CHAPTER 1
SUPPLY CHAIN MANAGEMENT, INTEGRATED PLANNING, AND MODELS

1.1 INTRODUCTION

Supply chain management is a relatively new term. It crystallizes concepts about integrated business planning that have been espoused by logistics experts, strategists, and operations research practitioners as far back as the 1950’s.¹ Today, integrated planning is finally possible due to advances in Information Technology (IT), but most companies still have much to learn about implementing new analytical tools needed to achieve it. They must also learn about adapting their business processes to exploit insights provided by these tools.

The information revolution has accelerated significantly in recent years. Astonishing gains in PC computing speed, e-commerce, and the power and flexibility of data management software have promoted a range of applications. Widespread implementation of Enterprise Resource Planning (ERP) systems offers the promise of homogeneous, transactional databases that will facilitate integration of supply chain activities. In many companies, however, the scope and flexibility of installed ERP systems have been less than expected or desired, and their contribution to integrated supply chain management has yet to be fully realized.

Moreover, competitive advantage in supply chain management is gained not simply through faster and cheaper communication of data. And, as many managers have come to realize, ready access to transactional data does not automatically lead to better decision-making. A guiding principle is:

To effectively apply IT in managing its supply chain, a company must distinguish between the form and function of Transactional IT and Analytical IT.

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Manufacturing and distribution companies in a wide range of industries have begun to appreciate this distinction. As a result, they are seeking to develop or acquire systems that analyze their corporate databases to identify plans for re-designing their supply chains and operating them more efficiently. An essential component of these systems are optimization models, which can unravel the complex interactions and ripple effects that make supply chain management difficult and important. They are the only analytical tools capable of fully evaluating large, numerical databases to identify optimal, or demonstrably good, plans. In addition to identifying cost minimizing or net revenue maximizing plans, optimization models can measure the tradeoffs among these objectives and cost, service, quality, and time.

The application of an optimization model in a company requires the construction of an optimization modeling system. A key element in such a system is the supply chain decision database, which is derived from, but significantly different than, the company’s corporate databases. It is constructed from aggregate descriptions of the company’s products, customers and vendors. It contains

- direct and indirect cost relationships
- sub-models of production, transportation, warehousing and inventory management
- cost and capacity information about commodities, parts, products offered by vendors
- order information and forecasts of demand for finished products

Finally, it combines data inputs with outputs from model optimizations in creating graphical mapping representations of the company’s current and future supply chain structure and activities.

The aim of this book is to examine in detail the roles of data, models and modeling systems in helping companies improve the management of their supply chains. Principles of supply chain decision database and modeling system implementation will be illustrated by many successful applications. The applications will be concerned with analyzing business problems at strategic, tactical, and operational levels of planning. The
ways in which companies must adapt their organizations to exploit modeling systems will also be examined.

In recent years, the number and scope of successful applications of models and modeling systems have grown significantly. Digital Equipment Corporation made extensive use of an optimization modeling system in developing downsizing strategies that produced documented net savings of over $100 million.\(^2\) Cerestar, Europe’s leading manufacturer of wheat- and corn-based starch products, implemented an optimization modeling system that increased average daily throughput by 20 percent, which lead to annual benefits in excess of $11 million.\(^3\) Other companies have realized similar benefits from optimization modeling systems, although many have not publicized their successes because they believe secrecy enables them to better retain the competitive advantage provided by these systems.

Companies selling ERP systems have added modeling modules to their offerings to help customers determine effective supply chain plans based on transactional data collected and managed by their systems. SAP is completing implementation of an add-on called APO, which is comprised of several modules for supply chain modeling. By acquiring CAPS Logistics, Baan added supply chain network optimization and vehicle routing modules to its suite of software packages. J. D. Edwards acquired Numetrix for similar reasons.

Despite these advances, most companies are still in the early stages of developing information technologies and implementing new business processes to promote effective supply chain management. In 1997, Boeing experienced a production foul-up that cost it billions of dollars; the company is only slowly developing new methods for lowering production costs.\(^4\) Conagra, a $24 billion dollar agri-business, has made a major commitment to tighter supply chain management as a means to lowering costs, in part by shutting down 15 production plants and 70 storage, distribution and processing sites.\(^5\) In short, in many companies, considerable room remains for improving supply chain management.

Our goal in this chapter is to set the stage for more detailed exploration of key concepts in later chapters. The topics we will cover are
Throughout, we will use the term optimization to indicate that the company seeks to render its supply chain as efficient, flexible and responsive as possible for the purposes of achieving competitive advantage. Improvements may be realized by making obvious changes in faulty business procedures, by strategic investment or divestment of assets, by better allocation of company resources, or by numerous other means. We shall argue that competitive advantage in supply chain management can be most fully realized by implementing and applying modeling systems to enhance managerial decision making.

1.2 FUNDAMENTALS OF SUPPLY CHAIN MANAGEMENT

A company’s supply chain is comprised of geographically dispersed facilities where raw materials, intermediate products, or finished products are acquired, transformed, stored, or sold, and transportation links connecting facilities along which products flow. The facilities may be operated by the company, or they may be operated by vendors, customers, third-party providers or other firms with which the company has business arrangements. The company’s goal is to add value to its products as they pass through its supply chain and transport them to geographically dispersed markets in the correct quantities, with the correct specifications, at the correct time, and at a competitive cost.

We distinguish between plants, which are manufacturing facilities where physical product transformations take place, and distribution centers, which are facilities where products are received, sorted, put away in inventory, picked from inventory, and dispatched, but not physically transformed. Of course, we shall occasionally consider
hybrid facilities, either plants with distribution capabilities, or distribution centers with physical product transformation capabilities.

SUPPLY CHAIN NETWORKS

The supply chain is often represented as a network similar to the one displayed in Figure 1.1. The nodes in the network represent facilities, which are connected by links that represent direct transportation connections permitted by the company in managing its supply chain. Although networks are a useful device for depicting and discussing models, keep in mind that the one displayed in Figure 1.1 provides only a high level view of a supply chain. Meaningful analysis requires the addition of considerable detail about
transformation activities and processes, resources, and capacities and costs that describe facilities and transportation links.

