ANALYSIS OF MANUFACTURING ENTERPRISES

An Approach to Leveraging Value Delivery Processes for Competitive Advantage

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ANALYSIS OF MANUFACTURING ENTERPRISES

An Approach to Leveraging Value Delivery Processes for Competitive Advantage

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Preface

Over the last three years, my endeavor has been to put together a textbook that will introduce to everyone concerned with manufacturing–students, researchers, teachers, planners, policymakers, managers, and entrepreneurs–the fundamentals of manufacturing enterprises or networks. I have attempted to achieve this through a systematic and unique presentation of concepts, methods, and examples. This book is designed to provide deep insights into enterprise physics and dynamics. This book is the first of its kind, and I hope it will serve as a step towards formulating and establishing a set of fundamental principles and methods based on which global manufacturing networks can be designed and operated.

I am confident that after reading this book, a research student will be able to embark directly on his or her dissertation in areas of analysis and performance evaluation of manufacturing enterprises; a working engineer will be able to confidently undertake process identification and redesign; a mature researcher will be able to quickly identify the areas for future research; and a manager will have a deep appreciation of the system-level issues in an enterprise. This material will useful in regular graduate courses on operations management, manufacturing systems analysis, and training courses on enterprise resource planning.

Acknowledgments

It is a pleasure to acknowledge the many individuals who have made this book possible.

I am a product of the Indian Institute of Science(IISc); from 1961 until recently, I spent my life there as an undergraduate, a graduate student, a faculty member, Chair of the Computer Science and Automation department, and Chair of the Electrical Sciences division. The best thing that has happened in my life has been to be a student and faculty member at IISc, which is indeed a great place that nurtures basic research in Engineering and Science. The writing of this book was done at National University of Singapore, where I have spent most of the last three years. The excellent library, the information technology facilities, and encouraging environment there have contributed greatly to the quality of this book. I would like to thank Professors C.C.Hang, S.K. Chou, T. S. Low, A.Y.C. Nee, and Y.S. Wong for their support.

I would like to thank Srinivasa Raghavan, my former Ph.D. student at IISc, for his help in converting my doodlings into excellent x-fig diagrams. His thesis on modeling and analysis of manufacturing enterprises also provided me with an incentive to probe deeply into the systemic aspects of manufacturing enterprises. My collaborator in manufacturing systems research for over 15 years, Y. Narahari, has helped me a great deal with his insightful comments on the content, presentation, and style of the book. I am thankful to him. N. Ravi, marketing manager at Sony (India), has provided great insights into the working of Indian manufacturing enterprises. Bharathi, plant biologist turned medical doctor, has helped a great deal to understand the healthcare enterprises. George Mathew, S. S. Keerthi, Raj Srinivasan, and A. Laxminarayanan have spent endless hours helping this adult student with Latex editing. Their help has indeed been a great support. Last but certainly not least, I would like to thank Mrs. Mary Azariah for her excellent understanding in making endless revisions of the book and for her high-quality skills in manuscript preparation.

In a professional life spanning more than three decades, it is but natural that one makes many friendships and that a few of them remain. Professors T. Kailath, S. K. Mitter, G. C. Verghese, Y. C. Ho, Peter B. Luh, Rajan Suri, Ram Akella, U. R. Prasad, H.N.R.Rao, and B.L.Deekhatulu have been constant sources of encouragement and inspiration on the professional front. Their affection and friendship I will cherish throughout this life. At the Indian Institute of Science, V. V. S. Sarma and I started our life together as undergraduate students, joined faculty, and shared several academic ventures. The IISc community calls us "the Electrical Engineering twins". Despite the pressures of competition and outside influences, our friendship has remained intact. I have immensely benefited from our partnership and friendship and I thank him and his family for this long friendship. I would like to thank Prof. R. Narasimha for his support in my scientific life at the Indian Academy of Sciences. I would like to thank Prof. Y. C. Ho, Editor of the Kluwer Series on Discrete Event Systems, for his support. I would also like to thank Mr. Scott E. Delman for his help in transforming this manuscript into a quality book.

I have crossed the midpoint in Shakespeare's "seven stages of man." My family grew from two individuals (Subhadra and myself) into a nuclear family (with my children Sundari, Murthy, and Kiran) and now it has become an enterprise. I had a title change recently from father to grandfather, thanks to Sairaj, son of my daughter Sundari and son-in-law Kaladhar. I would like to thank all my family members for their understanding and love.

Chapter 1

INTRODUCTION

Learning objectives

1 Introduce manufacturing enterprises.

2 Describe three typical enterprises in auto, food and apparel industries.

3 Provide an overview of the chapters in the book .

1. THE MANUFACTURING ENTERPRISE

A manufacturing enterprise is a group of independent companies, often located in different countries, forming a strategic alliance with the common goal of designing, manufacturing, and delivering right-quality products to customer groups faster than other alliance groups and vertically integrated firms. Such enterprises are common in all industrial sectors including the automobile, pharmaceutical, aerospace, electronics, computer, food, and apparel industries. The lowering of trade barriers by various countries, combined with rapid advances in logistics and information technology, has led to the proliferation of global manufacturing networks or enterprises. In global manufacturing of this kind, components may be sourced from several countries, assembled in yet another country, and distributed to the customers all over the world. These networks are not generally under single ownership but are group formations of independent companies in alliance for a specific and special purpose. The alliance between groups of companies creates enterprises

N. Viswanadham, *Analysis of Manufacturing Enterprises*

that compete with other cooperating groups. Thus, cooperation and competition occur at different levels. *Networks, constellations, groups, clusters, virtual corporations, and enterprises* are various names given to these cooperating entities about which there is vast amount of literature. However, all the books and journal articles concentrate on types of networks and strategies of alliance formation, and there is very little literature on analyzing these interesting entities called *manufacturing enterprises.*

The formation of manufacturing enterprises can be interpreted as the generalization of the concept of division of labor of Adam Smith [9]. He suggested that for production efficiency, work needs to be divided into tasks and tasks into subtasks, and workers need to be assigned subtasks. The overall coordination of work has created the hierarchical organizational structure, which is indeed the basis for mass production methods of Henry Ford. The concept of division of labor is also at the core of the formation of present-day manufacturing enterprises: each company in the alliance group specializes in what it does best, and the membership covers all competencies that are critical to the mission of value delivery to the customers. For a manufacturing enterprise to succeed, the critical competencies include product design and development, process design, production, distribution, logistics, product maintenance, information systems and processing, etc. No single company can have world-class competence in all these areas but an enterprise can. That is why a strategically formed enterprise can provide a formidable competitive advantage.

Figure 1.1 shows the enterprise in the context of competing with similar enterprises. As can be seen, all the enterprises draw from the same pool of resources, share the same customer pool, and work under identical environmental constraints. The figure also shows three prime-value delivery processes in a manufacturing enterprise. The basic resources, namely, capital, people, material and technology are first transformed into facilities and human resources with competencies to design, build, store, transport, install, and maintain the final products. Also, the customers are global, each from a different culture. The enterprise is designed by bringing together companies with complementary competencies, using appropriate automation and information technologies and mathematical optimization techniques with the primary goal of winning a sizable market share.

To win customers in the presence of competition, all the customer-facing processes have to be effective and efficient. Further, coordination of the goals of the constituent companies towards the enterprise goals is an important factor. Thus, for these enterprises to succeed, either

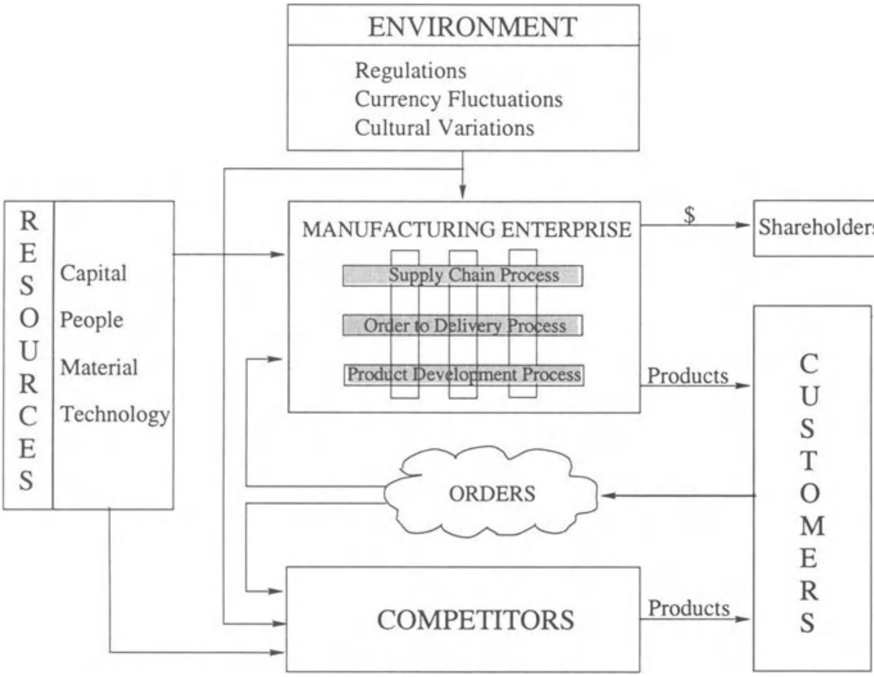

Figure 1.1. A competitive manufacturing enterprise

locally or globally, there is a need for optimal design and coordination of enterprisewide processes such as the order-to-delivery, supply chain, and new product development processes. This need calls for development of systematic analysis methodologies for evaluating the performance of value-delivery processes. This book, on Analysis of Manufacturing Enterprises, fills this vital need. In this book, we present a methodology that identifies the value delivery processes of a manufacturing enterprise, determines which of these are important for gaining competitive advantage, benchmarks their performance, and redesigns the organizational, technological, and human resource elements of the enterprise to gain superior operational and financial performance.

1.1 TRADITIONAL VS. MODERN ENTERPRISES

The emergence of manufacturing enterprises is a recent phenomenon. Modern-day enterprises are a result of the recent advances in international logistics and information technologies.

In a traditional enterprise, all companies involved in the product delivery, such as suppliers, manufacturers, distributors, retailers, and so on, act as islands of excellence producing goods to forecast or order. There is no coordination between various companies except for some contractual agreements for supply of materials. All the organizations, from raw material suppliers to retailers, make or order goods to forecast, guessing the requirements of their upstream supply chain neighbors. Information sharing across companies is a rare phenomenon. Even within a company, the three fundamental functions—procurement, production, and delivery—are managed independently, buffered by large inventories.

Generally, distribution centers collect customer orders and also forecast the demand. This information is used to project the replenishments needed from the manufacturing plants for several time periods into the future. This in turn will trigger the orders to the component and raw material suppliers. The continuity of material flow is maintained by holding inventories throughout the network in the form of raw materials, components, subassemblies and finished goods. The information flow is generally paper based.

Increasing competitive pressures and market globalization are forcing companies towards greater integration so that higher levels of service can be offered to customers at lower cost. Also, the recent advances in logistics and information technology have made possible material flow and information flow integration. This integration has had a profound effect on the inventory levels and also on the cost of delivery. Figure 1.2 shows the schematic of an integrated manufacturing enterprise. A well-designed logistics network provides a streamlined material flow, cutting down the lead time and cost of moving the raw materials, subassemblies, and finished goods to their destinations. The extranet, a secure and reliable communications network linking all the companies of the enterprise, provides the information integration. By providing the right information at the right time to all the stakeholders, the extranet enables efficient logistics and effective decision making. This kind of material flow and information flow integration in enterprises closely parallels the developments in flexible manufacturing systems in the late 1970s. The benefits are singularly profound.

The IT enabled integration we are concerned with here is different from the data integration that enterprise resource planning (ERP) packages such as SAP, People Soft, and BAAN promise. ERP software and the World Wide Web are the two of the most significant developments in corporate information technology. A good ERP package gives a standard solution to the information fragmentation problem in a single organization. At its core is a single comprehensive database, which collects data and feeds data into modular applications supporting all of a company's business activities. When new information is entered in at one place,

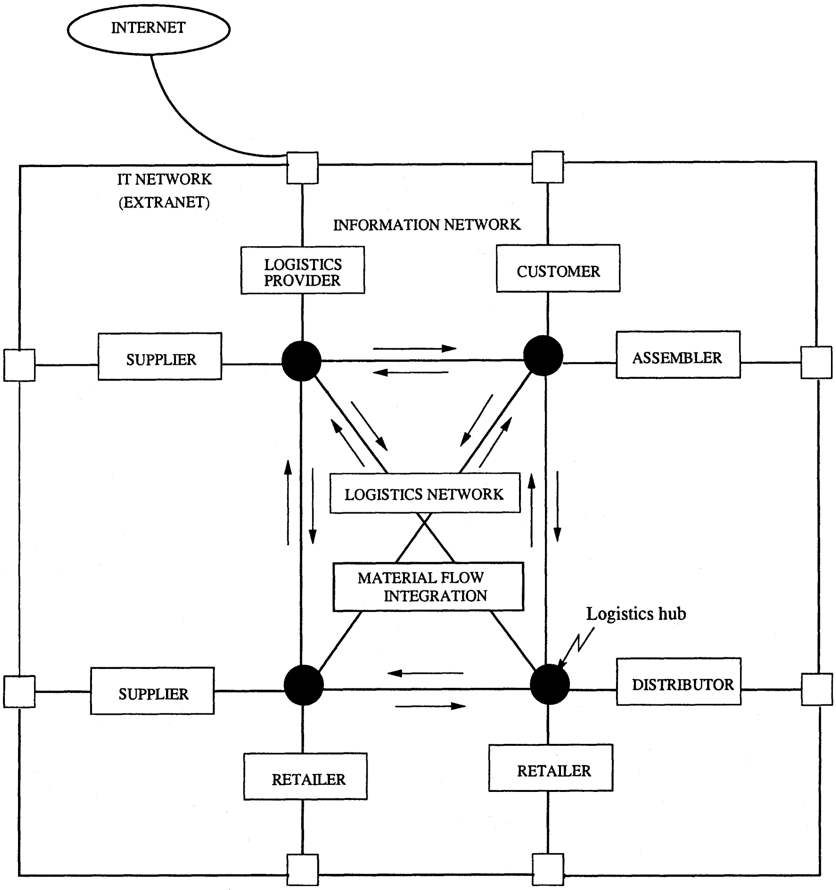

Figure 1.2. IT integrated manufacturing enterprise

all related information gets automatically updated. The ERP packages provide canned standard solutions to the businesses. To that extent, they also dictate the way one must do business, leading to rigidity or inflexibility. ERP vendors have a set of recommended best practices for value delivery processes (customer order taking, procurement, etc.) embedded into their software and encourage customers to use them. Any innovations need custom software development, which is expensive. For example, consider a company that has many loyal customers because it serves them well by circumventing formal procedures and systems. If this company follows ERP package-enabled strategies, their core source of competitive advantage may be at risk. The company has the choice of following the packaged practice or paying extra development costs. Thus, by centralizing the information and standardizing the actions, one is moving back to command-control organization structures. The company loses its individuality and follows the logic imposed by the ERP package. Another hazard is the problem of being lockedin to the ERP vendor. Upgrades come from the vendor, and hence the tone for subsequent system improvements is set by the vendor. This kind of package application strategy may contradict the philosophy of creating competitive advantage by developing company-specific core capabilities [21].

1.2 EXAMPLES

In this section, we give three examples of global manufacturing enterprises.

Auto Enterprises: The first and and probably the most important global enterprise even today is the auto industry. This industry has very well-organized networks of companies. The mass production and lean production systems were born in the auto world. Several best practices such as concurrent engineering, just-in-time (JIT) manufacturing, partnership sourcing, and information sharing were also developed in this industry. There have been recent advances such as the creation of auto exchanges called ANX, which are extranets for secure communication among the partners. Funds transfer, procurement, and location of suppliers are all performed on this net. Also, this industry is truly global in the sense that almost every country in the world has a car industry and automobiles form a significant percentage of international trade. This industry has very big players throughout the world.

Basically, the original equipment manufacturers (OEMs) control the enterprise. They have tier I , tier II and even tier III suppliers and the linkages between them are well organized. Because of their size and financial power, the OEMs control all the value delivery processes such as new model development, supply chains, procurement, facilities planning, etc. in a vertically integrated fashion. Until recently, most auto enterprises were confined to regions in a country, such as the Detroit region in the U.S. and Toyota City in Japan. The components and subassemblies are sourced from companies in the same city. This procedure also given rise to practices such as just-in-time deliveries, just-in-time purchasing, zero defects, and partnerships which were copied and followed by other industries. The fully assembled automobile is then surface transported to other regions in the world.

Several studies have been conducted on auto enterprises in recent years. The most significant study is the International Vehicle Project at MIT. The findings were summarized in several books [99] [12].

Food Enterprises: The grocery industry is another dominating contributor to global manufacturing and distribution. There are also big players here. This enterprise also has three dominant business processes. They include new product development, the make-to-forecast supply chain, and the distribution process through superstores. The grocery supply chain starts with the farmers and ends with the consumer procuring the item (such as a box of corn flakes or a carton of milk) from the superstore. The best practices from other industries have their influence here. Efficient consumer response (ECR), category management, supplier management, automated warehouse management, etc. are all being practiced or are under planning in this industry. In fact, barcoding of products was first started in the grocery industry.

The most important issue in a food enterprise is to provide fresh items on the shelf of the store so that the customer can find them easily when he or she needs them while maintaining the minimum possible inventory throughout the enterprise. It is also important to replenish the items as quickly as possible. The pipeline in this industry is long, and considerable inventory is tied up as transit inventory. For this reason, the grocery industry is witnessing ECR initiatives in a big way. The components of ECR include paperless communication throughout the enterprise using Electronic data interchange(EDI) or the Internet; information sharing between the partners (sharing of the point of sale data between the retailers and the manufacturers is an example); continuous or demand-generated replenishment; flowthrough distribution using practices such as cross-docking and monitoring the flow of items by using barcodes and wireless networks; partnerships between stake holders; etc. As an example, fast-food chains procure all their meat from a single source, partner with and finance the potato growers, have automated their cooking hardware, control the variety of items served, have standardize the packaging, and tightly monitor the quality and service. They even have a division to advise on restaurant layout and construction. Several companies have practiced partnering and deployed IT to tremendous advantage.

Apparel Networks: In the early 1970's the American textile manufacturers, warehousing networks and distribution networks were all acting in isolation as separate businesses, probably each attaining a best-of-the breed reputation in its business segment. But they lost a substantial portion of the market share to Asian businesses. They were delivering products to their customers while holding huge inventories.

This industry has since then seen several initiatives. The turnaround for the American apparel industry began with the initiative called quick response manufacturing (QRM), spearheaded by DuPont. Two value delivery processes are critical in the fashion-dominated apparel industry: one is garment design, and the other is a highly responsive supply chain. But in the 1970's the apparel supply chains were almost a year long and were very slow. Through the QRM initiative, the leaders of the American apparel industry have forged alliances to cut down the lead time and inventory. The QRM initiative involves sharing of the data and information among partners. The point of sale data from the retailers is transmitted to the manufacturers, and they in turn share their scheduling information with their suppliers. Information sharing has reduced the inventories, the lead time, the markdowns and the stock-outs. The textile enterprises have become highly competitive using two innovations: interorganizational partnerships and information sharing. AMTEX is an American initiative—a partnership formed between the fiber, textile, apparel, and garment manufacturers—with the goal of enhancing the competitiveness of the U.S. textile industry.

Benetton, the Italy-based retailer and manufacturer of garments, ships about 100 million items each year to 10,000 stores in 100 countries. A global information system links stores, sales agents, distributors, and Benetton. It has linkages with 400 small garment manufacturers who are the suppliers. The designs are done by Benetton using CAD workstations. The company also practices postponement strategies, i.e., the assembly of the final product is postponed until the customer is identified. For example, the garments are not colored until the seasonal trend is known. Benetton has developed fast-dying techniques whereby the garment is colored rather than being made from colored yarn. The company has a financial stake in all its supplier companies. Benetton production networks are very similar to those of Toyota.

There are several other examples of manufacturing enterprises in operation. Nike is a worldwide marketer of sports clothing and footwear. The company manufactures in Southeast Asia and markets in the U.S. and Europe, outsourcing all activities except product development, distribution, and sales. High technology products such as PCs, communications equipment, disk drives, deskJet printers, audio systems, and DVDs are manufactured and sold by enterprises. Here again, the product development and supply chain processes are very important. The disk drive manufacturer in Singapore sources PCBs and other electronics locally but sources other components from Japan and the U.S. The assembled drives go to the U.K. or the U.S.A. Similarly, the DeskJet printer is a high-volume product of the Hewlett-Packard Vancouver plant. Here again, most of the production is distributed overseas. The process industry also supplies a large number of capital-intensive enterprises. The oil industry has a long supply chain and rolls out a large number of new products. The pharmaceutical Industry has several big players, includ-

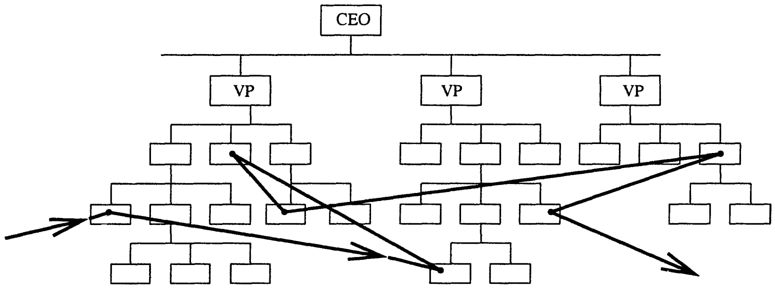

Figure 1.3. Typical work flow through a functional organization

ing Glaxo-Wellcome, where product development times are in decades and global distribution and marketing are crucial for survival. Several new innovations involving DNA, gene cloning etc. are on the table in this industry. It is expected that gene commerce will overtake all others in the next decade.

2. MOTIVATION AND APPROACH

In this book, we are concerned with integrated planning and coordination of the activities of the companies involved in value delivery to the customers. Thus, we are interested in the higher layer that plans and coordinates the business processes of the companies. The individual companies can use their own methodologies to execute of their part of the deal.

To further highlight the importance of our approach, we consider two illustrations:

1. When companies were holding huge inventories to hedge against uncertainty, and communications were paper based, manufacturing enterprises were weakly coupled. The performance and optimization studies on the constituent subsystems were used to obtain near optimal performance measures for the integrated system. In this way, organizations focused their efforts on making effective decisions within a facility or a function, thus reducing the complexity of the decision-making process. But now the situation has changed. Manufacturing enterprises are tightly coupled due to use of integrative information technologies and reduction or total elimination of inventories. Total systems analysis and optimization are necessary to define, determine, and improve performance.

2. In actual practice, a customer order goes through various functions such as order processing, suppliers, manufacturing, warehousing, trans-

port, accounts, and service (see Figure 1.3). Although individually all the functions work well and have locally optimized their operations, the customer order takes a long time to get processed, resulting in customer dissatisfaction. One of the reasons for this delay is that performance measures are defined and optimized for each function within an organization—manufacturing lead time, flexible manufacturing, supplier quality, logistics efficiency, number of orders for sales, responsiveness of distribution, etc.—but not for the entire value delivery process. It is known that functional optimization leads only to suboptimization of the total system. To see this, suppose sales are measured on the basis of the order bookings and maximize the orders booked; distribution dispatches items based on full-loading of trucks to maximize efficiency; and manufacturing is lean and mean with low lead times and high throughput. In isolation, all these functions are performing optimally, but since the activities are not defined and coordinated as a process, customer dissatisfaction and delays are inevitable. This is because manufacturing produces large batch sizes to maximize throughput, irrespective of what distribution has to fill in for the customer. Distribution determines the shipment dates based on "truck load" rather than customer deadlines. If all the organizations, and all the functions with in each organization share information as well as same goals such as cycle time reduction, six-sigma quality, on-time delivery, etc. ,then the performance measures can be defined, measured, and controlled throughout the enterprise.

It is important to realize that end user customer satisfaction is most important. The customer converts the product to cash and profit. This means that the cost, lead time, and defects to the customer must be minimal. This outcome cannot be achieved unless all organizations and their functions work in coordination. Concentrating on minimizing the cost, lead time, inventory, and defects within a given company or trying to push problems such as inventory to either upstream or downstream partners may in the short term, improve that company's performance but not of the entire value stream, and thus will not improve value for the end user customer. It is important to realize that performance and benefits perceived by the end user are important and that the entire enterprise performance is vital in addition to the individual company's performance.

In spite of the existence of several high-profile enterprises in operation, there have been very few books or courses on this topic. Our book will fill this gap by providing a totally system-oriented analytical treatment of the manufacturing enterprises.

In this book, we consider a manufacturing enterprise as a bundle of value delivery processes such as customer acquisition, strategy formulation, new product development, order-to-delivery, supply chain process management, etc. We present an integrated approach to manufacturing enterprise analysis and design by first decomposing it into value delivery processes and then designing the critical business processes for improved performance. We define and determine various performance measures by analyzing the business processes. This is a new viewpoint and has the potential to reveal opportunities for orders-of-magnitude improvement in performance attributes such as customer service, cost, flexibility and delivery time.

This book can logically be divided into two parts. The first part, consisting of chapters 2-5, focuses on generic value delivery processes that arise in a manufacturing enterprise, their performance measures and measurements, appropriate organization structures and redesign of the business processes to meet specifications on lead time, defect levels, etc. In the second part, three important value delivery processes—new product development, order-to-delivery, and supply chain processes—are studied in detail. We may mention that these three processes and their performance form a major portion of the winning criteria for the 1997 Malcolm Baldrige U.S. National Quality Award [24].

2.1 PART 1: FOUNDATIONS

In chapter 2, we first survey the history of manufacturing systems from the point of view of the changing basis of competition. We define a manufacturing enterprise and describe its subsystems in section 2.2. In section 2.3, we introduce the concept of a business process and also describe the decomposition of the manufacturing enterprise as a collection of value delivery processes such as new product development, production, supply chain, order to delivery, etc. In section 2.4, we identify the core, support, and managerial processes of an enterprise. We also describe some typical processes in section 2.5. We identify in section 2.6 the characteristics of a well-managed process. Later, in sections 2.7 and 2.8, we provide the linkages between the business processes, and the core competencies of the organization. Thus this chapter is foundational and is intended to provide a conceptual understanding of various issues connected with the analysis of manufacturing enterprises.

Management of the enterprises is an important issue. The trend is to move away from vertical hierarchical organization to process centered horizontal structures or trust-based networked organizations. In chapter 3, we present functional, product, matrix, process, and network organizational structures and compare their features.

Chapter 4 is a very important chapter. In section 4.1, we point out the deficiencies of function-based performance measures and make a case for the process-based performance measures. We define and develop the conceptual underpinnings of the seven process performance measures: lead time, variation, capacity, reliability, cost, flexibility, and asset utilization. We provide many numerical examples to illustrate concepts like process lead time, total cost, and process variability reduction.

In chapter 5, we define four fundamental process measurements: time, cost, defects, and variety. From these four, we show how all the process performance measures defined in chapter 4 can be computed. In section 5.1, we first establish the link between competitive strategy, the critical business processes, and the performance measurements. We briefly introduce in section 5.5 various types of benchmarking, best practices, enablers, and the benchmarking process. We present, in sections 5.6 and 5.7, the fundamental principles behind the design of high-performance value delivery processes. Before embarking on such a redesign exercise, it is important to determine the state of the process based on some accepted rating criteria. We identify five process levels (level 1 to level 5): They are chaotic, effective, efficient, best-in-class and world-class. Starting from the competitive strategy, we present a systematic method for design/redesign of value delivery processes and also transit from one level to another.

In summary, readers who go through chapters 2–5 will gain expertise in decomposing a manufacturing enterprise into business processes and determining which of these are important for gaining competitive advantage. Further, they can also define and determine the performance measures for these processes and can redesign the organizational, technological, and human resource elements of the enterprise to gain superior operational and financial performance.

2.2 PART 2: SPECIFIC BUSINESS PROCESSES

In chapters 6–8, we discuss in detail the new product development, order-to-delivery, and supply chain processes respectively. All these three processes are interdependent; issues such as design for logistics, design for supply chain management, and design for minimum total cost of delivery make the three processes closely intertwined (See Figure 2.11). This is the reason why we study all of them together in one book. In fact, there are several books in the literature dealing with individual processes particularly new product development and supply chain processes.

Chapter 6 deals with the new product development process. We describe in detail the product creation process and the organization structure suitable for product development. Also we define the performance measures: time to market and break-even time. A highlight of this chapter is a section on the effect of type I and type II errors on the reliability of the stage-gate process and computation of the probability of a successful product launch.

In chapter 7, we deal with the order-to-delivery process, which is a business-to-business or business-to-customer process. This process is most influenced by Internet technology. We flowchart the process and discuss automatic methods of controlling the order-to-delivery process. We present several numerical examples in this chapter to illustrate the computation of total process cost, reliability, and variation. We also present best practices such as vendor-managed inventories, supplier scheduling, interorganizational information systems, and supplier-vendor coordination.

Chapter 8 deals with the supply chain process and is another very important chapter. The operational excellence of supply chains is now recognized as the biggest opportunity for profitable growth. This chapter is designed to give the reader insights into how to achieve this operational excellence. We first define the supply chain process and discuss how to achieve competitive advantage. Also, we cover the following topics: supply chain configuration, effective supply chain management, influence of product design on the supply chain process, organization structure, and benchmarking. The section on effective supply chain management includes management of interfaces between supply chain partners, combined product-supply chain process design, and information systems. We define various performance measures such as lead time, cost, variation, and flexibility for supply chain processes in section 8.5.

