \theta_L(L_2 - L_1)$$

$$\lambda_2 = a - \beta_p p_2 + \theta_p(p_1 - p_2) - \beta_L L_2 + \theta_L(L_1 - L_2)$$

These demand relations suggest that demand for one product is decreasing when its price increases, and its lead time increases. But this same product attracts customers from the other product's demand if its price and lead time are lower. Now consider the cost associated with delivering this demand within the promised lead time. Given an exponential service time, the lead time distribution for retailer j is exponential, with a rate $\mu_j - \lambda_j$ (from standard single-server exponential interarrival and exponential service-time models), thus the service rate μ_j required to guarantee a lead time L_j can be expressed as $\lambda_j - \frac{ln(1-\alpha)}{L_j}$, where α is the desired service level within lead time L_j.

Finally we can express the expected profit for each retailer as $(p_1 - m)\lambda_1 + (p_2 - m)\lambda_2 - A_1\mu_1 - A_2\mu_2$. In this expression, A_1 and A_2 represent the per unit per unit of service costs for the service rates μ_1 and μ_2, respectively, and m represents the manufacturing (e.g., material) cost per unit of product. The retailer will have to choose optimal values of p_1, p_2, L_1, and L_2 so as to maximize profits across the two products.

We present the results using the following example, to provide intuition regarding the interaction across products. Results of the model are shown in Figure 3.1. The x-axis shows the impact of changes in the cost associated with offering a lower lead time for custom products, and the y-axis shows the corresponding on optimal lead times, pricing, total demand, and profitability. Consider the impact of logistics improvements and manufacturing changes so that A_1, the cost per unit time to deliver custom products, decreases (i.e., moves to the left on the x-axis). The graphs suggest that if A_1 decreases, it is then optimal to lower prices for custom products (Figure 3.1a), lower lead times offered (Figure 3.1b), thus increase demand for such products (Figure 3.1c) and significantly improve profitability (Figure 3.1d). Figure 3.1d also shows that changing the product mix by adjusting lead times and pricing can be very beneficial: notice the upper versus the lower line. In other words, efforts to reduce delivery lead times can improve industry profitability by permitting a shift to faster-response, higher-margin products supplied competitively.

The model described earlier was used to link improvements in local logistics, interpreted as decreasing A_1, to their impact on competitiveness (improved profitability).

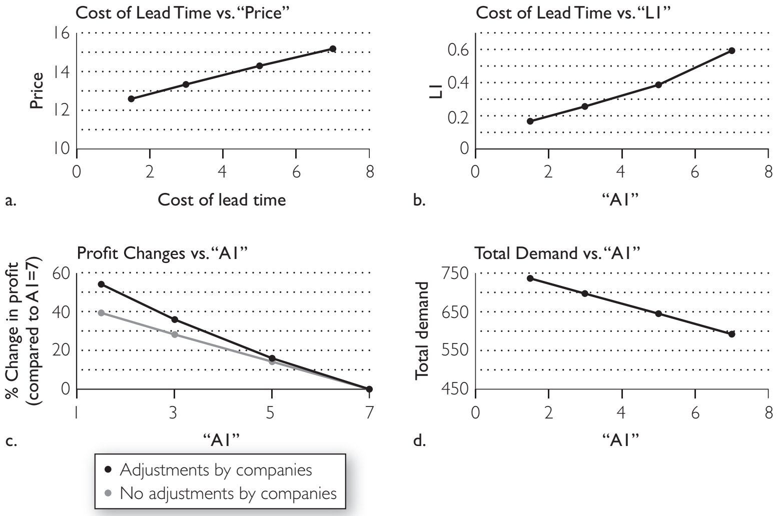


Figure 3.1 Impact of reducing cost to lower lead time

3.7 Advance Order Discounts Under Competition

Manufacturers often offer advance order discounts to attract retailers. Consider a supply chain where two retailers offer products to their separate customer bases. As is the practice in many industries, suppose one of these retailers offers a price discount for those who place orders in advance of the season. This discount may attract a portion of the demand from both retailers, depending on the relative size of the discounts offered by each retailer as well as the fraction of the customer base that will be sensitive to such early demand placement. Note that all deliveries take place during the season. This section provides a short summary of the model (details are in the paper [67]) and a numerical example.

While their in-season demand levels are correlated, both retailers have to order inventory in advance in the start of the season and thus face their own independent single-period demand uncertainty models (newsboy models). Let x_1 and x_2 refer to the discount factor for early orders, thus the retail prices are px_1 (for Retailer 1) and px_2 (for Retailer 2) for early orders.

As an example, consider Retailers 1 and 2, whose joint demand has the distribution in Table 3.7.

Note that in the absence of any advance orders, Retailer 1 faces a demand of 4 with probability 0.5 and 12 with probability 0.5. Similarly,

Table 3.7 Joint probability of demand for Retailers 1 and 2

Demand 1	Demand 2	Probability
4	4	0.2
4	12	0.3
12	4	0.2
12	12	0.3

Retailer 2 faces a demand of 4 with probability 0.4 and 12 with probability 0.6. If the retailer price during the season is \$1/unit, retailer cost is \$0.6/unit, salvage value of leftover inventory is \$0.4/unit, the optimal service level planned by each retailer is $\frac{p-c}{p-s} = 0.67$. Thus Retailer 1 and Retailer 2 would order 12 units and obtain expected profits of 2.4 and 2.88 respectively.

Suppose Retailer 1 offers an advance order discount of 30%, i.e., $x_1 = 0.7$. Also assume that $a = b = r_{1e} = r_{1s} = 0.4$. Note that when such a discount is offered, the fraction of demands that are observed are $R_{11} = 0.168$, $R_{12} = 0$, $R_{22} = 0$, $R_{21} = 0.168$. Thus we get the following set of values for the early demands $D_{11} = R_{11}D_1 + R_{21}D_2$, where D_{11} is the advance order observed by Retailer 1 and D_{21} is the regular season demand. Similarly, D_{22} is the regular season demand observed by Retailer 2 (see Table 3.8).

Thus the expected profit across all possible demand realizations is the product of the probabilities in the third column and the associated expected profit in the last column which is 2.545. The expected profit for Retailer 1 when $D_{11} = 1.344$ is $(px_1 - c)\, D_{11} + (p - c)\, D_{21} = (1 \times 0.7 - 0.6) \times 1.344 + (1 - 0.6) \times 3.328 = 1.4656$. Similar calculations apply when $D_{11} = 4.032$. However, when $D_{11} = 2.688$, the demand

Table 3.8 Expected profit for Retailer 1

D_1	D_2	Prob	D_{11}	D_{21}	D_{12}	D_{22}	Expected Profit Retailer 1
4	4	0.2	1.344	3.328	0	3.328	1.465
4	12	0.3	2.688	3.328	0	9.984	1.866
12	4	0.2	2.688	9.984	0	3.328	1.866
12	12	0.3	4.032	9.984	0	9.984	4.396

during the season can take values of 3.328 or 9.984 with respective probabilities of $\frac{0.3}{0.3 + 0.2} = 0.6$ and 0.4 respectively. To provide a service level of 0.67, Retailer 1 will thus order to cover D_{11} and order 9.984 units to cover the uncertain demand. A newsboy expected calculation for the in-season demand generates an expected profit of 1.597. Thus the total retailer expected profit when $D_{11} = 2.688$ is obtained as $((1 \times 0.7 - 0.6)$ $2.688) + 1.597 = 1.866$.

However, since Retailer 2 does not offer an advance order, the observed demand would be 3.328 and 9.984 with probabilities of 0.4 and 0.6 respectively. Thus Retailer 2 would order 9.984 units and get an expected profit of 2.396. The results show that Retailer 1 benefits from offering the advance orders because its expected profit increases from 2.4 to 2.545. Retailer 2 observes a profit decrease from 2.88 to 2.396.

Similar analysis will show that if Retailer 2 were to offer an advance order at a discount of 30%, i.e., $x_2 = 0.7$, and Retailer 1 did not, then the expected profit for Retailer 2 would increase (from the original 2.88) to 2.94. Retailer 1, on the other hand, would observe its expected profit decrease to 1.996. The analysis shows that the retailer who offers an advance order sees a benefit, to the detriment of the other retailer.

But suppose Retailer 1 offers an advance order, is it in Retailer 2's incentive to also offer an advanced order? We can analyze this question by considering the case when both retailers offer an advance order discount of 30%, i.e., $x_1 = x_2 = 0.7$. Consider the same parameters as earlier, i.e., $a = b = r_{1e} = R_{11} = R_{22} = R_{21} = 0.4$. The table provided can be used to verify that we get the values in Table 3.9.

Table 3.9 Expected profits for Retailers 1 and 2

D_1	D_2	Prob	D_{11}	D_{21}	D_{12}	D_{22}	Exp Profit Retailer 1	Exp Profit Retailer 2
4	4	0.2	1.152	2.848	1.152	2.848	1.254	1.254
4	12	0.3	2.304	2.848	2.304	8.544	1.597	2.28
12	4	0.2	2.304	8.544	2.304	2.848	1.597	2.28
12	12	0.3	3.456	8.544	3.456	8.544	3.763	3.763

Thus the corresponding expected profit for Retailer 1 is 2.178 and the corresponding profit for Retailer 2 is 2.52. These values are obtained by taking the product of the probability and expected profit. Thus, when both retailers offer an advance order discount, they see their expected profits drop from the original values of 2.4 and 2.88 to the new values of 2.178 and 2.52. Thus, competition can improve individual supply chain performance, but when matched by competitors, can create a prisoner's dilemma outcome (bad for all) when both retailers engage in the same action.

This example illustrates the counterintuitive effects of competition: it can cause actions that can worsen overall performance even when it would have been beneficial in a monopolistic context. The bottom line for companies is that not all actions can generate the planned beneficial outcome in the presence of competition.

3.8 Chapter Summary

This chapter showed how the choice of metric of competition and the existence of competitors affects the performance of a supply chain. The first part of the chapter examined the many alternate metrics that can determine performance, including costs, profitability, service, variety, and lead time. Each of these alternate metrics implies different choices for supply chain architecture as well as for the details of operation. In addition, in the presence of competitors, agreements that are good for the supply chain in a monopolistic setting may be bad for the supply chain in a competitive environment. Thus one may find an industry supply chain stuck in a bad equilibrium with frequent harmful promotions or advance order discounts, unable to pull itself out of this state due to competitive pressures. This chapter thus suggests that competitiveness can be a significant driver of supply chain performance.

CHAPTER 4

Capacity

Capacity refers to the designed maximum flow of work through a facility over a period of time. When used in the context of a warehouse, capacity refers to the amount that can be shipped in a given time period, every hour or day, for example. For truck transportation, capacity refers to the quantity that can be moved in a trip. For a retail store, capacity may refer to the maximum amount of inventory that can be held at the store or the maximum number of customers that can be served per hour to satisfy demand.

However, the available capacity in a period of time consists of a hardware decisions (those that deal with physical constraints) as well as software decisions (those that deal with scheduling or forecasting aspects of deployment). For example, at the business school I teach in, the physical space and classrooms in a new building were designed with a plan to accommodate a maximum of 250 students in any given year of our two-year MBA program. The associated room capacities then represent the hardware decision with respect to capacity. However, the actual deployment, i.e., classes offered, schedules, and enrollment of students, is adjusted as conditions evolve. These factors represent the software associated with the use of capacity. Often the hardware and software decisions are comingled during use and are thus difficult to disentangle.

A quick example regarding the hardware vs. software aspects of capacity occurred in a project dealing with deployment of Chicago's garbage trucks ([26]). The capacity of trucks (weight and volume) to pick up garbage was an input to the analysis. But we realized that if a garbage truck picked up garbage and, in the middle of the day, went to a dump site to drop it off and returned to continue garbage pick-up, it could pick up double its designed capacity during a single day. In other words, the deployment of the truck affected the daily garbage pick-up capacity. The same capacity increase is true if employees work overtime or if subcontracted capacity can be seamlessly added. Our first focus is on the hardware decision regarding capacity. This will be followed by a discussion of some of the software decisions to increase capacity.

Consider contexts when capacity decisions have to be made in advance of demand realization. In the apparel industry, capacity has to be chosen eight to twelve months ahead of demand. In the auto industry, plans for capacity configurations at plants are made several years in advance. For infrastructure decisions, such as highway construction, decisions may be made fifteen to twenty years in advance. In a just-in-time delivery context, decisions may be made four hours in advance ([52]). Clearly the main question is the extent of demand uncertainty when decisions are made and the consequences of having an inadequate level of capacity. In addition, if the capacity decision maker is different from the information provider, incentive effects have to be considered. Hence the need for coordination agreements (as discussed in Chapter 5). However, the availability of alternate sources of capacity, albeit at a higher cost, can relieve the pressure to commit to capacity in advance.

In other contexts, there may be a number of demands on capacity at the same time. In such cases, performance of the supply chain is affected by how this temporal supply-and-demand mismatch is resolved. Such contexts can best be viewed as queues, where requests for capacity await access to that capacity. Even in such cases, the configuration of access to capacity affects performance. In a queueing context, choice of priorities for different arrival streams can affect the realized performance; thus, matching priorities to the level of demand uncertainty may reduce overall inventories in a supply chain.

If the temporal demand levels can be forecast, then a dynamic adjustment of capacity to synchronize with demands may enable performance improvement without a significant increase in capacity levels. As an illustration, allocating employees to temporally staggered shifts can be a mechanism to manage the impact of demand variation.

The next few sections illustrate several capacity contexts and provide tools to effectively select and deploy capacity.

4.1 Capacity Choice in the Presence of Demand Uncertainty

Consider a company that is planning capacity but is unsure of the potential demand for products. Suppose the cost per unit of capacity is $25. Next, if demand is satisfied, the company gets revenue of $100 per unit. Leftover capacity can be used to satisfy secondary demand but generates revenue of only $10 per unit. There is sufficient capacity for this secondary demand. For purposes of clarity, assume that demand can take the values with associated probabilities as shown in Table 4.1.