The network of Figure 1.1 is comprised of four levels of facilities. Products flow downstream from vendors to plants, plants to distribution centers, and distribution centers to markets. In general, a supply chain network may be comprised of an arbitrary number of levels. Moreover, products may sometimes flow upstream as intermediate products are returned to plants for re-work, or re-usable products are returned from markets to distribution centers for re-cycling.
We will restrict our attention to firms that manufacture or distribute physical products. The physical products may be unusual, such as electrical energy, or industrial gases that are manufactured from air and electricity. Telecommunications networks could arguably be considered supply chains according to our definition. Moreover, optimization models have been successfully applied in analyzing their design and operations, although such models reflect operating characteristics that are peculiar to telecommunications.\(^6\)

Despite their importance, due to time and space limitations, we have omitted treatment of telecommunications networks in this book. Some service companies, such as banks or insurance companies, operate value chains comprised of networks of facilities for which coordinated planning is required, although no physical products flow. We will not address analysis of such chains in this book.

**INTEGRATED SUPPLY CHAIN PLANNING**

As we stated in the introduction, supply chain management refers to integrated planning. First, it is concerned with **functional integration** of purchasing, manufacturing, transportation and warehousing activities. It also refers to **spatial integration** of these activities across geographically dispersed vendors, facilities, and markets. Finally, it refers to **inter-temporal integration** of these activities over strategic, tactical and operational planning horizons. Roughly speaking, strategic planning involves resource acquisition decisions to be taken over long-term planning horizons, tactical planning involves resource allocation decisions over medium-term planning horizons, and operational planning involves decisions affecting the short-term execution of the company’s business.

Inter-temporal integration, which also is called **hierarchical planning**, requires consistency and coherence among overlapping supply chain decisions at the various levels of planning. Although it is not yet widely appreciated, inter-temporal integration is critical to the firm’s sustained competitive advantage. Efficient operations will not lead to superior profits if the company’s products are being manufactured in plants with outdated technologies that are poorly located relative to the company’s vendors and its markets. Conversely, to evaluate a new or re-designed supply chain network, we must, at least approximately, optimize operations to be carried out under the design.
Another aspect of inter-temporal planning is the need to optimize a product’s supply chain over its life cycle through the stages of design, introduction, growth, maturity and retirement. Like most areas of strategic planning, life-cycle planning requires integration of supply chain and demand management. For example, analysis of capital investment decisions in manufacturing equipment during the growth phase of a new product should take into account marketing decisions affecting product sales and gross revenues that may provide future returns sufficient to justify the investments.

Improved integration of activities across multiple companies sharing components of a supply chain is a concern of increasing interest and importance. Such integration is obviously relevant to the efficient operation of two companies after a merger or acquisition. It is also relevant to two companies that wish to tighten their working arrangements, such as a manufacturer of consumer durables and a major distributor of these durables, or a manufacturer of food products and a wholesale grocery distributor. In such instances, integration is complicated because both companies have other vendors and customers; that is, their supply chains overlap significantly but are far from identical. Moreover, enhanced integration implies greater sharing of confidential information about costs and capacities, as well as integrative management of business processes.

Developments in integrated supply chain planning have been both facilitated and required by advances in IT. Managers today have much faster access to much more complete databases than they did only five years ago. The challenge is to transform this capability into competitive advantage. IT developments are examined more fully in §1.4 and in greater detail throughout the book.

OBJECTIVES OF SUPPLY CHAIN MANAGEMENT

The traditional objective of supply chain management is to minimize total supply chain cost to meet fixed and given demand. This total cost may be comprised of a number of terms including

- raw material and other acquisition costs
- in-bound transportation costs
- facility investment costs
• direct and indirect manufacturing costs
• direct and indirect distribution center costs
• inventory holding costs
• inter-facility transportation costs
• out-bound transportation costs

In building a model for specific planning problems, we might decide to examine only a portion of the company’s entire supply chain and associated costs.

One can argue that total cost minimization is an inappropriate and timid objective for the firm to pursue when it analyzes its strategic and tactical supply chain plans. Instead, the firm should seek to maximize net revenues where

\[ \text{net revenues} = \text{gross revenues} - \text{total cost} \]

If demand is fixed and given, the implication is that gross revenues from meeting it are also fixed and given, and therefore, that the firm will maximize net revenues by minimizing total cost.

Our objection to focusing only on cost control when using an optimization model for strategic or tactical planning is that the model provides insights into product costs that should be exploited to increase net revenues by suitable adjustments in sales. For example, when planning for next year, information provided by a model about the marginal costs of products delivered to various markets could be used to change the projected sales plan. The company’s salesforce would be instructed to push products in markets with the highest margins, possibly at the expense of products in markets with low margins if total manufacturing capacity is limited.

The difficulty with trying to model decisions affecting demand management, even in the modest way we just described, is that it requires the commitment of marketing personnel, who generally feel uneasy with quantitative analysis. Moreover, once we commit to including marketing and sales decisions in a model, it is difficult to decide on the scope that can or should be considered. Nevertheless, integration of supply chain and
demand management is an area of growing interest in many companies, although it has not yet been widely addressed.

Similarly, supply chain and demand management decisions are closely linked to corporate financial decisions, especially when planning the firm’s strategy. Moreover, optimization models for exploring financial decisions linked to the corporate balance sheet, such as yearly changes in fixed assets and equity or dividends paid, have been proposed by academics for over twenty-five years, although not yet widely applied. Since these models can be seamlessly integrated with supply chain models, financial managers have recently become more interested in pursuing their implementation and use.

Of course, a company will also be concerned with non-monetary objectives, such as customer service, product variety, quality, and time. Some authors even suggest that cost or revenues are relatively unimportant and that the company should focus instead on time, product variety, or other attributes of their business to achieve competitive advantage. Such recommendations are misleading since the company exists to earn profits. From an analytic perspective, it is not necessary to choose one objective over another. Instead, optimization models can assist management in evaluating the tradeoffs among objectives.

As an example, consider the tradeoff analysis depicted in Figure 1.2 between customer service, measured in days of delivery time, and supply chain cost. By days of delivery time, we mean the maximal number of days allowed for delivery to customers.
from sourcing locations across the supply chain; many customers will have shorter delivery times. Our analysis considers the tradeoff of supply chain cost versus delivery times in the range of 1 to 4 days, which are the limits of interest to management. The curved line containing the point A is called the efficient frontier. Any supply chain strategy on the efficient frontier is undominated in the sense that no achievable strategy exists that is at least as good with respect to customer service and cost, and strictly better on one. The efficient frontier in Figure 1.2 can be generated by iteratively solving an optimization model that minimizes supply cost subject to constraints on the maximal
delivery time. The strategy A corresponds to a least cost strategy with a maximal delivery time of 2 days.