In summary, we present in this book all the analytical aspects of the value delivery processes in a manufacturing enterprise. The material presented in this book is foundational in the sense it presents the concepts, methods and techniques and can be used for building analytical or simulation-based performance evaluation packages. The process orientation in manufacturing networks is ahead of the theory, as can be seen from the large number of ERP implementations (SAP, BAAN, and People-Soft) throughout the world. This book presents the theoretical basis for developing a generalized ERP for global manufacturing networks.

The discussions in this book also provide the foundation for exploring several topics with a research flavor, such as developing stochastic models for performance evaluation and mathematical programming models for facilities location and scheduling. The research on mathematical modeling of business processes is still in the early stages. Our description of various process levels in chapter 5 could also be an interesting subject for further study. For a computer scientist, specification and verification of all the processes using business objects is an interesting area. Developing IDEF models for the supply chain process and the order-to-delivery process could yield very interesting and simplified ERP software.

3. CONCLUSIONS

In this chapter, we have provided an overview of manufacturing enterprises. They are a natural outgrowth of the advances in IT, global logistics, and the political and economic changes around the world. We also described briefly the auto, food, and apparel networks. Basically, enterprise formation is very natural and we are going to see more and more of enterprises in the future. It is important, therefore, to have in place the tools for analysis and design of manufacturing enterprises. Our objective in the following chapters is to provide such tools.

4. BIBLIOGRAPHIC NOTES

As we mentioned in the beginning of this chapter, the concepts of division of labor and core competencies are at the root of the formation of the manufacturing enterprises. A group of companies, each with distinct competence, form a network to deliver value to the customer. Figure 1.2 summarizes the roles of logistics and information technologies in the formation and growth of manufacturing enterprises. Gomes-Casseres in his book [9], as well as in a Harvard Business Review article [10], has echoed the same point of view. There are several books and articles on types of company networks and the strategy of network formation [75]. The articles by Womack [99] and Viswanadham et al. [93] have also dealt with enterprises and their properties. In the following chapters, we undertake much deeper studies of manufacturing enterprises by defining the performance measures, measurement systems, and methodologies for their design. As we mentioned earlier, the kind of integration we are seeking in an enterprise (as depicted in Figure 1.2) is different from the data integration achieved using ERP packages. A review by Davenport [21] provides a critical overview of the ERP and the benefits. See also [32] and [15]

Chapter 2

ARCHITECTURE OF A MANUFACTURING ENTERPRISE

Learning objectives

1 Understand the history of manufacturing from the point of view of the changing basis of competition and evolving management themes.

2 Describe subsystems and building blocks in a manufacturing enterprise.

3 Describe the business process concepts that are fundamental to deliver value to the customers.

4 Describe some important value-delivery processes in a manufacturing enterprise.

5 Enumerate and explain the characteristics of a well-managed process.

6 Explain the terms *core competencies* and *core capabilities* and relate them to business processes.

Recent years have seen the emergence of megamanufacturing systems, also called enterprises, that are integrated often globally, across continents. Through the use of information technology products such as electronic data interchange (EDI), the Internet, intranets, and other evolving communication techniques, large amounts of structured information can be transmitted securely and reliably over long distances. This has provided an impetus to locate product design centers far away from headquarters of companies. Development of high-speed logistics and fast customs clearance practices have led to the distribution across the globe of various facilities of a manufacturing enterprise in order to minimize either the total delivery cost or the delivery time. Thus, hardly any product worth its name is currently designed, manufactured, and sold in the same country.

Multinational companies have had a long history, but they have also had a different emphasis. Typically, they started out as strategic business units (SBUs), each serving a particular market. Each SBU, either operating in different geographical locations or manufacturing different products, is self-contained and has independent functional units such as R & D, manufacturing, finance, marketing, etc. What we are currently witnessing is globalization at the SBU level, i.e., each of the functions of the SBU is now located in a different country. Coordination of the functional units is very important but very complex and difficult.

The motivation behind global or international manufacturing is manifold. One motivation is to exploit the potential for cheap labor. Another is to be very close to emerging markets. Yet another is to create the ability to access knowledge from all over the world to design, produce, and deliver products to the world markets by sharing advertising and marketing strategies. The main assembly plant in Singapore, for example, procures components from the U.S., Japan, and its own neighboring countries and supplies the final product to U.K. or U.S. manufacturers. With the liberalization policies of most countries and lowering of trade barriers, we will see more and more internationalization of manufacturing activities. The coordination of the activities of different companies located in different countries and manned by people with different cultural backgrounds in the presence of volatile fluctuations in foreign exchange markets is a challenging problem.

The main goal of this chapter is to provide a methodology for analysis of geographically distributed, tightly coupled manufacturing enterprises. We do this by decomposing the megasystem into a collection of business processes, a concept borrowed from the total quality management (TQM) literature. This decomposition of an enterprise into value-delivery processes that start with a customer request and end with customer satisfaction is fundamental to our analysis.

We first provide a precise definition of a business process and consider its decomposition into work processes and various types of interfaces. We define the performance measures associated with a business process and also characterize a well-defined business process. We identify various types of customers and competitors for a given business. Some typical examples of important value delivery processes in a manufacturing enterprise are given. We link the concepts of core competencies and core

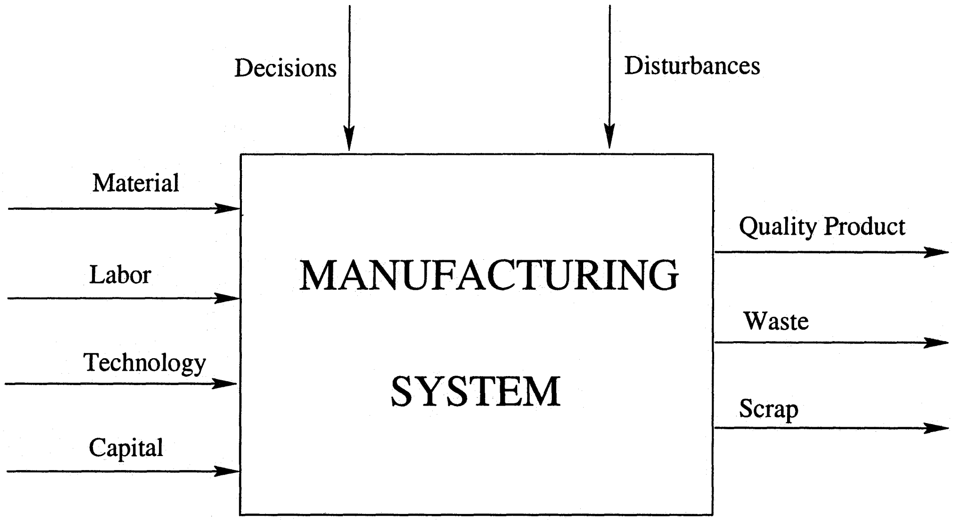

Figure 2.1. Input–output model of a manufacturing system

capabilities of an organization to the business process concept. Thus, this chapter forms the foundation for the following chapters in this book.

1. HISTORY OF MANUFACTURING

A manufacturing system can be represented by the input-output model shown in Figure 2.1. Here the inputs are shown as material, labor, energy, and technology. The raw material is converted into the final quality product. Labor, in the form of blue-collar and white-collar workers, is needed for designing the product, operating the equipment, loading and unloading the workpieces, and inspection. The recent trend is to automate most of these functions and to elevate the role of the human operator to one of a monitor and supervisor.

Manufacturing technology represents the sophistication and flexibility of the equipment and the extent of material flow integration and information integration built into the system. A manufacturing system can be manual or fully automated; highly dedicated or fully flexible; a collection of isolated machine tools or a fully integrated production system. The technology also determines whether the economies achieved are of the scale type or of the scope type. The mass production of a narrow range of products leads to economies of scale, while low-volume production of a wide variety of products leads to economies of scope. It is the level of technology that determines whether a given system can economically operate as a mass production system, job shop, batch production system, or a fully flexible machining system.

The manufacturing system produces three outputs: the completed workpiece or the quality product satisfying the customer requirements; scrap; and waste. Scrap is an inevitable by-product of metal cutting. Waste is of two types: the first is represented by tools consumed, products rejected during inspection, etc., and the second is generated by the use of system resources for non-value-adding operations. Of course, scrap and waste are undesirable outputs and should both be minimized [92].

There are two more inputs to a manufacturing system that are important and crucial for its performance. The first one is the set of decisions made at various levels of the hierarchy (long range, medium range, and short range) regarding products manufactured, equipment purchased, plant layout, sequencing and scheduling of parts, loading of parts, etc. These decisions are very important, and Viswanadham and Narahari[92] present tools for evaluating by analytical means the various decisions. The second kind of inputs are disturbances, including government action, foreign exchange and market fluctuations, competition, equipment failures, and labor problems.

Manufacturing has gone through successive periods of great changes. New materials, such as plastics, ceramics, and composites; new technologies, such as computer aided design (CAD), flexible manufacturing and inspection, and the Internet; new techniques, such as kanban and just-in-time (JIT); new bases for competition, such as cost, quality, time, or core competence have all been at the root of these changes. Currently, global competition, demanding customers, liberalization that provides a congenial environment for foreign direct investment, regulations on environment, emergence of common markets, disintegration of large states, volatile exchange markets, etc. have made manufacturing a more complex function. Customers want it all: low cost, low defect rates, high performance, on-the-spot delivery and maintenance-free long life. To meet such demanding customer needs while surviving in hostile environments is a complex problem involving technology choice, partnership, and effective management.

Several companies around the world have gone through the phases of high growth, decline, restructuring, steady growth, etc. Several revolutions have occurred in the manufacturing arena: just-in-time, total quality management, time-based competition, etc. In this section, we survey the history of manufacturing, with an emphasis on the changing basis for competition and also on the organization structure.

1.1 MASS PRODUCTION SYSTEM

In the early twentieth century, Henry Ford revolutionized manufacturing with the introduction of the transfer line for mass production. Complete and consistent interchangeability of parts and their assembly on a moving, continuous assembly line gave Ford tremendous advantages over competitors. Adam Smith's specialization and division of labor were the key concepts based on which both blue-and white-collar jobs were organized. Unskilled laborers were trained quickly, and supervisors, industrial engineers, and quality inspectors ensured consistency and accuracy. F. W. Taylor invented scientific management, which made work more specialized, precisely defined, interchangeable, and optimized. The white-collar jobs (so-called back-office work) were also broken down into small, repeatable tasks that were mechanized and automated. Alfred Sloan, as the President of General Motors, was responsible for developing the easily scalable, pyramid organizational structure by creating decentralized divisions managed by specialists and coordinated by corporate headquarters. The mass production system was thus born, and the fathers were Ford, Sloan, and Taylor [99].

The mass production system is characterized by assumptions of constancy and predictability of demand and the logic of economies of scale and division of labor. Characteristics of factories based on mass production systems include dedicated machines, long production runs, narrow product range, low-skilled workers, command and control management, vertical internal communication, high volume, sequential product development, high inventories, make-to-stock policies, limited communication with the customer, large number of suppliers and dealers, mass marketing, etc. This mass production paradigm has influenced generations of industrialists and has generated wealth for many Western nations for over four decades. Also, we can see that stable, homogeneous markets, standardized products with long life, dedicated mass production facilities, command and control organization structure, low-skilled labor, and long production runs are all mutually reinforcing [68].

1.2 MODERN MANUFACTURING SYSTEM

The face of manufacturing has changed. Dedicated equipment has been replaced by flexible machine tools and programmable multitasking production equipment [92]. Use of such equipment has reduced changeover times, and small batch size production has become economical. Small batch sizes have shortened production cycles and reduced work-in-process and finished-goods inventories. Advances in computers and communications have made possible direct contact with customers, suppliers, and dealers. Speedier transport and communications have resulted in global competition. These changes have created customers who make relentless demands in quality, service, and price, in contrast to the gentle, grateful, loyal customers of Ford and Sloan. Toyota, under the leadership of Ohno, perfected the lean manufacturing system with its emphasis on just-in-time deliveries, quality, and the planning of production and product development jointly with suppliers and dealers. Manufacturers now use point-of-sale information to determine the production schedules. There is a general strategic emphasis on speeding up all aspects of a firm's operations: shorter development cycles, quicker order processing, freedom from defects and speedier delivery. Make-to-order and almost instantaneous delivery has become more a rule than exception. Frequent product improvements and new product introductions, combined with the need for speed, have resulted in the use of cross–functional teams for design and manufacturing.

We see thus that Adam Smith's world has changed completely. Companies created to thrive on the mass production paradigm cannot succeed in the world of fast-changing customer demands, short product life cycles, changing technologies, fierce competition, and fluctuating exchange rates.

1.3 TYPES OF COMPETITION

The manufacturing world has gone through several periods of competition but with different emphasis during each period. The mass production era saw low cost as the competitive advantage. Then the focus shifted to high quality. The oil crisis in the early 1970s brought to the fore the importance and advantages of customization and flexibility. Basically, at the root of these advances are the automation technologies and synchronized organization of work, which provide variety and quality at only a marginal excess cost. Again driven by technology, this time by computer and communication technologies, and liberalization of economies around the globe, time compression has become an important issue. It is an obvious fact that unless a company excels in a few technologies that everyone wants and is supplemented by management and marketing skills, it cannot assume a leadership role. This fact has lead to the principle of competence-based competition. A recent change, possibly the most influential in terms of work reorganization and orders of magnitude benefit, is the process-based reorganization of work flow using information technologies. Basically, the manufacturing world is at a point now where operational improvements and redesign of work flow using technology, as well as political and geographical proximity to the customer, provide competitive advantage.

Cost-based competition: Henry Ford reduced the cost of automobile so that it was within reach of the economic middle class by streamlining the work flow and automating the transfer line. Ford thus became the pioneer of low-cost mass production. However, Western mass production had several wasteful ills, such as large inventories, storage, inspection, etc. The lean production system eliminates waste by using the just-in-time concepts. Waste, defined as any non-value-adding activity, such as storage, inventory, transport, inspection, setups, machine downtime, repair, etc. should be either eliminated or minimized. Toyota has relentlessly attacked all forms of waste: reduced setup times, given importance to "doing it right first time", eliminated inventories, introduced kanbans to trigger production, and used load-leveling methods to smooth the work flow. Toyota's methods of cost reduction during the energy crisis years of the 1970s made the company the leaders in world-class manufacturing. Also the new concept of target costing (i.e. price is not cost plus profit rather cost is market price minus profit) has been introduced [68].

Quality-based competition: The 1980s have seen the total quality management (TQM) revolution spreading from Japan to the West. TQM strives for a totally integrated effort towards continuous improvement in every function of the company: design, production, marketing, and sales. The ultimate beneficiary of TQM activity is the customer, who receives high-quality products/service at a reasonable cost. TQM involves process control rather than product testing. The aim is to produce zero-defect products through statistical process control and coordinated testing at input, production, and final delivery points. Company-wide education and training, as well as management commitment to design and implementation of an effective quality and performance measurement and reward system, are essential for the success of TQM programs [69].

Flexibility-based competition: Flexible automation involving numerically controlled machines connected by an automated material handling system and local area networks is the next important development [92]. Computer aided design and manufacture have made possible the production of a variety of products at mass production economies. Consistent quality and manufacturing flexibility are two distinguishing features of factory automation. Together with factory automation, production planning and control systems such as MRP-II also emerged. Managing flexible resources to make small-lot, faster deliveries to customers at the time and place of their choice is the main issue of flexibility management.

Time-based competition: Time-based competition is the issue occupying the minds of manufacturing executives even today. Customers want it all—price, quality and faster delivery—and hence firms must shrink the time from conception of new products to the consumption of these products by customers. Time reduction provides an important leverage not available in cost-reduction strategies. By removing time from their operations, costs are automatically reduced. In manufacturing industries, time compression requires that attention be given to all activities, including order processing, scheduling, distribution, and customer service i.e., time compression should include all activities, not just a single production function. On average, a product spends only 2%-10% of the time and 20%-30% of the cost in manufacturing; the rest of the cost and time goes into other activities. Time-based competitors concentrate on strategic business processes such as the supply chain process and the order-to-delivery process and remove all non-value-adding activities to compress the lead time [86].

Competence-based competition: A new way of organizing businesses based on core competencies is emerging in contrast to the product-centric view currently held by most companies [72]. Here, businesses nurture a bundle of competencies by developing skills, and capabilities that in turn allow the company to market a group of world class products. Core competencies developed over time by integrating the skills and resources in an organization will give the company a sustainable competitive advantage. Honda's know-how in engines, the logistics and inventory management of Federal Express, and Sharp's competencies in flat-screen displays have allowed these companies to manufacture a variety of products that appear diverse. Many companies are turning to the competence-centric view and are disinvesting in non-core sectors of their businesses.

Process-based competition: A recent trend is to view a manufacturing enterprise as a bundle of business processes delivering value to the customers rather than as a sequential arrangement of functions. By identifying and improving core business processes such as new product design and development, the supply chain process, the order-to-delivery process, etc., companies could get orders-of-magnitude more benefit than with function-based performance optimization [20]. Indeed, this book develops a theory using which companies can leverage business processes to gain competitive advantage by coordinating the range of activities along the core business processes.

We thus see that the logic of modern manufacturing is rooted in time- and competence-based competition, process management, flexibility, and scope economies.

2. THE MANUFACTURING ENTERPRISE

We now present an integrated view of a manufacturing enterprise. Traditionally, manufacturing meant just the factory floor, and during the 1970s and 1980s most efforts attempted to improve technologies (FMS, CIM), practices (JIT, TQM, TPM), and effectiveness. These efforts did not result in the expected gains because of two reasons: (i) most efforts were directed at redesigning administrative processes such as accounts payable rather than value-creating processes such as new product development or order fulfillment; and (ii) redesign efforts were limited within organizational boundaries, leaving intact the inefficient interorganizational interfaces. Further reasons for inefficient performance include the functional management structure, the function-based performance measurement and reward system, and lack of attention to interfaces between functions and between organizations. In this chapter, we deal with foundational issues concerning process-oriented organizations.

We now consider the description of a manufacturing enterprise. First we offer the following definition.

Definition: A *manufacturing enterprise* is a network of independent companies, possibly in different geographic locations, forming a strategic alliance towards the common goal of designing, manufacturing, and delivering right-quality products to customer groups faster than other alliance groups and vertically integrated firms.

Enterprise management differs from traditional contract-based cooperation between companies for procurement, manufacturing, logistics, and product delivery in at least three ways: (1) the enterprise acts as an interdependent system but not as a set of isolated independent companies; (2) all members of the enterprise share the same vision, mission, goals, and destiny; and (3) all members have a vested interest in the ultimate success of the enterprise by meeting the needs and expectations of the customers, and thus decisions are made to benefit the entire enterprise rather than the individual companies. Mutual trust and shared destiny are needed to reap the benefits of integration and coordinated planning. The interorganizational support systems are designed to maximize the sharing of the information, resources, and expertise. In this book, we assume that companies trust each other and develop methods of analysis and design of integrated, cooperating enterprises.

Various subsystems of a manufacturing enterprise are shown in Figure 2.2. These include the following.

Suppliers: Suppliers provide the subassemblies, components, or raw materials just in time to the factory floor and play a critical role. Their flexibility, agility, defect control, and organization structure should all be compatible with the goals, objectives, and vision of the manufacturing

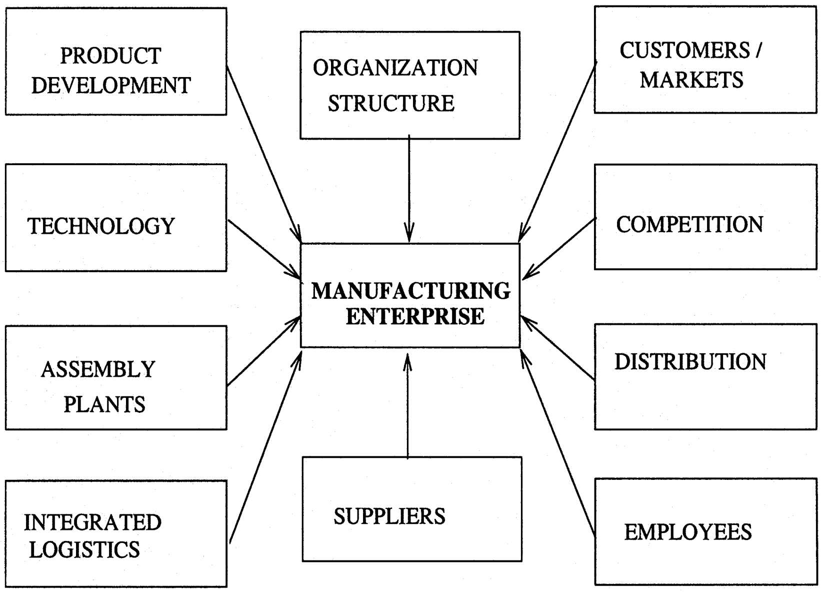

Figure 2.2. Subsystems in a manufacturing enterprise

enterprise. For example, suppliers of companies that frequently introduce new products should also have similar capabilities. Having only a few loyal suppliers and effectively communicating the product and process designs to them are some of the best practices that the Japanese have taught the rest of the world.

Product development: Being fast enough to be first in the market, with the right product, is worth more to the prosperity of most businesses than any other single manufacturing function. Aggressive global competition, emergence of new technologies, opportunities for high value of quality-of-life products, and legislative and environmental requirements are some of the drivers for new product development. Concurrent engineering, integrated product-process design, multifunctional team management, and customer voice incorporation are some of the enabling solutions for effective product development

Assembly plant: A flexible, low-inertia assembly factory responding quickly to design and demand changes of existing products and also to the need to produce new products is mandatory. The layout, the machines, the work force, and the instrumentation and control hardware and software are important elements of the factory floor. Recent trends include flexible manufacturing systems under computer control using client server architectures and agent-based scheduling strategies. Production planning and control packages (MRP-II, ERP) are also used.

Integrated logistics: Rapid response logistics to store and move raw materials, components, work-in-progress, and finished goods throughout the enterprise is another prime component of the manufacturing enterprise. In order to maintain just-in-time deliveries, on-time, to global customers and to make-to-order final products from subassemblies produced in several geographic locations, an agile logistic system that is both mix and volume flexible is essential.

Distributors: The ultimate customer is served through the distributors, which play a crucial role in marketing and selling the product to the customer. Distributors also provide feedback on customer voice and expectations. Direct marketing, telesales, and strategic alliances between distributors and manufacturers are some of the issues here. The architecture of the distribution system is also an important issue.

Customers: Customers are the ultimate users of products and services. They use the final output and generate revenue. Incorporating customer voice into the product design, delighting the customers with a smooth purchase process, ensuring benefits and value-delivery to the customer, analyzing customers complaints and defections, and removing defects in the process are mandatory exercises.

Organization structure: The design of a highly responsive organization structure through which information and decisions flow very quickly and which provides effective communication with other stakeholders is critical for success. The tendency nowadays is to replace the traditional bureaucratic organizational structure with flat process team-based structures. Management of end-to-end customer business processes such as order-to-delivery, new product and process development, etc., using multifunctional teams headed by the process owner is also a popular paradigm.

Employees: Human resource development involving motivation, training, retraining, rewards, and a safe work environment is an important issue. In certain domains, such as software, employees make a critical difference to the company.

Competition: We have seen in Figure 1.1 that competitors serve the same markets, with identical products generated drawing upon the same pool of resources under the same environmental regulations. Staying close to competitors, benchmarking their best practices, and winning their core customers are strategies for survival. Competitive intelligence is currently an art and involves inferring from publicly available data the methods and practices that are followed by a company.

Technology: Technology is the factor that pervades all the above subsystems. Successful manufacturing companies use advances in technology to introduce new products, to run the factories more efficiently and also to increase their customer reach. Information technology has had a tremendous impact on the control, instrumentation, and communication fields and also in the consumer electronics area. New materials technology can also provide a crucial competitive advantage. Information technology changes the way businesses are conducted [91]. The Internet, EDI, electronic funds transfer, and e-mail have made several traditional systems obsolete. CAD systems have speeded up the design and retrieval process, and CIM has enabled flexible manufacture of high-quality products. Management should appreciate the value of these technologies and integrate them into the company's activities through effective use of R & D.

It is very important to note that the ultimate goal of an enterprise is to make profits for its shareholders and to provide high-quality products packaged with value added services, to its customers. The enterprise operates in an environment with varying cultures, foreign exchange (FE) fluctuations, and environmental regulations. As shown in Figure 1.1, the markets in which the enterprise operates are also a playing ground for the competitors. It is essential that an enterprise differentiates itself from competitors by selling products with value-added services. The differentiation strategy has to pervade the enterprise, i.e., all its constituents.

3. BUSINESS PROCESSES

We defined an enterprise and identified its constituent subsystems in the previous section. In this section, we define the business process and introduce related concepts. We also decompose the enterprise horizontally into a number of value-delivery business processes with a view to model, analyze, and redesign them for improved performance.

3.1 FUNCTIONAL VS. PROCESS-CENTRIC ORGANIZATION

Traditionally, manufacturing enterprises and their constituents have been viewed as a sequential arrangement of functions such as design, manufacture, R & D, marketing, finance, etc. The recent view has been to consider manufacturing systems not in terms of functions, divisions, or products but as a collection of value-delivering processes. Functional or hierarchical structures typically present responsibilities and reporting relationships, whereas process structure is a dynamic view of how the organization delivers value to the customer.

Hierarchical organization structures based on functional divisions have several problems [42]. Each function works independently as a silo, and hands its output over the wall to the next function. Turf wars and the dominance of functions such as finance and marketing over others result in slow progress of work through the system. Lack of proper communication between functions results in work going back and forth with long iteration periods (see Figure 1.3). The hierarchical arrangements of the functions require that decisions be sought from the top so orders inch up and down the hierarchy ladder. Thus, one finds that the ratio of cycle time to processing time is enormously large and most of the time is spent in non-value-adding move, wait, and information collection. Despite the above criticisms, managements have for sometime recognized the advantages of grouping work on a functional basis either by skill, specialty or work activity. Grouping by function enables resources to be pooled among different work activities. It promotes specialization, transfer of skills, and efficient management of equally skilled personnel. That is why most organizations are still functionally structured.

In contrast, the process perspective views a manufacturing enterprise as a collection of business processes that deliver value to the customer by using cross-functional teams in a coordinated manner [20]. Examples include the new product development process, the supply chain process, and the order-to-delivery process, to mention a few. Process thinking originated with the quality movement, wherein the emphasis is on process control and teamwork rather than on product inspection and a command-and-control hierarchy. A process approach to business implies heavy emphasis on how work is done rather than a focus on specific products (see Figure 2.3). The work flow in a multiorganizational enterprise is shown in Figure 2.4.

3.2 DEFINITION AND CHARACTERISTICS

The value-delivery to the customer in an enterprise starts with an order from the customer and ends with customer satisfaction. This process consists of a series of activities, each performed by various subsystems of the enterprise. Thus some of the activities can be executed in parallel and some sequentially. Also, the activities could be executed either at the same place or in different countries. Thus the process consists of an ordered set of work processes distributed both in time and space and executed concurrently or sequentially. We now formally define a business process [20].

Definition: A *process* is a structured, measured set of activities ordered in time and space, designed to produce a customer-desired output.

Clearly, structured processes are amenable to measurement in a variety of dimensions: cycle time, defects, variability, variety, cost, etc. Examples of some typical processes include the order-to-delivery pro-

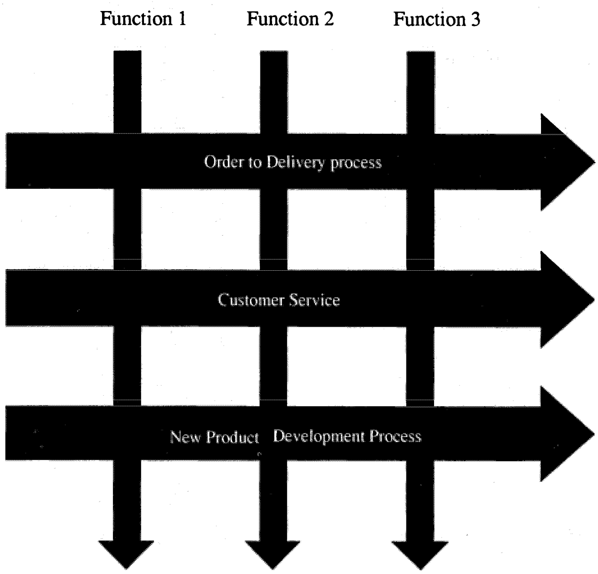

Figure 2.3. Functions and business processes in an organization

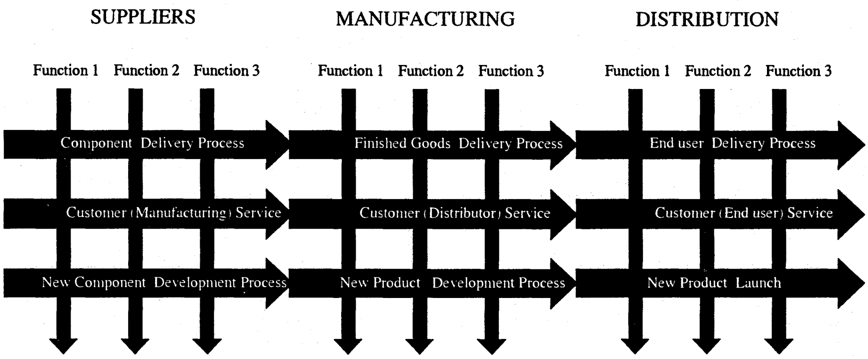

Figure 2.4. Business processes in a multiorganizational, multifunctional enterprise

cess, the new product development process, the production process, etc. A process perspective is a horizontal view of the manufacturing system that cuts across the organization, with product inputs at the beginning and customers at the end. Subscription to this view means deemphasizing the functional view of the business. The primary issue in vertical organization is the ill management of handoffs or interfaces between functions. Process orientation either eliminates handoffs or coordinates them effectively. Processes are typically cross-functional, as shown in Figure 2.3. Some processes, such as the supply chain process, are cross-organizational, as in Figure 2.4.