Now suppose the company were to obtain a capacity of 300 units. The associated expected profit can be calculated as

$$(-25 \times 300) + (100 \times 100 \times 0.6) + (100 \times 300 \times 0.3) \\ + (100 \times 300 \times 0.1) + (10 \times 200 \times 0.6) = 11{,}700$$

Repeating this exercise for each of the possible choices of capacity, i.e., 100, 300, and 500, provides the results in Table 4.2.

Table 4.2 suggests that an optimal capacity is 300 units. Thus the company will forgo some of the demand when the demand is 500 units. This decision maximizes the company's expected profit. It is also clear that if the company cares about unsatisfied demand and its effect on future customer arrivals, then there has to be a mechanism to account for the cost of this unsatisfied demand—perhaps by including a goodwill cost for

Table 4.1 Demands and associated probabilities

Demand	Probability
100	0.6
300	0.3
500	0.1

Table 4.2 Capacity choices and associated expected profit

Capacity	Expected Profit
100	7,500
300	11,500
500	10,500

unsatisfied demand. (This cost is the net present value of the margin associated with future lost sales caused by the unsatisfied demand this period.) If a goodwill cost is included, it may be optimal to increase capacity, depending on the level of this goodwill cost, to increased expected profits.

The decision described above is commonly termed the *newsboy model.* The optimal capacity decision can be obtained by identifying two costs: the marginal cost of excess capacity C_e and the marginal cost of capacity shortage C_s. In the example above, the marginal cost of excess capacity is $C_e = 25 - 10 = 15$ while the marginal cost of capacity shortage is $C_s = 100 - 25 = 75$. Thus the ratio is $\frac{75}{75+15} = 0.83$. The optimal capacity decision is to identify the lowest capacity level that guarantees that probability of satisfying the cumulative demand is at least 0.83. The corresponding decision is to choose a capacity of 300, which provides a probability of 90% of satisfaction of cumulative demand that is less than or equal to 300.

Now suppose it was possible for the company to obtain a perfect forecast of demand and then choose capacity. In such a case, it is optimal to choose a capacity level that matches demand. Such a context is called the perfect-information expected profit. The expected capacity would be

$$(100 \times 0.6) + (300 \times 0.3) + (500 \times 0.1) = 200$$

For this example, the expected profit under perfect information would be

$$((100 - 25) \times 100 \times 0.6) + ((100 - 25) \times 300 \times 0.3) \\ + ((100 - 25) \times 500 \times 0.1) = 15{,}000$$

The profit impact of demand uncertainty is thus $15{,}000 - 11{,}700 = 3300$, or 28.2% of expected profit. This example shows how demand uncertainty interacts with capacity to affect profit. It also shows the potential value of perfect information, obtained through sources such as market surveys, expert forecasts, and test markets.

This example also shows that one response to demand uncertainty is to add a capacity buffer, e.g., $(300 - 200) = 100$ units. The associated buffer is a hedge against demand uncertainty. Thus whenever capacity in a system is observed to be far greater than observed demand, it may in fact represent an optimal buffer size and an option to serve large potential demand.

4.2 Capacity Choice Given Lead Time

This section presents an example to illustrate the capacity impact of long lead times. Consider a manufacturer who faces demand for a fashion product that can take one of two levels, low and high. If the demand level is high, then the demand is expected to follow a uniform distribution between six and ten units. If the demand is low, then it is expected to be uniformly distributed between one and five units. Given the nature of manufacturing, capacity decisions have to be made many months in advance of demand. At the point in time that a capacity decision is made, suppose the manufacturer does not know if demand will be high or low, but the best estimate is that demand will be high or low with a 50% probability.

Suppose the cost of capacity for a certain manufacturer is $100 per unit and has to be incurred in advance, independent of actual demand. Suppose the revenue associated with satisfying demand is $200 per unit. The maximum quantity that can be produced is limited to the available capacity. Any unused capacity can be used to satisfy demand for low-margin products but yields a revenue of only $20 per unit. Any unsatisfied demand is estimated to have a goodwill impact of $200 per unit.

Given the lack of information regarding the demand level, the demand faced by the manufacturer is illustrated in Table 4.3.

Table 4.3 Demand faced by the manufacturer

Demand	Probability
1	0.1
2	0.1
3	0.1
4	0.1
5	0.1
6	0.1
7	0.1
8	0.1
9	0.1
10	0.1

Given that $r = 200$, $c = 100$, $s = 20$, $g = 200$, the value of $C_s = r + g - c = 300$ and $C_e = c - s = 80$. Thus the optimal service level is $\frac{C_s}{C_s + C_e} = 78.9\%$. Given this service level, the optimal capacity choice for the manufacturer is to choose a capacity to manufacture eight units. Using the same approach as in earlier sections, the expected profit associated with this capacity choice can be calculated to be $236.

Now suppose the manufacturer has access to data from related markets that enables a reliable estimate of whether the demand level is high or low. How does this affect the choice of capacity? Note that if the capacity decision has to be made when demand is low, it is optimal to have a capacity of four units to ensure a service level of 78.9%. Similarly when the demand is high, it is optimal to have a capacity of nine units to ensure a service level of 78.9%. Thus the expected capacity chosen is $(0.5 \times 4) + (0.5 \times 9) = 6.5$ units. In addition, because the capacity level is chosen to be synchronized with demand level, the expected profit when demand is low (with a capacity of four units) is $144, and the expected profit when demand is high (with a capacity of nine units) is $644. Thus the expected profit across demand levels is $(0.5 \times 144) + (0.5 \times 644) = \$394$.

This example shows the close interaction between information, lead time, and capacity choice in the presence of demand uncertainty. In the absence of information, capacity buffers are optimal. However, lower lead times may permit better demand information, thus leading to a better match between demand levels and capacity. This enables additional capacity to be planned when there is an upside potential associated with high demand and simultaneously lower capacity when demand levels are anticipated to be low. The net result is a higher profitability with lowered average capacity levels.

4.3 Capacity Choice to Maintain Service Lead Time

Often, orders placed in a supply chain face lead times for delivery based on the presence of supply constraints, or capacity constraints. We provide a model to understand the source of such lead times—in this case, it is due to capacity (or supply) and demand mismatches.

Consider a single location of capacity, such as a warehouse or manufacturer. Orders arrive to this location, and the facility operates in a make-to-order manner. Service is provided in order of arrival. The time to produce or service a given order follows an exponential distribution with parameter μ. If the orders come from many independent sources, then they can be described statistically as a rate. From a technical perspective, the interarrival rate (time between successive arrivals) of orders to this location can be expressed as an exponential distribution with a rate parameter λ. Thus orders arrive at a rate of λ orders per time unit, and the location can produce μ orders per time unit.

It can be shown that the probability that the location is busy or producing an order is $\frac{\lambda}{\mu}$. The ratio $\frac{\lambda}{\mu}$ is also known as the system load, often denoted by $\rho = \frac{\lambda}{\mu}$. The expected time an order spends in the system is

$$L = \frac{1}{\mu - \lambda}$$

Therefore the expected time an order spends in the queue waiting for service is

$$L_q = \frac{1}{\mu - \lambda} - \frac{1}{\mu}$$

A quick glance at the expressions shows that for the system to be stable (i.e., have lead times that are finite), the arrival rate of orders must be less than the service rate of orders. The difference between these two rates is the "buffer capacity" that the system needs to carry to deal with temporal supply-and-demand mismatches. How big should this buffer capacity be? Intuition suggests that the faster the need to respond, the higher the buffer capacity. To understand this idea, note that if the lead time has to be guaranteed to be lower than a fixed value, on average, then the service rate has to be proportionally larger than the arrival rate, i.e., $\mu = \lambda + \frac{1}{L}$. Note also the inverse relationship between lead time and service rate required. This means that as the system is forced to commit to faster service, the service rate grows exponentially larger than the arrival rate.

Every time you drive by a fire station, you observe the capacity that is ready to deploy but idle; this is buffer capacity that can be deployed as soon as a fire alarm is heard. This buffer capacity is the price that has to be paid to ensure prompt response.

A well-known result called Little's law yields the expected number of orders in the system:

$$N = \lambda L = \frac{\lambda}{\mu - \lambda}$$

and the expected number of orders in a queue:

$$N_q = \lambda L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$$

To illustrate these ideas, consider a numerical example with four orders arriving per hour to a location that can serve these orders at a rate of six orders per hour. The queuing template spreadsheet computes that the average lead time is 0.5 hour or 30 minutes and that there are average of 2 orders in the system. The lead time for an order consists of an average service time of 10 minutes (or 1/6 hour) and an average time spent waiting in the queue of 20 minutes. The average time spent waiting in the queue is directly affected by the buffer capacity in the system, i.e., the inverse of difference between the service rate (the capacity) and the arrival rate. Thus, a higher buffer capacity decreases order lead time. However, a higher buffer capacity also implies a lower capacity utilization.

Table 4.4 summarizes the effect of increasing the arrival rate of students while maintaining the service rate of six orders per hour. For each pair of arrival and service rates, the queueing template was used to obtain the average work-in-process inventory and the average lead time.

Table 4.4 Average WIP and lead time for different arrival rates

Arrival Rate	Average Work-In-Process	Average Lead Time
4	2 orders	0.5 hours
4.5	3 orders	0.667 hours
5	5 orders	1 hour
5.5	11 orders	2 hours
5.75	23 orders	4 hours
5.95	119 orders	20 hours

Observe that as the ratio of arrival rate to service rate increases, the capacity utilization at the location increases but the corresponding lead time faced by a customer increases. As an example, when the arrival rate increases to 5.5 orders per hour, the expected lead time is now 2 hours even though the service time (on average) is only 10 minutes. Thus, for high arrival rates (5.95 per hour), the waiting time in the system is 20 hours, while service time remains 10 minutes. This example shows that lead time consists of both service time as well as time spent waiting to access capacity. Intuitively, such congestion impacts model the delays one faces during rush hour traffic, i.e., road flow capacity remains constant while demand for that capacity grows, thus creating congestion.

But what can be done to decrease such congestion effects? The following sections suggest possible remedies.

4.4 Impact of Many Capacity Units Operating in Parallel

Consider a system consisting of *mc* independent capacity units operating in parallel, all capable of providing service to an arriving stream of orders, which are processed in order of arrival. Orders are allocated to the first available unit of capacity. Assume (as before) that the service time is exponentially distributed. The arrival of orders to the system has an interarrival time that is exponential with parameter λ. As stated earlier, from a theoretical perspective, this model of order arrivals approximates the combination of many independent order sources.

For such a system, there exist standard templates to analyze performance, such as the expected number of orders in the system, the expected lead time for an order, and so on. We will use such a template to apply the model to develop insights into the configuration of capacity.

4.4.1 Understanding the Benefits of Capacity Pooling

Consider a company with two independent locations, each of which serve orders for its own geographic territory. Each location receives, on average, about 4.375 orders per hour at each center, and each location has the capacity to process 5 orders per hour. There is some extra capacity to deal with demand and supply fluctuations, the same as described in the earlier section. The queuing template provides the expected lead time for an order and the expected number of orders waiting to be processed and verifies that the system will have an average work-in-process of 7 orders, and orders will face an average lead time of 1.6 hours. Across both locations there will be 14 orders in the system.

Now consider an option to combine the two locations and share their capacity. For now, assume that the location that delivers the product is irrelevant to satisfying the requirements of the order. Thus, the orders can take advantage of situations when queues exist at one location while the other location is free. Notice that under this pooled capacity system, the queueing template shows that the total pool of customers across both locations faces an arrival rate of 8.75 orders per hour. Suppose the service rate at each office, 5 orders per hour, remains the same. Using the queuing template with two locations, it can be seen that the resulting system will have 7.46 orders on average in work-in-process inventory and an average lead time of 0.853 hours.

Thus, as long as the pooled order stream can be served by any location, at the same rate, lead time is decreased by about 50% with the same capacity. This is the benefit of pooling capacity in a supply chain. But how did the same capacity, deployed differently, have such a significant impact on performance? Notice that in a pooled capacity system, any available unit of capacity can be used to satisfy a waiting order. This flexibility to use a larger pool of capacity at any time prevents queues, improving the performance of the supply chain.

4.5 Is Splitting Capacity Appropriate? The Impact of Order-Related Service Characteristics

The earlier section showed that pooling capacity can benefit the supply chain. But there are cases where splitting capacity may improve the system. To illustrate this issue, consider a supply chain where orders have different service requirements. When such orders share a location, a setup time or change-over time is introduced in order for the location to accommodate the requirements of disparate customers.

As an example, consider a supply chain with 16 machines that process orders placed by customers. Customer orders form a common queue and are allocated to the first available machine. The set-up time or change-over time for each customer order is 14.25 minutes. The service time after setups is 30 minutes. The total order arrival rate across all customers is 20 orders per hour. With a common queue, using the queueing template, we can see that the average lead time is 1.132 hours.

Consider an alternative in which customer orders are split into four similar groups (i.e., orders grouped together are similar to each other and thus incur lower change-over times), so that each group thus has an arrival rate of 5 orders per hour. Correspondingly, suppose the machines are divided into four sets of four machines, and each set only deals with a limited set of customer order requests. As a result, suppose the set-up time between orders in each group (because these orders are similar) decreases to 3 minutes per customer. Using the queueing template, the lead time for customers now drops to 0.773 hours.

Thus, even though the benefits of pooling capacity have been sacrificed, the supply chain benefits from the increased productivity of the specialized capacity. Therefore, even though capacity pooling increases potential access to capacity, the associated mix of tasks to be done at pooled locations may affect the supply of capacity available and thus worsen system performance. In other words, capacity configurations have to balance the benefits of pooling with the benefits of splitting capacity.

This idea of creating supply chains with unique characteristics constitutes one of the basic ideas behind the development of cellular manufacturing systems.