Suppose that, for the sake of argument, the company currently has a customer service policy guaranteeing delivery within 3 days and that the current supply chain cost corresponds to that of strategy B, which is off the efficient frontier. By using an optimization model, management has the opportunity to identify and implement the strategy $B^2$ on the efficient frontier that lowers cost while maintaining the same customer service policy. Alternatively, the company could consider spending the same amount of money on supply chain management but using it more effectively to improve customer service by implementing the undominated strategy $B^1$. A third choice would be to reduce delivery time to 2 days and reduce cost to that of the strategy A.

The selection of a specific strategy on the efficient frontier is left to managerial judgment, perhaps with the assistance of tools that help individual managers, or groups of managers, assess their preferences. Using a preference assessment tool becomes important when the number of objectives exceeds three because the tradeoffs cannot be easily depicted in graphical form. For such analyses, it may only be possible to sample efficient strategies, not to map out the entire frontier. In such a case, a preference assessment tool can be adapted to help managers search those areas of the efficient frontier of greatest interest.

Our assumption in promoting the use of models is that the company’s supply chain is not grossly inefficient and therefore global analysis is needed to make improvements. The strategy corresponding to B in Figure 1.2 represents such a situation in that we assume an optimization model is needed to identify the superior strategies corresponding to $B^1$, A, and $B^2$. By contrast, the strategy corresponding to C is so distant from the efficient frontier that significant improvements can be realized by obvious modifications of inefficient supply chain procedures.

For example, suppose that, due to sloppy management, cross-docking and dispatching at the company’s distribution centers take much longer than industry norms. Suppose further that tightening these practices will eliminate the inefficiencies and allow maximal delivery time to be reduced to 4 days at little or no increase in cost. Such improvements are clearly important, but they can be identified without recourse to a
supply chain model. Instead, they can be identified and implemented by pursuing supply chain best practices in a myopic manner.

### 1.3 OVERVIEW OF SUPPLY CHAIN MODELS AND MODELING SYSTEMS

In §1.1, we highlighted the need to augment Transactional IT with Analytical IT for the purposes of integrated supply chain planning. Analytical IT involves the implementation and application of two types of mathematical models. First, there are **descriptive models** that modeling practitioners develop to better understand functional relationships in the company and the outside world. Descriptive models include

- **forecasting models** that predict demand for the company’s finished products, the cost of raw materials, or other factors, based on historical data
- **cost relationships** that describe how direct and indirect costs vary as functions of cost drivers
- **resource utilization relationships** that describe how manufacturing activities consume scarce resources
- **simulation models** that describe how all or parts of the company’s supply chain will operate over time as a function of parameters and policies

This list is representative but not exhaustive of the wide range of descriptive models that the modeling practitioner might create to better understand a company’s supply chain.

Second, there are **normative models** that modeling practitioners develop to help managers make better decisions. The term normative refers to processes for identifying norms that the company should strive to achieve. Our viewpoint is that “normative models” and “optimization models” are synonyms. Further, we view “optimization models” as a synonym for “mathematical programming models,” a venerable class of mathematical models that have been studied by researchers and practitioners in the field of operations research for over fifty years. Henceforth, we will use the term optimization models to refer to models that might otherwise be termed normative or mathematical programming.
The construction of optimization models requires descriptive data and models as inputs. Clearly, the supply chain plan suggested by an optimization model will be no better than the inputs it receives, which is the familiar “garbage-in, garbage-out” problem. In many applications, however, the modeling practitioner is faced with the reality that although some data is not yet as accurate as it might be, using approximate data is better than abandoning the analysis. In other words, many model implementation projects pass through several stages of data and model validation until sufficient accuracy is achieved.

Supply chain managers should also realize that the development of accurate descriptive models is necessary but not sufficient for realizing effective decision-making. For example, accurate demand forecasts must be combined with other data in constructing a global optimization model to determine which plants should make which products to serve which distribution centers and markets so that demand is met at minimal supply chain cost. Similarly, an accurate management accounting model of manufacturing process costs is necessary but not sufficient for the purpose of identifying an optimal production schedule.

Of course, to be applied, a model conceptualized on paper must be realized by programs for generating a computer readable representation of it from input data. In addition, this representation must be optimized using a numerical algorithm, and the results gleaned from the output of the algorithm must be reported in managerial terms. Programs for viewing and managing input data and reports must be implemented. Depending on the application, the modeling system must also be integrated with other systems that collect data, disseminate reports, or optimize other aspects of the company’s supply chain. In short, an optimization model provides the inspiration for implementing, validating and applying a modeling system, but the great bulk of the work is required by these subsequent tasks.

Mathematical programming methods provide powerful and comprehensive tools for crunching large quantities of numerical data describing the supply chains of many companies. Experienced practitioners generally agree about what is, or is not, an accurate and complete model for a particular class of applications. Unfortunately, since most
managers are not modeling experts, they can easily be taken in by systems that translate input data into supply chain plans using ad hoc, mediocre models and methods.

The opportunity loss incurred by applying a mediocre modeling system is not simply one of mathematical or scientific purity. Although a mediocre system may identify plans that improve a company’s supply chain operations, a superior system will often identify much better plans, as measured by improvements to the company’s bottom line. For a company with annual sales in the hundreds of millions, rigorous analysis with a superior modeling system can add tens of millions dollars to the company’s net revenue, while analysis with a mediocre system may identify only a small portion of this amount. Such returns justify the time and effort required to develop and apply a superior system.

Thus, with the goal of converting non-experts to more knowledgeable consumers of models and modeling systems, we provide in later chapters a detailed introduction to mathematical modeling of supply chain decision problems. We also provide a brief exposure to algorithms for optimizing these models. The mathematical development uses algebraic methods that are taught in high school, which should render it no more painful to the reader than that he or she experienced during a typical algebra class in years gone by.

A more subtle, related point is that good models and modeling systems expand the consciousness of managers and analysts regarding decision options and methods for improving supply chain design and operations. Their expanded consciousness relies on translations of qualitative and quantitative concepts from diverse management disciplines into modeling constructs employed by a modeling system. These disciplines and the relevant concepts are discussed briefly in the following section, and in greater detail throughout the book.

Many of the ideas presented in this book stem from the author’s experiences in projects where optimization models were applied. Of particular relevance are applications of an off-the-shelf modeling system, called SLIM/2000, for analyzing strategic and tactical supply chain problems. The principles used in constructing and applying this system, and the connections between its optimization models and diverse management disciplines provided a cornerstone to our thinking.
1.4 SUPPLY CHAIN MODELING INCORPORATES CONCEPTS FROM SEVERAL MANAGEMENT DISCIPLINES

At the end of the previous section, we asserted that good models and modeling systems provide the manager with a framework for representing concepts from various management disciplines, especially those concerned with improving supply chain management using data and analysis. To emphasize this point, we discuss briefly the following disciplines from the perspective of supply chain management and models

- strategy formation and the theory of the firm
- logistics, production and inventory management
- management accounting
- demand forecasting and marketing science
- operations research

The relevance and application of each of these disciplines will be examined in more depth in the chapters that follow.