Processes can be minor or major. Examples of minor processes include answering a customer compliant or repairing of a failed machine. Major processes could include a new product development process, a supply chain process, an order-to-delivery process, etc. Major processes could be split into several smaller ones, but for purpose of redesign, large inclusive processes provide greater potential for radical benefit by improving the interfaces.

A process is essentially a mechanism for creating outputs that have greater economic value than inputs in a systematic way. As the work-piece or job moves through various work processes, a transformation occurs that adds value to it. The transformation could be physical, as in the case of construction, fabrication, and assembly; locational, as in moving goods from the warehouse to the point of use; transactional, as in banking and insurance; or informational, as in data processing and financial planning.

Thus, we find that products are produced and services are performed by means of processes. Businesses are composed of several interrelated processes that should be efficient and effective in order to gain competitive advantage. Competition will be in terms of processes rather than functions. This means that it is not enough to be a world-class manufacturer of a dishwasher or a washing machine; the company must ensure that its product reaches the customer in time and that he or she loves the product in all respects: looks, features, performance, durability, usability, economy of resources, and a variety of other values.

Real-value-adding and non-value-adding activities: Value is defined from the point of view of the end customer. The business process is a coordinated set of activities. The activities may be real-value adding or non-value adding from the point of view of the end customers. Recording of orders, manufacture of the products, moving the product to the customer site, etc., are all value-adding. Many activities, such as inspection, review, storage, and movement, are non-value adding. Some activities are performed to satisfy other stakeholders such as the corporate board and the shareholders and may not directly benefit the end user. Such activities include preparation of financial records, maintenance of personal records, etc. The idea is to remove the non-value-adding activities and to minimize the cost of real-value-adding activities. Often, redesign of the process or a subprocess, and use of information technologies such as electronic data exchange will eliminate several activities and reduce the cost.

Reducing the cycle time of the process is one of the important design issues. If the cycle time is zero, i.e., if products are delivered as soon as ordered, then there is no need for inventories and forecasting. As the process cycle time increases, the delay in supplying the customer increases. If the customer lead time is less than the process lead time, one has to maintain inventories based on forecasts. The accuracy of the forecasts decreases as the planning horizon increases. One of the obvious ways of reducing cycle time is to eliminate the non-value-adding activities and redesign others to improve quality and reduce cycle time.

3.3 BUSINESS PROCESS DECOMPOSITION

We defined a process as an end-to-end set of activities that ultimately delivers value to the customer. Thus it consists of several subprocesses that in turn consist of work processes. These work processes may be in different functions or in different organizations, depending on the context. Thus a process may be within a function or may cut across functions within an organization or may cut across different organizations. In general, a process is cross-functional and cross-organizational. Figure 2.5 shows a block diagram representation of the process, clearly identifying the interfaces (also called as white spaces) between functions as well as organizations.

There are several ways of decomposing a business process. We find it useful to decompose it into various subprocesses and work processes as shown in Figure 2.5. A business process can be decomposed into organizational subprocesses, which are in turn decomposed into functional subprocesses. Each functional subprocess can be divided into work processes. The interfaces between organizations, functions and work processes are also subprocesses. Thus, there are four different types of subprocesses in a business process. We briefly deal with each of them now.

Work process: The work process is a value-adding activity with well-defined inputs and outputs, with someone responsible for it. Examples include machining at a machine center, transportation from one location to another by a truck, bill processing by a clerk, etc.

Interface between work processes: Interfaces are white spaces between work processes, and interface management involves documented procedures for transfer of work from one work process to another. Some of the procedures may be automated, as in the case of transfer of work-piece from one machine to another. Generally, work processes are within the same function, and hence management may not be difficult.

Functional interfaces: These interfaces are the procedures to be followed when the output of a work process in a given function in an organization is transferred to another in a different function in the same organization. Interfaces between design, manufacturing, marketing, etc., come under this category. These are smoothed out by using cross-functional

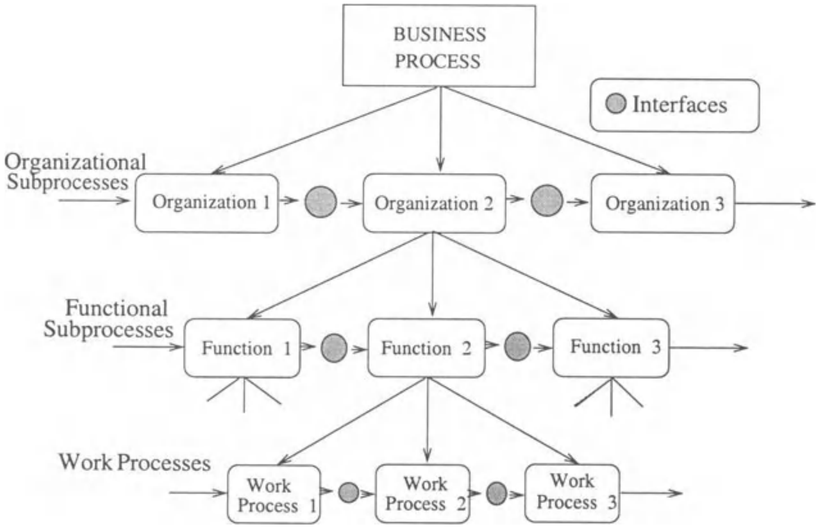

Figure 2.5. Business process hierarchy

teams to manage the subprocess in the organization and also by putting a measurement system in place that gives more weight to the contributions made to the process by individuals and functions. One of the biggest achievements of process orientation is recognizing the problems associated with functional interfaces and evolving procedures for managing them.

Organizational interfaces: These interfaces are again relationships, procedures, and activities performed when a process transits from one organization to another. These interfaces generally include the delivery subprocess of the vendor, the procurement subprocess of the buyer, and the logistics process of transfer of goods from vendor to buyer. Examples include relationships between a supplier and a manufacturer, a manufacturer, distributor and a retailer, and a distributor and a retailer. Here again, through certification and alliances one can smooth the interfaces and avoid all non-value-adding and time-consuming activities, such as selecting the suppliers through tendering; redundant activities, such as incoming inspection by customers and outgoing inspection by suppliers; financial guarantees; multisourcing for reliability reasons; etc. Through partnerships, one can avoid overhead costs and can smooth the work flow.

We make the point that interfaces and their management add substantially both to the cost of the final product and to the delivery time. Generally, organizational interfaces are unmanaged and functional in-

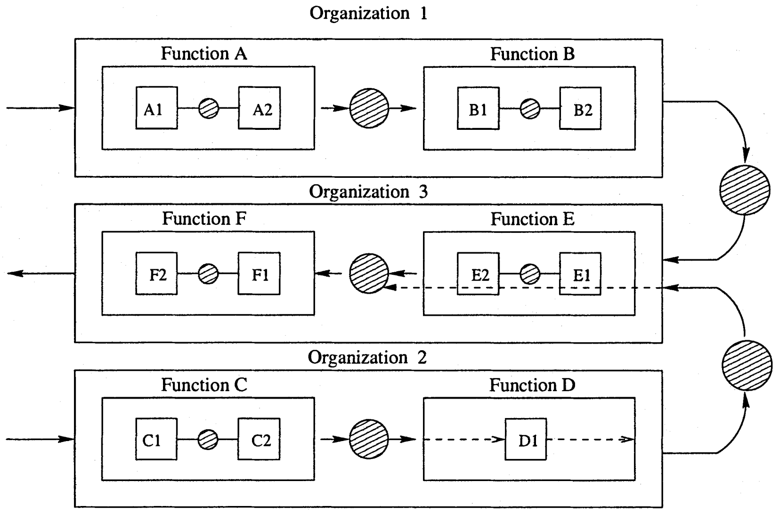

Figure 2.6. Example of a interfunctional, interorganizational business process with interfaces

terfaces are managed infrequently by higher levels of management. The management procedures, when they exist, are outdated. The prescription is to treat the interfaces also as work processes, and to monitor their performance by defining appropriate measures and ownership. The goal is to smooth the work flow and make it as continuous as possible. Figure 2.6 shows the work flow along with the interfaces for a business process that runs across three organizations, two functions in each organization, and one or two work processes in each function. Such a process arises in a two-supplier, one-manufacturer example. It is easy to see that the cycle time includes the interface times.

3.4 PROCESS EFFECTIVENESS AND EFFICIENCY

A process and the constituent work processes have clearly defined inputs and outputs (see Table 2.1). A process begins with a customer need and ends with customer satisfaction. The output of the process thus must meet the requirements of end customers in terms of defect rates, on-time delivery, product performance, and product variety. Also, the output of every work process should meet the input requirement of internal customers.

Thus in a process, customer interests, either internal or external, are represented both at the work process output level and at the process out-

Table 2.1. Inputs and outputs of business processes

Business process	Input	Output
Order-to-Delivery	Customer order	Delivery
Production	Procurement	Final product to distribution
Product development	Concept	Prototype
Human resource development	New employee	Trained employee
Strategy development	Inputs from markets and environment	Business strategy

put level. An important measure of the process is customer satisfaction with the output of the process.

Process effectiveness: Effectiveness is an indication how well the output of the process meets the requirements of the end customers and how well the output of every work process meets the requirements of the subsequent work process. Effectiveness measures the quality of the process. Typical lack-of-effectiveness symptoms include customer complaints, inconsistent output quality, long response times to complaints, no quality control program, and no monitoring and feedback control.

Delivery of complete order on time, every time is an indication of effectiveness of the process. To ensure that a process is effective, it is important to determine the customer needs and expectations and to describe them in measurable terms. Reliability, timeliness, responsiveness, cost, and performance are some of the measures the customers are looking for. In any case, it is important to treat the entire process from end to end and to control the organizational and functional subprocesses and their work processes so that the entire process is on target.

Process efficiency: Efficiency is a measure of how well the internal operations are performed and is often measured in terms of the resources required to achieve a specified quantum of output. Clearly, efficiency and effectiveness are not directly correlated. For example, the customer requirement may be delivery of the order the next day. In order to achieve this, the manufacturer has to maintain the inventory of the final assembly nearer to the customer. This may be an effective process but not an efficient one. If the product demands are met by a highly responsive but low-cost manufacturing system, then the system will be termed efficient. Symptoms of inefficient processes include numerous verification and inspection operations, redundant and non-value-adding operations, rework and reconciliation, and excessive costs of value-adding operations.

Efficiency is measured in terms of cycle time or as a ratio of output and input. Achieving process effectiveness is primarily for the benefit of customer, but process efficiency is for the benefit of the process owner.

3.5 PROCESS PERFORMANCE MEASURES

A process can be measured and improved along several dimensions. Since the process is the mechanism through which value is delivered to the customer, its performance measurement coincides with the measurement of customer service in various dimensions. Several performance measures can be defined and computed. They include the following.

Lead time: The interval between the start and end of a process is defined as the lead time. Lead time is the key issue in all critical business processes. Reducing lead time will eliminate all non-value-adding activities and will free resources, reduce cost, and improve quality. Lead time reduction strategies include reduction of interface lead times, removal of non-value-adding activities, and use of new technologies.

Customer service: Delivery of customer-desired products at the right time and right place and in the right quantities is the goal of all processes. It is essential to identify the customer chain, find out customer expectations on performance, and perform activities that add value for the customers.

Quality: Management of all work processes and the interfaces between them so that each is on target with low variability and the entire process is on target with low variability is the goal of total quality management. **Flexibility:** The ability to meet customer demands under various environmental uncertainties in various dimensions, such as delivery time, delivery schedules and ordered quantities, design, and demand and product mix changes, etc., is called flexibility. Some measures of flexibility include the product variety that is manufactured and delivered, the changeover times between products, and the time interval between successive new product introductions. **Cost:** The cost of the process, like the lead time, provides deep insights into process problems and inefficiencies. Interface costs, margins, costs in negotiations, procedures, inspection, etc., will provide avenues to cost reduction strategies.

Reliability and dependability: Here we are concerned with the reliability of product delivery as an operational issue. We measure the ability to manage disruptions such as machine failures, worker absenteeism, truck failure, supplier failures, etc. as well as rush orders.

Capacity: The total output rate of the business process is called the capacity. All the work processes and subprocesses are to be balanced in capacity; otherwise there will be bottlenecks and delays. Strategic alliances are common among various subprocess owners to provide for variable capacity. A little over-capacity to meet rush demands will improve the operational measures. **Asset utilization:** The assets in some business processes (like the supply chain process and the order-to-delivery process), such as manufacturing plants, warehouses, communications infrastructure, fleet of vehicles, etc., are worth billions of dollars. Their utilization is an important issue.

Together, the above measures–cost, lead time, quality, service, reliability, capacity, and flexibility–provide an indication of the capability of the process to achieve customer satisfaction.

3.6 CUSTOMERS AND COMPETITORS

Knowing what your customers want and knowing what your competitors are doing are two key issues for positioning a business to maximize the return on the investment. One needs to identify the best customer and the best competitor before targeting in order to learn from them. **Customers:** We have several types of customers for a business process, the most important one being the end user. By way of definition, we can say define that anyone receiving output either directly or indirectly from the process is a customer.

We identify three types of customers : end users, internal customers and indirect customers. End users are the consumers of the product. They are the final arbiters about its quality, usefulness, safety, durability, and so on. They are the ones who are directly affected. The design specification of the product should include "their voice", using techniques such as quality function deployment. Their satisfaction with the product or service is paramount. End user customers can be divided again into three categories: present, past, and future end users. The past customers tell you what went wrong with your product. The present customers tell you what is good about your product and how it fulfills their need. In an effort to gain customer satisfaction, companies should not get too locked into the present customers and spend time and effort in improving the existing product while ignoring future customers. The future customers tell you the features and quality attributes that are missing in your current product. For example, in the disk drive industry, leaders of 5.25-inch form factor drives got too locked in with the customers during 1980s and ignored signals from new players of laptop and notebook computers for 3.5-inch form factor drives; as a result lost their leadership.

End users could be a single consumers, as in case of food items or big companies, as in case of automobile, disk drive, and IC chip companies. The intermediate product manufacturers that are suppliers to equipment manufacturers have to be watchful of both current and future customers. The manufacturer's future depends on big and powerful customers, whose loyalty is important for survival.

Internal customers are those from within the organization working inside the boundaries of the process. They are the people in charge of various subprocesses, work processes, and interfaces. Every in charge of a work process should treat his or her following work process as a customer, and similarly every subprocess owner should treat the following subprocess as a customer. We thus generate a hierarchy of internal customers. Internal customers and their satisfaction are important to maintain process quality and delivery reliability.

Several other process customers are outside the process boundaries but directly or indirectly influence the end user. These could be distributors and retailers in a consumer market, consultants in a manufacturing system purchase and installation, doctors in the use of drugs for patients, hospital administration in the purchase of hospital products, crew in the maintenance of an aircraft, parents in the purchase of clothes and toys for children, etc. Identifying and acquiring the right customer is very important. A right customer is one who will provide a steady cash flow and whose loyalty has to be won and kept. All customers are not equal. The Pareto rule tells us that 20% of the customers give 80% of orders for 20% of products. This means that 4% of the customer–product space generates 80% of the revenue. These customers are invaluable.

Competitors: It is essential to identify the competitors and to target and win their customers. Also it is important to identify competitor's corresponding business processes and benchmark their best practices. Like customer identification, competitor identification is also not straightforward. First there are regional, product, and industry competitors. Any company who weans away your customers is a competitor. For example in document delivery, UPS, Federal Express, and DHL are direct competitors. An e-mail or Internet provider can be treated as an indirect competitor to a courier service. Is a fast-food outlet competition for a formal dining place? Most of the time identification of industry competitors is easy. What is more important is to identify these competitor's business processes, flow charts, and best practices. The number of suppliers, supplier management, customer engagement, employee retention mechanisms, and alliance management are some of the practices that may determine the competitiveness of the company. Competitive analysis, competitive intelligence, and benchmarking are some of the techniques used for identifying the best practices of the competitors, once someone is identified.

Table 2.2. Typical business processes in a manufacturing company

Core processes	*Customer engagement*: Customer acquisition, ensuring customer satisfaction and retention, assessing future customer requirements. *Order-to-delivery*: Receiving orders, fulfilling the orders, and collecting payment. *Supply chain*: Procurement involving supplier selection and logistics; manufacturing including layout and production planning and control; distribution and retailing. *New product development*: Design of new products and processes; market launch.
Support processes	*IT infrastructure*: Intranet and Internet connectivity, databases and data warehousing, groupware, decision support tools, electronic commerce. *Human resource development*: Recruitment, training, compensation, retention, and career planning. *Research and development*: Providing support to product development *Asset management*: Leased or own assets and their maintenance *Financial management*: Payroll and accounting, capital generation, and cash management.
Managerial processes	*Fund management* *Strategy development*: Market intelligence and business and manufacturing strategies. *Competitive intelligence*: Developing ideas for future products; assessing strengths and weaknesses of competition. *Mergers, acquisitions, and alliances*: Partnership selection; acquiring businesses. *Supplier and partnership management* *Process management*: Business process identification, measurement and benchmarking, process improvement methodologies, and techniques and technologies. *Technology and risk management*

4. TYPES OF PROCESSES

A process basically transforms inputs such as materials, people and technology into finished products through a series of value-added work processes. We can classify these into three different classes.

Core processes are those that are central to business functioning. They respond to a customer request and generate customer satisfaction. These include new product introduction, supply chain, and order-to-delivery processes. Core processes are highly structured. They are the critical processes that are to be excelled to beat the competition.

Support processes add value by supporting the core processes. These are administrative, financial, and infrastructural activities in the enterprise. Lots of reengineering efforts are directed towards improving these processes. Automating these processes through intranets, EDI, shared data bases, and combining many tasks into one will improve matters tremendously. Thus, improving support process will enhance internal efficiency and will have an indirect influence on business performance. These processes are also well structured.

Management processes are those using which a firm plans, organizes, and controls the resources. Essentially, a process encapsulates the need for interdependence, integration, and coordination of tasks, roles, people, functions, departments, and so on, -everything required to provide the internal or external customer with the product or service. To support the process management, some firms have redesigned their functional structures into process responsibilities, with process owners heading them. Some others have superimposed the process structure on the existing matrix organizational structures. Management processes are unstructured, involve complexity of human behavior, and are more knowledge based than task based.

Table 2.2 summarizes frequently occurring business processes in a manufacturing enterprise, under the above three categories.

5. SOME IMPORTANT BUSINESS PROCESSES

Each company has a few critical business processes, depending on the nature of the business and the customer service it wants to provide. These include financial management, human resource management, supplier management, customer engagement, product design and engineering, supply chain management, order fulfillment, IT infrastructure, billing and collection, business strategy development, and a variety of others. Here we consider four examples for the purpose of illustration.

5.1 NEW PRODUCT DEVELOPMENT PROCESS (NPDP)

The new product development process is very critical for a company's success. As shown in Figure 2.7, it includes needs analysis, research, market testing, product design, prototype testing, product release, process design, equipment acquisition, and the start of production. Each

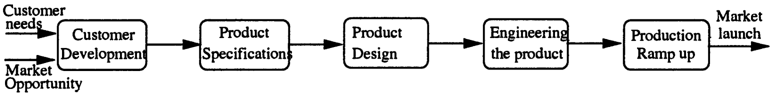

Figure 2.7. The new product development process

of these forms a work process. As will be shown later in Figure 2.13, suppliers, customers, and at times distribution also could be involved in the NPDP. A cross-functional, cross-organizational team with a process owner is ideal for managing the process. Each of the work processes can be analyzed for inputs, outputs, transformation mechanism, variabilities involved and their reduction, and so on. The time to market, costs involved, flexibility to generate a variety of products, time to next product or time between successive products, and defect rates (or reliability) are the important performance measures.

Benchmarking helps to identify best practices as well as the enablers for speeding up the process. Some of the enablers in an NPDP include QFD, rapid prototyping and CAD tools, groupware, project management, integrated product-process design, integrated material-product design, concurrent engineering, the Internet, modeling and analysis, and so on.

Several products are manufactured in stages, each stage in a different country. Evolving a modular product structure, taking into account the logistic costs, and delaying the customerization point (the point in time when product is identified with the customer) for as long as possible are some of the sought-after features for products marketed around the globe. This is called design for supply chain management and shows the interaction between the NPDP and the supply chain process (see Figure 2.12).

5.2 PRODUCTION PROCESS

A production process basically is the set of activities involved in the manufacture of the final product from various raw materials and components. The process is shown in Figure 2.8. The subsystems are suppliers, the factory floor and its computer control system, production planning and control systems, customers, and distribution. The factory floor organization, in terms of layout, material transport, scheduling and best practices, partnerships with suppliers, distributors, and customers is very important factors. Production control practices such as kanban, JIT, and MRP-II are to be considered. Technologies such as flexible manufacturing and assembly, guided vehicles for automatic material transport, and coordinated measuring machines for inspection and

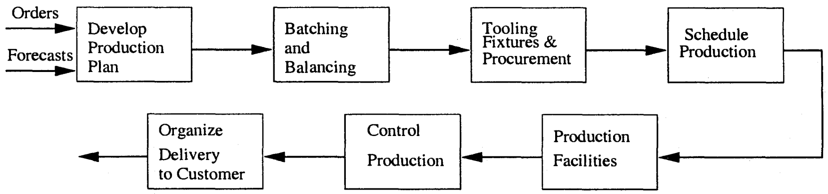

Figure 2.8. The production process

gauging are important as well. There are several issues that need to be considered in the location and staging of the manufacturing plant. To minimize logistic costs, manufacturing could be split into several stages, each stage being done in a different country. Transportation across continents, in-transit inventories, etc. then will become a part of the so-called virtual factory floor. Modular product structures amenable to international manufacturing generally permit customization at the very end, i.e., nearer to the customer. Variance reduction of the work processes, such as procurement and international transport, tuning production levels in various countries to exchange rates, and inventory management, which includes in-transit inventory, assume significance in international manufacturing.

Coordination of the manufacturing activity is extremely important; otherwise, enormous delays occur at interfaces. Internet and EDI communications among various companies and the process management team will help in coordination. Performance measures include manufacturing lead time, defect rates, product variety, and cost.

A factory floor is supposed to deliver high-quality products to its customers in the presence of competition from identical or substitute products. The products should either have low cost or high performance or excellent after-sales service advantage or innovation advantage. Product variety, also popularly called *customization*, and delivery reliability are also important. These performance requirements translate into the following five important measures of performance:

1. *Manufacturing lead time:* the total time spent by the workpiece on the factory floor.

2. *Work-in-Process:* the amount of semifinished product resident on the factory floor.

3. *Throughput:* the number of final products produced per unit time (also called the production rate).

4. *Flexibility:* the ability of the manufacturing system to respond effectively to changes in demand and design, productmix, and production volumes without a penalty in lead time or cost or quality.

5. *Quality:* conformance with customer expectations. Process control is emphasized.

5.3 SUPPLY CHAIN PROCESS (SCP)

The supply chain process is perhaps the most important process for a manufacturing company. Figure 2.9 shows the raw material suppliers, component and subassembly manufacturers, final assembly, distribution, and retailing. The speed of this process determines the delivery time in make-to-order environments. Supply chain costs and time depend on all the constituents of the supply chain. The variability of the lead time and defect rates sum up to make up the total chain lead time, variability, and defect rates, respectively.

The supply chain process (SCP) encompasses the full range of intracompany and intercompany activities beginning with raw material procurement by independent suppliers, through manufacturing and distribution, and concluding with successful delivery of the product to the retailer, or at times, to the customer. Supply chain management(SCM) is the coordination or integration of the activities/processes involved in procuring, producing, delivering, and maintaining products/services to the customers who are located in geographically different places (i.e., SCM is management of SCP). In short, SCM involves the production and distribution of multiple products and the order-to-delivery process. Traditionally, marketing, distribution, retailing, manufacturing and purchasing activities are performed independently, with their own functional objectives. SCM is a process-oriented approach and involves coordinating all the functional and organizational units involved in the order-to-delivery process as on a soccer team.

Supply chain management differs in at least three ways from conventional companies transacting business with each other to manage the procurement, logistics, and product delivery: (1) conventional companies optimize their own performance, whereas in an SCP we deal with the entire supply chain performance from raw material procurement to the end user (2) the supply chain process is a continuous business system rather than isolated businesses transacting business with each other and (3) all the stakeholders of the supply chain have a strong motivation for the success of the chain: they share information, expertise, and resources to reduce costs, improve speeds, and enhance quality.

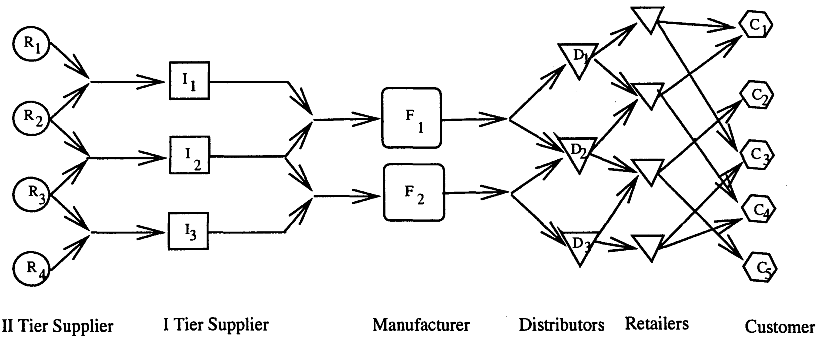

Figure 2.9. The supply chain process

To implement supply chain integration, companies have to smooth or eliminate the interfaces. They can start with mapping the process and eliminating dual inventories and inspection at the supplier's and manufacturer's end. Moving on further, they can share the point-of-sale and inventory information. This will enable the suppliers to replenish stocks overnight, thus saving on inventory costs. They can also develop process-based performance metrics discussed in chapter 4 of this book, so that decisions are made to optimize the entire supply chain performance rather than the individual companies.

Long-term issues in SCM involve location of production and inventory facilities, and the choice of alliance partners such as the suppliers, distributors, and logistic chain. The long-term decisions also include make-to-order or make-to-stock policies, the degree of vertical integration, the capacity decisions of various plants, the amount of flexibility in each of the subsystems, and so on. The operational issues in an SCP include scheduling each of the subsystems, cycle time computation, probability of on-time delivery, cost effectiveness, flexibility, and quality. Identification of customers and triggers for their loyalties (cost, after-sales service, on-time delivery) are also to be assessed.

The supply chain process is very similar to the value chain model due to Porter [71]. The primary activities of the value chain are those involved in raw material procurement (inbound logistics) and finished products storage and sales (outbound logistics), in production (manufacturing), and in marketing and sales. Procurement is listed as a centralized support activity. Several researchers have used the value chain framework to identify the critical success factors needed to achieve competitive superiority and also to understand the unique competencies that would provide sound business leadership. We say that the SCP includes the value chain as a special case. The fundamental difference is that the

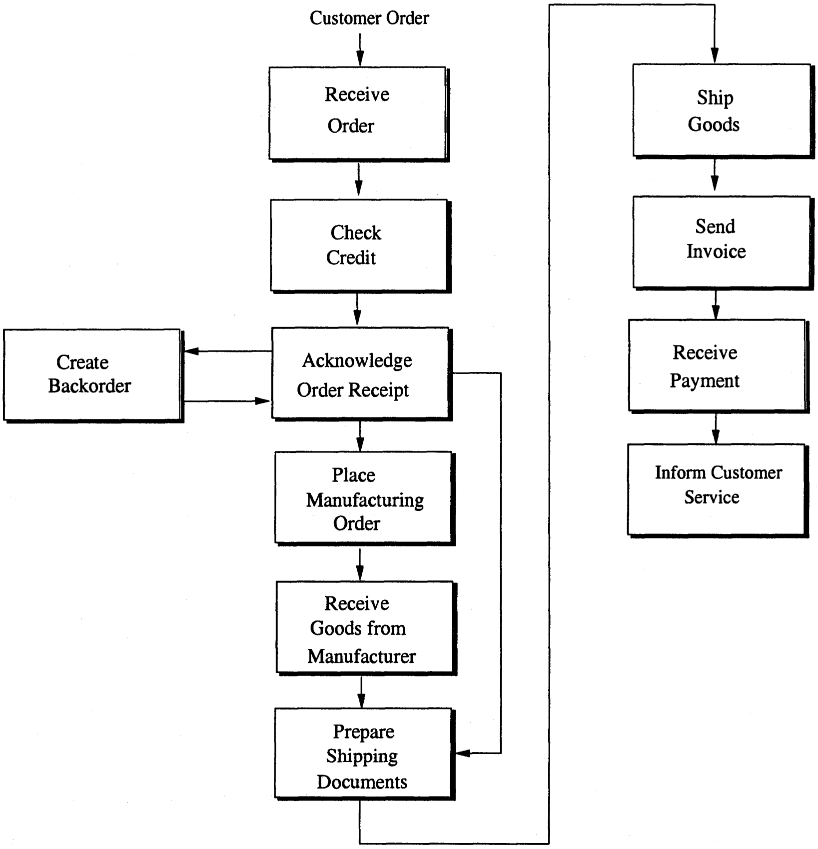

Figure 2.10. The order-to-delivery process

supply chain is viewed as a single process consisting of interdependent subprocesses, and all companies share a common destiny and work towards the success of the supply chain. The decisions of the individual companies are coordinated to benefit all the members of the chain and not just themselves. It would still be possible to perform the same kind of analysis to derive the competitive strategy for a SCP against other such processes. Our aim in this book, however, is distinctly different: to perform modeling and analysis of the supply chain and other processes.