4.6 Impact of a Series of Stages with Capacity: A Serial Production Line

The earlier sections considered a single stage of capacity. However, orders often have to be processed by many separate stages in order to be completed. Consider a supply chain where a given customer order has to go through a sequence of *MS* stages for the order to be served. The customer order starts at the first stage and moves from stage to stage (from stage 1 to stage *MS*) until all service is completed.

Suppose now that each stage (labeled $i = 1, 2, \ldots, MS$) has mc_i machines working in parallel. Suppose the time for a customer order to be served by a machine at stage i is exponentially distributed with parameter μ_i.

Then, if orders enter the first stage with interarrival time that is exponential with parameter λ, it can be shown statistically that they enter all stages with the same rate, λ. Thus, each stage can be analyzed independently. The expected lead time for a customer is the sum of lead times in each stage,

$$\text{Total lead time} = \sum_{i=1}^{MS} L_i$$

where L_i is the lead time for stage i.

To understand this analysis, consider a manufacturing system that processes orders using a make-to-order approach. This means that order processing begins only when the order reaches a certain stage. Suppose each order has three tasks that have to be done in series. All orders go from stage 1 to stage 2 to stage 3. Suppose stage 1 has one machine that does task 1 at the rate of 5 orders per hour. Stage 2 is done by three machines working in parallel, each operating at the rate of 1.4 orders per hour. Stage three is done by two machines operating in parallel, each operating at a rate of 2.2 orders per hour. Suppose job orders arrive at a rate of 4 orders per hour. What is the total lead time for an order to be processed across all the stages and delivered to the customer?

The total lead time is computed by taking each stage, evaluating it separately with the same arrival rate of orders, and adding up the resulting values. For stage 1, with a service rate of 5 orders per hour, an arrival rate of 4 orders per hour, and one machine, the lead time (from the queueing template) is 1 hour. For stage 2, with a service rate of 1.4 orders per hour, three machines working in parallel, and the arrival rate of 4 orders per hour, the lead time (from the queueing template) is 5.27 hours. Similarly, for stage 3, with a service rate of 2.2 orders per hour and two machines working in parallel, the lead time is 2.61 hours. The total time for an order to pass through all three stages is the sum of these lead times: 1 + 5.27 + 2.61, or 8.8 hours. Notice that the number of stages and the capacity at each stage influence the overall lead time observed by the customer.

The purpose of this section is to highlight the link between plant capacity configuration and the consequent impact on customer order lead time. Once the linkage is understood, the next step is to find a way to restructure capacity to improve lead time performance.

4.7 Lead Time in a Manufacturing System with Order Batches

Consider demand that consists of orders, where each order is for a batch of Q units. These orders are generated by the customer, for example, a retailer, either to (1) replenish manufacturer finished goods inventory or (2) represent an accumulation of customer demands for the product when the manufacturer carries *no* finished goods inventory. The main reason that manufacturing and ordering are done in batches is to optimize the impact of set-up times on the machine.

Consider production in batches of size Q units, where it takes t_s time units to set up a batch for production and t_p time units to produce each unit in a batch. The production time for a batch of Q units is modeled as exponentially distributed with a mean production batch rate of $\mu = \dfrac{1}{t_s + (t_p Q)}$. If D is the demand rate faced by the retailer, W is the number of independent inventory sites whose orders are supplied by this machine, and Q is the order batch size, then the arrival rate of order batches is $\lambda = \dfrac{WD}{Q}$. Note that the manufacturing lead time is given by the lead time for the corresponding queueing system.

Consider an example of the Instock store that sells ten different types of products. Demand for each product each day follows a normal distribution with a mean of 50 units and a standard deviation of 25 units. All these products are produced by a manufacturer who carries no finished goods inventory, i.e., operates a make-to-order system.

The manufacturer has 3 machines working in parallel, and production of a product requires a set-up time of 30 minutes and a processing time of 2 minutes per unit. This implies a set-up cost of \$50. The cost per unit of product charged by the manufacturer is \$25/unit. Instock's holding and storage cost are estimated to be 10% of the cost per unit. Assume that production occurs 8 hours per day, 5 days per week, 50 weeks per year, and that Instock's service level is 95%.

Question 1: What should be Instock's order size be for each product?

Answer 1: The order size is obtained as the economic order quantity:

$$EOQ = \sqrt{\frac{2 \times 50 \times 50 \times 50 \times 5}{0.1 \times 25}} = 707.1 \approx 708 \text{ units}$$

Question 2: What is the order arrival rate faced by the manufacturer?
Answer 2:

$$\lambda = \frac{50 \times 10}{708} = 0.707 \text{ orders/day}$$

Question 3: What is the lead time to fill a product's order?
Answer 3: All products require processing on 1 machine. All 3 machines are capable of processing all products. Thus

$$c = 3$$

$$\mu = \frac{1 \times 60 \times 8}{(30 + (2 \times 708))} = 0.3319 \text{ orders/day}$$

Read off the value from the queueing template for 3 machines working in parallel and the arrival rate and service rate as obtained earlier. Thus, the lead time is

$$L = 4.77 \text{ days}$$

Question 4: Provide an inventory policy for Instock. Provide the average inventory level and associated holding cost at Instock.
Answer 4: If Instock were to follow a (Q, r) policy, the reorder level r would be

$$r = (50 \times 4.77) + (Z_{0.95} \times 5 \times \sqrt{4.77}) = 256.4 \text{ units}$$

$$Q = 708 \text{ units as before.}$$

Also, the average inventory level at Instock is

$$\frac{Q}{2} + r - \mu L = \frac{708}{2} + 256.4 - (50 \times 4.77) = 372 \text{ units}$$

Thus, across the 10 products, the average inventory level is

$$372 \times 10 = 3{,}720 \text{ units}$$

The holding cost faced by Instock is

$$0.1 \times 25 \times 3{,}720 = \$9{,}300/\text{year}.$$

Question 5: The manufacturer is considering a reorganization of his machines. The new system will have 2 machines dedicated to producing 7 products and the remaining 1 machine dedicated to producing 3 products. Set-up time to change-over between products would now be 5 minutes. Consequently, the setup cost per order will be $5. Provide the impact on Instock's inventory level and the manufacturing lead time.

$$Q = \sqrt{\frac{2 \times 5 \times 50 \times 50 \times 5}{0.1 \times 25}} = 223.1 \approx 224 \text{ units}$$

We first examine the effect on the 7 products that share 2 machines.

$$\lambda = \frac{50 \times 7}{224} = 1.563 \text{ orders/day}$$
$$c = 2$$

$$\mu = \frac{1 \times 60 \times 8}{(5 + (2 \times 224))} = 1.059 \text{ orders/day}$$

Read off the values from the queueing template as

$$L = 2.07 \text{ days}$$
$$r = (50 \times 2.07) + (Z_{0.95} \times 5 \times \sqrt{2.07}) = 115.33$$
$$Q = 224 \text{ units as before.}$$

Also, the average inventory level at Instock is

$$\frac{Q}{2} + r - \mu L = \frac{224}{2} + 115.33 - (50 \times 2.07) = 123.83 \text{ units}$$

For the 3 products that share a machine, we have

$$\lambda = \frac{50 \times 3}{224} = 0.6696 \text{ orders/day}$$

From the queueing template, we get

$$L = 2.56 \text{ days}$$
$$r = (50 \times 2.56) + (1.65 \times 5 \times \sqrt{2.56}) = 141.2 \text{ units}$$

The average inventory level for each of these three products is

$$\frac{224}{2} + (141.2 - (50 \times 2.56)) = 125.2 \text{ units}$$

Overall inventory level = $(123.83 \times 7) + (125.2 \times 3) =$ 1,242.42 units.

Holding cost = $0.1 \times 25 \times 1{,}242.42 = \$3{,}106.07$

Reduction in holding costs as a result of this reorganization of machines is

$$\$9{,}300 - \$3{,}106.07 = \$6{,}193.93$$

Notice that in this example, adjustments in capacity impacted both the lead time at the manufacturer as well as the consequent buffer inventory at the retailer. In addition, changing the capacity configuration and lowering the set-up time also decreased the incentive to batch as well as the system inventory and lead time.

4.8 Tailored Logistics Systems

In section 4.5 we suggested that grouping similar tasks together may enable a supply chain to perform effectively. Fuller et al. ([35]) describe examples where tailoring the supply chain to product characteristics improved performance significantly. In an applied context, Eisenstein and Iyer ([27]) describe their intervention in the Chicago Public Schools logistics system. The main change they suggested was to split the system, which originally processed all orders with a common pool of capacity. The new system consisted of two separate tailored logistics systems and associated capacity, each of which provided service to its own set of orders.

How can tailored systems improve a supply chain? To provide some intuition, consider a manufacturer who receives orders for two products. Orders for product 1 arrive at the rate of λ_1 orders per day. Orders for product 2 arrive at the rate of λ_2 orders per day. The number of orders received each day $\lambda = \lambda_1 + \lambda_2$. Both products share a common production facility that produces products at the rate of μ per day. Assume that each order is for Q units of product and that $\mu = \frac{1}{A + (tQ)}$, where A is the setup time and t is the production time per unit.

If orders are processed in their order of arrival (first in, first out), the lead time for any product order is

$$L = \frac{1}{\mu - \lambda}$$

Suppose that demand per day for the first product follows a normal distribution with a mean of m, and a standard deviation of σ_1. Also the second product demand has a mean of m_2 and a standard deviation of σ_2. Assume that $\sigma_1 \geq \sigma_2$.

The average inventory level across the two products is

$$\frac{Q}{2} + (Z_{ser}\sigma_1\sqrt{L}) + (Z_{ser}\sigma_2\sqrt{L}).$$

What can the manufacturer do to decrease inventory levels for these products?

Suppose we manage the production facility so that we prioritize product 1 over product 2. Thus orders for product 1 are processed before we process orders for product 2.

The impact of providing higher priority for product 1 is to generate a lead time for product 1, L_1, as follows:

$$L_1 = \frac{1}{\mu} + \frac{\lambda}{\mu(\mu - \lambda_1)}$$

Also the lower priority for product 2 generates a lead time for product 2, L_2, as follows:

$$L_2 = \frac{1}{\mu} + \frac{\lambda}{(\mu - \lambda) \times (\mu - \lambda_1)}$$

The new average inventory levels across both products is

$$\frac{Q}{2} + (Z_{ser}\sigma_1\sqrt{L_1}) + (Z_{ser}\sigma_2\sqrt{L_2})$$

Can prioritization of orders improve the system performance? Consider a numerical example with demand rates for each of the two products that are $m_1 = 140$ units per day and $m_2 = 60$ units per day, and variability of $\sigma_1 = 125$ units and $\sigma_2 = 25$ units. Next, assume that the batch size for both products is 100 units. Thus, the order batch rate from each product would be $\lambda_1 = 1.4$ orders per day and $\lambda_2 = 0.6$ orders per day respectively for a total arrival rate of 2 orders per day across both products. Given the batch size, suppose the set-up time for an order is 0.1 days and the processing time per unit is 0.003 days. The corresponding service rate for any order batch of 100 units is 2.5 orders per day, or $\frac{1}{0.1 + (0.003 \times 100)}$.

Notice that if both products were accessing capacity in order of arrival, with no priority, they would both face the same lead time of 2 days. The corresponding impact on their safety stock would be 363.05 units for the first product and 72.61 units for the second product (obtained using the formula $Z\sigma\sqrt{L}$). Thus the total inventory across both products would be 435.66 units.

However, if we prioritize access to capacity for product 1 (which has a higher variability), then the new lead times, using the formulas provided earlier, would be $L_1 = 1.12$ and $L_2 = 4.03$ days. With these lead times, notice that the corresponding safety stock for the first product would be 272.55 units (which decreases from the earlier case), while the safety stock for the second product would be 103.15 units (which increases from the earlier case). Note that the total inventory across both products is now 375.72 units. This decrease in inventory reflects the benefit of tailoring access to the supply chain based on product demand characteristics. Notice that giving priority to the more variable product permits its lead time to decrease, thus decreasing the safety stock for that product. But clearly this comes at a cost to the less variable product, whose lead time increases but at a slower rate. Thus, we have traded off lead time customization for an aggregate decrease in the overall inventory.

In other words, it may be worth reconsidering how orders get access to capacity. Tailoring the access to capacity based on product characteristics can improve the overall supply chain performance.

4.9 The Make-Buy Decision and Capacity

In the earlier sections, we considered how to improve performance by splitting capacity or tailoring access to capacity. We expand the notion of providing different paths for orders to a supply chain by examining the choice of the mix of orders a company may choose to make vs. the orders that they may subcontract in a supply chain.

A procurement manager has access to both capacity within the company as well as capacity at a subcontractor. All orders accepted have to be satisfied per company policy. Thus revenue is fixed, and maximizing profit implies minimizing cost. With each order the manager has to decide how much the company should make and how much it should buy, so as to minimize the costs to satisfy product demand. To illustrate this scenario, consider an example and an associated process to make the optimal decision ([83]).

Company Makebuy has just received an order for making three different kinds of products: A, B, and C. Each product must be processed on two machines: X and Y. Table 4.5 summarizes the requirements for the three models.

However, the company has only limited capacity on machines X and Y, given prior commitments. The available capacity during lead time for machine X is 6,000 hours, while the capacity for machine Y is 3,000 hours. The company has the option to buy the products from an outside contractor, who charges the following and can deliver within the lead time. Table 4.6 summarizes the costs for the company.

How should the order be produced: what mix of make vs. buy should be used to minimize costs? This decision can be made by framing the problem as a linear program and using available solution packages, e.g., the Solver package in Excel. To frame the problem, we define a set of decisions X_{i1}, $i = 1, 2, 3$ as the amount of products 1, 2, and 3 that are made in house and X_{i2}, $i = 1, 2, 3$ as the amount of products 1, 2, and 3 that are subcontracted. Let C_{ij}, $i = 1, 2, 3$ and $j = 1, 2$ refer to the costs associated with each of the decisions (Table 4.6) and d_i refer to the quantity of product i demanded.