STRATEGY FORMATION AND THE THEORY OF THE FIRM

A number of important and useful concepts for analyzing supply chains from a strategic, top-down perspective, are available from the field of strategy formation and related economic fields concerned with theories of the firm and how they compete. Most thinking in these fields has either been qualitative, or theoretically quantitative in the sense that mathematical models are used to derive qualitative insights into the behavior of and competition among firms, not as templates for the collection and analysis of data and strategy. We can hope that strategic supply chain models to be discussed here will provide a mechanism for greater empirical testing of existing theories, and that such applications will open up new areas of theoretical work.
The Value Chain

In his widely read book, Michael Porter espouses the concept of the value chain, which he describes as 9

“Every firm is a collection of activities that are performed to design, produce, market, deliver, and support its product. A firm’s value chain and the way it performs individual activities are a reflection of its history, its strategy, its approach to implementing its strategy, and the underlying economics of the activities themselves.”

The supply chain is a special case of the value chain for those companies that manufacture or distribute physical products. The value chain has also been called the “value added” chain to focus attention on the firm’s ultimate objective of adding value to its products or services at each stage in the chain. By studying its value chain, a company acknowledges that successful implementation of high level strategy requires careful coordination of its activities at a detailed, operational level. Competitive advantage will accrue to those companies that control value chain costs better than their competitors and/or differentiate their products by providing some combination of superior quality, customer service, product variety, unique market presence, and so on.

According to Porter, the generic value chain consists of nine activity types. We have reproduced it here as shown in Figure 1.3 where we have added two new support activities, information technology and supply chain management. 10 Margin, or net revenue, is the difference between gross revenue and total cost, which is comprised of the costs associated with individual activities. Controlling these costs, and adding value to individual activities, is crucial to achieving and maintaining competitive advantage as measured by the firm’s short and long term profits.

Figure 1.3 reflects the trend that support activities, especially the two we have added, are becoming a larger portion of overall value chain activity, while pure primary activities are becoming a smaller portion. Moreover, people responsible for primary activities are participating more heavily in support activities, especially those relating to
global supply chain management. Organizational structures to facilitate this matrix responsibility of supply chain managers are yet to be fully understood and implemented.

Porter emphasizes the importance of effective linkages among the activities in the value chain.\(^{11}\)

“Linkages can lead to competitive advantage in two ways: optimization and coordination. Linkages often reflect tradeoffs among activities to achieve the same overall result...A firm must optimize such linkages reflecting its strategy in order to achieve competitive advantage...The ability to coordinate linkages often reduces costs or enhances differentiation...Linkages imply that a firm’s cost or differentiation is not merely the result of efforts to reduce cost or improve performance in each value chain activity individually.”

By optimize, Porter means “to make best” by whatever organizational or planning methods that the company can bring to bear on its value chain. The theme of this book is that, to be competitive, the firm can and must use data, models and modeling systems to optimize and coordinate its value chain. This approach is obviously appropriate to the minimization of total cost. But, as we argued in the previous section, competitive advantage based on product differentiation also requires quantitative analysis to determine if the cost of differentiation is justified. If so, modeling systems can help identify cost effective plans that sustain the company’s superior level of customer service, quality, or some other differentiating factor.

**The Theory of the Firm**

The supply chain concept is, to a large extent, a managerial interpretation of well-established microeconomic models and theories. Microeconomics, or industrial organization economics as the field has been more recently named, is concerned with the construction and interpretation of models describing in mathematical terms how firms operate, expand, merge, and contract according to economic principles. It is also
The Value Chain

Figure 1.3

Microeconomic models are highly relevant to the optimization models that we will be discussing because both types of models address supply chain decisions facing the firm. A major difference between them is their intention rather than their mathematical form. Optimization models are empirical; that is, they process numerical data describing a specific supply chain problem to identify optimal strategies for that problem. By contrast, microeconomic models, although they also employ mathematical constructions, are intended to provide qualitative insights into the economics of the firm and competition among firms in an industry. In Chapter 3, we reconcile the differences in objectives between the two disciplines by using microeconomic theory to explain and interpret optimal strategies computed by optimization models.

Subtle issues arise when the reality of a supply chain problem is not perfectly suited to microeconomic theory. Consider, for example, a company that establishes a policy restricting the acquisition of a critical raw material to at least two vendors with no vendor providing less than 20% of the total volume. Management has imposed the policy despite the fact that a particular vendor is offering to sell the raw material in unlimited quantities at significantly lower cost than other vendors.

This type of policy constraint is labeled an “externality” by economists, which means it is a planning factor that is not immediately justifiable by economic arguments. One might attempt to elicit management's reasoning for such an externality, and to extend the theory of the firm to incorporate it. This is not practical because the purchasing manager requires immediate advice on how best to acquire the raw materials. She does not have the time to analyze the rationality or irrationality of this, and many other, externalities.

By contrast, as we shall demonstrate, optimization models can readily incorporate policy constraints such as the one just described, and many others. Moreover, they can provide information regarding the cost of imposing such constraints. Procedures are available to vary the effect of policy constraints if the manager is somewhat unsure about how severe he wishes to make them. In short, optimization models can perform policy analyses pragmatically and expeditiously.
Microeconomic theory is based on felicitous assumptions about the underlying structures of mathematical models that permit well-behaved results to be derived describing the firm's operations. Unfortunately, data from the real world do not always support these assumptions. For example, fixed costs and economies of scale associated with manufacturing or distribution activities raise havoc with standard microeconomic theory. If such phenomena exist in an industry, there is no guarantee, from a theoretical viewpoint, that an equilibrium among competing firms will exist; that is, that each firm has geographical markets where it is dominant. Of course, disequilibrium may be a reality, but it is a messy concept that is more difficult to characterize.

Clearly, such phenomena are widespread. Mixed integer programming models, a special type of optimization model which we shall examine in later chapters, can readily capture a variety of complicating characteristics of real-life business planning environments. Thus, a difference between microeconomics and optimization models is that the latter can more readily accommodate real-world complications that may be poorly behaved from a mathematical or theoretical viewpoint.