5.4 ORDER-TO-DELIVERY PROCESS (ODP)

The order to delivery process (ODP) is another important business process of a company and directly involves the customer. As shown in Figure 2.10, the ODP starts with the order from the customer and ends with the use of the product by the customer. In fact, some companies also consider after-sales support and the return and recycling of the used product as a part of the ODP. The ODP (see Figure 2.10) involves receiving the customer order, picking up the goods from the manufacturer and warehouse, and delivering them to the customer. The ODP arises in various contexts in a supply chain: between manufacturers and suppliers, between distributors and manufacturers, and between the end user and the distributor and retailer. Depending on the relationship between the buyer and the seller, the ODP could be a very simple transaction or a complex process involving bidding, selection, transport, delivery, billing, and payment.

The main goals of order processing are short delivery times and superior service with less inventory and lower cost, for the given capacity. The ODP should accommodate the delivery times and lot sizes dictated by the customer. Superior service as mentioned above, should mean that missed deliveries, wrong deliveries, and defective deliveries should be measured in terms of Defective deliveries per million (DDPM). A more detailed description of the ODP is considered in chapter 7.

5.5 INTERACTION AMONG PROCESSES

Although the processes are well defined by themselves, they are seldom independent. For example, the new product development process itself influences and is influenced by the production and supply chain processes. The design of products as modular assemblies, staged manufacturing (i.e., performing the manufacturing function in different locations), and performing the final assembly in the distribution center or at the customer's site are all actions to minimize the supply chain costs [60]. Figure 2.11 well illustrates these interactions. Figure 2.12 illustrates the interaction among the three important processes: the new product design, supply chain, and order-to-delivery processes. The customer orders and forecasts, combined with intelligence information about the competitor and the data on customers, suppliers, distributors, etc., will determine the product mix, volumes, suppliers, priorities, and marketing channels. The production schedules of the suppliers and manufacturers are generated and the logistics of moving components and finished goods from supplier to manufacturer and manufacturer to distributor are also planned. The scheduling is also influenced by the loyalty of the customers and also the partnership arrangement with the manufacturer. New or alternate product designs could be planned depending on the need. The order-taking mechanism, amount of inventories maintained, planning of the delivery schedules, etc. are all important for the performance of the order-to-delivery process. Measurement of the

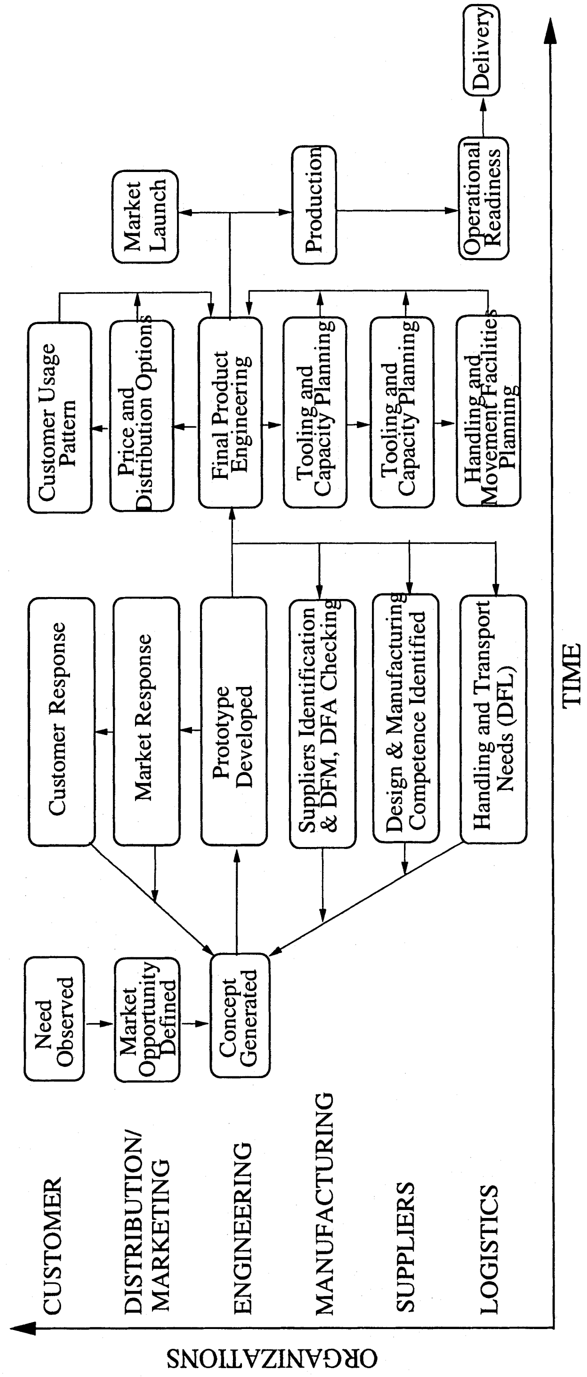

Figure 2.11. Cross-organizational, cross-functional work flow in the NPDP

lead times in product design, production, supply chain network, and the order delivery mechanism is very important. All the processes cross various organizations and need cross-organizational teams for effective coordination.

6. CHARACTERISTICS OF A WELL-MANAGED PROCESS

Examples of well-managed processes can be found in the manufacturing domain and poorly managed processes in the service domain. We present some of the characteristics of good process management below.

6.1 PROCESS OWNERSHIP

A traditional process, which hands over work from one organization to another or from one function to another, cannot move quickly, since there are segments in the path where no one is responsible. Work flow is horizontal in nature, flowing through functional entities organized in a vertical command structure. Coordination of work flow is difficult and nonexistent in these organization structures(see Figure 1.3).

A process owner is accountable for the functioning and performance of a process from beginning to end and has the authority to make or oversee the making of changes to it. The identification of process owner is critical to improving the business processes. Determining ownership is not an easy matter in organizations where processes traverse geographic locations, functions, or organizations as well as national boundaries. The owner should be high enough in the organizational hierarchy to see the process as a part of the larger picture, to influence the policy affecting the process, and to commit to a plan for improvement. In multinational companies, vice presidents are named as owners of specific business processes that cross national boundaries. In cross-functional cases, operational ownership is assigned to the manager who is most affected by the process. The main job of a process owner is to manage the interfaces between organizations and functions. A process owner, whether an individual or a team, is fully responsible for coordination, yield, cost, quality, and schedule and manages the process to achieve the targets. Establishing and assigning ownership is fundamental to managing the processes.

A process owner is ultimately responsible for running and improving the process and is empowered to take all actions to ensure that the efficiency and effectiveness of the entire process. His or her major responsibility is to manage the interfaces and see that all the functional goals are aligned towards the process goals. The process owner should

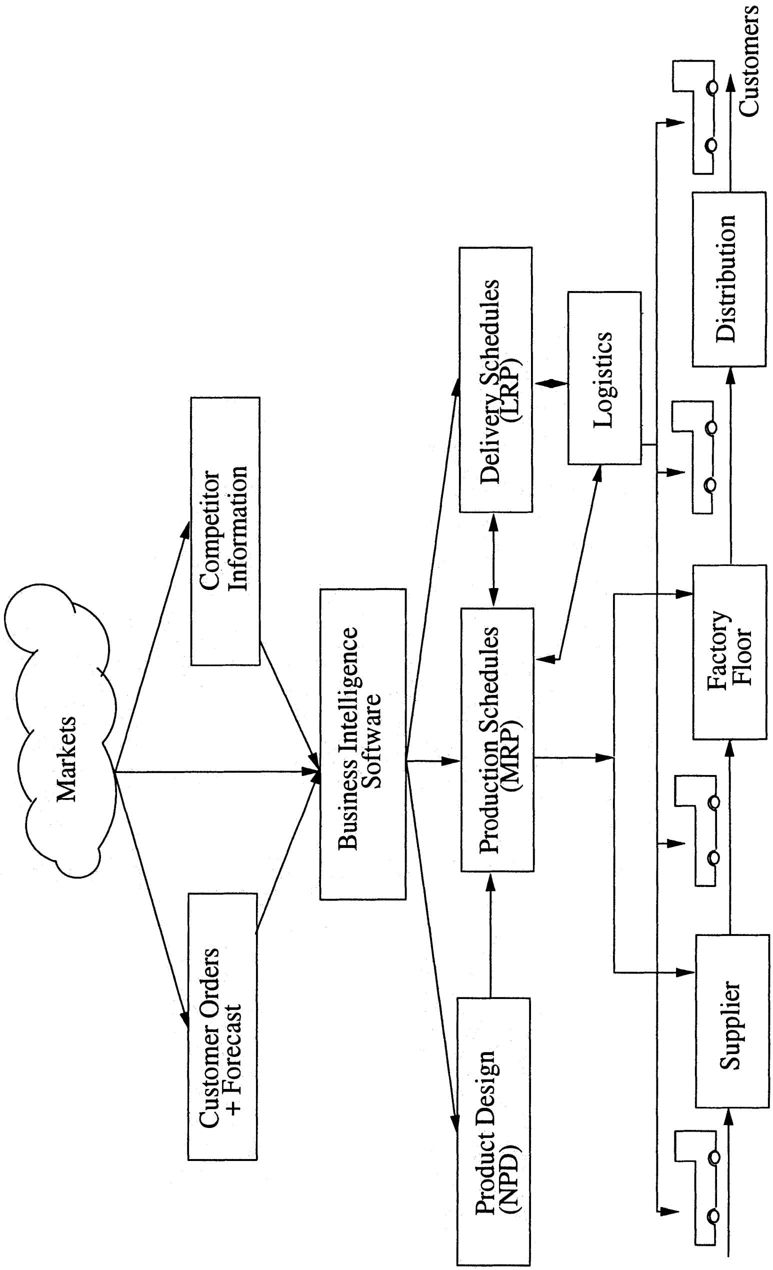

Figure 2.12. The interaction between NPDP, SCP and ODP

- Define the subprocesses, appoint their owners, and monitor their performance
- Identify the interorganizational and interfunctional interfaces and put in place the procedures for their management
- Identify the customers, trigger their loyalties, and understand their expectations
- Identify the competitors and their best practices
- Identify the critical success factors and the competitive advantage and establish a measurement system that attempts to improve the gaps by eliminating the root causes
- Identify the new technologies that could affect the process and monitor the patents in the area

Interface Management:
We know that a business process consists of an ordered set of work processes separated by cross-functional and cross-organizational interfaces. The work processes are thus logically related but physically and organizationally dispersed. The organizational structure in most companies follows hierarchical or functional lines. Therefore, people focus on specific objectives, measurements, and improvements exclusively within a function or organization and hand the process information "over the wall" to the next in the chain. The process flow across functions and organizations cause disconnects, spaces of no-man's land. What is needed, therefore, is to wire together in a horizontal management chain all the functional and organizational subprocesses of the business process.

We have identified several types of interfaces between work processes, between functions, and between organizations. Ideally, the most effective business process is one where no interfaces exist that detract from the quality of the work flow, and where the output of the work process meets the requirements of the customer. In practice, this does not often happen. Regardless of the organization structure, work invariably flows in a horizontal fashion, as shown in Figure 2.4. Interfaces represent the points within the process at which the work product leaves one organization or function or work process and enters the next. Upon crossing the interface, the work process becomes an input to the next step in the process. Interfaces are managed through partnerships, contracts, automation, cross-functional teams, etc. Several good examples of excellent interface management exist in the literature. These include the partnership between Proctor & Gamble and Wal-mart , Benetton's relationship with its suppliers, quick response manufacturing strategies, and efficient consumer response strategies.

6.2 WELL-DEFINED BOUNDARIES

Processes have to have a clearly defined beginning and end. The inputs and outputs should be clear and unambiguous. Customer needs drive the process, and customer satisfaction terminates the process. Boundaries of the process define the limits. Longer processes, even if they cut across departments, functions, and organizations, are preferred for analysis and redesign. A production process could begin with supplier outputs and end with creating input to the distribution. By enlarging this process to include suppliers and distribution to a supply chain process, an opportunity for interface management arises with tremendous benefits in cycle time and cost. It is important to define the core processes and their boundaries in the beginning of the analysis.

In process management, boundaries are intended to demarcate the input and output sides of the work flow domain. Defining boundaries will identify the activities inside the system as well as the critical interfaces of the process. The input boundaries define the interfaces with suppliers to the process and the output boundaries with the receiver of the output. Internal interfaces are transition points where the work output of one activity becomes an input to the next activity. This could be between two machines, between manufacturing and a transporter or between two clerks. Many problems relating to work flow originate at the interfaces and these are caused by lack of communication between the producer of work and receiver of the output. Use of quality function deployment matrices, and negotiation with the producer and receiver will help in interface management.

6.3 WELL-DEFINED WORK FLOW

A process flow chart documenting the flow of work, including the interfaces, provides the sequence of operations. Smooth flow of material and information should be ensured. Well-documented procedures for dealing with out-of-ordinary situations such as machine failures, rush orders, or quality control problems would improve operational flexibility. Representation of the process as a flow graph will help in complete understanding of the process. It is also important to find out who the customers are, how many different kinds of customers there are (occasional, regular), and who is contributing to the orders and sales.

6.4 PERFORMANCE MEASUREMENT SYSTEM

Process measurements are important and are used in two ways: (1) to monitor and control the work processes, the interface processes, and the entire process by measuring process variables such as material flows, dimensions of finished parts, delivery times, and defect rates, and (2) to determine the effectiveness of each of the functions based on its contribution to the process (otherwise, each function may optimize only locally, leading to total-process suboptimization). The reward system should be tuned to the contribution to the process rather than to functions. Also, the measurement system should be able to improve the effectiveness of the interfaces. We consider some of these issues below.

Improving the interfaces between organizations: As often quoted, Lord Kelvin said that when you cannot measure and express in numbers whatever you want to improve, your knowledge of it is meager and your improvement methods will be ineffective. The interface effectiveness can be measured in several ways depending on the item that flows across the interface. Consider the interface between a supplier and a manufacturer with supplier agreeing to supply the variety and quantity ordered by EDI, with prespecified quality. The interface activity can be monitored for agreed terms and also for whether the expected benefits result from the partnership. The supplier performance can be monitored for delivery reliability, flexibility of various types, lead time, defect levels, cash flow, and overall benefit to the relationship. In a similar way, the supplier can measure the cash flow; direct and active help in design, management and worker training; and overall benefit to itself from the relationship. The partnership is regularly reviewed and continually improved. Ideally, the interface activity itself should take zero time, should have zero defects, should incur zero cost, and should provide infinite flexibility.

In summary, to improve the effectiveness of the interfaces, one has to document interface management (partnership) procedures; try to remove all non-value-adding activities such as repeated data entry, inspection, packaging, etc.; conduct periodic reviews regarding the relationship; monitor the partnership effectiveness, and determine the time and cost consumed and the value additions at the interface.

Improving the interfaces between functions: To some extent, the above attitude of treating the next operation as a valued customer and of having a good functional relationship and co-destiny is important in cross-functional interface management as well. The only difference, however, is that all the functions are under the same company management. In process-based organizations, the performance of the functions is measured and judged based on its contribution to the process. Here again, a good strategy would be to determine major functions in the subprocess, the time and cost consumed and the value added at their interfaces, and finally the effectiveness of the interfaces in terms of timeliness, cooperation, defect rate, and throughput. Improving communication between functions and managing interfunctional interfaces using cross-functional teams, as in design for manufacture and design for assembly, are good practices.

Improving the interfaces between work processes: Interfaces between work processes are more structured and are generally amenable to automation using computer and communication technologies. For example, transfer of a workpiece between two workstations can be automated using an automated material handling system. Similarly, a file can be transferred between two clerks electronically. In both cases, we have smoothed the interface between the work processes. The statistical process control procedures can determine the quality problems, and root-cause analysis can find the cause of the problems. The interfaces are improved by removing the causes of defects.

6.5 CONTROL OF PROCESS DEVIATIONS

In a well-managed process, corrective action is performed in a timely manner whenever a process deviation occurs. Through process capability studies, each work process is controlled to minimize the deviations, and the overall process is under control [45]. Control mechanisms are established at various points along the path to ensure proper functioning of the process. These points include inspection, statistical process control, design reviews, and so on. One can easily see from Figure 2.5 that the variability of each work process and the interfaces of all types add up to make the total variability of the entire process. Each work process and the interface processes have to be tightly controlled to minimize the total process variability. One way of doing this is to follow the customer-producer-supplier model described below.

Customer-producer-supplier model: This model is the familiar total quality model wherein the output of each work process must satisfy the next work process requirements [66]. The customer may be an internal customer or the end user. If the work output is not acceptable to the customer, then it is either rejected or modified. In either case the result is waste of resources. Complete and clear understanding of the work product, which is well documented, is essential. The classical feedback loop corrects the process for any deviations between the actual output and the expected ones. The customer process sends feedback after using the output for possible corrections and modifications. Use of statistical process control to detect any problems with the process and regulating it would be more effective than reactive feedback control based on deviations between the expected and actual outputs. Typically, these measures include conformance measures (specification requirements), response time measures (time interval between request and its satisfaction), and service levels (availability of equipment, auxiliary services).

6.6 PROCESS ENABLERS

Webster's defines enabler as something that supplies the means, knowledge, or opportunity to be able or to make feasible or possible to do something. Enablers are helpful in effective implementation of process improvement methods. Best practices are specific methods to achieve an enhanced performance objective. Enablers are a broad set of activities that enhance implementability. Employee communications, use of IT, training, organizational change, cultural change, human resource training, and policies are all examples of enablers [20].

Information technology: Computers, communications (wireless, e-mail, fax, electronic data interchange, electronic funds transfer), software in the form of databases, decision support systems, expert systems, groupware, executive support systems, the Internet and intranets, Imaging, and many other technologies are used in industry and business. Feedback computer control, diagnostic expert systems, tracking systems, and inter-organizational communications all enhance process performance. Indeed, most businesses processes came into existence much before the IT revolution. Their processes could be redesigned, incorporating newer technologies to obtain orders-of-magnitude improvement.

However, existing computer systems, software and culture can also impede radical redesign. Mainframes, previous-generation programming languages, databases, applications software–all such legacy systems form obstacles. It is often not possible to abandon all existing systems and start on a clean sheet. Thus process redesign or innovation is constrained by legacy.

Information systems: Information plays a key role in improving and innovating business processes, including performance monitoring, and process output customization, and for integrating information across and within the process. Through the use of barcodes, information collected at the point of sale can be combined with customer survey information in order to schedule product manufacture; information collected on quality and other performance measures can be used to fine-tune the process. Operational processes such as the order-to-delivery process have information about customers, products, prices, credit policies, inventory levels at warehouse, manufacturing and suppliers, shipment schedules, and several others, to configure, price, and schedule a customer order. Building information warehouses in the form of multiple linked databases, stored in an easily accessible form for use by all the process stakeholders is a routine exercise in most companies. Also, policies of sharing information across functions and organizations have to be evolved.

Organizational enablers: Both social and technical factors are important agents of change. If process redesign efforts are to succeed, the human side of change involving organizational structure and human resource policy must be aligned in balance with IT and information enablers. One of the major shifts in organization structure is management by teams. Suppose a cross-functional team, with one representative from each function involved, is responsible for a product development process. The most difficult issue that requires resolution is the relationship between team members and the functional heads in the organization. Several IT-based innovations facilitate the working of teams. Groupware, a software that supports structured discussion, group communication via electronic bulletin boards, electronic mail, and group access to database records, helps teamwork.

An important shift in organization culture has been in the direction of greater empowerment and participation in decision making and more open and less hierarchical communications. Customer-facing processes such as order management are well suited for empowerment of front-line employees. Not all processes are suitable for empowerment. In processes with low skills and high labor turnover, such as the fast-food and lodging industries, jobs are efficiently executed only through a command-and-control culture. Information can support both control and empowerment. It can supply employees with information to make their own decisions, or it can dictate instructions as to how to perform each step.

Human resource enablers: Process orientation and management require new skills from employees. The empowerment and case-manager type of team structures require new skills that involve greater depth of job knowledge and greater breadth of task expertise. A worker is expected to be a generalist and must learn the jobs of other team members in addition to acquiring skills to make decisions and use new technologies. A variety of training programs must be organized for the employees. Human resource policies than enable process innovation include compensation based on performance. Given the strong measurement orientation of the process approach, it becomes relatively easy to compensate based on performance. Career paths are another important issue; they are likely to be more lateral than upward (as in functional organizations).

Also, work role rotation ensures that each worker is familiar with all related jobs that constitute a process.

We have described above, the important enablers of process change—information technology, information, organization, and human factors. Acting in concert, these enablers can lead to radical enhancement in process performance [20].

In this section, we have identified various attributes of a well managed process. A process with all the above attributes is supposed to be managed well. As we said before, an enterprise is as good as its processes. It is through the processes that we implement the strategy and vision and also deliver value to the customers. In the following section, we discuss the issues of transforming business processes into core capability by combining core competencies with core business processes.

7. COMPETITIVE STRATEGY AND BUSINESS PROCESSES

While all processes are important for the business to succeed, some are more critical than others. If wrong processes such as inventory control are improved when the need is to supply fresh and new products, then the business will sink. The selection of processes for improvement is very important. Often management gets carried away and starts improving several processes simultaneously or starts with the least important one with an idea to start somewhere. This kind of unthoughtful approach could be disastrous. We discuss a simple method to select the critical processes for improvement.

There are, of course, several informal ways of getting a feel for what is going wrong and what needs improvement. Processes with long cycle times, high cost, quality problems, or internal and external customer complaints are natural targets. Also, processes that industry competitors are improving, and processes where new technologies are making strong impact could be targets for improvement. It is important, however, before trying to change the process, to be sure of the importance of the process to the business, the customer impact the improvement will have, the performance improvement in comparison with the competition, and more importantly, the resources and competencies required to improve and maintain the quality of the process. The resources, risks, and returns are to be assessed before spending a lot of time and effort on process improvement.

It is also important to establish the process objectives and attributes of the critical business processes. Process objectives include overall process goals, the specific types of improvements desired, a numerical target, and a time frame. As we show below, these objectives are derived from the enterprise objectives. Examples of well-defined process and rather radical objectives include "reduce product development time by 50% in the next three years," "reduce the defect levels by 50% in the next year," "target being at the SEI Level 5 process in the next two years," etc. It is very important that these objectives be derived from strategy, critical success factors, and customer preferences. Stressing product variety when customers urgently want standard products is an example of misalignment between process objectives and customer preferences. There are also process operating policy issues that have to be specified. How involved is the corporate office in decision making such as pricing? Can the decision making be pushed downward to eliminate middle management? How much involvement should be permitted from the customer side? What information is exchanged with the suppliers? How should the distribution system be organized: direct delivery to the customer, or via the warehouse, etc.? There are several enablers and best practices that have to be determined.

7.1 CRITICAL BUSINESS PROCESSES

A manufacturing enterprise is a bundle of value-delivering business processes, and it will be as effective and efficient as its processes. While all processes are important, some are more critical than others for the success of the enterprise. This means that the critical value-delivery processes should show exemplary performance levels to enable the organization to attain its goals. It is very important to identify these critical processes so that their performance can be improved or so that they can be radically redesigned.

Enterprise goals reflect the expectations of the customers for the product quality, cost, and delivery reliability. They are derived from what constitutes the competitive advantage and also the critical success factors for the business segment in which the enterprise operates. Goals are the endpoints the enterprise hopes to reach. We first explain the terms *competitive advantage* and *critical success factors* and then link them with the business processes.

Critical success factors: The competitive strategy of an enterprise is the set of objectives, plans and policies that will enable the enterprise to compete successfully in the markets. The competitive strategy specifies what the organization's competitive advantage is and how it can be achieved and sustained. Critical success factors (CSFs) are the things that must go right for any business to flourish. They are the factors that support the attainment of company goals and when properly managed will have a high impact on the company's competitiveness. A CSF can be a characteristic such as price, quality, or delivery time or an industry structural characteristic such as vertical integration. In short, CSFs are factors that give the customers the value that they are looking for. For example, in the semiconductor industry, R & D, manufacturing, and development of generations of new products are major factors that enable a company to succeed. In the automobile industry, styling, cost, dealer network, safety features, etc. may be CSFs. In the food processing industry, new product development, good distribution, and effective advertising are the major success factors. Having the right product mix available on the shelves at the right price at each local store and making this known to all the customers through effective marketing are the CSFs for supermarkets. A comparison of a company's CSFs with those of the competition is important. Also, the company's operating strategies should be in line with CSFs. In other words, if the CSFs are price and easy accessibility, then one should view the superstore as a marketing channel, and an alliance with a chain store may be a CSF apart from producing products at the target price. On the other hand, if the company emphasizes on-time delivery through a logistics partner, it may not be worth the effort, and the price would be high.

Enterprise goals: Basically, enterprise goals are quantitative, customer oriented, competitive advantage driven, and based on the critical success factors in the business segment. Some examples of enterprise goals are

- Capturing half the manufacturing software market within the next two years
- Introducing two new products each year for the next three years
- Reducing the order-to-delivery time by half in the next year
- Reaching six-sigma delivery by the end of two years quality

The enterprise goals are to be achieved through its processes. Process goals should be consistent with the enterprise goals, and congruence or alignment between strategy and processes is essential. Process goals drive the function goals, and conversely, each functional activity should reflect its contribution to the overall process goals. Similarly, the goals of the work processes should be consistent with the goals and measures of the entire process.

Critical business processes: First, it is important to identify the set of critical processes that support the CSFs and form the basis for attaining competitive advantage. If rapid introduction of generations of new products is perceived as the key to gaining competitive advantage by the company and is declared as the enterprise goal, then the new product development process is the core process. If, on the other hand, faster delivery to the customers provides competitive advantage, then the order-to-delivery process and supplier management are the critical processes. If the cost of producing a product is central to the enterprise goals and provides competitive advantage, then design, manufacturing, purchasing, and materials management (i.e., the supply chain process) are critical processes. If the ability to respond to rapidly changing markets is a competitive advantage, then market research and planning and risk management are core processes. Thus a well-defined strategy and enterprise goals provide the context as well as motivation for change.

It is also important to streamline business processes and other change initiatives that do not embed a vision or strategy and that would end up automating yesterday's processes or automating the material or information flow between work processes. These simplifications involve elimination of obvious bottlenecks with no business vision as context. A value-delivery process in a changed strategic context may be more complex or can be entirely different from the earlier one. Consider the example of streamlining libraries with automatic checkouts and on-line databases. If the objective is to provide 24-hour access to information, then one should be thinking of Web-based digital libraries.

From the above discussion, it is clear that the primary decision to be made concerns what provides the competitive advantage—cost, quality, delivery time, new products, flexibility, etc.—and also to identify the CSFs. The competitive advantage dimension determines the critical business processes that need to be converted as core capabilities with well identified attributes and measurable objectives. Conversely, the business processes developed as core capabilities can enable a company to create a new competitive advantage. The literature is full of such examples: Federal Express, 3M, and Xerox are classic examples where core capabilities were leveraged to get into new businesses. To convert a business process into core capability is hard work: one needs to develop an appropriate performance measurement system, compare the measures against the best-in-class, and strive to close the gap. Further, an analysis of the competencies of the organization and their contribution to the core business processes is also of paramount importance (see Figure 2.13).

We also need to point out that the competitive advantage, CSFs, and thus the critical processes as well as the competencies change with time. If the competitive advantage changes from price (volume) to features (variety) or from standardization to customization, then there would be a big change in the critical processes and needed core competencies. In the following section, we develop a heuristic procedure for identifying and developing core capabilities.

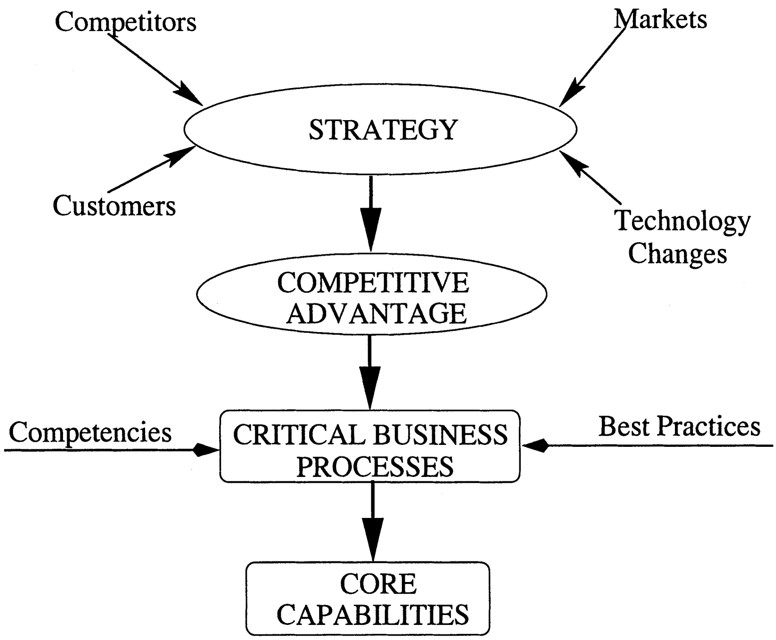

Figure 2.13. Strategy, critical business processes, and core capabilities

8. CORE COMPETENCIES AND CORE CAPABILITIES

In this section, we discuss two important concepts: core competencies and core capabilities, the latter associated very closely with business processes. It is almost the unanimous opinion among operational and strategic experts that nurturing and developing core competencies and capabilities is the only way to maintain competitive advantage in the everchanging business world. These concepts have their origins in the resource economics field. We connect the business process concepts to this area.