Then the goal is to minimize $\sigma_{ij} c_{ij} X_{ij}$.

Table 4.5 Product volume and processing requirements on each machine

	Product A	Product B	Product C
Number ordered	2,000	1,000	500
Hours required on X per unit	2	3	1
Hours required on Y per unit	1	1	1

Table 4.6 Company costs for make vs. buy for each product

	Product A	Product B	Product C
Costs per unit to make	\$40	\$73	\$100
Costs per unit to buy from outside	\$55	\$93	\$125

There are two constraint sets that have to be satisfied. We need to have enough product to satisfy the demand for each product, i.e.,

$$\Sigma_j X_{ij} = d_i$$

We also need to check that we do not exceed the available capacity on each of the machines X and Y, i.e.,

$$(2X_{11}) + (3X_{21}) + (1X_{31}) \leq 6000$$

$$(1X_{11}) + (1X_{21}) + (1X_{31}) \leq 3000$$

The model described above is a linear program and can be solved using the Solver model in Excel. The solution to this model is shown in Table 4.7.

Note that in the solution, the cost per unit to subcontract product B is \$20 (i.e., 93 − 73), while the cost of outsourcing product A is \$15 per unit. Why is it optimal for the company to outsource product B instead of product A? It is clear that product B uses more bottleneck resources, i.e., the capacity of machine X, than product A. In other words, the make-buy decision now requires identifying the internal bottleneck resource and then finding the best way to minimize cost using the internal resource. The linear programming tool enables this bottleneck resource to be identified and generates the optimal make-buy decision.

This section thus suggests that careful choice of the products that use up internal capacity vs. those that can use externally available capacity should consider the marginal benefit per unit of the bottleneck internal capacity. Such an analysis gets complicated because the bottleneck resources are, in turn, defined by the mix of products that are made vs. outsourced. The use of tools such as linear programming enables this issue to be resolved by considering the entire problem simultaneously. Such tools enable the optimal choice of bottleneck resources that minimize supply chain costs.

Table 4.7 Optimal make vs. buy decisions for products

	Product A	Product B	Product C
Units to make	2,000	500	500
Units to subcontract	0	500	0

4.10 Capacity as an Operational Hedge to Regulatory Changes

When capacity is chosen in a global supply chain, it may be necessary to anticipate possible opportunities that may arise as countries change their trade agreements, for example. Having locations that can make use of the operational flexibility can have benefits. But all this means paying a price in terms of current performance in order to position the supply chain to have a higher level of average performance. To illustrate such issues, we provide a numerical example.

Company ABC has two plants manufacturing product A. The first plant is located in Illinois, while the second plant is located in Germany. Both plants have a capacity of 500,000 units per year. These plants have been built primarily to serve two markets: the United States and Europe. The unit production cost at the Illinois plant is $1 per unit, while the unit production cost at the plant in Germany is $1.25 per unit. The product demand for the US market is 250,000 units per year, while the demand for the European market is 200,000 units per year. The cost of transporting between Europe and the United States is $0.10 per unit. Also, the average import duty for goods imported into Europe is 30%, while there is no import duty for goods imported to United States. Also, for the purpose of maintaining uniform quality, company ABC has decided that each demand region will be supplied by a single plant only.

Consider possible solutions to the production and sourcing decisions under the above cost structure.

Sourcing decision:

1. US market
   If supplied by the Illinois plant, unit cost is $1.
   If supplied by the German plant, unit cost is $1.25 + 0.1 = $1.35.
   The product is cheaper if supplied by the Illinois plant.
2. European market
   If supplied by the Illinois plant, unit cost is $1 + 0.1 + 0.3 = $1.4.
   If supplied by the German plant, unit cost is $1.25.
   The product is cheaper if supplied by the German plant.

3. Optimal production decision
   The Illinois plant produces 250,000 units per year.
   The German plant produces 200,000 units per year.

Now suppose that Europe were to adopt a free trade agreement and drop the import duty. How would the production and sourcing decisions change?

Sourcing decision (under Free Trade Agreement with Europe)

1. US market
   If supplied by the Illinois plant, unit cost is \$1.
   If supplied by the German plant, unit cost is \$1.25 + 0.1 = \$1.35.
   It is thus optimal to be supplied by Illinois plant.
2. European market
   If supplied by the Illinois plant, unit cost is \$1 + 0.1 = \$1.1.
   If supplied by the German plant, unit cost is \$1.25.
   It is again optimal to be supplied by the Illinois plant.
3. Optimal production decision
   The Illinois plant produces 450,000 units per year.
   The German plant has no production.

Next, suppose the German plant has improved its efficiency and hence its production costs have dropped to \$0.85 per unit. How would your production and sourcing decisions change? What is the value of excess capacity at the German plant under this scenario?

Sourcing decision

1. US market
   If supplied by the Illinois plant, unit cost is \$1.
   If supplied by the German plant, unit cost is \$0.85 + 0.1 = \$0.95.
   It is optimal to supply the US market from the German plant.
2. European market
   If supplied by the Illinois plant, unit cost is \$1 + 0.1 = \$1.1.
   If supplied by the German plant, unit cost is \$0.85.
   It is optimal to supply Europe from the German plant.
3. Optimal production decision
   The Illinois plant has no production.
   The German plant produces 450,000 units per year.

What do all these alternative capacity configurations suggest? All along, if we carry excess capacity, we can avail of these opportunities as they arise. The extra capacity does not have to remain idle; it needs to remain flexible so that it can be used when conditions are right. This example shows how excess capacity in a global supply chain provides a "real option" that can be exercised as business conditions unfold. Eliminating excess capacity will reduce the options available to operate a global supply chain.

4.11 Temporal Adjustment of Capacity through Choice of Employee Schedules

Finally, consider how availability of capacity across time can be adjusted through choice of capacity in shifts, when employees represent the source of capacity. This view of capacity is temporal and thus adjustable. Such models come under the general topic of tactical scheduling. Scheduling models specifically focus on taking available shifts for personnel and attempt to have sufficient people in each time period (e.g., half-hour or one-hour intervals) to cover projected demand over time. For a comprehensive description of techniques for solving such systems, please see [83].

In many systems, e.g., nursing requirements, airline airport staff, reservations personnel, the demand during the day displays significant variation. However, for convenience, the staff may have to be scheduled around standard shifts. The main scheduling problem is to minimize costs while maximizing utilization of the staff across the hours of the shift.

Consider the following scheduling model: Let the day be divided into N time periods (say half-hour intervals). Let d_i be the demand (in number of staff) required in time period i (where $i = 1, 2, \ldots, N$. Let a_{ij} be equal to 1 if a person working on shift j is available in period i. Let C_j be the cost for a person to work in shift j.

The problem we want to solve is the following:

$$\text{Minimize } \Sigma_j c_j X_j.$$

$$\Sigma_j a_{ij} X_j \geq d_i \text{ for all } i = 1, 2, \ldots, N$$

$$X_j \text{ are restricted to be integer values.}$$

The solution allocates people to shifts in a way that allows us to provide adequate staff during each time period of the day. We now provide an example to illustrate this model.

Consider a service system that has divided time during the day into 6 periods. Demand for service personnel each period is as follows: {5, 8, 15, 12, 8, 13}. Each person works three periods, and there are five possible shifts as follows:

Shift 1: Work periods 1,2,3 Cost = \$100/person
Shift 2: Work periods 2,3,4 Cost = \$90/person
Shift 3: Work periods 1,3,4 Cost = \$120/person
Shift 4: Work periods 4,5,6 Cost = \$105/person
Shift 5: Work periods 2,5,6 Cost = \$125/person

We thus formulate the model with

X_1 = number of people working shift 1
X_2 = number of people working shift 2
X_3 = number of people working shift 3
X_4 = number of people working shift 4
X_5 = number of people working shift 5

The equations are

Minimize $((100 \times X_1) + (90 \times X_2) + (120 \times X_3) + (105 \times X_4) + (125 \times X_5)$

$$
\begin{gathered}
X_1 + X_3 \geq 5 \\
X_1 + X_2 + X_5 \geq 8 \\
X_1 + X_2 + X_3 \geq 15 \\
X_2 + X_3 + X_4 \geq 12 \\
X_4 + X_5 \geq 8 \\
X_4 + X_5 \geq 13 \\
\text{All } X_1, X_2, X_3, X_4, X_5 \geq 0
\end{gathered}
$$

If we set this program up in Excel and solve it, we generate the solution

$$X_1 = 5, X_2 = 10, X_3 = 0, X_4 = 13$$

The corresponding cost is $2,765.

Notice that under this scheme, we have the following number of people each period:

$$\{5, 15, 15, 23, 13, 13\}$$

Thus in periods 2, 4, and 5 we have more staff than we need.

This model shows that it may make sense to have more capacity than required in some periods in order to save overall costs to cover demand across all periods. In other words, since the shifts are not flexible to the specific demand requirements over time, the extra slack capacity in some periods enables the supply demand mismatch to be solved cost effectively. It is thus worth considering the allocation of shifts to employees to optimize overall supply costs.

4.12 Chapter Summary

In this chapter we focused on the drivers of capacity and the impact of capacity on supply chain performance. Capacity affects service levels offered and lead times experienced by customers. In the presence of long lead times to establish capacity, forecast error may lead to required buffer capacity for optimal performance of the supply chain. The capacity configuration that optimizes performance requires careful consideration of the impact of pooling on set-up and processing times. Excess capacity in a supply chain network may provide an option that can be exercised if parameters change. In the presence of capacity constraints, competition for capacity may result in local decisions generating nonoptimal outcomes. Finally, in the presence of varying demands, a carefully optimized temporal capacity plan may generate competitive outcomes.

CHAPTER 5

Coordination

The Oxford Dictionary ([80]) defines the verb *to coordinate* as to "bring elements (of a complex activity or organization) into a harmonious or efficient To coordinate, a supply chain manager may have "to negotiate with others in order effectively" or "to match or harmonize" the needs of multiple constituents. For supply coordination of flows of physical goods, information, and money is challenging because modern supply chains frequently have several independent owners with individual goals. Thus, coordination of disparate entities is a key feature of a supply chain's architecture and has an impact on observed performance and therefore on competitiveness. The performance of a supply chain is often difficult without coordinating agreements. An appropriate coordination mechanism, along with associated sharing rules, can often result in improved performance across all supply chain entities.

The first step to develop coordination agreements is to identify the goals of individual decision makers in the supply chain and the associated observed performance in the absence of any agreements. Then, consider the best possible performance of the supply chain, as if all ownership were with one entity. The difference between these two measures of performance indicates the maximum value that can be released by the use of coordination agreements. A supply chain coordinating agreement is an agreement that adjusts performance of each of the independent decision makers such that the total supply chain performance matches that generated by a single owner of the system. The key difference between a coordinated supply chain and a vertically integrated supply chain is that independent ownership of the entities in the supply chain is maintained, but coordination agreements enable an overall performance that matches that of a system with a single owner.

One possible goal for coordination agreements is to generate Pareto-improving performance, i.e., no party to the agreement is worse off and at least one is strictly better off.

While Chapter 5 assumes coordination to be a good thing to do, there are contexts in which no coordination is assumed to be best. Some of these examples appear in the context of humanitarian logistics and arise primarily due to different mandates across participating entities.

This chapter will provide tools and associated concepts to develop coordination agreements. First, some specific examples to illustrate the use of coordination agreements.

5.1 The Coast Guard and the Value of Coordination

The following project is described in detail in Deshpande et al. ([23]). The United States Coast Guard (USCG) protects the US coastline, using ships and airplanes. The Coast Guard operates twenty-six air stations, which are spread across the coast. Each air station operates a subset of ten different aircraft types. There are over 200 aircrafts across these twenty-six air stations, consisting of fixed-wing and rotary-wing aircrafts. The focus of the study was the Aircraft Repair and Supply Center located in Elizabeth City, North Carolina.

The process of operation of the supply chain is as follows. When aircrafts generate demand for replacements, also called service parts. These service parts are supplied from the local inventory at air stations. This inventory is replenished by the central warehouse facility at Elizabeth City. In 2001, the total number of individual parts managed at the central facility exceeded 60,000 parts, and the total value of the inventory exceeded $70 million. When working parts are shipped from the warehouse to the air station to satisfy aircraft demand, the salvageable broken components, from all air stations, are shipped back to the warehouse for repair and reuse. The aircraft from all air stations also come for periodic overhaul (depot maintenance) to the Elizabeth City facility, and thus generate demand for parts. Of the total parts in the system, about 6,000 are repaired both internally and by outside commercial vendors. The total annual budget for parts purchases, parts repair, and depot-level maintenance exceeds $140 million.

All repair and supply activities were subject to detailed tracking in two separate databases: Aviation Computerized Maintenance System (ACMS) and Aviation Maintenance Management System (AMMIS). The ACMS database tracks all individual parts installed on individual aircraft, flags the required maintenance, and records the history of repairs using each part's unique serial number. The AMMIS database in contrast tracks every step of the process once the part comes off the aircraft. It tracks demand requisitions (orders) placed to the warehouse, and the shipment of good parts to the air stations and maintenance facility, as well as the receipt of failed parts (carcasses), their shipment to vendors or in-house for repair, and their induction back into the system. Historically, there was no connection between the AMMIS and ACMS systems, and there was no advance information regarding impending demands or repair lead times.

The project by Deshpande, Iyer, and Cho [23] describes an effort to coordinate these two information sets. The models developed connected the two databases. The consequent data were used, along with part age signals, to adjust inventory levels and thus reduce supply chain costs. But how does this scheme work? An indicator level was set for each part so that whenever the part reached a threshold age, a part age signal was sent to the ARSC facility. Given these part age signals, the inventory levels of repaired components could be adjusted to repair both in anticipation of demand and following the rest of demand. This required a correlation between the signal and the demand over the repair lead time. Figure 5.1 shows the empirical data regarding the correlation between demand and signal for different thresholds for the main gearbox. Intuitively, the optimal threshold is the one that maximizes the correlation because it provides the best signal regarding impending demand.