Recently, research on strategy formation has turned to a new paradigm, called the resource-based view of the firm, with close ties to industrial organization economics. Its philosophy is that a firm’s sustainable competitive advantage depends heavily on the firm’s resources and how they are used. In particular, the theory assumes that superior firms possess heterogeneous resources that differentiate them from other firms and permit them to earn rents; that is, the market price received by the superior firm for its product exceeds its average cost to supply the product. Roughly speaking, heterogeneous resources are not easily imitated, substituted for by other resources, or transferred.

The concept of a firm’s core competencies in an important idea linked to the resource based view of the firm. Core competencies refer to the heterogeneous resources possessed by the superior firm that provide it with sustainable competitive advantage. Although the term enjoys widespread use, managers often cannot precisely identify their firm’s core competencies, nor how they should be protected and enhanced.

The resource-based view of the firm is a new theory that has not yet produced empirical methods for identifying and measuring heterogeneous resources and core competencies. Clearly, some heterogeneous resources are qualitative and cannot be
readily or easily measured; for example, the expertise of the company’s design engineers. But many others can be measured; for example, costs and capacities associated with a product protected by patent. As we will argue in a later chapter, data-driven optimization models of the firm’s supply chain can help management identify its heterogeneous resources and categorize them by their absolute and relative values. These models can also identify and categorize stranded resources that the firm should consider retiring or selling off.

Conversely, concepts from the resource-based view of the firm suggest directions for expanding the scope of optimization models for supply chain management in important ways. This is important because managers and practitioners remain tentative about extensions, although supply chain modeling applications are proliferating. Examples include:

- Models that explicitly analyze the company's resources in selecting plans to expand efficient resources while contracting inefficient resources
- Models that explicitly address strategic uncertainties in demand when determining resource acquisition plans for the firm’s supply chain
- Models that analyze the firm’s product line from a strategic perspective by simultaneously considering new product introductions, life cycle management, and product retirement

**LOGISTICS, PRODUCTION, AND INVENTORY MANAGEMENT**

By contrast to the top-down, high-level, strategic issues examined in the previous subsection, logistics, production, and inventory management are concerned with managing supply chain operations from the bottom-up. Nevertheless, experts in these areas have long recognized the need for integrated planning.

Academic research and writing in these fields goes back a long way, beginning with publication of the original paper on Economic Order Quantity (EOQ). Although motivated by real-world operational problems, many papers published in academic journals over the years have approached these problems in a theoretical manner, yielding results that have only a distant relevance to practical solutions. In the past, this
phenomenon was the result of a lack of data and managerial interest in applying the theories. The situation has changed significantly in recent years as companies have begun to actively seek analytic tools to help them improve operations. Still, it will take time to overcome legacy thinking to create robust and powerful modeling approaches and modeling systems for operational problems.

**Logistics**

Logistics is concerned with managing transportation, warehousing, and inventory stocking activities. Transportation planning is a vast field unto itself that involves complex decisions about transportation modes, carriers, vehicle scheduling and routing, and many other activities that serve to move products through the company’s supply chain. Optimization models and modeling systems have been successfully applied to these decision problems and applied research continues to seek faster and more powerful methods.

In the U.S., de-regulation of air freight, trucking and railroads has generally led to more competitive prices, while expanding the transportation options that the company must consider.\textsuperscript{16} Advances in IT, such as the capability to select carriers over the Internet, have also expanded these options and will continue to do so for several years. The spot market in transportation will probably become much more sophisticated and spawn the need for new tools in selecting carriers.

About the same time that strategic thinkers like Michael Porter with top-down perspectives began to articulate the importance of integrated supply chain management, logistics experts with bottom-up perspectives from top-down came to the same conclusions. According to Stock and Lambert\textsuperscript{17}

“The foundation of the integrated logistics management concept is total cost analysis, which we have defined as minimizing the cost of transportation, warehousing, inventory, order processing and information systems, and lot quantity cost, while achieving a desired customer service level.”
Several conclusions can be drawn from this sentence.

First, Stock and Lambert correctly allude to the indirect costs, probably substantial, of IT needed to achieve integrated supply chain management. Second, they allude to the need to balance non-monetary objectives, such as customer service, against cost minimization. Third, they offer the lot quantity cost as a surrogate for manufacturing costs. As such, it reflects the past and still current viewpoint of logistics managers that their responsibilities need not or cannot be integrated with those of manufacturing managers.

Expanding the scope of total cost analysis is important to future improvements in supply chain management practices. In the typical consumer products company, for example, sales strategies for next year are determined by marketing managers. Their plan is passed to manufacturing managers who are asked to develop an appropriate production strategy. The joint marketing and manufacturing strategy is then passed to logistics managers who are given the responsibility of developing appropriate transportation, warehousing and inventory strategies to meet it. Thus, although the logistics managers may seek to minimize total logistics costs, larger issues of integrating strategies for logistics, manufacturing and even marketing are not addressed. As a result, the overall supply chain strategy of the consumer products company may be significantly sub-optimal.

Production Management

Production planning varies significantly across industries. Process manufacturing, which characterizes production in oil refineries or breweries, involves expensive, capital equipment that is run continuously with infrequent changeovers. Discrete parts manufacturing, which characterizes the production of automobiles and their components or printed circuit boards, involves multiple stage product lines with set-ups at each stage for intermediate products. Buffer stocks are maintained between stages to promote continuous production. Job-shop scheduling, which characterizes repair operations on aircraft engines or finishing operations in a paper mill, involves facilities with capital equipment that is used sporadically as individual jobs with different profiles of tasks to be completed are undertaken.
Thus, at the operational level, optimization models and modeling systems for production scheduling must be customized to the peculiarities of the production environment, particularly those associated with the timing of set-ups, changeovers, production run lengths, and so on. Such models and modeling systems are needed to provide master schedule information to Materials Requirements Planning systems that produce detailed bill-of-materials instructions for managers charged with running operations. For some production environments, these modeling systems can also assist production managers in evaluating short-term make-or-buy decisions.

At the tactical and strategic planning levels where timing details are less important, the various classes of production planning problems can often be accurately modeled by general-purpose models and modeling systems that address multi-stage and multi-period planning decisions. Still, inter-temporal coordination of strategic, tactical, and operational production plans is very important, which presents the modeling practitioner with the challenge of coherently linking detailed operational models with more aggregate tactical models.