8.1 RESOURCE-BASED VIEW OF AN ENTERPRISE

Traditionally, companies are viewed as a bundle of products or businesses. Here, we view an enterprise as a bundle of resources. It is generally agreed that the primary economic function of an enterprise is to make use of its resources for the purpose of supplying goods and services to the economy. The physical resources of the enterprise consist of such tangible things as plants, equipment, land and natural resources, and semifinished and finished goods. There are human resources–unskilled and skilled labor and administrative, financial, legal, technical, and managerial staff. There are also intangible resources such as brand names, reputation, and technological know-how. The managerial and organizational processes, the way things are done in an enterprise, are also very important resources. They determine the efficient and effective ways in which managers coordinate the internal activities such as production planning and the external partnerships such as the buyer-vendor relationships. They can be inimitable and unique resources for the enterprise or a particular company.

For a firm or enterprise, the products and resources are two sides of the same coin. Most products require services of several resources, and most resources are used for creating several products. In a dynamic environment, however, the products are quickly obsolete, and static competitive positions are rapidly overtaken. The ability to respond consistently to changing markets and ever challenging competitiveness comes from the creation of facilities, technological assets, and human, knowledge-based, and organizational resources. Superior competitive advantage stems from developing a competitively distinct set of resources and deploying them in a well-conceived strategy.

Why do firms differ? While they have the same physical resources and adopt similar competitive strategies, one ends up far more successful than the other. While their physical assets may be same, two companies may have different collections of intangible and organizational skills that determine how efficiently and effectively they perform the activities. Such capabilities and skills which are difficult to imitate, purchase, assimilate, and develop, make the organization unique.

As we have said many times earlier, the business processes are the vehicles for delivering value to the customers in a manufacturing enterprise. Internal coordination within each firm and linkages between the firms forming the enterprise are important. They are the interorganizational interfaces that add value and can differentiate one enterprise from another. Our aim here is to show how the critical business processes that we defined earlier can be transformed into core capabilities. Capabilities are value-delivery processes along the dimensions that are important to the customers. Core capabilities are critical business processes developed over time into world class vehicles for value delivery; they involve the skills and learning of several teams of workers and managers and procedures for smooth transfer of work across organizations and functions.

8.2 CORE COMPETENCIES

Core competencies reside at the heart of the process of leverage and the creation of new business opportunities. They are defined as the collective learning in the organization, achieved through coordination of diverse production skills and integration of multiple streams of technologies. It is the integration that is the distinguishing hallmark of a core competence, rather than a single, discrete skill or technology [40].

For example, miniaturization, which was a unique trademark at Sony, requires expertise in several core technologies such as microprocessors, miniature power sources, power management, packaging, manufacturing, and several other factors involved with customerization of consumer electronic products. Similarly, 3M's extensive growth has been founded on its R & D skills in three critical technologies: abrasives, adhesives, and coating-bonding. By combining these skill depths with its innovation culture and broad-based distribution system, 3M was able to develop a wide variety of products and sustain an annual growth rate of 10%. Thus a key characteristic of core competencies is that they are a creative bundling of multiple technologies along with customer knowledge, market intuition, and the skill to manage these synergistically.

A core competence can be identified by applying four simple tests [72]. They include the following:

1. Is it a significant source of competitive differentiation? A core competence should be unique to the company, like miniaturization at Sony or user friendliness at Apple. This does not mean that these competencies are uniquely held by a single company but that its level of competence is substantially superior to all others.

2. Is it hard for competitors to imitate? Because competencies require management of complex interactive processes, creative bundling of technologies, and integrated learning throughout the organization, they are difficult to imitate.

3. Is it perceived by the customer as adding value to the end product? Core competencies are skills that enable a firm to deliver a fundamental customer benefit. Examples of such a benefit might be reliability, superior fuel economy, less noise, user-friendly interface, etc. What is visible to the customer is the benefit, not the technical nuances of the competence that underlies the benefit. The driving experience is what the end customer feels while driving a Honda, although he or she may not know why it is better. Similarly, one finds that Macintosh is easy to use than other computers. The core competencies that go into making these products are not always visible to the customer.

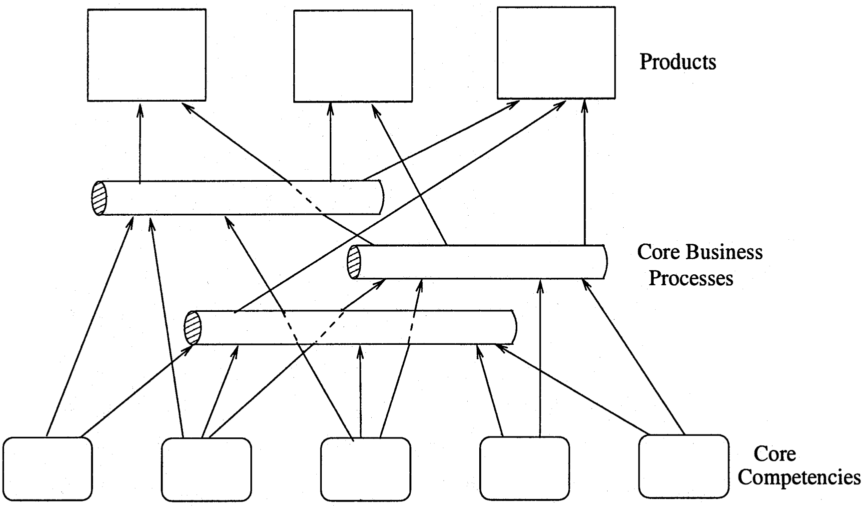

Figure 2.14. Core competencies, core business processes, and products

(4.) Does it lead to new products? Core competencies are gateways to new markets. Sharp's flat screen displays give it access to product markets as diverse as laptop computers, video projection screens, pocket televisions, etc. SKF is a leading manufacture of bearings and a careful analysis points out that it has competencies in antifriction products, in precision engineering, and in making perfectly spherical devices. SKF can manufacture recording heads and other very-low-friction spherical balls.

In short, core competencies reside in an organization as skills, work culture, innovation, and learning capabilities and they manifest themselves to the customers as orders-of-magnitude end user benefits.

Core products: Core products are components or subassemblies that actually contribute to the value of the end product. A core product may lead to several end products, and the market share for a core product could be much different from the end product. For example, Cannon sells a wide variety of end products, copiers, laser printers, fax machines, cameras, and camcorders. All these businesses share access to core products (or components) such as Cannon lens systems, miniature motors, and laser engines. Cannon also markets a laser engine, and it has more than 80% share for this core product. But it is a small player in the laser printer market(see Figure 2.14).

It is important to realize that competition for core products is distinctly different from competition for end products and services. Consider, for example, the color TV: the core products are picture tubes, digital signal processing chips, etc. Controlling the core technology products gives one a competitive advantage. World-class companies now concentrate on developing a few competencies that lead to core products that in turn produce a stream of new products to satisfy future customer demand. These companies seek to outsource those activities where the company is not preeminent and that do not support the core product.

Corporate strategy has typically been concerned with the management of the portfolio of businesses. It is useful in view of the above to conceive of a firm as a portfolio of competencies. This view allows a firm to expand its view of potential opportunities. If Cannon perceived itself as a company of cameras and copiers, then it would not have entered the market for other products such as laser printers, fax machines, etc. Likewise, Honda would have stopped at motorcycles. Companies should identify the core products and maximize the market share in these products. It is important to recognize that competition takes place on multiple planes: at the end-product level, it is price-performance based; at the core product level, it is the capacity to produce new products; at the core competence level, it is the capacity to create new businesses.

Types of competencies [39]: One can distinguish between three types of core competencies, namely,

- Market-access competencies: all skills that would put a company in close contact with the customer, such as distribution, logistics, technical support, sales and marketing, etc.

- Integrity-related competencies: all skills that would enable a company to deliver a customer a perfect order on time with all items. Quality, cycle time management, inventory management, and logistics management are all issues here.

- Functionally related competencies: skills that would enable a company to generate products with distinct, unique functionality that would benefit the customers, such as noiseless, low-fuel consumption engines, combined TV-Telephone-Computer products, etc.

All companies are converging towards high standards of customer service through alliances and acquisitions. Hence, functionally related competencies will become more important in the future. Also, it is important to assess the core competencies relative to the competitors. As we have said several times before, it is important to know what activities one is good at relative to the competition.

8.3 CORE CAPABILITIES

A capability is a set of business processes that deliver value to the customers and impact the critical success factors of the company. For example, in the high-tech electronics industry, the ability to quickly develop new state-of-the-art products with features and performance that deliver superior value to the customers creates an enduring advantage. In the automobile industry, the critical success factors could be styling, a strong dealer network, and target cost production. Developing capabilities involves the employees, organization structure, infrastructure, and technology. The goal is to identify and develop the hard-to-imitate organizational capabilities that distinguish a company from its competitors in the eyes of the customers. Well-managed interfaces, excellent communication between employees, performance measurement that supports the competitive strategy, benchmarking with world-class processes, and continuous redesign of the business processes by leveraging new technologies are all essential for a company to attain world-class status. The location of the facilities involved in the value-delivering process should take into consideration benefits based not on a single function but the entire process and the net value addition to the company. For a global company, the aim should be to build a network of capabilities, not a network of facilities. Weaving business processes together into organizational capabilities is the new logic of vertical integration or virtual integration. Federal Express and Wal-Mart differentiated themselves by owning their own transportation fleet. There are other companies that outsource from other carriers. The important issue in the latter case is the robustness of the virtual integration and the management of interfaces between partners.

Honda is a perfect example of how all the competencies can be converted into a core capability to outpace competition. Honda has brought together its functional core competencies in the design and building of small, smooth-running engines and power trains, in human resource development skills in training dealers so that they can become successful businessmen, and in the use of computerized dealer management systems [40].

In summary, one should think of companies as bundles of capabilities rather than as bundles of products and businesses. If a supplier possesses capabilities that are essential to a company's competitive success, the company must either work to assimilate these capabilities or develop very close partnership with that supplier. Also, the employees as well as the organization culture play an important role in developing core capabilities. Statements such as "that is not our business; let us leave it to the experts" will destroy the initiative to innovate. Most best practices are not accidental discoveries but are developed over time. Building a business process into a core capability that provides a basis for competitive advantage takes time, resources, and a dedication approaching fanaticism.

How does one transform a business process into a core capability? Basically it is done by developing the functional competencies and integrating them into critical value-delivery processes. Competitive success depends on transforming a company's core business processes into core capabilities that consistently delivers superior value to the customer. Companies can create the core capabilities by integrating functional competencies (to develop generations of core products), integrity-related competencies (to produce and deliver products in a effective and efficient manner), and market access competencies (to advertise and market in an effective manner). It is important to mention that its relative performance with reference to the competition is the final test for a capability to be core and or a valuable resource to a company. Thus, each company need to look inward to understand and develop its own capabilities and outward to identify the opportunities the markets provide. Gaining competitive advantage results from the company's ability, using its capabilities, to exploit the opportunities the markets and competition provide.

An organization's capabilities are circumscribed by the capabilities of the people within the organization. Naturally, the group has a wider set of capabilities than the individuals. But the organization's capabilities are a function of the working relationships among its individuals. So building organization capabilities requires building both individual capabilities and the linkages among them. Conscious efforts to manage the processes by cross-functional teams, encouraging people to undertake a variety of assignments, team-based performance measurement, and reward systems are some of the ways to improve organizational communication. Being proactive in customer relations–driving the customers than being driven–will nurture capabilities in the company envisions rather than pursuing short-term customer satisfaction measures. Being too close to the customer; asking R & D to generate money from projects of short-term interest will destroy even existing capabilities.

Earlier in this chapter, we said that a company is a bundle of business processes. We end this chapter by saying that core capabilities are the most critical and distinctive resources a company possesses. They provide the company with its competitive advantage.

9. CONCLUSIONS

In this chapter, we have defined the manufacturing enterprise as a network of companies coming together to design, manufacture, and deliver high-quality products to the customers. We have decomposed the enterprise into a set of value-delivery processes, identified the attributes of a well-managed process, defined the performance measures, and enumerated the possible best practices in a manufacturing environment. Thus, we have shown in this chapter that the consequences of process thinking include simplified and streamlined value-delivery processes focused on customer requirements. We have defined the core capabilities of an organization and established the relationship between business processes and core capabilities that provide sustainable, decisive competitive advantage to the companies. The principles and development presented in this chapter will provide the foundation for the analysis and design of competitive manufacturing enterprises.

10. BIBLIOGRAPHIC NOTES

Several books have appeared that deal with business processes and their redesign or transformation. These include books by Davenport [20], Harrington [45], and Melan [66]. The paper by Davenport and Short [22] clearly explains the process concepts. In the area of reengineering, several hundred books of varying quality have appeared, starting with Hammer and Champy [42]. While the concept of a manufacturing enterprise has existed for a long time, it has never been formally defined. Our history of manufacturing basically follows Womack et al. [99]. The fundamentals of business processes, their characteristics, and their well-managedness are all available in the literature, and we have attempted a concise and coherent presentation here. The subsection on process enablers is extracted from several sources, including Davenport [20]. Core competencies and core capabilities are well discussed in the literature. Good sources include Prahlad [40] and Hamel [39]. The connection between business processes and core capabilities is evident in Stalk et al. [85] and in Collins and Montgomery [15]. Hayes et al. [49] have collected a variety of case studies dealing with capability development. Vollman [94] has also written a good book on this subject.

Chapter 3

ORGANIZATION STRUCTURE

Learning objectives

1 Understand the importance of organization structure in the implementation of strategy and in gaining competitive advantage.

2 Describe a variety of organization structures that are in existence in the business world.

3 Discuss process-based and network-based organization structures.

4 Bring out the trade-offs to be considered in choosing the most appropriate organization structure.

1. INTRODUCTION

Organizations are formed whenever the pursuit of an objective requires the realization of a task that calls for the joint efforts of two or more individuals. *Organization structure* is defined as the relatively enduring allocation of work roles and administrative mechanisms that creates a pattern of interrelated work activities and allows the organization to conduct, coordinate, and control its work activities. A good definition of organization structure accomplish the following:

- It describes the allocation of tasks and responsibilities to individuals and departments throughout the organization.

N. Viswanadham, *Analysis of Manufacturing Enterprises*

- It designates formal reporting relationships, the number of levels of hierarchy, and the span of control.
- It identifies the grouping of individuals into functional departments.
- It includes systems for effective communication, coordination, and integration of effort in both the horizontal and vertical directions.

The organization structure is reflected in the organization chart, which gives each employee his or her place in the organization, tasks and responsibilities, and supervisors. Reporting relationships show the lines of authority. Employees are grouped together either by the function or product, and they report to a common supervisor. Grouping is important because the employees in a group share common resources and are jointly responsible for performance. The negative outcome of grouping is that coordination may be difficult across groups, thus creating white spaces. Additional mechanisms called *linkages* may be needed to facilitate communication and coordination across departmental boundaries. Vertical linkages coordinate the information flow through the levels of hierarchy. Horizontal linkages provide facilities for communication and coordination across departments. A variety of structural devices are used to create vertical linkages, including hierarchy (referring to the next level in case of problems), rules and procedures for standardized tasks, and plans and schedules (employees are empowered within their budgetary constraints), etc. Horizontal linkages are provided by sending memos and reports and creating liaison roles, task forces, or an integrator to coordinate activities in designated departments. Generally, vertical linkages are stronger because they have a formal sanction and are reinforced by the departmental grouping.

1.1 MECHANISTIC AND ORGANIC ORGANIZATIONS

Organizations are embedded in an environment comprising several sectors such as industry, government, financial, etc. The external environment for each sector could be different, and it could be static or changing. Even in the industry sector, the environment facing each industry could be different. The environments for the cement, steel, or paper industries are quite stable, whereas the consumer electronics or PC industries are characterized by innovative changes. Mechanistic organizations thrive in routine and stable environments where efficiency is paramount as in mass production environments. These organizations are characterized by

- Close adherence to a chain of command and rules

- Vertical employee communication
- Rigid definition of tasks, subtasks, and their coordination
- Highly specialized task execution following the superior's orders
- Knowledge and control of tasks centralized at the top

On the other hand, an organic management structure emphasizes creativity rather than efficiency, innovation rather than sticking to the rules. Employees are delegated the decision making powers, and they exercise self-control in getting the job done. Such organizations are characterized by

- Less preoccupation with adhering to chain of command
- Jobs defined, refined, and redefined to suit the situation
- Lateral rather than vertical communication
- Knowledge and control everywhere in the organization

In mechanistic organizations, each employee's rights and obligations are precisely defined; formal procedures tell him what to do and how and when to do it. Further, in mechanistic organizations, employees are encouraged to pursue their own narrow specialization and refer all unspecified issues to the superiors. There are several reasons why organizations try to formalize behavior:

- To reduce variability: every task is performed consistently
- To ensure coordination: everyone precisely knows what to do and when
- To ensure fair treatment: everyone knows that all employees are treated as per the rules

The arguments against formalization are that it reduces responsiveness in innovation and under competitive pressures. It has been found that in organizations where work content is low in variability, formalization is more prevalent. In firms operating under high rates of technological and other changes, managers and employees interact in order to get the tasks and their work content defined, and formal written communications are discouraged. Communications in organic systems are informal and frequent and are encouraged by providing facilities. Informal and frequent communication can act as a remarkably effective control system, and since everyone knows about all the projects and how they are going, things can never get too far out of control.

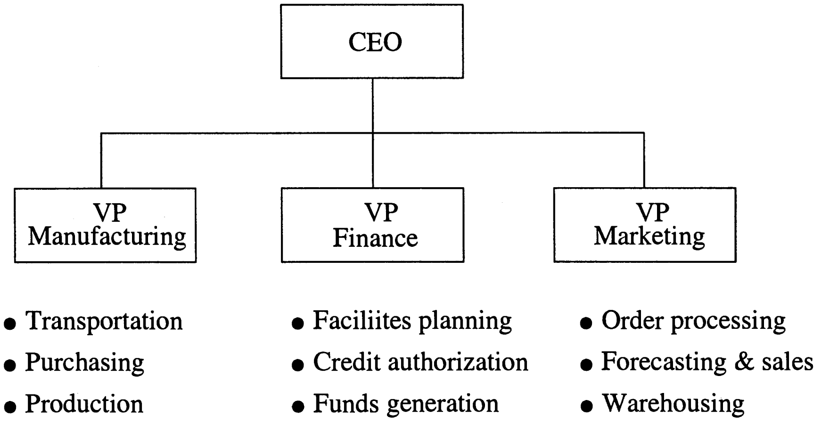

Figure 3.1. Functional organization structure

2. TYPES OF ORGANIZATION STRUCTURES

Organization structure must accomplish two things: (1) provide a framework for tasks, responsibilities, and reporting relationships, and (2) provide mechanisms for coordinating the elements into a coherent whole. Coordination is achieved in organizations by dividing them into smaller interdependent groups and establishing mechanisms for information transfer and decision making. We describe below some typical organizational structures that are currently in practice and discuss their applicability in a variety of environments.

2.1 FUNCTIONAL STRUCTURE

The distinctive feature of a functional structure is that people and activities are grouped by resources or inputs such as finance, marketing, engineering, research and development, and human resource management, etc.(see Figure 3.1). Organizing companies around functions has several advantages. It is a simple, straightforward, and logical way to build departments around basic functions in which the enterprise is engaged. It is the best way when the organizational context stresses specialization, efficiency, and quality. Employees in similar functions adopt similar values, goals, and orientations, which encourages collaboration and makes communication easy. However, coordination and cooperation across departments is difficult; even with integrators and task forces, the allegiance of the employees will be towards the goals of the functions.

Functional organizations have single large departments like sales, marketing, production, design, purchasing, finance, etc. that serve the entire company. The volume of business is high, resulting in economies of scale, promotion of standardization, and reduction of duplication. Also, the specialized functions can procure the best equipment which is timeshared by the entire company's products, and provide in-depth skill development programs to company employees.

The functional structure is most effective when the environment is stable, functions are relatively independent, product variety is small, company size is small or medium, and organization goals assert internal efficiency and functional specialization. This structure is therefore more appropriate in mechanistic situations like production plants and low-variety standardized companies as in the steel industry, where efficiency rather then flexibility is paramount.

Coordination is the process of achieving unity of action among interdependent activities aimed at achieving a common goal. If the work to be done is predictable and is planned in advance, the supervisor can specify or schedule the actions of his subordinates ahead of time. Rules and procedures are thus useful in coordinating routine and recurring activities. The virtue of rules is that they eliminate the need for communication between interdependent parties and between the superior and subordinate.

As the task uncertainty—the difference between the amount of information required to perform the task and the amount of information possessed by the person performing the task–increases, fewer situations can be programmed in advance, and more exceptions arise that are referred upward in the hierarchy. Thus, the hierarchy will become overloaded and serious delays will occur.

Authority means the right to take action, to make decisions, and to direct the work of others. It is an essential feature in organizing. In a functional structure, the final authority and responsibility of coordinating diverse departments such as R & D, human resource management, production, finance, and marketing rests with the president. This may be too taxing to one person and the organization may lose its responsiveness.

Employees in functions get only a part of the big picture of the company and its goals, and this inhibits innovation. Horizontal processes such as new product development, order fulfillment, etc. move very slowly through the functions, as we mentioned before. Mass customization, short product life cycles, rapid product development cycles, etc. simply overwhelm the functional organization.

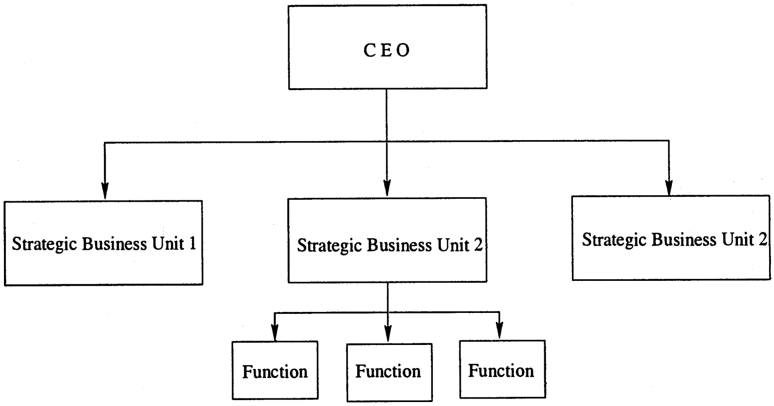

Figure 3.2. Product organization structure

The functional organization is declining in popularity because in many industries, speed is more important than scale and responsiveness to variety is essential for survival.

2.2 PRODUCT STRUCTURE

The product or multidivisional form is structured according to the outputs such as products, services, programs, and projects. The company creates multiple functional organizations, each with its own product line. Heads of divisions are in charge of self-contained companies. Since the units are small, employees identify themselves more with products than with functions.

Figure 3.2 shows the organization structure of a manufacturing enterprise where each product is independently coordinated through a strategic business unit that in turn has a functional structure. General Motors is one of the earliest and best-known examples of the divisional form, with separate divisions for Buick, Cadillac, Oldsmobile, Pontiac, Chevrolet, and Trucks. Hewlett-Packard and 3M also followed this structure. The product structure has several strengths. It is suited for fast and unstable environments and provides high product visibility. The coordination across functions is excellent because of small size and focused goals. The products can be customized to individual customers or regions. The need for new product development is much less than in functional organizations. Further, each employee is familiar with the entire divisional activities and has a better picture of the company.

Product structures also have some serious disadvantages. Each division tries to reinvent the wheel, duplicating resources and missing opportunities for resource sharing. If functions are small, there is a loss of economies of scale. Sometimes a critical mass for innovation and research is lost, and since each company is autonomous, the top management may lose control. Also, supplier management and customer engagement functions multiply with the number of divisions. Furthermore, coordination across product divisions is difficult.

In summary, the product structure was and still is the structure of choice for manufacturing companies, enabling product diversification and rapid product development. The negative features are generally compensated by for introducing some centralized functions, leading to mixed structures.

2.3 CUSTOMER-BASED STRUCTURE

In customer based structures, departments are organized to meet the need of groups of customers. General Electric was organized into the aerospace group, appliance group, construction industries group, industrial group, and power generation group. While customer service could be better in this organization structure, there could be duplication of efforts and resources.

This structure is popular because large buyers such as the big department stores insist on dedicated units to serve their needs. Also, companies organized around customers have superior knowledge about the particular market segment, which provides competitive advantage. Use of barcode data and access to databases and the Internet supplement knowledge about the preferences, buying habits, and life-styles of customers. Service industries such as banks, telecommunication firms, hotels, and construction firms focus on specific customer groups, and hence the popularity of this structure in such enterprises.

Organization structures based on customer-based divisions are becoming very popular, since they are compatible with the present day emphasis on customer focus, outsourcing based on core competencies, and competitive advantage through market knowledge and information.

2.4 GEOGRAPHY-BASED STRUCTURE

Geography-based structures are popular in industries like coal, timber, and steel, which need to be located near the raw materials. There was a need in these industries to be close to the customer to minimize the supply chain costs. Low-cost commodities with high transportation costs use geographic structures. Service businesses have always been organized geographically: Frito-Lay, McDonald's, and Pizza Hut use geographical organizational structures.

Technology has now made possible the creation of smaller, more efficient and flexible plants that can be located closer to the customer. Previously in the service industry (e.g. elevators) a worldwide service network was a competitive advantage. However, the recent advances in reliable electronic controls and remote or telemonitoring smart sensors have made possible repair by customers under guidance from experts. Thus, many service activities are becoming location free. In the automobile and consumer electronic industries, separate operations in various countries such as the U.S., Europe, the Far East, the Middle East, and Japan are common. Each unit operates independently. In multinational corporations, geographic structures typically operate as multidomestic corporations, with each strategic business unit run as a separate firm.

2.5 HYBRID STRUCTURES

The logic of either the functional or product grouping underlies virtually all organization structures. In practice, most structures are not implemented in pure form. A hybrid structure incorporates the characteristics of both functional and product structures.

In a hybrid structure, companies are organized by the product structure, but some functions that are important to each product or market are centralized. The centralized functions are relatively stable and require economies of scale and in-depth specialization. Hybrid structures incorporate the strengths of both functional and product structures and avoid some weaknesses. The main advantage of the hybrid form is that it can help reduce the duplication that is inherent in the compartmentalization around products, customers, market channels, or territory.

2.6 MATRIX STRUCTURE

The matrix structure may be the answer when the organization needs both technological expertise within functions and horizontal coordination of the product line for the same departments. The unique characteristic of the matrix organization is that both product and functional structures are implemented simultaneously. The product managers and functional managers are equally powerful, and employees report to both of them. The manager of the project is given authority and responsibility with a separate budget and resources. His manpower resources come from the functions. On completion of the project, the personnel return to their functional departments. NASA and other space agencies have used this structure. Figure 3.3 shows the logistics activity in an organization implemented using the matrix structure.

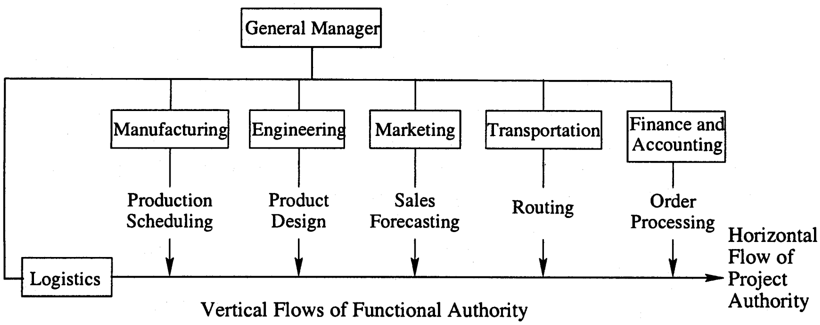

Figure 3.3. Matrix organization structure

The matrix structure is good for non-routine technologies that have interdependencies both within and across functions. The matrix is an organic structure that facilitates discussion and adaptation to unexpected problems. Matrix organizations have several disadvantages, the primary one being the two-boss structure, which is frustrating and confusing. During an economic crunch, the overheads that are necessary to make the matrix structure work, such as meetings, administrative staff, etc., are cut, crippling the organization. Furthermore, because projects are temporary, knowledge created during project execution is not easily transferred to the functions.

2.7 PROCESS-BASED STRUCTURE

We have reviewed several traditional organization structures in earlier sections. In all these structures, the focus shifts among functions, products, customers, or territories without serious redesign of the basic work processes. Because such realignment assumes that functional organizations continue to do the basic work, little or no difference results in actual practice. In essence, while transiting from one structure to another, companies are refocusing on old business practices rather than redesigning new, efficient and effective processes. In traditional organization structures, interface management is not seriously undertaken, although conflict occurrence and avoidance are touched upon.

Organizing using process structures starts with selecting core processes of the company and creating an organization structure to manage these processes. A cross-functional team headed by a process owner administers the process. As we mentioned in chapter 2, each process starts with a customer request and ends with the promised delivery to the customers. Customer satisfaction thus becomes the primary performance measure as well as the driver for the process.

The process structure is the culmination of three strategic initiatives that have focused on work flow processes and have fought against the disconnects created by the interfaces in functional structures. These are total quality management (TQM), time-based competition (TBC), and reengineering. TQM efforts promote understanding and controlling processes and improving them to gain customer satisfaction. Team-based management was suggested by TQM consultants. Time-based competition essentially involves identifying the core end-to-end processes, removing the non-value-adding and redundant activities, and and coordinating the process. Reengineering has given impetus to the process view and has brought in information technology for redesign of business processes. Clearly, the momentum for a process orientation has been building up for quite somet ime. Process management however, involves, , more than defining and streamlining processes to get operational improvements, as in TQM and TBC. Process management [76] is concerned with

- Goal management: The process goals should serve as the basis for the establishment of subgoals for the subprocesses and the work processes. Thus, the functional goals are more oriented towards process goals.