The resulting system, customized for each one of forty-one prototype products, permitted coordination between part maintenance data and inventory data. In this context coordination used part age signals to adjust the inventory level and thus improve overall system performance. Estimated savings due to moving to a signal-driven inventory system were estimated to be 18%–22% of inventory costs. In short, data sharing

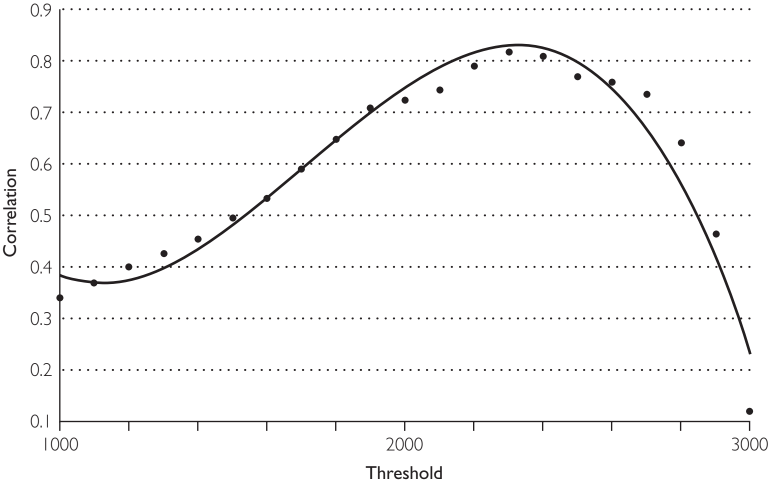


Figure 5.1 Correlation between signal and demand for different thresholds

between maintenance and inventory systems and consequent coordination of the repair inventory permitted higher service levels with lower inventory.

5.2 Industrial Revenue Sharing Agreements

Revenue-sharing agreements are an approach to coordinate a supply chain. For example, Lorain County in Ohio and a wind turbine installer established a revenue-sharing agreement that states that the county will receive 20% of the revenues from energy generated in return for land leases ([100]). GoodmanSparks in the United Kingdom supplies, installs, and maintains coin-operated laundry equipment in return for a share of the revenues generated when students use the facilities ([36]). In the aviation industry, Lucas Aerospace entered into contracts with Rolls Royce to supply engine and fuel control systems for the new generation of Trent engines. Under the terms of the deal, Lucas would invest $122 million and receive 3%–5% of the total revenues from the engines ([2]).

To provide an example that is closer to the customer, consider the problem faced in past years by Blockbuster Video, a renter of videotapes ([37]). Movie studios had charged video rental companies $65 to $100 per tape. Blockbuster and other rental companies had an exclusive time window before the tapes were sold to other channels (such as cable and video-on-demand). Blockbuster had to choose the number of copies of a given movie to stock to maintain profitability. Most retail data showed that stockouts were about 30% in the industry with poor availability.

Then a revenue-sharing solution came on the market, pioneered by Rentrak, an information services company. Rentrak negotiated with movie studios to introduce a pay-per-transaction revenue sharing program. Under the program, studios were paid close to $8 per tape initially, and close to 40% of the $3 rental fee per transaction. The impact on the industry was substantial. Retail tape inventory increased, stockouts were cut in half, and retailer revenues soared. Film studios, too, now obtained a large fraction of their revenues from retail sales. In all, revenue sharing represented a win-win proposition. Large stores such as Blockbuster Video avoided Rentrak and struck deals directly with movie studios. Smaller stores could go to Rentrak, which aggregated their demands and thus provided scale economies.

But disagreements among supply chain partners caused Disney to sue Blockbuster, alleging accounting irregularities that failed to account for hundreds of thousands of tapes under a 1997 revenue-sharing agreement and suggesting that Disney was cheated out of $120 million. Blockbuster denied the allegations. Independent video retailers sued Blockbuster and the studios, claiming that the studios were discriminating against the independents in violation of the Robinson-Patman Act. The case was dismissed in US district court.

Soon Blockbuster announced that it will not be renewing the revenue-sharing deals in the industry. The key reason was that DVDs entered the market and were sold at $15 per unit. Blockbuster did not sign any revenue-sharing contracts for DVDs. In addition, because the DVD did not incur as many costs (such as rewinding), DVD rentals were $1.20 vs. $1.80 for a video. In fact, both Blockbuster and the studios competed to sell DVDs to the public. It was projected that the net result of the cancellation of revenue-sharing contracts would be to increase DVD prices, thus helping both Blockbuster and the studios. But customers could buy DVDs from mass merchants rather than renting or buying from Blockbuster, creating a whole new set of supply chain challenges.

The main message is that revenue-sharing agreements need an effective information system to guarantee compliance. But, as we shall see later in this chapter, they enable supply chain coordination and can thus generate Pareto-improving outcomes for participating companies.

5.3 Humanitarian Logistics and Coordination

Historically, the United Nations Joint Logistics Committee (UNJLC) was a coordination body within the United Nations (UN) system whose goal was to coordinate logistics across independent agencies both the UN and governmental and nongovernmental organizations (such as the Red Cross). Over the years the UNJLC has played a key role in conflict resolution and facilitating the delivery of humanitarian aid in several contexts, as the following examples illustrate.

As described in a case written by Levins, Samii, and Van Wassenhove ([68]), when relief organizations were rushing in to provide aid in Afghanistan, a landlocked country, many organizations attempted to enter the country through Uzbekistan and send supplies on barges down the river. Hundreds of relief organizations tried to enter Afghanistan, each operating independently, which created such chaos that the Uzbek government shut down access to Afghanistan. The UNJLC played the role of "traffic cop," improving the situation by establishing a regular barge schedule and smoothing the flow of aid through the Uzbek entry point. Coordinating the independent relief organizations increased capacity and decreased lead time for everyone. Such a role can be considered as *coordination by command,* i.e., a centralized external scheduler who delivers value to all parties by coordinating the system and improving overall performance.

Another case written by Samii and Van Wassenhove ([86]) describes a situation when the World Food Program (WFP) was shipping in food for hungry Rwandans, while the United Nations High Commissioner of Refugees (UNHCR) was shipping out Rwandan refugees from the war-stricken areas. Given the floods, the main mode of transport was by air. WFP was flying in food and flying out empty, while the UNHCR was flying in empty and flying out full. The UNJLC coordinated the schedules across the two agencies so that the WFP aircraft flew back with refugees, while the UNHCR aircraft flew in food supplies. The adjustments in flight schedules had to take into account loading issues and food and refugee arrival at each end, as well as safety and security. But coordination enabled improved utilization and higher capacity at about the same cost. This is called *coordination by consensus* across the relief organizations.

In yet another case by Samii and Van Wassenhove ([85]), in Afghanistan, they describe a UNJLC website that provided security and weather updates, requests for logistics shipments (similar to a ride board in most campuses), road conditions, and more. The remaining coordination was left to individual agencies who used this information to seek out interested parties to share resources. This minimal coordination is termed *coordination by default.*

The previous examples illustrate three forms of coordination: (1) coordination by command, a centralized approach; (2) coordination by consensus, cooperative Pareto- improving solutions; and (3) coordination by default, or no coordination except perhaps information sharing.

5.4 A Model of Coordination

Consider a supply chain consisting of a single manufacturer who produces a product and sells it to a retailer, who, in turn, sells the product to the final customer. Suppose that in order to produce the product, the manufacturer has to choose to reserve a capacity level K at a cost per unit of c_k. Retail price per unit is r, the wholesale price is set at w, and the cost per unit to manufacture is set at c. This notation and description we follow is from Ozer and Wei [81].

Three important characteristics are (1) the timing of data received by manufacturer and retailer, (2) the extent of information shared, and (3) the timing of decisions. The capacity decision is made by the manufacturer and the orders are placed by the retailer.

5.5 Manufacturer Chooses Capacity

In this section we will look at scenarios in which the retailer waits for demands to be known before placing his order. The manufacturer has to order before the demands occur, so the manufacturer orders at time 0.

Assume that retail demand follows a distribution with mean μ and standard deviation σ. The retailer orders at L, after observing demand. Decisions have to be timed so that capacity is reserved by the manufacturer in advance of retailer order. However, the manufacturer selection of capacity will then restrict the retail demand that can be satisfied. This suggests the need to coordinate decisions made by the manufacturer with those that are ideal for the retailer.

5.6 Supply Chain Profit

Once the manufacturer and retailer decisions are made, the combined profit across the two firms is termed the *supply chain profit.* Notice that when the profits of the manufacturer and retailer are added together, the wholesale price level does not affect this total as it is merely a transfer payment from the retailer to the manufacturer. The supply chain as a whole thus attempts to choose a capacity level K that will maximize supply chain profit.

Intuitively, the supply chain manager chooses a capacity level that sets the expected revenue associated with increasing capacity equal to the expected cost associated with increasing capacity. Thus, following the newsvendor model, the optimal capacity has to satisfy

$$\text{Probability (Demand} \leq K_C) \; \frac{r - c - c_k}{r - c}$$

This capacity level K_C and the associated supply chain profit maximize the profits of the supply chain.

Consider an example with a retailer whose demand follows a uniform distribution with values between 8 and 22, see Table 5.1. Thus the probability of demand taking each value between 8 and 22 is equal to $\frac{1}{15}$. Suppose $r = 4$, $w = 2$, $c = 0.6$, $c_k = 0.5$. Following the steps defined earlier, the optimal service level for the supply chain is $\frac{r - c - c_k}{r - c} = 0.852$. Thus the optimal capacity level is obtained as $K = 20$, using the values in Table 5.2.

The corresponding supply chain profit can be calculated as 40.32. Table 5.2 shows the steps in this calculation for the supply chain profit.

Table 5.1 Demands and associated probabilities

Demand	Probability	Cumulative
8	0.067	0.067
9	0.067	0.133
10	0.067	0.2
11	0.067	0.267
12	0.067	0.333
13	0.067	0.4
14	0.067	0.467
15	0.067	0.533
16	0.067	0.6
17	0.067	0.667
18	0.067	0.733
19	0.067	0.8
20	0.067	0.867
21	0.067	0.933
22	0.067	1

Table 5.2 Calculation of supply chain profit; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 20$

Demand	Prob	CumProb	Revenue	CapCommit	Execution	Profit × Probability
8	0.067	0.0667	32	10	4.8	1.147
9	0.067	0.1333	36	10	5.4	1.373
10	0.067	0.2	40	10	6	1.6
11	0.067	0.267	44	10	6.6	1.8267
12	0.067	0.333	48	10	7.2	2.053
13	0.067	0.4	52	10	7.8	2.28
14	0.067	0.467	56	10	8.4	2.507
15	0.067	0.533	60	10	9	2.733
16	0.067	0.6	64	10	9.6	2.96
17	0.067	0.667	68	10	10.2	3.186
18	0.067	0.733	72	10	10.8	3.413
19	0.067	0.8	76	10	11.4	3.64
20	0.067	0.867	80	10	12	3.867
21	0.067	0.933	80	10	12	3.867
22	0.067	1	80	10	12	3.867

The first column shows the demand; the second the probability associated with each demand level (equal to $\frac{1}{15}$); and the third column, the cumulative probability. The fourth column shows the revenue for each demand realization, i.e., the minimum of the demand and the capacity ($K = 20$) times the revenue of \$4 per unit of demand satisfied. The fifth column provides the cost to reserve capacity, i.e., c_kK. The sixth column shows the cost to execute the capacity cMin(Demand, K). The seventh column shows the product of the net profit for each demand realization times the probability. The sum of the entries in the last column provides the expected profit = 40.32.

Notice that the manufacturer and retailer are separate companies so they need some mechanism to attain this maximum profit. The next few sections will explore several agreements and determine if they attain the maximum supply chain profit. If they do so, such agreements are said to be coordinating agreements. If they do not, they are considered to be agreements that generate an uncoordinated supply chain.

5.7 Wholesale Price Agreements

Consider the case when the manufacturer and retailer are separate companies, each optimizing their profits. Because the manufacturer has to choose capacity to optimize his profits, he will consider the wholesale margin $w - c - c_k$ associated with a sale as against the loss associated with wasted capacity of c_k. The manufacturer will thus choose capacity to offer a service level of Probability(Demand $\leq K_w$) = $\dfrac{w - c - c_k}{w - c}$. Given this manufacturer choice of capacity, the retailer's profits are affected because his supply is constrained by the manufacturer's choice of capacity.

Consider the supply chain example discussed earlier, but for this decentralized supply chain decision-making environment. Using the numerical example from the earlier section, the manufacturer's optimal service level is $\dfrac{2 - 0.6 - 0.5}{2 - 0.6} = 0.643$. Using the probabilities in Table 5.1, this service level implies a capacity decision by the manufacturer of $Kw = 17$. Notice that $K_w \leq K_C$, i.e., the manufacturer invests in less capacity than is

Table 5.3 Wholesale price agreement calculations for the manufacturer; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 17$

Demand	Prob	CumProb	Revenue	CapCommit	Execution	Profit × Probability
8	0.067	0.067	16	8.5	4.8	0.18
9	0.067	0.133	18	8.5	5.4	0.273
10	0.067	0.2	20	8.5	6	0.367
11	0.067	0.267	22	8.5	6.6	0.46
12	0.067	0.333	24	8.5	7.2	0.553
13	0.067	0.4	26	8.5	7.8	0.6467
14	0.067	0.467	28	8.5	8.4	0.74
15	0.067	0.533	30	8.5	9	0.833
16	0.067	0.6	32	8.5	9.6	0.9267
17	0.067	0.667	34	8.5	10.2	1.02
18	0.067	0.733	34	8.5	10.2	1.02
19	0.067	0.8	34	8.5	10.2	1.02
20	0.067	0.867	34	8.5	10.2	1.02
21	0.067	0.933	34	8.5	10.2	1.02
22	0.067	1	34	8.5	10.2	1.02

desired by the entire supply chain. The impact of this underinvestment in capacity is that the retailer's expected profit is now 28, the manufacturer's expected profit is 11.1, and the supply chain profit, which is the sum of manufacturer and retailer expected profits, is 39.1. The details of this calculation are shown in Table 5.3.