Production planning and scheduling models can play an important role in implementing new qualitative methods for improving production, such as lean production or agile manufacturing. Lean production refers to the reduction of waste in the production line including reduction of inventory, shortening of set-up times, and improvement in quality. Although lean production rests heavily on the creation and use of interdisciplinary teams that foster better communication among production managers and workers, optimization models play an important role in identifying plans that squeeze out additional waste. Agile manufacturing refers to production environments that are more agile with respect to product customization and re-engineering, product changeovers, changes in customer orders, and so on. Again, optimization models can be used to advantage in helping design and operate agile manufacturing lines.

Inventory Management

A company may hold inventories of raw materials, parts, work-in-process, or finished products for a variety of reasons. Inventories can serve to hedge against the uncertainties of supply and demand, or to take advantage of economies of scale.
associated with manufacturing or acquiring products in large batches. Inventories are also essential to build up reserves for seasonal demands or promotional sales.

Recently, attention has been focused on creating business processes that reduce or eliminate inventories, mainly by reducing or eliminating the uncertainties that make them necessary. These efforts have been motivated in part by the recognition that metrics describing the performance of a company’s inventory management practices can be important signals to shareholders regarding the efficiency of the company’s operations, and hence its profitability. Just-in-time inventory practices, which found widespread application in recent years, have been tempered by the realization that they may incur significant hidden costs in some situations, such as those realized by small suppliers to large companies in the automotive and aerospace industries.

Inventory management problems are characterized by holding costs, shortage costs, and demand distributions for products specified at a detailed SKU level. Models for optimizing inventory policies for individual items use arguments and methods from statistics and applied probability theory. As such, they are structurally very different from deterministic optimization models, which broadly consider products, facilities and transportation flows in analyzing resource acquisition and allocation decisions.

In this book, we study models for inventory management with an emphasis on approaches for integrating inventory decisions with other supply chain decisions. This perspective, which is sometimes overlooked by managers responsible for controlling inventories, is crucial because holding costs are only one element of total supply chain cost. As we shall see, incorporating inventory decisions in supply chain optimization models is difficult because they involve parameters and relationships, such as variances of market demands and delivery times and their impact on stock outages, which are not easily represented in optimization models. Nevertheless, depending on the scope of analysis, acceptable approximations of inventory costs can be developed. Improving these approximations is an important area of applied research.

**MANAGEMENT ACCOUNTING**

Management accounting is “the process of identifying, measuring, reporting and analyzing information about the economic events of organizations.” It is concerned with
helping managers make better decisions and providing feedback and control on current performance. By contrast, financial accounting is responsible for reporting results about historical performance to the company’s external constituencies comprised of stockholders, creditors, and tax authorities. Over the past century, developments in management accounting to support internal decision making and control were inhibited because government regulations imposed strict rules on financial accounting. Implementation of management accounting methods also require information technologies that have only become available in recent years.

Management accounting methods for supply chain planning are closely linked to methods for creating and applying optimization models. In fact, the two disciplines overlap considerably in their approaches to analyzing business problems. Our discussion of the overlap will focus on two main tasks needed to create cost data for and from supply chain models:

- Develop causal cost relationships of direct and indirect costs
- Compute transfer, product, and customer costs from an optimal solution to a supply chain model

An optimization model requires inputs reflecting cost behavior as well as numbers, hence the emphasis on cost relationships. These are relationships between natural categories of direct and indirect costs discussed above and independent factors, called cost drivers. To provide managers with useful insights into costs and decisions, we seek causal cost relationships employing cost drivers that accurately and comprehensively reflect supply chain activities causing cost and value to be added to the firms products and services. Cost behavior also refers to forecasts or projections about how costs will change as operations in the future differ in volume and mix from historical operations. Finally, it refers to costs and cost relationships involving new products, markets, vendors, facilities and transportation activities that the company wishes to evaluate as part of its strategic and tactical planning exercises.

Selecting cost drivers for direct cost relationships is often straightforward since direct manufacturing and distribution activities usually depend on machines, people and
raw materials in obvious ways. Selecting cost drivers for indirect cost relationships is more difficult. It requires management account expertise plus knowledge of the company’s business. Developments in activity-based costing methods, which is an important new area of management accounting, are aimed at identifying cost drivers for indirect costs.

**DEMAND FORECASTING AND MARKETING SCIENCE**

Demand forecasting refers to quantitative methods for predicting future demand for products sold by the company. Such forecasts are obviously essential for the construction of a supply chain model, either a total cost minimization model to meet a specific demand forecast, or a net revenue maximization model incorporating functions relating demand to product prices, product sourcing locations, or other factors. Uncertainties in the demand forecasts should be used in constructing multiple demand scenarios to be optimized by the supply chain model.

Demand forecasting techniques are primarily statistical methods. Analysts apply them to project future sales patterns from historical data about past sales, and possibly other data about the company, its industry, the national economy, and the global economy. Time series analysis is a large class of methods for developing forecasts simply from historical databases. The well-known technique of exponential smoothing is a simple type of time series model.

In constructing a time series model, the practitioner attempts to find patterns in the historical data, such as seasonal effects or trends, that produces a good fit to the data as measured by the variance of the forecast. Sometimes patterns causing variability in the data are subtle. In such cases, considerable expertise by the modeling practitioner may be needed to produce a good model. In short, in addition to its mathematical underpinnings, demand forecasting has a decided artistic side, which may be difficult to document or explain to a non-expert.

Time series models have a fatalistic aspect to them in that they assume the past will repeat itself without being influenced by external factors. Thus, the company may be well advised to combine statistical analysis with managerial judgment about the short, medium and long-term outlooks for company sales to customers and markets. At the
other extreme, supply chain planning based purely on intuitive, managerial judgments without recourse to formal predictive methods using data, is not recommended.

Another large class of forecasting models, which includes regression and econometric methods, goes somewhat beyond the fatalism of time series techniques in seeking to provide insights into the product demand process through causal relationships, or at least explanatory factors, that link independent variables to demand forecasts. For example, by forecasting the increase in product demand as a function of the increase in GDP, or the decrease in demand as a function of an increase in product price. But even causal models are susceptible to an over-reliance on historical data, which again suggest the need to combine them with managerial judgments.

Once we open up our analysis of demand forecasts to causal modeling, a natural next step is to investigate marketing science models that relate forecasted sales to values of decision variables determined by the marketing department such as price, promotion, advertising, and salesforce effort. Since the cost of marketing strategies involving these decision variables will be significant, we must consider extended models that integrate supply chain management decisions with demand management decisions. Although such models have not yet been widely implemented, there is growing interest in them.