- Performance management: Measurement systems should be in place to measure indicators of the performance of the process. Process improvement based on these measurements is an important issue in process management.

- Resource management: Resource allocation is done for each of the processes based on the capital and people needed to achieve the specified levels of performance. Functions are then allocated their share based on their contribution to various processes.

- Interface management: Management of interfunctional and interorganizational interfaces is an important process management function.

A process owner is responsible for the entire core process, which cuts across various functions and organizations. He is the leader of a cross-functional, cross-organizational team. He is responsible for the performance of the process and also for the four functions mentioned above. Given this pivotal role, the process owner should be someone who holds a senior management position, understands the working of the entire process, has the personal ability to influence decisions and people, and holds a major share of the process activities.

Comparison with other structures: There are many similarities between the matrix structure and the process structure. Like the ma-

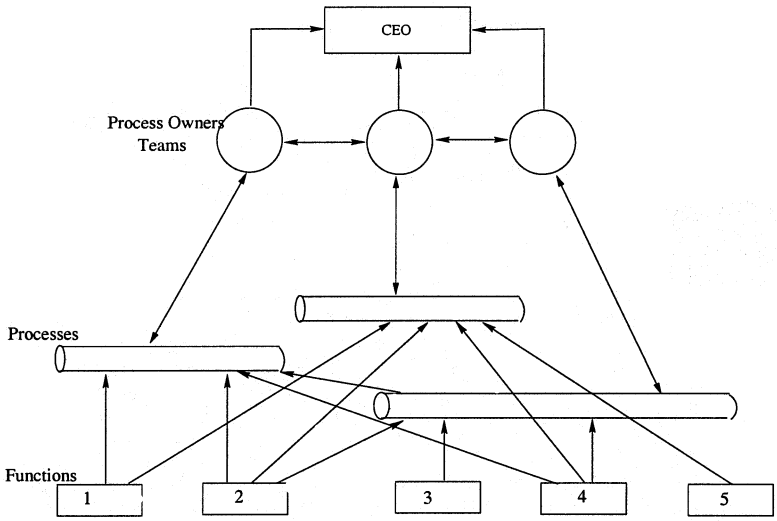

Figure 3.4. Process management structure

trix manager, the process owner also oversees the cross-functional performance of the process. The process owner, however, is no threat to the functional manager. The reporting relationships remain vertical. Processes are permanent, unlike products and projects that come and go. The process owner makes sure that interfaces are managed well and that processes are performing well. Researchers think that a process focus within product structures will prove to be a powerful alternative. Process management can coexist within a functional organization because (1)the direction of business is not changed, (2) the organization map and reporting relationships are not changed, (3) functional goals are more focused towards process goals, and finally (4) the process owner manages only the white spaces between functions.

In summary, in the process structure, we have for each process:

- A clearly defined mission and the results expected
- A flow chart of the process that clearly identifies the work processes, interfaces between work processes, functions, organizations, and interfaces between them (See Figure 2.5)
- A process owner and his/her team consisting of subprocess owners and work process owners
- A responsibility chart showing the monitors for each work process and various interfaces, as shown in Figure 3.4

- Resource allocation to the processes
- A set of process performance measures that drive the the subprocesses below and sets goals and targets for them
- Operational readiness to resolve expected problems through well-designed procedures for problem solving such as root cause analysis

Process management is one of the leading criteria for the Malcom Baldrige national quality award in the U.S. Several leading companies have developed process management maturity levels based on the process orientation (see section 5.6).

Role of top management: A carefully articulated process management can work wonders in terms of performance. Since the process runs through several functions and organizations, chances of conflict are greater initially, which could jeopardize the institutionalization plan. The top management should carefully introduce process management in selected high-performance processes. Thus the top management is responsible for

- Identifying the core processes
- Appointing process owners and their teams
- Using process measures for performance evaluation, rewards, and troubleshooting
- Conducting process review
- Chairing the panel of process owners
- Installing and managing a process planning system that prepares budget and resource requirements

Cultural change: Although the changes in the reporting relationships and the organization map between functional and process structures are not many, there are cultural and performance-related changes. In terms of cultural changes, the message goes through to the functional heads that the top management cares for the overall business performance, for not the functional excellence. Because budget and other resource allocations are directly linked to the performance of the process, interactions among functions tend to be of a win-win problem solving nature, rather than confrontational. Since employees are rewarded for their organizational contributions, they understand the big picture, function-to-function linkages, and the need to collaborate. They also understand the customer since customer satisfaction dominates the performance measurement system. It is true that this kind of cultural change is implicit in product and matrix structures as well. In process structures, however, it is made explicit through the institution of process-based performance measurement systems, resource allocation policy, and goal setting.

Disadvantages: There are several disadvantages of the process-based organization structures. They include the following

1. Although the process structure knocks down functional barriers by creating mechanisms for interface management, it creates its own barriers: interfaces between processes. For example, handoffs exist between the new product development process and the production process groups, and also between the product launch and the order fulfillment groups. Management of these interfaces is also necessary.

2. The most apparent drawback of the process structure managed by a process owner is the decreased participation by the top management. Senior management should be a visible and committed champion of the process.

3. The process structure should also be followed by a process-based performance measurement and reward system. If this is not done, functional managers can sideline the process.

4. Finally, since the process structure is new and its installation requires streamlining of the old processes, enormous amounts of time and energy may be spent on setting up the process and the organization structure. Initially, at least, there may be little emphasis on the actual management of the core processes.

2.8 THE NETWORK ORGANIZATION

Probably the most suitable organization structure for global manufacturing companies is the network organization. It is also called the *modular corporation* or *virtual corporation* and has much in common with the process-based structures discussed earlier. In a network organization, a number of independent companies, each concentrating on its core businesses, form an alliance towards a specific goal. They act together as though they were virtually a single corporation performing activities along an industry's value chain. This approach opposite of what big international firms like IBM, GE, GM, etc. practice, namely, vertical integration, which is ownership of all the activities along the chain. A network organization in contrast is virtually integrated. We identify two broad types of networks namely, vertical networks and horizontal networks, and discuss them below.

Vertical networks are formed when the original equipment manufacturer (OEM) forms a strategic alliance with component suppliers and the

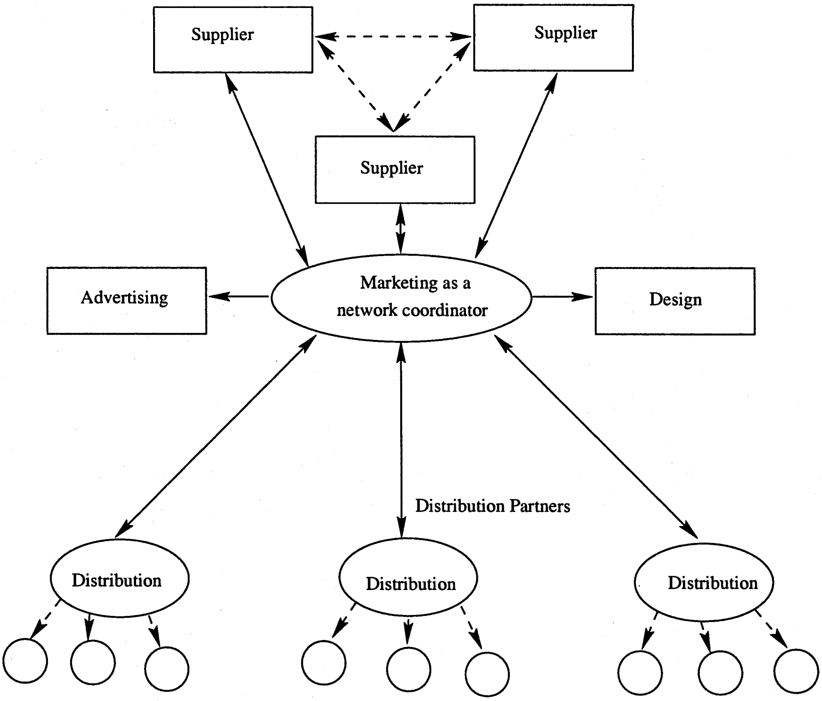

Figure 3.5. The network organization structure in the garment industry

distribution or the customer. The Japanese have perfected this system; Toyota is the best-known example. Disk drive manufacturers like Seagate have alliances with customers who are PC or laptop manufacturers. Benneton, the Italian garment manufacture has created a network with franchises as well as with suppliers (see Figure 3.5).

Vertical networks are found in supply chain processes throughout the world. In the automobile industry, component manufacturers form alliances with several automobile manufacturers and share design and production information. The OEMs encourage the supplier to have linkages with other manufacturers so that the supplier can maintain economies of scale.

Horizontal networks are alliances between firms with similar markets, like the airlines for the purpose of developing a technology or penetrating a geographical market segment. The Toyota-GM venture is a good example of this type of network. Partner selection is crucial to network corporation: the potential partner's strategic intentions, management style, values, goals, and performance are all considered. The selection process takes much time and effort. The administering of the joint activities could be done as an autonomous activity or by dividing

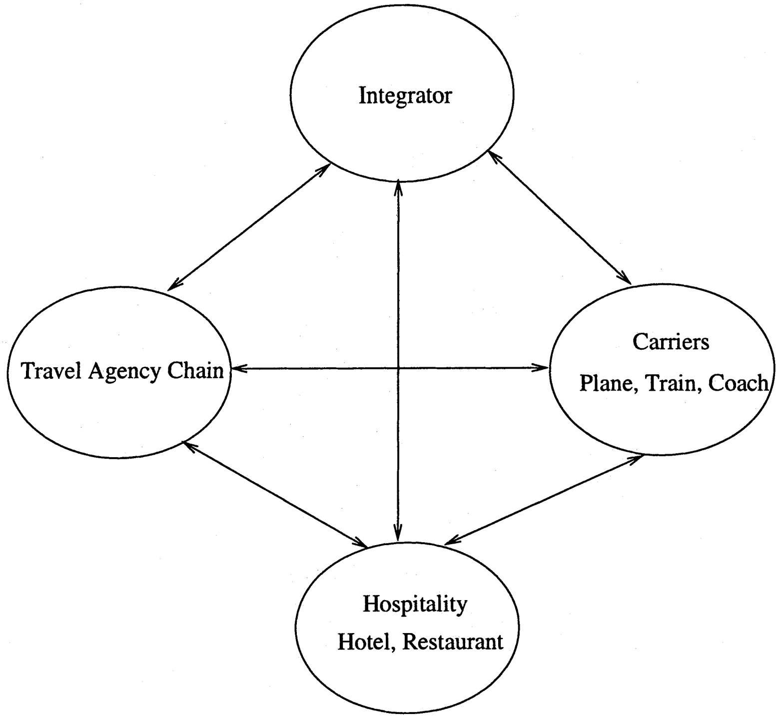

Figure 3.6. Network organization for the hospitality industry

the responsibility among partners, or one of the partners could take the management responsibility. Figure 3.6 shows a horizontal network in the hospitality industry.

Integrator: In a network organization, the leadership role is generally played by one of the partners who is either an original equipment manufacturer or who has the proprietary technology or financial capability. The leader, who coordinates the work flow among all the partners, is also called the *integrator*. The integrator develops the strategy, conceives winning products and markets, and coordinates the work flows so that the network performance is better than other networks or vertically integrated companies. The integrator very often uses its size as leverage to negotiate with partners. Big auto manufacturers use their buying power to their own and their network's advantage. Some integrators, like Apple, use their proprietary technology to gain leverage. Several big companies develop software for Apple, which protects itself through non-disclosure agreements and non-compete clauses and also by rapidly moving to new technologies. Nowadays, information owners, particularly those with information about the customers, markets, and products, are

leveraging their information to become the integrators. Bookstores in the publishing industry, supermarkets, and chain stores leverage their closeness to the customers to play an integrator role. Financiers have always been the traditional integrators and their approach is now being used by investment bankers to fund and manage networks. Training of human resources is also done by the integrator. Benneton, Mark and Spencer, and Nike are the best-known network integrators outside of the automobile industry. Integrators take responsibility for recovery action in case something goes wrong. Virtual integration is made possible by recent advances in the Internet and intranets. Orders and funds flow using EDI and EFT. On-line sales information is transmitted to central computer systems using barcodes and this is used for production scheduling by the OEM and suppliers.
Advantages: There are several advantages of the network organization structure. They include:

1. Independent companies within the network can pool their purchases and the integrator can buy for all companies getting volume discounts. Benneton contracts out most manufacturing to 350 small firms and buys the material for all of them. The variety and flexibility needed to supply the rapidly changing fashion merchandise is achieved by subcontracting the orders to 25 sewing and packing firms. All this shows that the network gets the advantages of large firms as well as the flexibility of smaller firms.

2. By changing its alliance partners, OEMs can speedily adapt to new technologies. When flash memories were replaced by hot disk drives, Apple and many other PC manufacturers quickly changed their sources of supply.

Disadvantages: We enumerate possible disadvantages below.

1. The greatest disadvantage in network structure-based management is the loss of proprietary knowledge and the creation of potential competitors.

2. As more and more activities are outsourced, more profits are given out. Conflicts may arise if a network partner tries to move either up or down the value chain to add more profits, or for other reasons such as maintenance of quality.

3. There could be loss of control over parts of the business in case of conflicts. Skillful partnering is needed to minimize the disagreements among coalition partners.

3. CHOOSING THE RIGHT STRUCTURE

The first organizational design choice is the basic structure. This choice process begins with an understanding of the strategy and the diversity of the business one is dealing with. By matching what is required by the strategy to the strengths of various structures, a decision can be made. It may be noted that no one structure meets all the business requirements under all conditions. The kinds of strategies executed best by the basic structures are listed below. It is important to periodically evaluate the organization structure to determine whether it is still appropriate to the changing needs.

Functional

- Small-medium size, single-product line, and long product development and life cycles
- Differentiation by cost
- Scale or expertise within the function
- Internal efficiency and quality paramount
- Suited for stable and less uncertain environment

Product based

- Moderate to high uncertainty
- Product focus with short product development and life cycle
- Expertise by products
- Effectiveness, flexibility, and customer satisfaction paramount
- Minimum efficient scale for functions or outsourcing.

Customer structure

- Important market segments
- Product or service unique to segment
- Buyer strength
- Customer knowledge advantage
- Rapid customer service and product cycles
- Minimum efficient scale in functions or outsourcing

Geography based

- Low value-to-transport cost ratio
- Service delivery on-site
- Closeness to customer for delivery or support
- Perception of the organization as local
- Geographical market segments needed

Process based

- Best seen as an alternative to the functional structure
- Potential for radical change in process management
- Increased attention to interfaces
- Attention to end to end process performance measures

Network structure

- Preferred structure in global manufacturing networks
- Similar to process structure
- Reduced risk to any one partner
- Trust between partners crucial for success
- Information sharing among partners
- Provides global reach with international alliances
- Reduced cycle times

Unfortunately, in the typical situation no single type of structure best fits the business strategy. The decision maker should list the strengths and weaknesses of each structural alternative and also develop business priorities for attributes such as cycle-time reduction or scale/scope of manufacturing, etc. Then the choice of structure can be made to meet the top priorities.

4. CONCLUSIONS

In this chapter, we have presented an overview of various organizational structures that are useful in managing a manufacturing company or a network of companies. The recent literature on quality management and reengineering has emphasized the need for choosing a flexible and responsive organization structure for companies to meet high levels of customer satisfaction. The literature also points outs the possible delays and many other ills of the functional structure. It is important to recognize the advantages and disadvantages of various structures and also to exercise the right choice. The reader can explore the voluminous literature on the organization structures with the background gained from this chapter.

5. BIBLIOGRAPHIC NOTES

There is a significant amount of literature on organizations and their structure and design. Books by Galbraith [29, 30] and Daft [19] are standard textbooks on organization theory and design. There is much interest now a days in the redesign of organizations as reflected in the magazine articles by Byrne [7] and Treece [89]. The book by Galbraith [30] covers all the organization structures briefly and lucidly. The network organization structure is dealt with nicely by Hinterhuber and Levin [53] and Shiva Ramu [75]. Malone has provided a series of articles dealing with modeling of organizations using queueing networks [62, 63, 64]. The reliability of organizational structures is an important issue [52].

Chapter 4

PROCESS PERFORMANCE MEASURES

Learning objectives

1 Explain the deficiencies of functional measures of performance and the need for developing process-based performance measures.

3 Provide an in-depth discussion on lead time, variation, capacity, cost, reliability, and flexibility.

1. INTRODUCTION

Performance measures are useful to monitor, evaluate, and improve the business processes. They can also be used to compare similar processes in different companies for benchmarking purposes. World-class companies recognize the importance of metrics in helping to define the goals and performance expectations for the organizations. Performance measures are generally defined for an organization and are typically financial in nature. For example, original equipment manufacturers (OEMs) define their own market share, return on sales, or investment. Suppliers and distributors, similarly, define their own metrics. However, this approach is fraught with many ills. First of all, financial indicators are lagging metrics that are a result of past decisions and are too old to be useful in operational performance improvement. Secondly, since most companies do business with multiple partners selling multiple products, individual financial statements do not delineate the winners and the losers. More importantly, when several organizations are involved

N. Viswanadham, *Analysis of Manufacturing Enterprises*

in product manufacture and delivery to the customers, individual financial statements do not give a complete picture of the performance of the product or the delivery process. In this chapter, we identify the nonfinancial measures that would indicate the health of the entire value delivery process and hence the health of all organizations involved in it. More specifically, we define seven performance measures - lead time, quality, cost, capacity, reliability, asset utilization, and flexibility - and discuss methods for their determination and improvement.

1.1 FUNCTIONAL VS. PROCESS MEASURES

As discussed earlier, process orientation and process-based performance measures are very important. Also it is important that all the companies involved in the process chain share the same goals, such as cycle time reduction, six-sigma on-time delivery, or quality or customer-perceived service levels, etc., and exchange information and expertise for the benefit of the entire chain. If, on the other hand, performance measures are defined for functions within an organization, such as manufacturing system flexibility, manufacturing lead time, supplier quality, etc.. and improve only those without regard for the entire process, the expected benefits may not result. To illustrate our point, we consider two examples.

Example 4.1 : Suppose one company in a supply chain, say an intermediate component manufacturer, follows lean manufacturing principles of low cycle time and on-time delivery, but the upstream raw material vendor is not quality conscious and is unreliable in deliveries, and the downstream original equipment manufacturer follows chaotic ordering policies and maintains large work-in-process inventories (see Figure 4.1). Then the lean middle man will have to maintain a huge output inventory to cope with the unpredictable ordering patterns of the OEM and will soon become heavy. Also to counter the unreliable deliveries and low quality of the supplier, the company has to have input inspections and safety stocks. This example well illustrates the fact that performance measures should be defined and measured for the entire process and that performance goals should be shared by all members of the process.

Example 4.2: Here we consider a functionally organized company and show that function-based goal optimization could sometimes lead to disaster and may often lead to poor suboptimization of the overall system. The company has functions such as sales, distribution, manufacturing, and R & D, each having their own measurement system and all decisions are taken with no communication among the functions. Suppose, that sales are measured on the basis of the company's order bookings, distribution is measured on the basis of number of full-load trucks dispatched, and manufacturing is measured on the basis of the company's throughput. Viewed in isolation, the performance measures look very good. Let us look at the effect of these measures on the supply chain process. First, the process is not coordinated and will result in customer delays. Manufacturing will produce large batches to maximize throughput

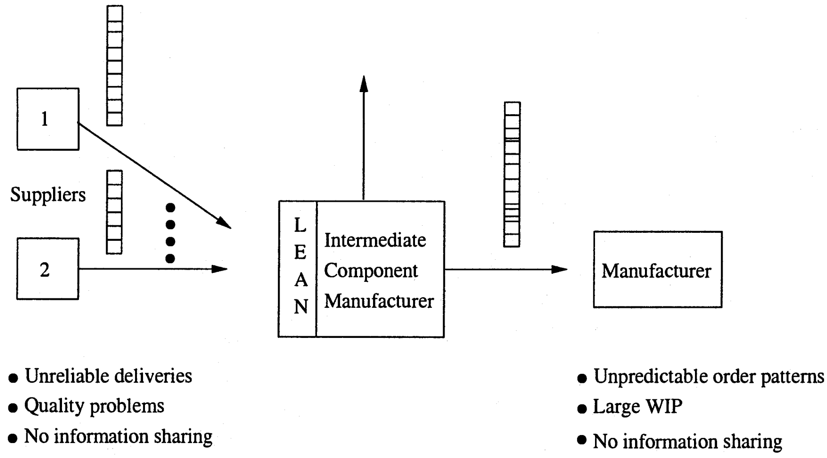

Figure 4.1. Lean component manufacturer between an unreliable supplier and a conventional manufacturer

and will probably be producing a different product than what distribution needs to fill in a customer order. Product shipment dates are determined by "when the truck is full" rather than the "date on which the customer needs it." All these procedures will result in inventories, delays, and customer dissatisfaction. This example illustrates the need for coordination among functions and also for defining the process based performance measures.

In this chapter, we define performance measures for end-to-end business processes such as order-to-delivery, new product development, supply chain, customer acquisition, etc. The performance measures include lead time, quality, cost, reliability, capacity, asset utilization, and flexibility. These process performance measures summarize directly the product and the manufacturing enterprise performances as well as the customer satisfaction levels. This is because a business process is cross-functional and cross-organizational, has a well-defined starting and end-points, and the customer is generally the recipient of the final delivery. Measuring the quality along an order-to-delivery process will directly measure customer satisfaction levels. It will also present information on defects in products, missed deliveries, wrong deliveries, incomplete deliveries, delayed installation, etc. Monitoring these measures will help correct the defects and conduct continuous improvement. Similarly, cycle time monitoring in the supply chain networks will help reduce the inventories, establish good supplier relationships, reduce setup times, etc.

The traditional method of functional performance measurement had a limited purpose and presented only a partial picture of the process.

One could enumerate the following reasons why the process view of an enterprise has not yet gained popularity.

1. The need for managing geographically distributed but virtually integrated enterprises is just arising. Until now, even multinationals had self-contained business units in several geographic locations. The centralized mass production model that we described in chapter 2 still operates in most companies.

2. Developments in logistics with competency to operate on a global scale have occurred only in the decade of the late 1980s and early 1990s. These have gained momentum, with many companies following the make-to-order philosophies to cut inventories and thus costs.

3. Reliable interorganizational communication and secure financial transactions over the telecommunication media are only now gaining acceptance , due to rapid advances in computers, communication, and encryption.

1.2 PROCESS PERFORMANCE MEASURES

In this chapter, we consider the following seven performance measures for a generic value delivery process.

1. **Lead time:** The lead time of a business process is the interval between the start and end of the process. It is the concept-to-market time in the case of the product development process; the clock time between placing an order to the delivery at the customer site in the case of the order-to-delivery process; and the time elapsed from raw material ordering until the final assembly reaching the retailer in the case of the supply chain process. Lead time reduction by removing non-value-adding activities; using information technologies such as EDI, databases, etc.; and effectively managing interfaces with suppliers, manufacturing, logistics, and distributors is an important exercise.

2. **Quality:** Quality is management of all the work processes so that they are on design target with low variation. This goal is achieved through monitoring the performance for defects, conducting root-cause analysis of defects, and and eliminating the sources of defects.

3. **Reliability and dependability:** Here we are concerned with the reliability of product delivery as an operational issue. We measure the ability to manage disruptions such as machine failures, worker absenteeism, truck failures, supplier failures, etc. as well as rush orders.

4. **Flexibility:** Flexibility is the ability to meet customer requirements under various environmental uncertainties in various dimensions such as delivery time, schedules, design and demand changes, etc. Flexibility of business processes is closely related to product structure and to the technology. Modular designs and automation technologies enhance the ability of the company to meet the customer preferences.

5. **Cost:** Like the lead time, cost also provides tremendous insights into process problems and inefficiencies. Interface costs, margins, and costs in negotiations and inspection are a waste and provide avenues for cost cutting.

6. **Capacity:** The maximum output rate of the business is called the capacity. process. All the work processes and subprocesses must be balanced in capacity, otherwise, there will be bottlenecks and delays. Strategic alliances are common among various subprocess owners in order to have variable capacity. A little overcapacity to meet rush demands can improve the operational measures.

7. **Asset utilization:** The assets in some business processes (like the supply chain process and the order-to-delivery process), such as manufacturing plants, warehouses, communications infrastructure, fleets of vehicles, etc., are worth billions of dollars. Their utilization is an important issue.

The above seven measures are very generic and from them the customer satisfaction levels and the operational effectiveness and efficiency of the value delivery process can be computed.

It is often argued that if the fundamental performance measures are managed well, then outstanding financial performance will follow automatically. However, several companies that went out of business after winning quality awards bear witness to the fact that nontraditional performance measures are necessary but not sufficient for sustainable excellence. Thus it is also important to measure the financial performance of the company in terms of the return on investment and market share. The financial performance by itself is not enough, since it can sometimes result from cost-cutting measures and underinvestment in long-term value creation. Concentrating only on the satisfaction of current customers and losing sight of the future products and customers and/or concentrating only on improving cycle times, defect rates, reliability, and flexibility of existing business processes while ignoring financial performance could spell disaster. This can happen when conditions change and new products and new markets emerge. We consider balanced performance measurement in chapter 5.

In times of constant change, as we have witnessed in recent years, nothing should be assumed to be fixed: products, customers, markets, businesses, and technology all change. Business managers have to suitably change strategies, nurture appropriate business processes, and define and adapt suitable performance measures and measurement systems to stay in business.

Defining the performance measures for a value delivery process is generally done by a cross-functional team with members for all functions involved in the exercise. Reaching a consensus on the relative importance of the performance measures is difficult because of the dominant functional culture in the organizations and each function trying to protect its turf. Further, in certain industries certain functions dominate and push hard for their own importance. For example, in consumer goods companies, sales and marketing functions dominate compared to design and manufacturing. In high-tech organizations such as aircraft and automobile companies, engineering functions dominate compared to manufacturing. Oil companies have strong refinery technology, and cost focus and marketing are quite mundane. The voice of the members of the functions in the team determines the relative importance of the functional measures in the total process performance measure of the value delivery process. The process owner or the network integrator have to take care that balanced performance measures are defined that reflect all the functions.

We now study each of the performance measures in the context of general or particular business processes.

2. LEAD TIME

The lead time of a business process is the clock time from the start of the process to its completion. The process could be new product development, order-to-delivery, customer acquisition, or any other process that satisfies the definition of chapter 2. The cycle time or lead time of a process is a fundamental metric that implies all other measures, including quality and cost. Low quality leads to inspection and reworking and such processes have long lead times. Low lead time means an effective and efficient process and hence low cost. Also, lead time reductions are actually a war on waste or non-value-adding operations such as tendering to select the least-cost supplier, waiting time at machines, the supplier's output and manufacturer's input inspections, machine and transport breakdowns, poor scheduling, etc. Thus, low lead time improves cost as well as quality.

In section 3 of chapter 2, we presented the business process hierarchy as a collection of organizational subprocesses, separated by organizational interfaces. Each of these subprocesses in turn was divided into functional subprocesses separated by functional interfaces. The functional subprocesses are further subdivided into work processes and the interfaces between them. We note that value addition occurs only at the work process level. The interfaces consume lots of time if they are not managed well. Also, not all work processes are value adding; some could be eliminated. The procedure followed for lead time compression is to smooth all types of interfaces and eliminate the non-value-adding components in a work process. To proceed further, we divide the lead time consumed in a work process into a collection of task times as follows.

1. **Processing time**: Actual processing time of the order, batch, or part, as the case may be, during which value is being added.

2. **Setup time**: The time required by the resources processing a part, order, or batch, to change over to another one. This time is generally non-value adding, and companies should minimize it. Reduction of setup times is an activity that could consume resources. In a factory floor environment, setup time and setup cost reduction is a well-studied subject and is now standard practice in most world-class organizations.

3. **Waiting time**: Time spent by an order or batch or part waiting for a resource to get released. The resource could be an assembly station or a truck or a design team. Waiting time is a function of the inventory levels in the organization and also of the capacity of the resources. It generally forms a large percentage of the work process time.

4. **Move time**: Time spent in moving a job or batch or order from one resource to another or from one function to another or from one organization to another or to the customer.

5. **Synchronization time**: Time spent waiting for multiple resources to become available. These could be components, subassemblies from external organizations, or availability of men and machines at the same time and so on. We show this separately from waiting time, since procedures for reducing synchronization time require coordination of different organizations.

6. **Decision-making time**: Time spent in setting priorities, work allocation and other unstructured problem-solving activities. This time is important, since in a quick-response environment, there is a need for quick mechanisms for decision making. This time component is dependent on the organizational structure.

We now consider methods used for lead time reduction.

2.1 PROCESS REDESIGN AND AUTOMATION

We need to make sure that business processes are designed to meet the goals of low lead times while maintaining low cost and high quality of products. Towards this end, several non-value-adding activities contributing to the lead time need to be eliminated or minimized. This exercise generally takes lots of time and effort.

Subprocesses can be redesigned by removing non-value-adding activities such as duplicate inspection, waste such as storage and packing-unpacking, and inventory, by direct delivery at the point of use in the upstream activities and by joint scheduling. Also, if we look at a process flow diagram we can find other ways of reducing lead time, such as

1. Combining several jobs into one
2. Minimizing reconciliation
3. Reducing checks and controls
4. Empowering front-line staff

Increasing the speed of the work processes by use of technology is another option. Technologies such as automated machine tools, assembly stations, material handling and storage and retrieval systems, electronic data interchange, e-mail, and electronic commerce can be investigated and adopted to speed up the work processes. Decision-making time can be reduced by following flat organizational structures, by empowerment, and by training of employees in decision making using automated tools.