The manufacturer's expected profit is obtained by adding the entries in the last column to yield manufacturer's expected profit of 11.1. The impact of the manufacturer's choice on the retailer's expected profit is calculated in Table 5.4.

Again the retailer's profit is the sum of the entries in the last column and is equal to 28. Notice that the supply chain profit is lower than the maximum supply chain profit possible of 40.32. Note that for any wholesale price such that $c + c_k < w < r$, then $K_C > K_w$, if the service levels are greater than 50%. Thus the supply chain profits are not maximized, and the supply chain is termed *uncoordinated*. Notice that this remains the case even when the wholesale price varies from the current level. In general,

Table 5.4 Wholesale price agreement calculations for the retailer; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $Kw = 17$

Demand	Revenue	Cost	Profit	Profit × Probability
8	32	16	16	1.067
9	36	18	18	1.2
10	40	20	20	1.333
11	44	22	22	1.467
12	48	24	24	1.6
13	52	26	26	1.733
14	56	28	28	1.867
15	60	30	30	2
16	64	32	32	2.133
17	68	34	34	2.267
18	68	34	34	2.267
19	68	34	34	2.267
20	68	34	34	2.267
21	68	34	34	2.267
22	68	34	34	2.267

wholesale price agreements cannot coordinate the supply chain. The reason for this inability to coordinate is that both manufacturer and retailer consider their individual margins when making decisions. This is termed *double marginalization*.

Figure 5.2 shows the manufacturer, retailer and supply chain profits for different possible values of the manufacturer capacity. Notice from this picture that it is optimal for the manufacturer to choose a capacity of 17 units because that capacity maximizes the manufacturer's profits. Notice, however, that the capacity level does not maximize the supply chain profits. This example illustrates that wholesale price agreements may not be able to coordinate a supply chain.

It is thus clear that the wholesale price contract cannot always create a coordinated supply chain, that is, that the profits added across individual companies do not attain the supply chain maximum profit because the optimal capacity decision, from a supply chain perspective, is not chosen. The next section describes a coordinating agreement that can generate a coordinated supply chain.

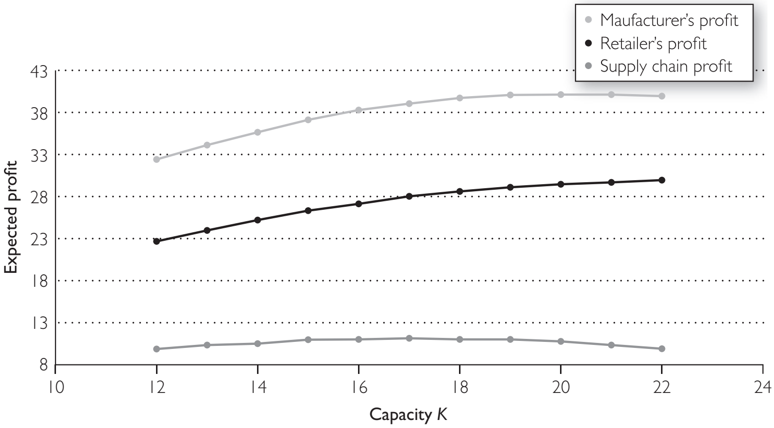


Figure 5.2 Manufacturer, retailer and supply chain profits for different "K" values

5.8 Take-or-Pay Contracts

Consider a coordination agreement in which the retailer pays w for each unit purchased as well as τ per unit of leftover unused capacity. Such contracts are termed take-or-pay contracts and are found commonly in many Just-In-Time contexts. For example, it is reported ([52]) that Toyota guarantees that its actual orders will deviate by no more than 10% around forecasted offtakes and will pay for any deviations. In the transportation industry, Reynolds commits to minimum volumes to carriers and will pay if observed demand falls short of these minimum volumes. Eppen and Iyer [29] describe a backup agreement in the apparel industry, which consists of a payment of w per unit taken and a payment of b per unit not taken.

The manufacturer profit can then be written as $(w - c)E(min(demand, K)) + \tau E(max(K - demand, 0)) - c_k K$. The corresponding retailer profit can be written as $(r - w)E(min(demand, K)) - \tau E(max(K - demand, 0))$. Given these profit structures, the manufacturer will choose a capacity level to offer a service of $\frac{w - c - c_k}{w - c - \tau}$. Notice that if $\tau = \frac{(r - w)c_k}{r - c - c_k}$, the manufacturer will choose a capacity level that is the same as the supply chain profit maximizing level.

5.8.1 A Numerical Example

Consider the example described earlier. Suppose the manufacturer were to lower the wholesale price to 1.95 but receive a payment for leftover capacity of t obtained as $\frac{(4-1.95)0.5}{4-0.6-0.5} = 0.35$ (see [90] for details). With this payment for leftover capacity at the manufacturer, the manufacturer chooses an optimal capacity that is exactly equal to the capacity that optimizes supply chain profits, i.e., $K = 20$. The corresponding expected profit for the manufacturer is 11.81, while that for the retailer is 28.5, and thus the total supply chain profit is 40.32, which attains the maximum supply chain profit. The payback agreement thus coordinates the supply chain. The details of these expected profit calculations for the manufacturer are shown in Table 5.5. The corresponding expected profit calculations for the retailer are shown in Table 5.6.

Table 5.5 Manufacturer expected profit calculations a take-or-pay contract; $r = 4$, $w = 1.95$, $c_k = 0.5$, $c = 0.6$, $K = 20$, payback credit = 0.35

Demand	Prob	Cumulative	Revenue	Cap Commit	Exec Cost	Credit	Profit × Probability
8	0.067	0.067	15.6	10	4.8	4.241	0.3360
9	0.067	0.133	17.55	10	5.4	3.887	0.4025
10	0.067	0.2	19.5	10	6	3.534	0.468
11	0.067	0.267	21.45	10	6.6	3.181	0.535
12	0.067	0.333	23.4	10	7.2	2.827	0.601
13	0.067	0.4	25.35	10	7.8	2.4741	0.668
14	0.067	0.467	27.3	10	8.4	2.120	0.734
15	0.067	0.533	29.25	10	9	1.767	0.801
16	0.067	0.6	31.2	10	9.6	1.4133	0.867
17	0.067	0.667	33.15	10	10.2	1.060	0.934
18	0.067	0.733	35.1	10	10.8	0.706	1.0004
19	0.067	0.8	37.05	10	11.4	0.353	1.066
20	0.067	0.867	39	10	12	0	1.133
21	0.067	0.933	39	10	12	0	1.133
22	0.067	1	39	10	12	0	1.133

Table 5.6 Retailer expected profit calculations a take-or-pay contract; $r = 4$, $w = 1.95$, $c_k = 0.5$, $c = 0.6$, $K = 20$, payback credit = 0.35

Revenue	Cost	Capacity Credit	Profit × Probability
32	15.6	4.241	0.810
36	17.55	3.887	0.970
40	19.5	3.534	1.131
44	21.45	3.181	1.291
48	23.4	2.827	1.451
52	25.35	2.474	1.611
56	27.3	2.120	1.771
60	29.25	1.767	1.932
64	31.2	1.413	2.092
68	33.15	1.060	2.252
72	35.1	0.706	2.412
76	37.05	0.353	2.573
80	39	0	2.733
80	39	0	2.733
80	39	0	2.7333

The associated manufacturer expected profit (sum of the last column) is 11.82, which is larger than the values under the no-coordination system. The corresponding retailer profits are shown in Table 5.6.

The associated retailer profit, which is the sum of the values in the last column, is 28.50, which again exceeds the profit under the no-coordination wholesale price system. In fact the sum of the manufacturer's and retailer's profits now match the single supply chain profit, thus generating a coordinated supply chain. In summary, not only is the supply chain coordinated, but the manufacturer's profits increase from 11.1 under the wholesale price agreement to 11.81. In addition, the retailer profit increased from 28 to 28.5. Since both manufacturer and retailer see their profits increase under this agreement, such agreements are called **Pareto-improving agreements**. In addition, the supply chain profit attains the maximum possible for the supply chain, thus the payback agreement coordinates the supply chain. Figure 5.3 shows the effect of different *K* values on the manufacturer's and retailer's profits, as well as the supply chain profit. Notice that the manufacturer's optimal *K* (when

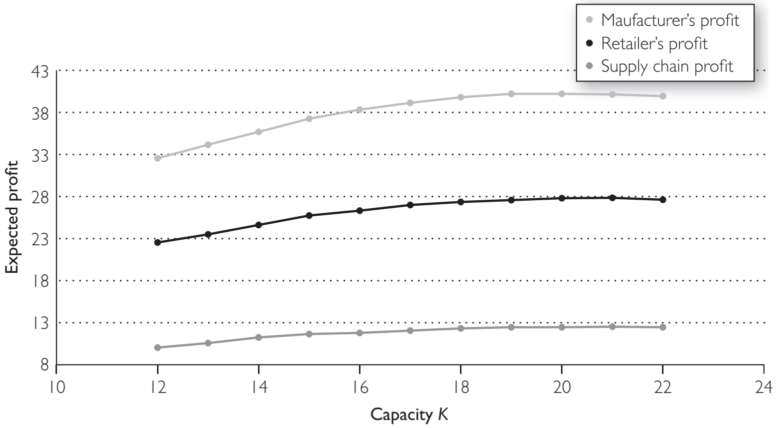


Figure 5.3 Manufacturer, retailer, and supply chain profits with payback for different K values

equal to 20) now coincides with the optimal K_C for the supply chain as in the earlier section.

Why does the payback contract coordinate the supply chain? Notice that the effect of the payback agreement is to adjust the wholesale price and the payback rate to get the manufacturer to choose a capacity that is optimal for the supply chain. In effect, the retailer creates an incentive for the manufacturer for carrying excess capacity by covering part of the downside risk, thus controlling the supply chain. Hence the agreement generates supply chain coordination. Note also that for each setting of w, there is a setting of τ that coordinates the supply chain. The main difference between alternate pairs of w and τ is that they correspond to the different possible splits of the total supply chain pie of profits. Also, for a given wholesale price level as in the previous section, there often exists a w and τ combination that can increase profits for both manufacturer and retailer.

5.9 Capacity Reservation Contracts

Another possible contract is one in which the retailer is charged p per unit to reserve capacity and then w to use this reserved capacity. The manufacturer builds this reserved capacity and the retailer then uses capacity based on the observed demand. Intuitively this agreement spreads the risk between retailer and manufacturer. Since the retailer absorbs some of the manufacturer's risk, this contract has the potential to coordinate the supply chain.

The manufacturer profit can then be written as $(\mathrm{w} - c)E(min(demand, K)) + (p - c_k)K$. The corresponding retailer profit can be written as $(\mathrm{r} - w)E(min(demand, K)) - pK$. Given these profit structures, notice that if the parameters are set such that $\frac{r-w}{r-c} = \frac{p}{c_k} = \theta$, then the manufacturer and retailer profits are proportional to the supply chain profit. The corresponding value of p is $\frac{(r-w)c_k}{r-c}$. This guarantees that the manufacturer decision will coincide with the supply chain profit maximizing level.

Notice also that for any take-or-pay contract there is an equivalent capacity reservation contract. Setting $p = \tau$ and $w' = w - \tau$ generates exactly the same manufacturer and retailer profits as the payback contract.

5.9.1 A Numerical Example

Consider the example described earlier. Set the cost to reserve capacity as $p = 0.35$ (equal to τ set in section 5.8.1) and set the cost to execute capacity as $w = 1.95 - 0.35 = 1.60$. The corresponding calculations for the manufacturer's expected profits are shown in Table 5.7 and the retailer's expected profits are shown in Table 5.8.

The associated manufacturer profit obtained by adding the values in the last column in Table 5.7 is 11.817.

The associated retailer profit obtained by adding the values in the last column in Table 5.8 is 28.50.

Notice that this agreement also generates a Pareto-improving contract. Also, because the supply chain profit attains the maximum possible level, the agreement coordinates the supply chain. As before, any of the different w and p combinations correspond to the different possible splits of the total supply chain pie of profits. Details regarding the negotiations to split increased profits will be left out of this discussion.

Table 5.7 Manufacturer expected profit calculations for a capacity reservation contract; $r = 4$, $w = 1.6$, $c_k = 0.5$, $c = 0.6$, $K = 20$, $p = 0.35$

Demand	Prob	Cumulative	Revenue	Cap Commit	Exec Cost	Cap Reserve	Profit × Probability
8	0.067	0.067	12.772	10	4.8	7.068	0.336
9	0.067	0.133	14.368	10	5.4	7.068	0.402
10	0.067	0.2	15.965	10	6	7.068	0.468
11	0.067	0.267	17.562	10	6.6	7.068	0.535
12	0.067	0.333	19.158	10	7.2	7.068	0.601
13	0.067	0.4	20.755	10	7.8	7.068	0.668
14	0.067	0.467	22.351	10	8.4	7.068	0.734
15	0.067	0.533	23.948	10	9	7.068	0.801
16	0.067	0.6	25.544	10	9.6	7.068	0.867
17	0.067	0.667	27.141	10	10.2	7.068	0.934
18	0.067	0.733	28.737	10	10.8	7.068	1.000
19	0.067	0.8	30.334	10	11.4	7.068	1.066
20	0.067	0.867	31.931	10	12	7.068	1.133
21	0.067	0.933	31.931	10	12	7.068	1.133
22	0.067	1	31.931	10	12	7.068	1.133

Table 5.8 Retailer expected profit calculations for a capacity reservation contract; $r = 4$, $w = 1.6$, $c_k = 0.5$, $c = 0.6$, $K = 20$, $p = 0.35$

Revenue	CapCommit	Exec Cost	Profit × Probability
32	7.069	12.772	0.810
36	7.0689	14.368	0.970
40	7.0689	15.965	1.131
44	7.0689	17.562	1.291
48	7.0689	19.158	1.451
52	7.0689	20.755	1.611
56	7.0689	22.351	1.771
60	7.0689	23.948	1.932
64	7.0689	25.544	2.0924
68	7.0689	27.141	2.252
72	7.0689	28.737	2.412
76	7.0689	30.334	2.573
80	7.0689	31.931	2.733
80	7.0689	31.931	2.733
80	7.0689	31.931	2.733

5.10 Advance Order Quantity

Consider another coordination agreement in which the retailer is offered an incentive to place advance orders, i.e., orders in advance of demand realization. Suppose the retailer is charged w_a per unit for these orders and w per unit for later orders. As long as $w_a \leq w$, the retailer may have an incentive to place advance orders. In addition, the manufacturer will offer this contract only if $w_a \geq c + c_k$. Notice that if the retailer places an advance order of y, the manufacturer will order the maximum of y and the quantity that generates a service level of $\frac{w - c - c_k}{w - c}$. The retailer's choice of y is thus the value that maximizes the retail profit. The manufacturer builds more than the planned service level only if the retailer order exceeds that implied by the service level. This happens if $w_a < \frac{wc_k}{w - c}$.