When a company faces the introduction of a new product, it has no historical data upon which to base its forecasts. In many instances, though, historical data is available for similar products. The challenge is to develop initial forecasts of the new product based on forecasting parameters extracted from historical data of these similar products. For example, the diffusion model for new products relates sales to parameters describing the rates at which two types of customers, innovators and imitators, decide to buy the product. This model has been used successfully to forecast new sales of new consumer durable, electronic and high-tech products. Once a profile of the new product sales begins to emerge, the a priori parameters can be revised.

**OPERATIONS RESEARCH**

Operations research has been called the science and technology of decision making. The scientific component is concerned with ideas and processes for articulating and modeling decision problems by determining the decision maker's objectives and the
constraints under which he or she must, or wishes, to operate. It is also concerned with mathematical methods, called **algorithms**, for optimizing the numerical systems that result when data is used to populate models. The technological component is concerned with software and hardware tools for collecting and communicating data, organizing them, using them to generate models, optimizing these models, and reporting results.

Operations research models and methods have demonstrated their relevance in a wide range of applications. This generality creates opportunities and challenges. A major opportunity is that many supply chain problems can be analyzed using optimization models and algorithms taken more or less “off-the-shelf” and quickly adapted for use. But the details of a given problem matter. A major challenge in any specific situation, therefore, is to precisely define an appropriate model. This book is devoted to an examination and elaboration of these opportunities and challenges.

Operations research was one of the disciplines that sprang to life at the start of the information revolution in the mid 1940’s. The revolution began with the need for numerical computing in military operations during World War II. Despite these very early applications, subsequent advances of information technology in business were concerned with methods for data acquisition, communication and management, as opposed to numerical computation. These concerns persisted until very recently. Now the interest in numerical computation in business has greatly increased as witnessed by the widespread use of electronic spreadsheet and sophisticated graphics programs as well as a renewed interest in operations research models.

Unfortunately, between 1970 and 1985, operations research drifted away from its origins because companies were more concerned with methods for acquiring data than methods for analyzing them. During that period, information technology to support practical implementations of operations research models lagged behind the theory. Often the data required for a realistic model were not readily available, or could not be acquired in a timely manner. Without opportunities to work on real-world problems, academics and other researchers in the field kept busy by extending the theory, too often in directions with little practical relevance.

Despite the shortcomings of the past, the future of operations research is bright, especially for new and expanded applications. The growing interest by managers in
supply chain management has opened up important opportunities for model building and analysis. At the same time, software packages for optimizing models have evolved to the point that they can be easily integrated with other system modules. Today's desktop computers have the power to optimize large scale models in run times that are at least commensurate with those of mainframe computers of only a few years ago. For these reasons, operations research has become an important element in the methodologies of information technology.

1.5 INNOVATIONS IN INFORMATION TECHNOLOGY REQUIRE AND SUPPORT SUPPLY CHAIN MODELING

In this section, we examine further the synergy between IT and supply chain modeling. As we observed in §1.1, recent developments in ERP systems provide the promise, and sometimes the reality, of transactional databases that are comprehensive and easily accessed. Such databases are the foundation from which we can construct and apply supply chain modeling systems. Conversely, supply chain modeling systems are critically needed to help management extract effective plans from these transactional databases.

To emphasize the need for modeling systems, we highlight two serious problems involving data currently faced by managers.

Data Problem One: There is an overabundance of transactional data for the purposes of managerial decision making.

Managers have faced this problem for twenty years, or more, although it has become more acute in recent years due to the advent of ERP, Point-of-sales Systems and other systems focused on streamlining the collection and communication of transactional data.

Equally serious for the purposes of integrated supply chain management is

Data Problem Two: Managers do not know what the data in the company’s transactional databases imply about how to integrate their
activities with the supply chain activities of other managers in the company, and with those of the company’s vendors and customers.

As we have discussed several times in this chapter, integrated supply chain planning will not occur magically once systems for managing transactional data are in place.

Solutions to these problems are the major theme of this book. At an abstract level, the solutions may be succinctly stated, but their execution requires technological development, learning, and business process re-design on the part of the company and its supply chain partners. The solution has two aspects. First, there is the

**Technological Solution:** Develop and deploy modeling systems for analyzing strategic, tactical and operational decisions affecting the company’s supply chain.

We emphasize that the technological solution involves the construction and application of modeling systems for all levels of planning, strategic, tactical and operational. Implicit is the need to implement supply chain decision databases feeding these modeling systems that are consistent and coherent in their descriptions of products, markets, vendors, facility activities, transportation activities, and a host of other factors. Moreover, supply chain decisions suggested by the various models must be consistent and coherent in their treatment of strategic, tactical and operational plans.

Given the capabilities of today’s software and hardware, achieving a technological solution to the analytical problems of interpreting transactional data is not a barrier. Instead, the barrier to integrated supply chain management is in realizing the

**Organizational Solution:** Re-design company processes and revise managerial incentive schemes to promote and facilitate competitive strategies for supply chain management based on data, models, and modeling systems.
The process re-design requirements needed to exploit insights provided by modeling systems are not yet well understood or appreciated by most managers. Simply stated, the company must commit to routine application of the modeling tools where the cycle time for their use depends on the type of analysis they perform. Strategic planning may be performed once a year, tactical planning once a quarter or once a month, and operational planning once a week or once a day. Business processes must be put in place to update the supply chain decision databases, to perform modeling analyses, to resolve conflicts among managers about proposed plans, and to disseminate the plans once they have been identified and agreed upon.

The execution of these tasks involves the creation of new types of jobs for individuals that combine skills in information technology with knowledge about business problems and analysis. Moreover, the company must revise its managerial incentive schemes so that plant managers, distribution managers, and others middle and upper-middle level managers are encouraged to make decisions and pursue plans that serve to globally optimize the company’s supply chain. Creating such incentive schemes is not easy because the success or failure of global supply chain optimization in a company may involve many aspects of the company’s performance that are beyond the control of the individual manager. As a result, the manager may feel that his or her yearly bonus and prospects for promotion are unconnected with his or her job performance.