Interorganizational interface lead times are to be reduced by forming partnerships, co-ownership, or strategic alliances. Having good relationships with smaller number of organizations who have capacity, flexibility, expertise, and human resources will shorten these lead times. Examples of such partnerships suppliers in automobile industry making JIT deliveries directly to the factory floor of the manufacturer and consumer product manufacturers monitoring and replenishing shelf space in supermarkets. Here the organizations act as though they are vertically integrated, scheduling operations together, and making frequent small-lot deliveries to the point of work. We will talk more about this under Partnership Sourcing in chapter 8. The partnership relationships and trust will avoid the need for open-tender quotation exercises and switching suppliers. Also, the stability of a relationship will commit both partners to improvements through investment in new technologies, new production methods, and new management methodologies. Effective partnerships are critical for short lead times.

Interfunctional interfaces are easier to deal with because they are in the same organization. Turf-Wars, Over the Wall types of communication, and functional optimization all increase the lead time. Sharing information regarding schedules and designs via groupware and having common goals for the entire business process will reduce tensions and also the lead time. Use of cross-functional teams to manage the business process, and defining roles, responsibilities, and relationships, will ensure smooth flow of work at the interfaces.

Interfaces between work processes say, between machine centers in manufacturing must also be managed by quick transfer of work from one work process to another. This transfer could involve telecommunications, automated guided vehicles, or road or rail or air transport, as the case may be.

2.2 METHODS TO REDUCE LEAD TIME

The following issues should be considered for lead time reduction.

Process management structure: The entire business process should be managed by a cross-functional, cross-organizational team with a process owner. Good enablers include a process map highlighting the roles and responsibilities of all parties involved in the process, a performance measurement system that supports teamwork and innovation, and a phased review of the technical, commercial, and organizational performances focusing on problem anticipation and problem solving.

Shared understanding of the process: Management can enable shared understanding of the process by developing and disseminating a simple yet comprehensive map of the entire process. Using a uniform vocabulary, the map should identify various subprocesses, organizational boundaries, work processes, functional boundaries, and finally, various elements. The maps should also highlight the interfaces, setup reductions, and other time-consuming organizational matters.

Concurrency exploitation: A business process is a task graph and the lead time is the execution time of the graph on various resources. Looking at the precedence relationships, one could schedule tasks concurrently to minimize the lead time. Concurrent product-process development, overlapping design, etc. are used to reduce the new product development time. Similarly, simultaneous execution of parallel activities in a supply chain process will reduce the product delivery lead time.

Reduce changes: Late changes in the product mix for preferred customers is one of the causes of variation in value-delivery processes such as the supply chain process. Similarly, in a new product development process, design changes during the later stages or towards the market launch are very expensive and often disastrous because they throw the system out of gear. Determining the productmix on a weekly or monthly basis after consulting all the parties involved, including the customers, will minimize late changes. Changes can take a variety of forms: reassigning orders to another customer at some stage in the supply chain process and making changes in the product design after designs have been frozen, are two examples. These changes could lead to customer dissatisfaction in the first case and cost and time overruns in the second case. Market intelligence and customer monitoring will enable companies to gain advance knowledge of customer requirements.

Avoid errors: In all business processes, the work is done to satisfy the needs of either an internal or an external customer. Errors of many kinds are very common due to various reasons including improper understanding of customer orders, miscommunication among various stakeholders, and forgetting to document certain changes . Errors in order taking, quotations, and invoices will lead to deliveries unacceptable to customers. In product development, errors can occur at any stage from concept to final prototype building due to improper understanding of the market and customer requirements. The creation of redundant information structures, design reviews, and careful auditing by independent teams will reduce the defects due to errors.

Reduce product diversity: Product variety creates an enormous amount of complexity because it increases the number of suppliers, product designs, and interfaces. Consequently, the cost and time spent in managing these will go up. Product proliferation should remain skin deep. Options to customers should come from as few technical platforms and components as possible. Excessive, uncontrolled diversity will lead to large lead times. Conducting a simple analysis to find out the preferred customers and fastmoving and profit-making products would be helpful in reducing unnecessary variety. It is often said that 80% of orders come from 20% of customers for 20% of products. Identifying these customers and products would help a lot in planning and reducing unwanted features.

2.3 EXAMPLES

The four examples below are designed to illustrate the method of computing and analyzing the factors influencing the lead time.

Example 4.3: Consider a supply chain with two suppliers, one manufacturer, and two distributors. The manufacturer assembles the product from the subassemblies received from the two suppliers and transports the product overseas to the distributors. In this example, we consider a make-to-order situation of a product whose designs,

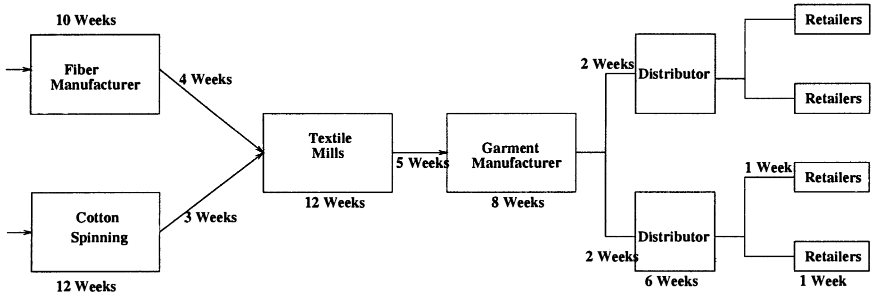

Figure 4.2. Lead times in apparel supply chains

process plans, and machine tools are all available from the suppliers and manufacturers. The average waiting time of an order at supplier 1 is 10 days, processing takes 2 days, and transport and delivery to the manufacturer takes 2 days. Supplier 2 follows the lean manufacturing principles; the order waiting time is 2 days, processing time is 1 day and delivery takes 2 days. The manufacturer schedules the order only a week after all the materials are received from the suppliers. Thus the waiting time is one week and the assembly takes another week to be complete.

The manufacturer subcontracts the delivery of final goods to two third-party logistics providers, one supplying to distributor 1 and the other to distributor 2. The clearance of customs at both ends and transport takes 10 days for logistics provider 1 and 3 weeks for logistics provider 2. Our aim is to compute the lead time.

The problem can be visualized by drawing a graph. Supplier 1 takes 10+2+2 = 14 days for supplying the components to the manufacturer, whereas supplier 2 takes only 2+1+2 = 5 days. Since the manufacturer needs the components from both suppliers for assembly, it will schedule production only after 14 days. Because supplier 1 is a slow company, the agility of supplier 2 is not felt at all. Once the material from the suppliers arrives, the assembly takes 7(waiting)+7(processing)= 14 days. Thus the assembly is ready for shipment after 28 days.

Logistics provider 1 takes 10 days to deliver the order to distributor 1, so the lead time for distributor 1 is 38 days. Logistics provider 2 takes 21 days for delivery to distributor 2; hence, the lead time for distributor 2 is 49 days. If we define the lead time of the supply chain as the time interval between the start and finish of the process, then the lead time is 49 days. An interesting issue will be the ratio between processing time and the total lead time.

Example 4.4: The apparel supply chain is long and slow (see Figure 4.2) It begins with natural/synthetic fiber, moves through thread spinning and weaving or knitting, assembly, packing, labeling, warehouse, distributors, and retailers. Typically more than a year elapses between the time an order arrives at the textile manufacturer and the time the dress appears in a retail store. Inventory holding in the chain is about 60 weeks. DuPont started the quick response (QR) strategy, which is a working partnership among participants in a product's life cycle - suppliers, manufacturers, distributors, and retailers - working as partners that act as though they belong to a vertically integrated enterprise. QR strategy includes time compression and getting closer to the customer. Retailers keep track of sales volumes and returns and also conduct customer surveys. EDI, barcodes, and the Internet are used to speed up the information processing and information sharing. Suppose the lead times are as shown in Figure 4.2 and that we need to compute the total supply chain lead time. From Figure 4.2, we see that

Lead time = Max(10+4,12+3)+ 12 + 5 + 8 + 2 + 6 + 1 + 1 = 50 weeks

Example 4.5 : Consider a supply chain formed out of four companies with a series configuration. Each of them performs three activities: procure, make, and deliver. The first company procures raw materials, and the last company delivers the final product to the customers. For the intermediate companies, the delivery process of the upstream member interacts with the procurement process of the downstream member. In our terminology, together they form the interface process. Assuming that all the activities are independent random variables with known distributions, find the mean and standard deviation of the lead time.

Let M_{pi},M_{mi},M_{di} be the means of the lead time for procurement, manufacture, and delivery, respectively, of the ith company. Also let M_{Iij} be the mean of the interface process between the ith and jth company. Then the mean of the total lead time is given by

$$\text{Mean Lead Time} = M_{p1} + M_{I12} + M_{I23} + M_{I34} + M_{m1} + M_{m2} + M_{m3} + M_{m4} + M_{d4}$$

The expression for the variance can be written under the usual assumptions of mutual independence of all random variables, as $\sigma^2 = \sigma_{p1}^2 + ... + \sigma_{d4}^2$

Example 4.6: Suppose a customer order is served from the warehouse with a probability of 0.6 with a lead time of one day, with a probability of 0.2 it is assembled to order, packed, and transported with a lead time of one week, and with a probability of 0.2 it is made to order with a lead time of one month. Find the expected value of the total lead time.

$$\begin{aligned}\text{Average lead time} &= 0.6 * 1 + 0.2 * 7 + 0.2 * 30 \\ &= 0.6 + 1.4 + 6 \\ &\doteq 8 \text{ days}\end{aligned}$$

3. QUALITY

Quality is hard to define, difficult to measure, but easy to recognize when missing. It is not a single attribute but an aura, atmosphere, and overpowering feeling of the practice of excellence. Crossby defined quality as “a defect-free product or act”. Juran identified quality as “fitness for use”. The essence of all these studies is that the customer, who uses the product or service, has the final word. He or she judges the product, relative to competitive offerings over its lifetime, on all the attributes important in its use. Garwin [31] identified eight dimensions of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. Each category is self-contained and distinct. No company can provide all the attributes. Multiple dimensions imply that the product can be differentiated in a multitude of ways. By selecting the dimensions that are well matched to the market or customer needs, one can outdo the competitors.

It is often very expensive and technically very difficult to excel in all elements of world-class quality simultaneously. Not all customers may perceive all aspects to be of the same importance. To determine the needs, requirements, and perceptions of the customer, it is necessary to be in constant contact with the customer. Customer satisfaction surveys are conducted on product-related factors such as reliability, appearance, and packaging, and service-related factors such as delivery reliability, warranty service, financing, etc. Any instances of customer dissatisfaction should be analyzed using root-cause analysis, and the delivery processes should continuously improved.

3.1 CONTROLLING THE VARIATION

Variation is the tendency of a process to produce different results under almost identical conditions. It is a natural law of life. No two items machined on the same machine by the same operator one after another will have the same dimensions. The transport time between two destinations is different for each trip made. The level of variation will directly affect the output quality of the process. The goal should be to produce products to the design target value all the time. Any departure from the target value means an increase in customer dissatisfaction, inspection, and reworking - which in turn is a departure from the traditional mind-set of conformance to specification limits. Customers want consistency in products, which is possible only when products are targeted towards design limits.

What is six-sigma product delivery? The six sigma is an interesting and relatively new way of measuring how good a business process is. When an order-to-delivery process is six sigma, it implies that the probability of a defective delivery of a defective product is extremely low, equal to 3-4 defective deliveries per million. Fundamental to this analysis is the normality assumption of each of the work processes and interface processes (see Figure 4.3).

To illustrate how the normal distribution is used, consider an order-to-delivery process with a mean of $\mu = 10$ days and standard deviation of $\sigma = 1$. How many deliveries are made within between 9 and 11 days? From the normal distribution curve we see that 68.26% of the deliveries are made between $\mu \pm \sigma$ days, i.e. between 9 and 11 days. Also, 99.73% of deliveries are made between 7 and 13, or μ $\pm 3\sigma$, days. Alternatively, 0.27% of deliveries are missed or defective, this means that 2700 missed. Six-sigma process delivers defect-free 99.9999998%, i.e., 0.002 ddpm.

It is often possible that the mean of the process itself changes over time. It is found that a variation of $\pm 1.5\sigma$ in the mean is commonly considered for most practical situations. When the mean oscillates be-

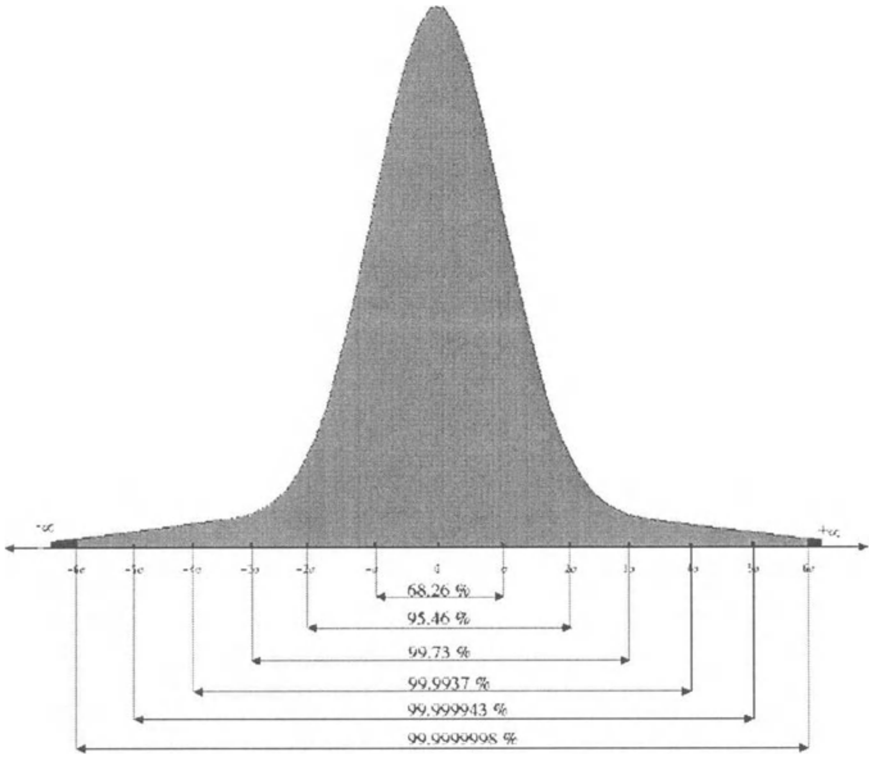

Figure 4.3. Typical areas under normal curve

tween μ and $\mu \pm 1.5\sigma$, then 6 σ translates to 3.4 ddpm. In the TQM literature, two important measures are defined for variations namely C_p and C_{pk}.

Process capability: Process capability is the ability of the process to produce products whose variation is within customer specifications and is centered at the design target value. Reducing variation begins with an understanding of two types of variation: common-cause variation and special-cause variation. Common causes are variations inherent in a process and are random in nature. Close monitoring and control and continuous incremental efforts are needed to reduce variability due to common causes. Special causes of variation are specific, assignable causes that lie outside of the process and are identifiable by use of control charts [82]. They are removed by process correction. Common-cause variations are difficult to reduce. We assume that the process is in a state of statistical control and that special causes of variation are eliminated. We can define two indices to measure variation.

C_p, a measure of process spread: The C_p index measures the actual spread of process variability and is defined as

$$C_p = \frac{\text{Customer Specification Width}}{\text{Natural Width}}$$

where the natural width is the range of six standard deviations of the data points and the customer specification width is the difference between upper and lower specification limits. If $C_p < 1$, then the process is not functioning properly and $C_p = 2$ is necessary for the six-sigma process. Figure 4.4 shows a capable process. The C_p index basically forces the choice of parameters and control variables so that the products or deliveries are as close to the mean as possible. To that extent, the choice of the most desirable mean as well as the reduction of variation around the mean are both important.

Yet another capability index is C_{pk}, which takes into account the changing nature of the mean from lot to lot or from order to order. It was assumed that, on average, the mean changes by about $\pm 1.5\sigma$. As shown in Figure 4.4, as the mean shifts, the process capability changes and the number of defective items increase. In the shifted mean case, the long-term yield is not 99.999998% but 99.99966% i.e., 3.4 ddpm.

C_{p_k}, a better measure of process capability: The C_p index measures the spread only and does not take into account the non-centering of the process relative to the specification limits. We define C_{p_k}, another measure, as

$$C_{p_k} = \text{Min}(\text{x}_1, \text{x}_2)$$

where

$x_1 =$ (Upper specification limit − Process mean)$/3\sigma$

$x_2 =$ (Process mean − lower specification)$/3\sigma$

Because it takes into account both spread and non-centering, C_{p_k} is an excellent measure of variability and process capability. We see that C_p and C_{pk} are related through a parameter k, which is given by

$$k = \frac{|\tau - \mu|}{(\frac{U-L}{2})}$$

$$C_{pk} = C_p(1 - k)$$

where the numerator represents the bias or shift in the mean and the denominator the tolerance. Since k is always between 0 and 1, $C_{pk} \leq C_p$. The index C_{pk} is the process performance and C_p is the process potential.

Business process quality: Quality management of business processes emphasizes understanding, stabilizing, and continuously reducing

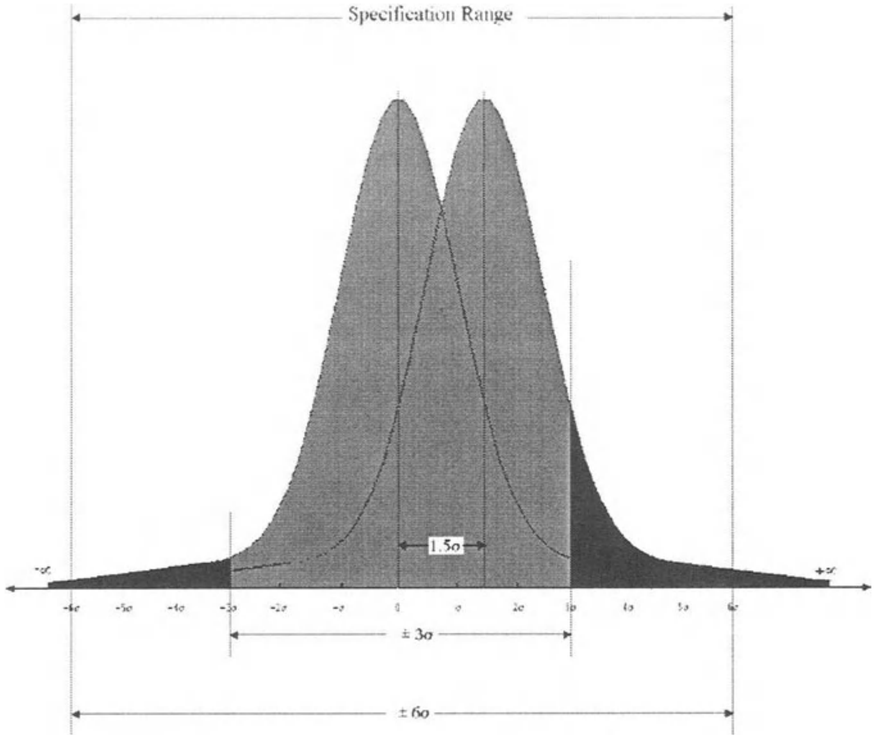

Figure 4.4. Process mean shift and six-sigma quality

variations. Each work process and interface processes could be individually controlled to have a C_{p_k} of 1 to 2 so that the entire business process has an appropriate C_{p_k}. The upper and lower specification limits are to be fixed for the entire business process first. Then, for the individual work processes, specification limits are to be worked out. The work process variation is to be controlled to be within these specification limits. The business process hierarchy diagram is very useful even here. We see in Figure 8.13 the variations for a supply chain process in terms of its constituent work and interface processes. Use of C_p and C_{pk} ratios to reduce the variation improves quality because of the following factors (see also Figure 4.5):

1. Fewer defects: reducing variation reduces the number of defects

2. Widened operating windows: reducing variation results in wider operating windows, making the process easier to control

3. Increased customer satisfaction

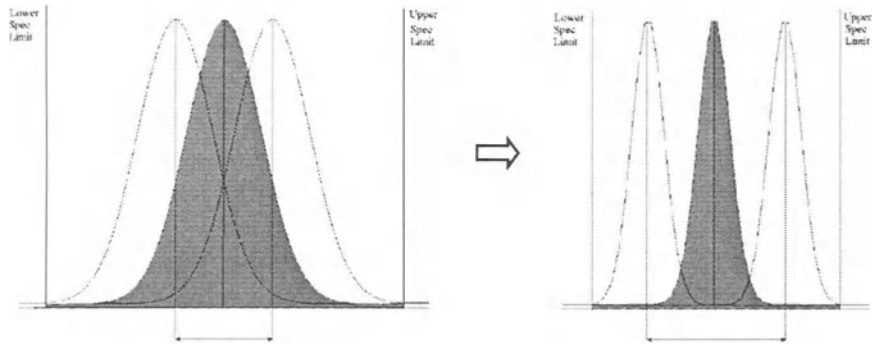

Figure 4.5. Widened operating windows with higher process capability

3.2 EXAMPLES

Example 4.7: A typical order-to-delivery process between a buyer and a vendor consists of five activities whose lead times are normally distributed. The mean and standard deviation of these times measured in days, are given within the brackets for each. The five activities include : order placement (1.2, 0.3), order processing (1.8, 0.8), order preparation (2.0, 0.4), order shipment (2.0, 0.6), and delivery and installation (1.0, 0.5). Find the mean and variability of the order lead time. Suppose the customer wants delivery between 6 to 10 days. Find the C_p.

The mean lead time is equal to the sum of the means of the activities and is given by

$$\text{Mean lead time} = 1.2{+}1.8{+}2.0{+}2.0{+}1.0 = 8.0$$

The variance of the order lead time is given by the sum of the variances and is given by

$$\text{Variance of the lead time} = 0.09{+}\ 0.64{+}\ 0.09{+}0.36{+}0.25 = 1.43$$

Thus the standard deviation of the lead time is approximately 1.2 days. The natural width is then 7.2 days. The customer specification width is given as 4 days. Assume no mean shift. Then C_p of the delivery process in the window (6, 10) is

$$C_p = \frac{10-6}{6(1.2)} = \frac{4}{7.2}$$

If the delivery window is wider, say (4, 12), then C_p will be correspondingly higher:

$$C_p = \frac{12-4}{7.22)} = \frac{8}{7.2}$$

For this delivery process to be six sigma, the delivery window should be (0.8, 15.2).

If the delivery window is fixed, say (6, 10), and we want a high-capability process, say $C_p = 2$, then the σ of the process should be very low:

$$\sigma = \frac{U-L}{6C_p} = \frac{4}{12} = 0.3$$

If now we consider a mean shift of 1.5σ, then C_{pk} turns out to be 1.5, and we thus get a six-sigma delivery process. So $C_p = 4/7.2 = 0.555$. Suppose we want $C_p = 1.33$; then the standard deviation needs to be 0.5. This can be achieved using IT tools for order placement, processing and preparation.

Example 4.8: Consider the order-to-delivery process in Example 4.7. Now compute the days of inventory the buyer should maintain so that he or she can maintain a continuous production rate with 0.97 probability.

The allowed probability of production stoppage is 0.03. This is called the *service level* and is a policy decision. It determines the safety stock, which is an extra inventory above the average consumption. The safety stock is the expected demand in number of standard deviations from the mean to obtain the desired service level and is obtained from the normal distribution tables. For a service level of 0.97 , the safety stock turns out to be 1.88. Thus, the amount of inventory consists of two parts: the amount consumed during the mean lead time plus the safety stock to keep the production going with probability 0.97.
The total inventory at the buyer's end is 8.0 +1.88 x 1.2 = 10.256 days of production.

Example 4.9: A PC manufacturer purchases the subassemblies from various suppliers. For one component, namely, the monitor the manufacturer has a choice between two suppliers. Both quote a mean delivery time of 10 days. The data analysis shows that the standard deviation of supplier 1 delivery time is 1 day and that of supplier 2 is 5 days. For a 99% service level, how many day's inventory is needed for both cases?
For this service level, $z = 2.33$. This means that the manufacturer has to keep an inventory of (10 + 2.33 x 1) = 12.33 days if he buys from supplier 1. If he procures from supplier 2, then he has to keep 10+ 2.33 x 5 = 21.65 days of inventory. Thus if he chooses supplier 2, he has to keep much more inventory.

4. CAPACITY

The capacity of functional divisions such as design, manufacturing, sales, and transport can be measured by the number of design engineers, machine hours, number of sales personnel, number of vehicles or tonnage of material that can be transported, etc. Here, we are concerned about the capacity of a business process. In a supply chain process, for example, the manufacturing facility has several suppliers, distributors, and logistics providers. All the subsystems should be properly balanced in terms of capacity so that the entire process works like a seamless pipe. Otherwise, facilities will become bottlenecks and will increase the delay or the inventory.

The capacity of a business process can be defined as the maximum rate at which a process can convert the inputs to the outputs. This rate can be computed by looking at the capacities of various subsystems in the process. The process capacity will then be less than the capacity of the slowest element on the critical path. If one wants to be a quick response manufacturer, without keeping inventories, then all units should have capacities matching the customer demand profile.

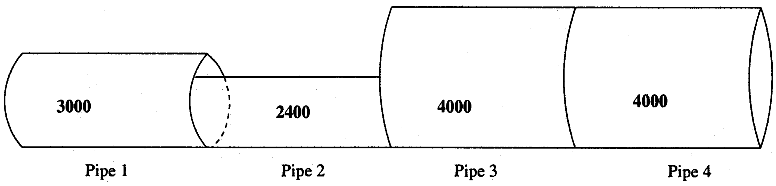

Figure 4.6. Supply chain capacities in example 4.10

The ability of the business process to attain its full-potential capacity is limited for several reasons. Many issues have profound effect on the actual capacity, including interface management techniques such as strategic alliances and vendor managed inventories, maintenance and TQM policies that are followed by suppliers, manufacturers, and logistics partners; training of the work force; best practices, such as cross–docking [86], and information exchange among partners and scheduling and balancing of work among all subsystems. Capacity acquisition or capacity requirements planning has to be done while keeping in view all the core business processes such as the supply chain, order-to-delivery, new product development, etc.

In manufacturing, the classical ways to meet short-term and long-term capacity demand imbalances are met, are through hiring or firing workers, subcontracting and being a subcontractor, adding or selling machines or equipment or trucks, having more shifts or less shifts, and finally by keeping inventories. In the case of business processes, where multiple organizations are involved, capacity balancing could be done through strategic alliances, changing the suppliers, subcontracting, and maintaining inventories.

4.1 EXAMPLES

We present below two examples. They illustrate the importance of bottleneck analysis in supply chains.

Example 4.10: Suppose that in Figure 4.6 we have a supply chain with the following capacities:

Pipe 1 —- Iron Ore Mining and Processing (3000 tons/ day)
Pipe 2 —- Material Transport (Conveyor)(2400 tons/day)
Pipe 3 —- Blast Furnace (4000 tons/day)
Pipe 4 —- Basic Oxygen Furnace (4000 tons/day)

It is obvious that the conveyor (pipe 2) is the bottleneck. Doubling the capacity of either the blast furnace or the basic oxygen furnace will not increase the output of the system. The system capacity can be increased by modernizing the material handling system. A large increase in its capacity will be a waste because some other facility will become a bottleneck. Suppose we increase the conveyor capacity to 4000

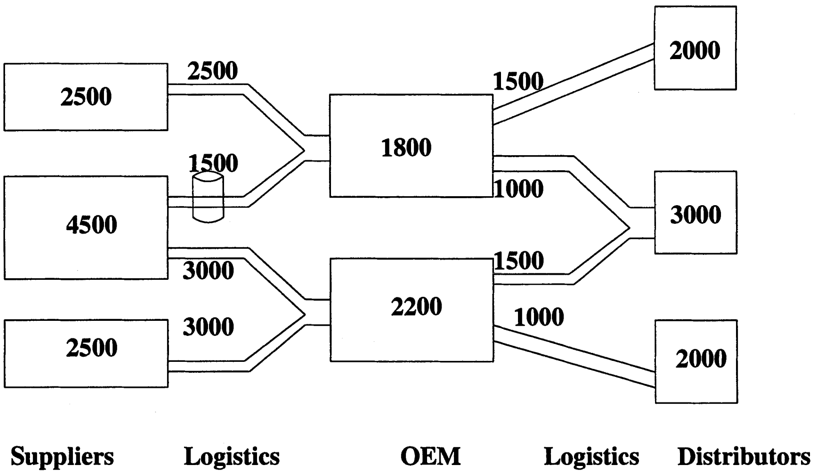

Figure 4.7. Capacity bottleneck in a supply chain process

tons/ day. The mining process will become a bottleneck unless improved, and the system throughput will stay at 3000 tons/day.

Example 4.11: Consider a supply chain process with three suppliers, two OEMs, and three distributors. There are eight logistics operators. All the capacities of the facilities and subsystems are shown in Figure 4.7.

We find that the capacity of the logistics provider from supplier 2 to OEM1 is only 1500 and is the bottleneck. Suppose OEM1 enters into strategic alliance with supplier 2 and the logistics provider and increases the capacity to 2000 items/day. Then OEM1 itself becomes the bottleneck. We can increase the OEM1 capacity to 2500; then we see that the bottleneck shifts elsewhere.