Consider a numerical example with $w_a = 1.5$ and the remaining parameters as in the earlier example. Note that the retailer now has the incentive to order in advance. The manufacturer plans a service level of $\frac{2 - 0.5 - 0.6}{2 - 0.5} = 0.6$. The retailer finds it optimal to place an advance order for 17 units. Thus the manufacturer produces 17 units and delivers them to the retailer. The corresponding expected profits are \$6.8 for the manufacturer and \$30.5 for the retailer. The supply chain profit is thus \$37.3. Clearly these parameters do not coordinate the supply chain. It can be shown that this agreement cannot guarantee that the supply chain coordination is achieved for many problem instances for any parameter setting (other than the elimination of one participant).

It is possible to choose w_a such that the retailer purchases an amount equal to the capacity in the supply chain profit maximizing system. This is obtained by setting $w_a = \frac{rc_k}{r - c} < \frac{wc_k}{w - c}$. However, even then the supply chain maximum profit is not attained because even if the decentralized supply chain builds the same capacity as the centralized supply chain, the capacity is built ahead of demand, thus generating the risk of overproduction. It is this inflexibility in the contract that prevents supply chain coordination.

5.11 Retailer Absorbs Risk

In all the examples discussed until this point, the manufacturer chose capacity and thus absorbed supply chain risk. Consider the case where the retailer has to order ahead of observing demand (i.e., at time L before the start of the season), while the manufacturer produces this certain order. The retailer thus absorbs all demand risk through its choice of inventory. Given that demand is variable, this demand risk manifests itself at the end of the season through either excess inventory that has to be salvaged or shortages that generate opportunity costs.

5.12 Supply Chain Profit

The main difference between this case and the case when the retailer orders after observing demand is that the supply chain, too, has to make decisions before observing demand. Thus, all orders have to be placed and produced at L units of time before the start of the season. The effect is that the retailer places orders for K units of inventory, the manufacturer produces the entire order and incurs $c + c_k$ per unit, and the supply chain has inventory ready before the season demand unfolds. The supply chain expected profit is $rMin(Demand, K) - (c + c_k)K$. This profit is maximized by a choice of K that offers a service level of $\frac{r - c - c_k}{r}$.

Consider the same example as before, with the manufacturer costs of $c + c_k = 1.1$, $w = 2$, and $r = 4$ and the demand uniformly distributed between 8 and 22. The optimal supply chain service level is $\frac{4 - 0.5 - 0.6}{4} = 0.725$. The corresponding optimal inventory is thus $K_c = 18$. Table 5.9 shows the corresponding calculations for the maximum supply chain profit, which is equal to \$37.53.

Note that since the supply chain is forced to make decisions before demand realization, the expected profit in this case is lower than the case discussed earlier, when decisions regarding execution of capacity were made after demand realization.

Table 5.9 Supply chain expected profit calculations when the retailer absorbs risk; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K_c = 18$, optimal service level = 0.725

Demand	Prob	CumProb	Revenue	CapCost	Cost
8	0.067	0.067	32	19.8	0.8133
9	0.067	0.133	36	19.8	1.08
10	0.067	0.2	40	19.8	1.3467
11	0.067	0.267	44	19.8	1.613
12	0.067	0.333	48	19.8	1.88
13	0.067	0.4	52	19.8	2.147
14	0.067	0.467	56	19.8	2.413
15	0.067	0.533	60	19.8	2.68
16	0.067	0.6	64	19.8	2.946
17	0.067	0.667	68	19.8	3.213
18	0.067	0.733	72	19.8	3.48
19	0.067	0.8	72	19.8	3.48
20	0.067	0.867	72	19.8	3.48
21	0.067	0.933	72	19.8	3.48
22	0.067	1	72	19.8	3.48

5.13 Wholesale Price Agreement

Suppose the manufacturer and retailer were separate entities, linked only by the fact that the retailer has to pay the manufacturer a wholesale price of w per unit for the product and place the entire order in advance of demand realization. The manufacturer, in turn, produces the entire order in advance and incurs a cost of $c + c_k$ to produce each unit.

The retailer's expected profit would thus be equal to $rMin(Demand, K) - wK$ while the manufacturer's expected profit would be equal to $(w - c - c_k)K$. The optimal service level desired by the retailer to maximize its profit is thus equal to $\frac{r - w}{r}$. This order size by the retailer is produced and delivered by the manufacturer.

Consider the example described in the previous section with the same demand and cost parameters. The retailer optimal service level would thus be $\frac{4 - 2}{2} = 0.5$. The corresponding retailer order would be $K = 15$ units.

Table 5.10 shows the retailer's expected profits for the order of 15 units. The retailer's profit is obtained as \$22.53. The manufacturer expected profit will be $(2 - 0.5 - 0.6) \times 15 = 13.5$.

The retailer's and manufacturer's profits and supply chain profit for different K values are shown in Figure 5.4. In Figure 5.4, notice that the retailer's expected profits are maximized at $K = 15$, as we calculated earlier. However, at that inventory level, the supply chain profit, which is the sum of manufacturer's and retailer's profits is \$36.03, which is lower than the maximum supply chain profit obtained earlier. This is observed in Figure 5.4, which shows that the maximum supply chain profit is attained at $K = 18$, rather than at the inventory decision of $K = 15$ obtained in this case.

This difference in supply chain profit arises because of double marginalization, i.e., the retailer does not see the supply chain margin associated with each sale realized or lost and thus makes inventory decisions that are lower than the supply chain optimal decisions (for service levels > 0.5).

Table 5.10 Retailer expected profit calculations for wholesale price agreement when the retailer absorbs risk; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 15$, optimal service level = 0.5

Demand	Prob	CumProb	Revenue	CapCost	Profit × Prob
8	0.067	0.067	32	30	0.133
9	0.067	0.133	36	30	0.4
10	0.067	0.2	40	30	0.667
11	0.067	0.267	44	30	0.9333
12	0.067	0.333	48	30	1.2
13	0.067	0.4	52	30	1.467
14	0.067	0.467	56	30	1.733
15	0.067	0.533	60	30	2
16	0.067	0.6	60	30	2
17	0.067	0.667	60	30	2
18	0.067	0.733	60	30	2
19	0.067	0.8	60	30	2
20	0.067	0.867	60	30	2
21	0.067	0.933	60	30	2
22	0.067	1	60	30	2

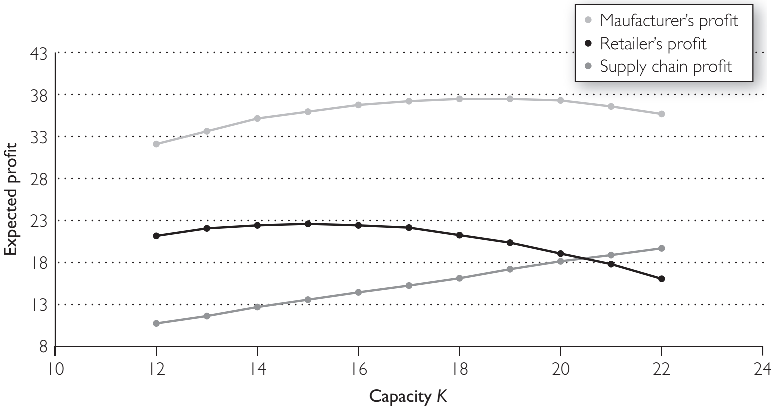


Figure 5.4 Manufacturer, retailer and supply chain profits for different K values when retailer bears the risk

How does the problem change from the discussions in earlier sections where the manufacturer absorbs all risk? Notice that all of the contracts we discussed earlier can now be considered for this case. As before, double marginalization will prevent the supply chain from being coordinated with a wholesale price only contract. A payback contract now becomes a returns contract, where the manufacturer takes back leftover product from the retailer with an associated payment for returns. The payback contract can coordinate the supply chain in this case. The capacity reservation contract also coordinates the supply chain in this case due to its equivalence to the returns contract, as discussed earlier.

5.14 Retailer Information Improvement

Consider the case where the retailer realizes that if he or she could wait to place an order at L_1 ($< L$) closer to the start of the season, better information would be available. Assume that the demand levels are low, medium, or high. Suppose a low demand level implies that the realized demand takes values (uniformly) between 8 and 12; a medium demand level has values between 13 and 17; and a high demand level has values between 18 and 22. In addition, suppose the demand level is low, medium, or high with probability $\frac{1}{3}$. Suppose the demand level is known to the retailer L_1

units of time before the start of the season. The manufacturer produces the order placed by the retailer.

How would permitting the retailer to order at L_1 affect manufacturer and retailer profits compared to the values under the wholesale price agreement in the earlier section? If all costs remain the same as in the previous sections, the retailer would continue to choose an order, given the demand level, that generates a service level of 0.5. Thus, if the demand level is low, the retailer orders 10 units; if medium, the retailer orders 15 units; and if high, the retailer orders 20 units.

If we calculate the expected order received by the manufacturer, it is $(\frac{1}{3} \times 10) + (\frac{1}{3} \times 15) + (\frac{1}{3} \times 30) = 15$ units. Thus the manufacturer's expected profit remains $(2 - 0.5 - 0.6)15 = 13.5$. Note that while the manufacturer's expected profit remains the same, the manufacturer does absorb more risk than before, because his order could be lower or higher than 15 with a probability of $\frac{2}{3}$.

The retailer adjusts his or her order with the known demand level. Calculating the expected profits for each demand level as shown in Table 5.11, we get the retailer profit under a low demand level of \$17.6, under a medium demand level of \$27.6, and under a high demand level of \$37.6.

The retailer's expected profit across all the possible demand realizations is thus $\dfrac{17.6 + 27.6 + 37.6}{3} = 27.6$. Notice that this increases the retailer's expected profit above the value generated when orders had to be placed at time L, while the manufacturer's expected profit remains the same as before. How did the retailer's expected profits increase? Better information when retailer orders are placed permits the supply to be more responsive to demand. This improved matching of supply to demand increases retailer profits.

In the apparel industry, quick response is a movement that tries to get orders placed closer to the start of the season.

5.15 Chapter Summary

This chapter focused on coordination as an important component of supply chain management. We presented three cases focused on coordination decisions to develop a problem context. We then discussed several supply

***Table 5.11 Retailer expected profit calculations under information improvement*. Low Demand Level; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 10$, retailer optimal service level = 0.5**

Demand	Prob	CumProb	Revenue	Inventory	Profit × Probability
8	0.2	0.2	32	20	2.4
9	0.2	0.4	36	20	3.2
10	0.2	0.6	40	20	4
11	0.2	0.8	40	20	4
12	0.2	1	40	20	4

Retailer profit under low demand is $17.6

Medium Demand Level; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 15$, retailer optimal service level = 0.5

Demand	Prob	CumProb	Revenue	Inventory	Profit × Probability
13	0.2	0.2	52	30	4.4
14	0.2	0.4	56	30	5.2
15	0.2	0.6	60	30	6
16	0.2	0.8	60	30	6
17	0.2	1	60	30	6

Retailer profit under medium demand is $27.6

High Demand Level; $r = 4$, $w = 2$, $c_k = 0.5$, $c = 0.6$, $K = 20$, retailer optimal service level = 0.5

Demand	Prob	CumProb	Revenue	Inventory	Profit × Probability
18	0.2	0.2	72	40	6.4
19	0.2	0.4	76	40	7.2
20	0.2	0.6	80	40	8
21	0.2	0.8	80	40	8
22	0.2	1	80	40	8

Retailer expected profit under a high demand is $37.6

chains that were uncoordinated but could be coordinated using Pareto-improving agreements. We also showed that the availability of better information can decrease demand risk, better match demand and supply, and thus improve supply chain profits.

The key message is that in many supply chain contexts coordinating agreements can deliver significant improvements that all involve expanding the supply chain profit pie, thus enabling Pareto-improving profit situations.

CHAPTER 6

Information Systems to Track, Report, and Adapt Supply Chains

The frequency and level of detail of information regarding product flows in a global supply chain can impact the chain's cost and performance. Technologies such as smartphones and radio frequency identification (RFID) tags, as well as new software that can be delivered as a service and reconfigured as needed, have changed customer expectations. This chapter provides a summary of a few emerging information-driven changes to supply chains, but the real objective for a supply chain is to leverage all possible information to impact performance.

The chain structure of the supply chain suggests the number of different entities that have to share data to enable detection of contamination or enable end-to-end visibility. When real-time information can be used to adjust to current events, firms such as the chemical company BASF claim success in adjusting capacity in response to data regarding current hurricane paths. But information from product tags also enables coordination between manufacturers and retailers, as described by Gillette and its retailers ([93]). Data collected regarding individual products enables Walmart to drive sustainability targets while simultaneously decreasing costs and enhancing their competitiveness. Retailers such as Metro and manufacturers such as Gillette claim success in better synchronizing promotion to current conditions using electronic product identification, thus enhancing their competitiveness. Information and its use impact the Four Cs of the supply chain.