We are at a crossroad in the information revolution that is familiar to philosophers and historians who have studied human progress. The revolution began with the thesis that computers and communications networks must provide managers with timely and complete data about their company’s operations, its suppliers, and the markets in which the company’s products are sold. No one doubted the benefits to be gained by pursuing this thesis, which today is approaching realization. Still, the business community is now faced with an antithesis characterized by the two Data Problems stated above. History has shown that antitheses can and will be overcome by evolving technologies to form a synthesis, which becomes the new thesis and the process is repeated. Our contention is that the Technical Solution and the Organizational Solution characterize the synthesis sought by participants in the information revolution. Furthermore, we can hasten its arrival by articulating and promoting it.
1.6 ORGANIZATIONAL ADAPTATION TO INTEGRATED
SUPPLY CHAIN MANAGEMENT AND MODELING

In the previous section, we observed that the barriers to integrated supply chain management are organizational not technical. Although myopic improvements in supply chain management can be achieved by elimination of obvious, inefficient, non-value adding activities, our interest here is in promoting the much larger improvements that can be realized when managers use modeling systems to achieve true integrated planning. Conveying the form and function of such systems is the goal of this book. Once a company’s management understands them, it can begin to adapt its business processes to allow insights provided by modeling systems to be exploited.

Most companies are undergoing radical change due to a host of inter-connected factors. It is difficult to separate cause and effect from among

- globalization
- e-commerce
- enterprise resource planning systems
- business process re-engineering
- organizational learning and change management
- integrated supply chain management

A great deal has already been written about these phenomena, and even more will be written in the future. Our contention is that considerable discipline may be imposed on supply chain management by creating modeling systems, implementing their supporting decision databases, and then adapting the organization to exploit them. While this contention may seem presumptuous, possibly even ludicrous, to someone unfamiliar with modeling technologies, we counter with the observation that an increasing number of managers in a wide range of companies are seeking to manage their supply chains based on facts, that is, data.

The application of modeling systems to enhance the rationality of supply chain management flies in the face of past research into human and organizational decision-
making, which has shown that timeless issues of ignorance, superstition, conflict, and self-seeking behavior still abound. Business process re-engineering is needed to assist humans and organizations to make better decisions in spite of themselves. Suggestions for achieving this goal are made in the final chapter of this book.

1.7 OVERVIEW OF THE BOOK

The book is divided into four sections.

Part I - Introduction to Supply Chain Management
Part II - Modeling and Solution Methods
Part III - Applications
Part IV - The Future

In Part I, which is comprised of this Chapter and Chapter 2, we discuss motivations for using models to analyze supply chain problems. Particular attention is paid to developments in IT that have spawned an interest in and a need for integrated supply chain modeling and management. We also examine a hierarchy of linked supply chain modeling systems to support operational, tactical and strategic decision making.

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

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

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

In Chapter 9, we present modeling approaches for optimizing corporate financial planning decisions and for integrating them with models for optimizing supply chain decisions. We also discuss integrated models for multi-national corporations that allow managers to blend decisions involving financial flows with those involving physical flows in maximizing after-tax profits that are repatriated to the parent company. Modeling systems for operational planning are examined in Chapter 10, including in-depth reviews of a vehicle routing system for an e-commerce company and a production planning and scheduling system for a semi-conductor company. The chapter also contains brief discussions of several other modeling applications to operational problems arising in production scheduling, vehicle routing and human resources planning.

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

Finally, in Part IV, which consists of Chapter 12, we discuss human and organizational issues surrounding a firm’s efforts to exploit data and modeling systems in improving their supply chain management. We discuss at length the conflict between a firm’s desire to achieve fact-based supply chain management and its ecology of decision making that conspires to work against it. The Chapter contains suggestions about
business process re-design to meet the goals of fact-based decision making while overcoming organizational barriers. We also discuss factors that influence the role played by IT in providing the firm with competitive advantage in supply chain management. The Chapter and the book conclude with a forecast of developments in supply chain management and over the next 10 years.
1.8 NOTES

1 The publications by Hanssman [1959], Lalonde et al [1970] and Porter [1985] discuss integrated planning from different perspectives. They illustrate how theory often precedes practice, sometimes by many years. The difficulty is to recognize when the world is ready for practical applications drawn from a theoretical base. In the case of supply chain management, the indications are strong that the time has arrived.

2 These applications are discussed in Arntzen et al [1995].

3 See Rajaram et al [1999].

4 Boeing’s ongoing problems are discussed in Zuckerman [1999], who contrasts their supply chain with the more efficient one of Airbus.

5 Conagra’s situation is discussed in Barboza [1999], who expressed the widely held view that the company is too large to operate its supply chains efficiently.


7 Mathematical programming models and methods include linear programming, mixed integer programming, nonlinear programming, stochastic programming and other classes of models and methods. Schrage [1997] and Winston [1995] contain broad treatments of mathematical programming that assume the reader has an intermediate level of mathematical sophistication. Recent developments in heuristic optimization methods (see Refeves [1993]) are complementary to mathematical programming and extend their ability to extract useful plans from complex, mixed integer programming models.

8 An overview of an early version of SLIM/2000 and its application in a post merger consolidation study is found in Shapiro, Singhal, and Wagner [1993]. Since then, the system has been applied to supply chain problems in more than two dozen companies. None of these companies has displayed serious interest in publishing details of their use of the system. In most instances, the system helped management identify savings in the millions, sometimes even tens of millions, of dollars.

9 See Porter [1985, 36].

10 The omission of information technology as an instrument of competitive advantage reflects the attitude about its importance held by many senior managers during the 1980’s. Porter recognized this omission of his original concept of the value chain in the paper Porter and Millar [1985]. The perception that the company needs cross-cutting activities to support global supply chain management is still emerging.
See Porter [1985, 48].

The book by Cohen and Cyert [1965] was an important early contribution to the theory of the firm as it can be examined by mathematical models. More recent results are summarized in Holmstrom and Tirole [1988].

Wernerfelt [1984] coined the term resource-based view of the firm. Conner [1991] compares and contrasts the resource-based view of the firm with other theories from industrial organization. The resource-based view if the firm is discussed in more detail in Chapter 7.

The seminal paper on core competencies is Pralahad and Hamel [1990].

According to Sipper and Bulfin [1997], the original EOQ model was introduced by Harris [1915], although it was Wilson [1934] who widely promoted it.

Crum and Holcomb [1994] discuss improvements in the transportation industry since de-regulation and the associated challenges.

See Stock and Lambert [1987, 39].

Shapiro [1993] provides an overview of models for different classes of production environments.

Lean production is a concept articulated by Womack et al [1990] following their study of the automotive industries in Japan, the U.S. and Europe. Agile manufacturing is a concept proposed by Goldman and Preis [1991].

See Atkinson et al [1997; 3].

For an overview of forecasting methods, see Winston [1994; Chapter 24] or Makridakis and Wheelwright [1986]

Marketing science models and their integration with supply chain models are discussed in §8.2.

These issues are examined in detail by March [1994].
1.9 REFERENCES


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