6.1 Ubiquitous Data from RFID Tags

New technologies incorporated into products enable even more information to be leveraged by the supply chain. Radio frequency identification tags (RFID) represent one approach that could, theoretically, enable even a single unit of a product to be tracked. An RFID system "transmits the identity (in the form of a unique serial number) of an object or person wirelessly, using radio waves" ([2]).

The system consists of "a tag which contains information regarding the unit it is attached to, an antenna which send signals to the tag to activate it, a reader that emits radio waves, decodes the data received and sends it to a computer for processing" ([2]). There are different types of RFID tags—passive, semiactive, and active. Passive RFID tags have no power supply and depend on the signal sent to the tag for energy. Semiactive tags have power for the tag but not to broadcast. Active tags contain power for the device and can transmit. The prices for these tags vary from $0.10 to $0.20 for passive tags to as much as $100 for an active tag. An electronic product code (EPC) enables tracking of individual product units using a unique serial number.

In 2003, the Metro retail chain in Germany opened a store equipped with RFID tags for many of its items. Over time, this "store of the future" has used the technology to adjust promotions and develop a smart scale that automatically detects items, such as fruit, providing easier checkout and tracking, and so on. Since RFID readers can track items as they are loaded on to a customer's cart, it saves customers the need to wait at checkout. Such tracking at the warehouse level would enable pallet loads to be distributed anywhere in the warehouse and still enable quick identification and shipping. The main challenge is to have RFID readers at a close enough proximity, 10 to 20 feet, to enable accuracy while preventing signal confusion from multiple reads.

Once a pallet of product or a single item can be tracked, the associated information regarding product status in the supply chain is immediately available. Sensors can transmit product location, temperature, and quantity, as well as whether there were any changes in the status of the container or product over time. Such information can assure the customer that there was no tampering or counterfeit product supplied.

The shaving products company Gillette, owned by P&G, claimed a 25% return over a ten-year period, using RFID tags on its products ([24]). Product tracking showed that the time from production to store was six days and ten hours, of which about three days was the time to move from the manufacturer to the retailer distribution center, and a significant portion of the remaining time (three days) was spent reaching the store. Data showed that many promotional items remained at the back of the store and generated out-of-stocks at the retail store. This information enabled the manufacturer and retailer to work on a smoother flow of product to decrease stockouts, increasing sales by 28% during promotions at test locations.

Military convoys with smart tags (RFIDs with independent power sources) have been used to facilitate information gathering in the field as deployment changes and conditions unfold. Continuous monitoring of engine conditions or blades in aircraft enable proactive maintenance, thus enabling quick aircraft turnaround.

But similar changes are occurring as smartphones enable the detection of potential customers, using global positioning systems (GPS) tracking. A customer whose location is known to a retailer can be offered service commensurate with their importance to the firm, using shopping assistance, prioritized service, and special coupons sent to the cellphone.

As the need to pair individual product units with the appropriate customers increases, the role of the supply chain in enabling such a union offers fascinating challenges.

6.2 Rating a Product Based on Supply Chain Choices

The availability of smartphones that can run apps, read barcodes using the phone's camera, and pull information from the web means that data regarding the suppply chain's choices may well impact a consumer's purchase decision and thus demand. Goodguide is such a company, whose website contains an index summarizing information regarding over 100,000 products (in July 2012) ([45]). A consumer with a smartphone can install an app, direct the camera to the barcode of a product, and immediately receive a product rating that also provides details regarding all supply chain choices made by the company.

As an example, in July 2012, I downloaded information regarding a specific kind of Crest toothpaste—the Crest ProHealth Multiprotection rinse, Clean Mint, 16.9 oz. made by Procter & Gamble. This product was shown as having a rating of 7.4 out of a maximum of 10. The rating combined three scores for this product—Health (10), Environment (6.2), and Society (6.0). Each of these criteria has several specific measures that are directly impacted by the supply chain. Under the Environment metric, the section on governance includes the supply chain, the role of suppliers, waste management, emissions tracking, and so on. For each of these criteria, data are gathered about reports filed and whether specific targets were set, with scores set higher if specific steps were taken to improve on each dimension. For example, under the reporting criteria, specific initiatives to reduce product transport, disclose the identity of top suppliers, and reduce waste and emissions are measured. Each of these initiatives ends with a judgment regarding the appropriate measurement and mitigation plans. Under the impact on society, the metric records whether specific steps have been taken to protect worker rights and whether suppliers are evaluated based on their sustainability performance. The site provides a measure for each product, but also computes the data across all products to reflect the company's commitment to sustain ability initiatives. For example, P&G has its own aggregate rating of 6.1, measured as an aggregate over its processes and products. Similarly, across all Crest products, the site provides an average rating of 5.9. This information enables customers to assess their view of the company as well as the brand sold by the company.

How does the supply chain impact a product's score? Notice that several of the decisions we discussed in previous chapters have a direct impact on a product and a company's score: supplier management, transportation, emissions, waste, recycling, packaging, and so on. As more customers start comparing products and making purchase decisions reflecting their individual preferences, the supply chain will impact the top line revenues, in addition to the costs.

6.3 Tracing and Tracking Products

In this section, we will discuss a challenge associated with tracing food supply. As food moves through the supply chain, there is potential for contamination at each step in the process. For example, a pathogen like *E. coli* could enter the food system at any number of stages, such as production, transport, processing, distribution, or retail sales points.

There are many stages that livestock products go through to reach the consumer, and, given the large market, there is a lot of product volume involved. For example, in 2011, 34.1 million head of cattle were slaughtered [120] with the average weight of these animals was on the order of 1,277 pounds. Assuming a dressing percentage of 50% to account for the skin, bones, and offal, and assuming an average retail package size of three pounds, the number of packages of beef to be tracked annually is on the order of 8.1 billion. This tracking represents an interesting challenge: if a slice of beef purchased at a retail outlet is contaminated, how can the other potentially affected products be traced to protect the food supply?

Of course a large fraction of beef that is ultimately consumed does not go through retail outlets but rather is delivered to consumers via the restaurant and food service industries. Thus, given the scale of US food production, automated systems will be required to identify the source of the contamination, take effective and remedial measures to identify and isolate the contaminated food, and inform the public of the possible risks. One example of such a system is available to consumers of Japanese Wagyu beef who can key in the product code associated with a unit sold and obtain all information regarding the animal, its feed and treatment, and its pedigree ([17]).

But if sensors were used all along the life of the animal, to track position and health indicators (e.g., body temperature, heart rate, respiration rate) of individual animals, the data from a herd of beef cattle could be used to gauge herd health and disease spread. In addition, knowledge of disease incubation periods coupled with animal health information can provide useful information on the potential for hazardous infection in animals that have already been harvested for food production.

Another detail is that there are many participants in the supply chain from the farm to the consumer. At the farm level, genetics and feed are combined to produce livestock products. Beyond the farm, the livestock product is transported, processed, and packaged for retail distribution, typically passing through the hands of several agents who are receiving nearly identical inputs from a large number of sources. In addition, animals move about, interacting with their cohorts and the environment. A further complication is that at various points along the supply chain, one animal may be divided into several products and distributed through different channels. Because of this branching in the supply chain, it is important to identify the path of livestock products both backward and forward through the supply chain.

Imagine that contamination is detected and there is the need to trace the origin of the animal. The data necessary are spread across the private databases of the various enterprises that make up the supply chain, from farms to grocery stores. The technical challenge for data management thus comes from the need to integrate data from numerous independent databases while preserving privacy. Due to the significant risk of losing competitive advantage, most of these entities are unwilling to freely share this information. Thus an acceptable solution must provide privacy guarantees for the large number of entities involved.

6.4 Green Reports

In 2005, Walmart CEO Lee Scott declared specific sustainability goals ([107]), driven by the principles that the company would work towards zero waste, use 100% renewable energy, and sell products that were sustainable in their use of resources and the impact on the environment. These broad goals were converted into specific goals that included (1) increasing their transportation fleet's efficiency by 25% in three years and doubling it in the next ten years, (2) eliminating 30% of the energy used in stores and, (3) reducing greenhouse gas emissions by 20% in seven years. The goals were all attained with the help of the supply chain, but they also created a model of creating savings while being sustainable.

In a milestone meeting in April 2012 ([31]), the company highlighted specific product changes that impact sustainability. An initiative to replace the metal wires used in packaging toys with natural fibers was estimated to have saved 1.6 billion feet of wire from 2010 through 2012. A focus on reducing waste had managed to decrease the waste down to 20% at all stores, thus preventing material from going to the landfill. The recycling efforts at stores focused on packaging, saved the company

$231 million in 2012. Driving 28 million fewer miles saved $75 million in fuel costs. Every one of these specific savings for Walmart can be tracked to alternate decisions in the supply chain.

One example involving a focus on wheat production described exploration of backhaul movement of manure from poultry farms to wheat farms to decrease use of fertilizer while improving soil performance. In another context, Pepsico worked to decrease the need to grow rice saplings but instead grew from seeds. The savings in water from adoption of such farming techniques compared to water used for the soft-drink manufacturing enabled the firm to claim to be a negative water footprint company in India. Product specification changes, supplier innovation, better movement, all generated sustainable solutions that also decreased costs, lowered prices, and improved quality.

Companies like Walmart provide annual global responsibility reports that summarize the overall impact of the supply chain on the environment ([30]) along with progress towards the goals stated earlier. A review of this report suggests that the choices in the global supply chain of this company will directly impact this external reporting of the company's performance and thus increases the scrutiny of the supply chain. There are many companies that have significant efforts to increase their product and supply chain's sustainability, including Starbucks, Nike, Samsung, Unilever, and Subaru. In other words, the supply chain is now in a glass box: its choices are more transparent and of greater consequence to the performance of the company.

In addition to companies themselves, there are nongovernmental organizations (NGOs) like Greenpeace that also focus on the global supply chain. The Greenpeace report on apparel ([50]) tracks the input of hazardous chemicals used in apparel manufacturing. In particular, the report focuses on nonylphenol ethoxylates, their use in manufacturing, and their subsequent release into the water supply, which impacts the food supply. Such reports put pressure on apparel manufacturers to take responsibility for manufacturing choices across the supply chain. In the electronics industry, specific laws such as the Conflict Materials Trade Act also impact the sourcing of materials used and hold companies responsible for guaranteeing that their products do not contain any minerals mined in conflict regions.

6.5 Sourcemap

In addition to summary reports regarding the supply chain, there are efforts to track the specific details for individual companies sourcing of their products. An open source software application called Sourcemap ([113]) maps supply chains linked to a dictionary of details such as their carbon footprint, greenhouse gas emissions, lead time, and more. The open source nature of the software enables crowdsourcing of supply chain maps and enables tracking down to the raw material source. The site contains source-maps for electronic products, apparel, food, and many others. The software permits any user to create such maps based on the data they possess and then pass the data along to others to edit and develop.

But individual firms can use these maps to work with their suppliers to ensure that the associated supply chains conform to regulations or the company's ethical constraints, inform the customer regarding the environmental impact of the product sourcing, and so on. For example, the site shows the sourcing of chocolate across the world ([15]), along with specific supplier-related issues that are causes for concern. The data in these supply chain maps, similar to the NGO reports, potentially impact consumer choices and put pressure on companies to make changes.

6.6 Information Systems to Adapt to Contingencies

Consider supply chains that face significant short-term changes: events that require rapid adjustment and adaptation of flows. In a book titled *Orchestrating Supply Chain Opportunities,* Iyer and Zelikovsky [63] focus on the information system as one tool to manage events that include weather-related disruptions (like Hurricane Katrina), product failures that require rapid redesign (like the Kryptonite bicycle lock), demand surges (such as those faced by Amazon.com), among others.

One example focuses on BASF, a global chemical company, and how it used its event-based enterprise system to manage the impact of hurricanes Katrina and Rita using SAP's event management software ([104]). When the hurricanes hit, several of the shipments to the United States were in transit on ships. The choreography of the changes to the supply chain had to synchronize with information regarding the path of the hurricane and its landfall. The company had to account for safety of personnel, potential product vulnerability, security issues, requirements by customs rules, and specific requirements of critical components. The specific needs were confirmed just one day before Hurricane Katrina hit. "BASF knew which consignments were still in port, which ones were in transit, and which ones had already reached their destination port in Houston or New Orleans. BASF could therefore take the necessary steps to ensure that its customers suffered as little as possible," explains European project team member Peter Nikolaus ([104], p. 4).

BASF claims that their enterprise event management software helped orchestrate the reconfiguration of its supply chain while the events were happening. Ships were dynamically rerouted to safe harbors, in some cases several times, as the situation changed. BASF's customers were kept informed as the company adjusted its supply chain to maintain its level of service. Enterprise systems, of which SAP is one example, provide event management, detection of changes, and response opportunities all the way to the batch level. The software tracks serial numbers beginning with manufacturing, thus possessing a complete picture of everything that goes on in the supply chain from manufacturing to distribution to supply logistics and finally to point of sale. Moreover, this visibility extends beyond a single client into global movement of goods and services. Putting these product tiers in one cohesive solution set gives clients the visibility and reconfiguration capability to manage stretch goals.

The ability to track product at the unit level across the supply chain provides the ability to adapt to events, thus providing the flexibility required to face volatile demand environments with significant short-term shifts.

6.7 Chapter Summary

Information systems provide supply chains the opportunity to both capitalize on opportunities and react to shifts. As ownership of supply chains becomes more fragmented, technologies such as RFID and enterprise software such as SAP enable firms to react efficiently, minimizing costs to maintain performance. Threats such as food contamination, hurricanes, and product failures, as well as opportunities such as new designs that improve product sustainability and monitor global supply chain performance to guarantee ethical practices, all rely on an effective information system.

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Introduction to the Four Cs of Supply Chain Management

Chain Structure, Competition, Capacity and Coordination

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