5. PROCESS RELIABILITY

Since the business process is a collection of work processes separated by interfaces, defect-free operation of each work process and interface processes is important for the entire process to work well. The reliability of the business process is in fact the product of the reliabilities of the individual work and the interface processes. This figure will be very low unless the individual work processes have close to unit reliability. Late deliveries from critical suppliers, breakdown of critical equipment of manufacturers, employee problems of the logistics provider, etc., are some of the contributors to work process unreliabilities. The alliance partnerships and their reliabilities also contribute to the overall reliability; their effect on the lead times, fill rates, and defect rates, etc. can be determined via discrete event simulation.

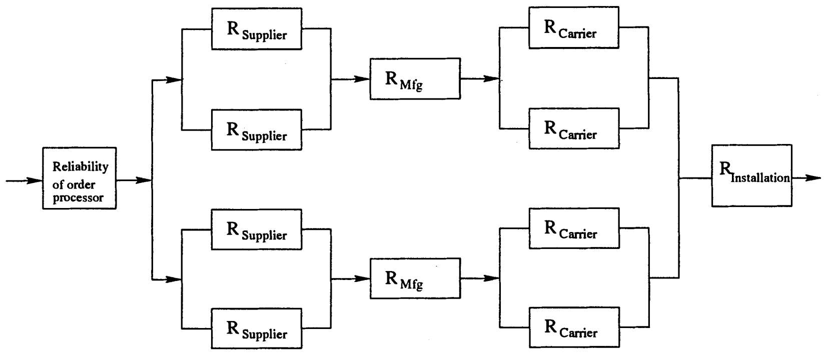

Figure 4.8. Reliability of a supply chain

To predict the reliability of the process, one has to develop a reliability flow chart, identify major failure modes, and design ways in which failure can be prevented. Redundant equipment, multiple suppliers, multiple carriers, and excess capacity are some of the means to increase the reliability.

Example 4.12: A manufacturer purchases a component from a supplier, which he then processes and delivers to the customer. For reliability reasons, he sources from two suppliers and uses two carriers to transport, just in case one fails to turn up. Compute the reliability of his product delivery. The reliability can be obtained by computing the reliability of the upper limb of the reliability diagram in Figure 4.8:

$$R_{UL} = R_{LL} = \left[1 - (1 - R_{sup})^2\right] R_{mfg} \left[1 - (1 - R_{car})^2\right]$$

Example 4.13: A manufacturer has two different plants, located in different countries. For each plant, it sources components for assembly from two different regional suppliers. He also uses two different logistic operators. Suppose orders are taken centrally for both plants. Find the reliability of product delivery.

The solution can be obtained by computing the reliability of the series parallel diagram in Figure 4.8:

$$\text{Reliability} = R_{op}[1 - (1 - R_{UL})(1 - R_{LL})]R_{Inst}$$

5.1 DEPENDABILITY

Dependability of a delivery process is the trustworthiness of product delivery and means delivery promise. It is intimately related to the lead times of the process. One can achieve high dependability by quoting long delivery times but this will divert the customer towards more responsive competition. Also, longer delivery times will mask signs of inefficiency of the process, just as inventory will mask longer manufacturing lead times and will make the organization totally uncompetitive in the longer run.

Further, delivery dependability and low lead times are both customer satisfaction measures. Delivery reliability is also a user-oriented measure, meaning that late deliveries even if 1% on average, will affect 1 out of 100 customers 100%. Also, predictable dependability, where everything works on time, is a big morale booster, saving much otherwise wasted time on customer complaints, expediting, and other follow-up activities. Without dependability, other improvements in speed, flexibility, quality, and productivity will never reach the full potential. Monitoring equipment, preventive maintenance, flexibility in operations, choice of the right product mix, capacity slack, and partnerships with suppliers and distributors are essential for high dependability.

6. COST

We are concerned here with the cost of value delivery to the customer. Either in new product development or supply chain processes, the job visits several functions and organizations. When the job or order transits from one organization to another interface costs of negotiation, procurement, logistics and delivery are incurred. Also each organization incurs material, processing, inventory and overhead costs whenever a job visits and has its own profit margins. Thus (see Figure 4.9) the total cost to the customer is the sum of processing and handling costs incurred, margins, and interface costs for all the functions and organizations [44].

Continuous improvement involves a never ending search for reducing the total cost of product delivery. This can be done by efficiently performing value-added activities and by reducing or eliminating the non-value-adding activities. All the organizations involved should work together to reduce interface and non-value adding costs. There are several costing methods, such as job costing, processing costing, customer costing, target costing etc. We refer the reader to [54] for further details.

It is also important to make proper cost allocation to various processes; otherwise, wrong inferences can be made. For example, manufacturing facilities are used by both the new product development process and the supply chain process. It is only appropriate to include the costs incurred in the initial testing, and redesign costs can be included in the new product development costs. Then research and development people will be able to better appreciate the economics of new product development and the costs involved.

We now bring to attention the importance of total cost analysis, both at the value delivery process and the individual company levels by considering the supply chain process [47]. From Figure 4.9 we see that the customer actually pays the total supply chain cost. This figure also illustrates two points:

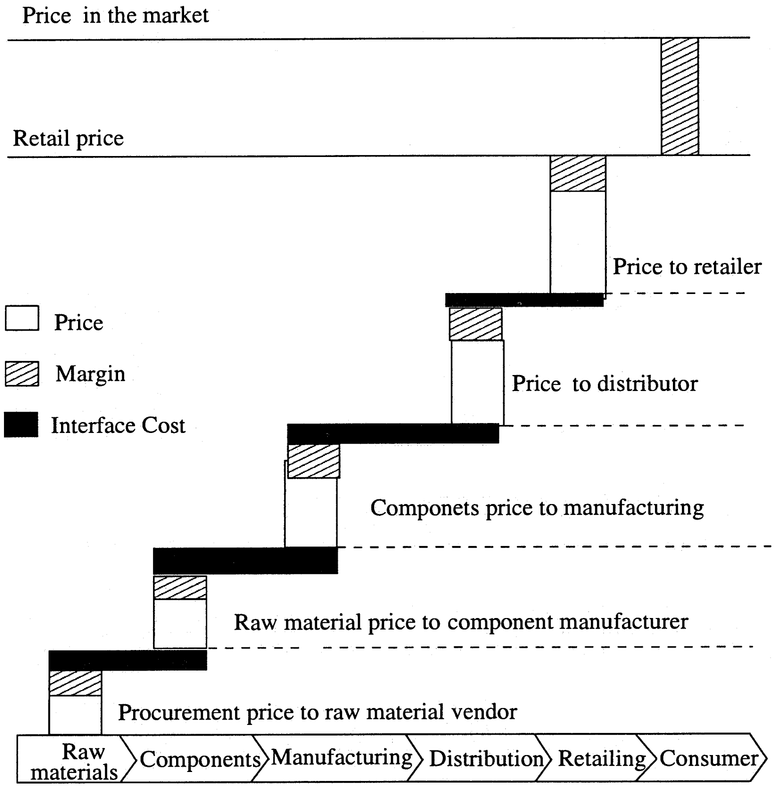

Figure 4.9. Supply chain costs and margins (Adapted from [44])

- The individual company excellence in low-cost production and distribution is necessary but not enough from the customer point of view. Cost cutting all along the supply chain is needed.

- Transfer of costs to the neighbors may yield cost reduction for the company but will not have an influence on the supply chain cost that the customer actually pays.

In a similar way, in purchasing, the total cost of procurement is more important than the unit price. Consider a manufacturer sourcing from a component manufacturer. Low unit price may indeed turn out to be expensive in the following way:

- If the supplier delivers in large batches, then the manufacturer has to incur storage capital and obsolescence costs

- If the supplier does not have good quality control practices in place, then the OEM incurs inspection and replacement costs

- If the supplier is not reliable in delivery matters, the manufacturer has to pay for safety stocks, rescheduling, loss of production, and expediting

Thus, the lowest total purchase cost supplier need not be lowest unit cost supplier. One should include the ordering, production, inspection, storage, and delivery costs to the work site in computing the total cost of a product.

6.1 EXAMPLES

Example 4.14 : Life cycle costing tracks all costs attributable to the product from start to finish. The terms cradle-to-grave costing or womb-to-tomb costing convey the intent to capture all costs associated with all stages of the product life cycle. Suppose a product is designed, prototyped, tested, produced, and distributed by a company. Suppose the product and process development costs are $4 million and the process installation charges are $3 million. The distribution has three divisions: marketing, sales, and customer service. These were set up at costs of $1 million, $0.5 million, $0.8 million respectively. A total of 10,000 items are expected to be sold in the first instance. The production, logistics, marketing, sales, and service costs per product are $300, $80, $240, $160, and $270, respectively. Find the product price that would make a profit of $4 million for the company.
The fixed costs of product design and process installation are (4.0+3.0+1.0+0.5+0.8) =$ 9.3 million. The operating costs per product are (320+80+240+160+270)= $1070. Thus the cost of making and selling 10,000 items is $ (9.3 + 10.7)= $20 million. The expected profit is $4 million. To realize this profit, each product has to be priced at $2400.
Example 4.15: A different notion of life cycle costing called *customer life cycle costing* focuses on the total cost to the customer of acquiring and using a product. This cost important both in business-to-business commerce and business-to-customer commerce. In the case of consumer goods, such as air conditioners, refrigerators, and microwave ovens, the costing is done by allocating direct and indirect costs. The direct costs include the material, manufacturing, and warranty costs. In the case of a refrigerator, these costs are $70, $145, and $45 respectively, for a total cost $ 260. The indirect costs associated with this product are for design, marketing, and delivery. There are six indirect cost pools, given below:

$$\begin{aligned}
\text{Procurement}\ \ (80\ \text{parts}; \$0.60/\text{part}) &= \$48 \\
\text{Production}\ \ (3.5\ \text{hours}; \$16/\text{hour}) &= \$56 \\
\text{Qualitytests}\ \ (1.0\ \text{hr}; \$36/\text{hour}) &= \$36 \\
\text{Distribution}\ \ (50\ \text{cft}; \$2/\text{cft}) &= \$100 \\
\text{Marketing}\ \ (\$60/\text{unit}) &= \$60 \\
\text{Delivery}\ \ (\$30/\text{unit}) &= \$30
\end{aligned}$$

We thus have indirect costs amounting to $330. The total cost of the refrigerator is $ 590.
Example 4.16: In this example, we compare the domestic and international supply chains. All domestic shoes have a lead time of 2 days and are sold at $50 each. The international product has a lead time of 2 weeks and is sold at $21 each. The domestic version is of good quality. The other variety is sold to low-income groups to nurture

Table 4.1. Costs for national and international supply chains

Item	National	International
Labor	3.15	0.13
Materials	7.85	5.30
Assembly	5.60	5.23
Transport	—	0.36
Overhead	4.77	—
Inventory	1.33	0.93
Cost	23.93	11.95

the brand name and to maintain the slogan "we have a shoe that fits your foot and bill." The costs of the national and international brands are given in Table 4.1.

We see that the international supply chain is cheaper and may be of lower quality. The overhead is charged on the national product and not on the international product because the design and development are done nationally. Supplier development could be included as an overhead cost in the international chains.

7. ASSET UTILIZATION

Any company must create or outsource several facilities for research and development, testing, prototype building, transport, manufacture, storage etc. These facilities cost lots of money. If these are owned, it is important to maximize their utilization. For example, one could maximize the storage usage by increasing the number of inventory turns. In the case of R&D, a good measure might be the number of new products generated by the R&D team.

Measures to improve asset utilization may focus on improving productivity from capital investment projects and may also accelerate the capital investment process so that the cash returns from these investments are realized earlier. Also, all assets have a life cycle and need replacement overtime. In effect, one would like to reduce the cash-to-cash cycle time for investments made in creating the physical and intellectual resources while improving the productivity.

For example, a supply chain network has several resources requiring considerable investments. These include information systems, distribution facilities, warehouses, material handling equipment and transportation, production plants, and other facilities. There are many intellectual assets and knowledge resources. Companies can increase the utilization of the infrastructure by sharing them across multiple business units, reducing unproductive times such as setup time, subcontracting the underutilized resources, etc. It is also important that companies measure quantities such as cash-to-cash cycle time in capital investments such as tendering to installation to writing off, and value added work coming out of expensive machines, warehouses, etc. While full utilization of all the facilities is an impossible goal to achieve, it may also not be desirable, since the lead time and the inventories increase enormously with high utilization levels. Balancing the workload, effective scheduling of the orders along the supply chain, reducing variability in the lead times of all the facilities, correct choice of batch size at each facility, reduction of reworking and working towards low defect levels at all subprocesses are all important factors in improving the asset utilization.

Example 4.17: In this example, we compute the inventory turns, which is a measure of the utilization of a warehouse or a distribution center. Think of your supply chain as a pipeline and the product flowing from one end to the other. Imagine each of the facilities as holding tanks with control valves. There are two ways of increasing the throughput of a supply chain: by increasing the diameter of the pipe or by increasing the velocity of the flow of the product through the pipe. The latter approach has the advantage of increased utilization of the tanks, reduced inventories, and a supply fresh products. The inventory turns of a warehouse or distribution center relate to the velocity of the product flow and are defined as the ratio of the annual sales to the annual investment in the inventory.

Suppose we have a distribution center that has 25 monthly working days and 250 annual working days. Suppose that the monthly sales volume is $100,000 and the end of the month inventory is worth $200,000. Then the inventory turns can be easily computed as

$$\text{Inventory turns} = (100{,}000 \text{ x } 250) \ / \ (200{,}000 \text{ x } 25) = 5$$

One can also find itemwise or classwise (A or B or C) inventory turns. Suppose the class A items group has a monthly sales of $50,000 and an end-of-the-month inventory of $75,000. Then the inventory turns for the class A item are 50,000 x 250 / 75,000 x25 = 6.66.

Example 4.18: In this example, we compute the order-fill ratio. It provides the measure of the out-of -stock condition. It is computed for all classes of materials from raw materials to the finished goods.. Suppose in a given month that 200 orders are processed and 162 of them are filled completely; then the order-fill ratio is given by 162/200 = 0.81.

8. FLEXIBILITY

The literature defines *flexibility* as a system's capability to cope effectively with a wide range of environmental changes and internal variations without deterioration in system performance in terms of cost, quality, lead time, and on-time delivery. Flexibility is certainly a virtue for a manufacturing system in these times of global competition, turbulent changes, and mass customization. It is certainly not a new concept and has been studied in the economic and organizational context. Earlier studies in the manufacturing context emphasized flexibility in the context of the factory floor. In this section, in contrast, we are concerned with the flexibility of the entire business process.

Since a business process is an ordered set of work processes, it is essential that the work processes be flexible for the business process to be flexible. Flexibility improves performance measures such as lead time, quality, and on-time delivery. It also allows the manufacturing system to cope with uncertainties such as the following.

Resource changes: Variations in the number of human and machine resources on a factory floor due to machine failure, absenteeism, etc., transport breakdown in a logistic system, and rush orders from valued customers are issues that arise routinely. The process management should be able to cope with changes.

Design and demand changes in the product: These changes could be either planned or unplanned. Customer demand is random and, with inaccurate forecasting, will cause uncertainty in the design and mix of products. Proactive introduction of new products to beat the competition will reflect as planned change.

Technology changes: These could be continuous or discontinuous. Discontinuous technology changes such as those in the PC industry and hard disk drives, are difficult to cope with. The company should have the ability to predict and develop competencies in new technologies for future product generations and also have the capability to evaluate the risk associated with new ventures.

Sociopolitical changes: The deregulation of telecommunications, airlines, and transportation networks has had a big impact on existing players. The liberalization of certain closed economies has had the same impact. Legislation on health care has had tremendous impact on hospital and health insurance systems.

8.1 COPING WITH UNCERTAINTY

As we move from resource changes to design and demand changes in the product to sociopolitical changes, we see that both the magnitude and the effect of change will increase. Changes can be classified as operational, tactical, and strategic and the flexibility strategies could be correspondingly named. Resource changes occur daily, and appropriate procedures have to be designed and built into the system. Events such as failure of a machine or a truck or a rush order occur at random times and places. Procedures such as those in hospitals and civil defense should be evolved for all frequently occurring events. Design and demand changes occur, say, weekly, and they have to be met through proper scheduling of orders. They are tactical in nature and involve suppliers, logistics, and distributors. Technology changes are sporadic but occur in a predictable way for companies with learning capabilities. Some companies see the opportunity and lead the change in an offensive way. They are strategic in nature and involve proactive strategies for product development, technology adaptation, etc. Sociopolitical changes are outside company control but some companies turn these into opportunities.

The flexibilities built into the enterprise should be able to cope with these changes. These abilities are built into the enterprise via technology, procedures, and control mechanisms such as scheduling, information processing, etc. It is important to analyze the changes to which a system is subjected so that appropriate flexibility strategies can be designed and implemented.

The best way to cope with uncertainty is to eliminate its sources. This may not always be possible, but certainly one can reduce the amount of change. For example, customer surveys and monitoring of point-of-sale information, redesigning product range to increase part commonality, and delaying final assembly until receipt of order will reduce demand uncertainty; preventive maintenance, use of diagnostic expert systems, and built-in fault tolerance will reduce downtime and increase the system availability; and quick adoption of new technologies such as IT and their proper implementation will remove all non-value-adding activities and cut costs and delivery time to a minimum. Then one will be able to confidently face or even lead price wars in the face of deregulation.

At times, replacing a rough terrain with a smooth road, rather than trying to cope would help eliminate the need for change. By providing a smooth road and a constant environment for a vehicle, one avoids the need for flexible legs. By providing a transfer mechanism in an automobile assembly that can transfer the workpiece across machine tools, one has eliminated the need for sensory and manipulative human functions. Group technology cells, each focusing on a product family, streamlined the product flow on the factory floor, thus eliminating the need for sophisticated material tracking and scheduling algorithms [92].

A flexible manufacturing enterprise whose business processes can cope with all the above changes will be extremely complex, expensive, and time consuming to install. Such an enterprise requires redundancy in terms of excess capacity, space, and time, which again will increase the cost of the products. In an environment of fast-changing technologies, shrinking product life cycles, and changing customer attitudes, one should strike a balance between cost and time for implementation and hedge against near term uncertainties. One has to recognize that each industry/firm has only a finite life and eventually has to open new factories for new products and has to phase out old ones.

Thus we see that a preliminary analysis of the uncertainties will lead to an appropriate manufacturing system configuration that can effectively cope with changes induced by these uncertainties.

8.2 FLEXIBILITY IN BUSINESS PROCESSES

It is a common misunderstanding that flexibility is achieved through flexible machine or computer hardware acquisition. The truth is far from that. Indeed, several companies have incurred losses because productivity declined with the introduction of new manufacturing hardware. Process variety complicates the parts supply and assembly processes because more parts require a greater coordination to get the right part into the worker's hands at the exact instant the guided vehicle brings the part to the worker's station. Because of the complexity induced by variety, many companies view flexibility management as a necessary evil [81].

Manufacturing enterprises increasingly look like fast-food chains. Customers place their orders. Waiters transmit the specification to the kitchen, and a team of cooks assembles the product. The products are designed already, and part-programs are available; as soon as customers order from a menu, the products are scheduled and delivered. This kind of flexibility is static flexibility or a product-centric view of flexibility. On the other hand, dynamic flexibility is creation of the capability to act in response to opportunities as they arise over time. Competencies to develop new designs and new products, to manufacture customer-desired products, and to deliver these faster than the competition are tenets of dynamic flexibility.

There are four basic types of flexibility: mix, volume, new product, and delivery time (see Table 4.2). Each is important in a different environment [87]. These flexibilities are implemented through a variety of factors such as production technology, product management techniques, relationship with suppliers and distributors, human resource management, and product design. It is important to realize that different types of flexibilities are important in different competitive situations. For example, mix flexibility is important when a firm has a broad product line and caters to different market segments. There are several ways of achieving each type of flexibility. Mix flexibility may be achieved through skilled workers or programmable equipment. New product flexibility is needed in technology-intensive markets. Volume flexibility is important in volatile markets.

Table 4.2. Types of flexibility in a manufacturing enterprise

Mix Flexibility	Ability of an enterprise to simultaneously produce a number of different products in a given period.
Volume Flexibility	Ability of an enterprise to change significantly the production level and the composition of the product mix in a short time span.
New Product Flexibility	Ability of an enterprise to add or substitute new products to the product mix over time.
Delivery Time Flexibility	Ability of an enterprise to reduce the order-to-delivery time

Flexibility management is a competence that involves skillfully managing several resources of the enterprise, including automation hardware, software, people, organization structure, suppliers, customers, distribution channels, and factory floor control systems. It is an integrity-related competence and involves collective learning in the organization, coordination of diverse production skills, and integration of multiple streams of technologies. It is a capability to deploy various resources of the company using the organizational processes to efficiently and economically produce a wide variety of part types. We elaborate this point with respect to the relationship with suppliers and distributors.

A formal relationship between suppliers and distributors is essential for a positively correlated flexibility-productivity relationship. First, the capability of a manufacturer to offer a variety of products is dependent on supplier's capability to produce a variety of component parts, i.e., the supplier's flexibility in several dimensions: delivery time, mix, volume, and new product. If the components for each product in the mix are sourced from different suppliers, then the management overhead increases enormously. Secondly, when a plant has machine failure problems or when there are sudden volume surges, time-sensitive orders can be subcontracted to dependable contractors.

The ability of the manufacturing enterprise to produce a variety of products should be matched with the ability of the distributor to pass the variety on to the customer by proper advertising and by maintaining appropriate inventory levels. Also, through their close interaction with the customer, distributors can easily identify the true needs and preferences of the customer so that the company can produce what sells rather than trying to sell what is produced, thus minimizing "market defects", i.e.,- producing products that customers do not want. One cannot underestimate the influence of distributors in variety management, both in information collection and also in sales. Further, use of information technology tools such as electronic data interchange, electronic funds transfer, and customer sales tracking systems by the dealers and suppliers would enhance the delivery time flexibility.

From the above discussion, it is clear that flexibility needs to be defined, designed, and created for end-to-end business processes.

Definition: A business process is flexible if it can effectively manage or react to change with little penalty in time, cost, quality, or performance.

This definition is of course very general and abstract. Our discussion in this section will concentrate on issues concerning any business process; the specific concerns of new product development, supply chain, and order-to-delivery processes will be dealt with in the corresponding chapters. As we saw earlier, a business process is an ordered set of work processes and interfaces (both functional and organizational). It is essential that the interfaces are smoothed out and that work processes are flexible for the entire business process to be flexible.

Now we consider three specific business processes and discuss the flexibility issue.

Example 4.19: A product development process (PDP) is flexible if generations of several new products can be rapidly designed and prototype tested. This process is very important for most manufacturing companies. A cross-functional team with a process owner manages the process, with reviews and testing at intermediate points in the process to maintain design quality. The team has members from suppliers, distributors, and at times customers apart from functions within the organization so that the designed set of products is manufacturable, salable, and satisfies customer specifications. Time to market is critical for this process to gain the first-mover advantage. Patenting, navigating through regulatory agencies, production, marketing, etc. augment new product development capability. For example, pharmaceutical companies are most R & D intensive, and the high cost of drug production mandates introduction of the drug worldwide to make most from the effort. Thus a company should not only have the capability to innovate new drugs but also the downstream capabilities to navigate it through regulatory mechanisms, manufacturing, marketing, and distribution in domestic and foreign markets. This discussion illustrates the interaction between the new product development, the supply chain process, and the the order to delivery process. Perhaps gaps between them may have to be managed by a cross-process team (see also Figure 2.12).

Example 4.20: A flexible supply chain process is one that responds effectively to changes in volume, product mix, delivery times, and delivery routes without deterioration in cost, quality, and lead time. It is essential that all subsystems be flexible for the supply chain process to be flexible. Flexibility management is a capability that has to be built up over time through use of a skilled work force, automated equipment, IT tools, computer control systems, benchmarking, and the implementation of the best practice and the like.

9. CONCLUSIONS

In this chapter, we have brought out the deficiencies of functional performance measures and have established the need for process-based measures. We have identified and discussed seven performance measures: lead time, quality, capacity, reliability, flexibility, cost, and asset utilization. We have provided an in-depth discussion on lead time and its reduction strategies. We have defined business process variation as a measure of quality and have brought out the importance of interface smoothing in variation reduction. We have defined the process capability indices and their role in the design of low-variability business processes. Capacity and bottleneck analysis have been illustrated using two good examples. The total cost analysis of a business process has also been illustrated through examples. We have brought out the importance of reliability of a value delivery process. Also, we have defined flexibility of a value delivery process and provided definitions of flexibilities for new product development and supply chain processes. This chapter is foundational, and researchers can use it to begin stochastic modeling of value delivery processes.

10. BIBLIOGRAPHIC NOTES

The importance of process-based measures in comparison with functional measures has been mentioned by several authors [27, 57]. The analysis of interfaces was given attention in [76, 61]. The books by Stalk and Hout [86] and Meyer [67] bring out the importance of cycle time reduction. Variability reduction in supply chain processes has been emphasized by Christopher [11] and many others. Flexibility is discussed in [93] and [87]. The delivery reliability material is from [92]. Overall, this chapter has been put together from several sources in a coherent fashion.

Chapter 5

PROCESS MEASUREMENT AND REDESIGN

Learning objectives

1 Explain the features of an ideal performance measurement and control system.

2 Establish the linkage between strategy, business processes, and process performance measurement.

3 Establish the relationship between the four basic measurements (defects, time, cost, and variety) and the performance measures.

4 Summarize the process of benchmarking and its role in enterprise management.

5 Introduce five levels for business processes and the rating criteria as a basis for performance improvement.

6 Describe a systematic procedure for process redesign and illustrate with an example.

1. INTRODUCTION

Measurement is fundamental to process management. It is also the primary tool for monitoring and evaluating performance, communicating directions of improvement, establishing accountability, defining roles, and allocating resources. The selection of metrics for measurement is the greatest single factor that determines the effectiveness of the orga-

N. Viswanadham, *Analysis of Manufacturing Enterprises*

nization. Without measurements, we do not know the performance of the company. With wrong measures, we suboptimize the system performance. Performance measures, as measured or computed from raw data, are used to communicate results to subordinates, to identify performance gaps that should be analyzed and closed, and to support decision making regarding resource allocation, scheduling, and action plans.

Basically, we have a business enterprise that is a collection of value delivery processes, each with specific inputs and outputs. The measurements conducted on various processes should indicate the health of the system and also actions for its betterment. An ideal performance measurement system should be

1. Dynamic, changing, and supportive of the critical value delivery processes and the competitive strategy not static and monolithic

2. A balanced presentation of both operational and financial measures

3. Process-based measures rather than function-based measures

4. Both inward and outward looking–benchmarking critical processes with the best in class is essential

5. Useful for both monitoring and control as well as for predicting future performance

6. Supportive of continuous improvement, innovation, and organizational learning of all value delivery processes so as to effectively and efficiently serve both present and future customers

The first characteristic asserts the relationship or the alignment between the competitive strategy, core business processes, and the performance measurement system. For example, if a low-cost mass producer wants to adopt a new competitive priority such as flexibility and variety, a review of the critical value delivery processes and the performance measurement system is needed.

Measurement systems are used in the chemical industry for feedback purposes i.e., to design corrective strategies for improving the performance. In discrete production systems, however, the feedback control is limited to the work process level (e.g., adaptive control of machine centers) and also to factory floors using inspection and quality control mechanisms. To be completely successful, a measurement system should record both variables such as defects, lead times, variety, and cost and best practices, such as use of barcoding and electronic data exchange. A good measurement system should trigger performance improvement programs by showing the performance gaps. It is also important for giving

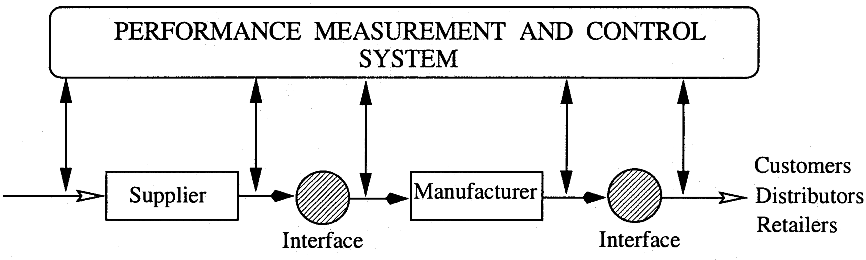

Figure 5.1. Performance measurement and control system

bonuses and rewards to employees and also for benchmarking with competitors and other best-in-class performers. In short, the performance measurement system should provide information to the board room as well as to the control room.

When companies collect data from their processes, they have a variety of purposes in mind. These include the following.

Process monitoring and control: These measurements are used to diagnose causes for malfunctioning or inferior performance and to remove them. They include measurements, defect analysis, and changing control inputs to return the process to the desired state. Process control activities such as statistical process control using control charts are performed at the work process level. At the subprocess level and process level, the process capability measures C_p and C_{p_k} are maintained at target values so that the process delivers defect-free output. Monitoring the interfaces between functions and organizations provides feedback on the functioning of the alliances (see Figure 5.1).

Process management: Here the issues of importance are scheduling, staffing, procedures, and practices. Supplier management, customer engagement, asset maintenance, and work force training are some of the items not directly classified under operational and financial measures but important for the overall health of the system.

Strategic decision making: The performance measurement system should help in making decisions concerning new product development, capacity acquisition, new alliances and mergers, new techniques of process management, and new technologies affecting the performance of the business system.

External reporting: The company has to report to the outside world its assets, inventories, profits, and market share.

In this chapter, we are concerned with performance measurement, competitive benchmarking, and performance improvement systems. In the following section, we relate strategy, critical business processes, and performance measures. Very briefly, the competitive strategy will determine the critical business processes and the directions of improvement, and the performance measures are determined for the critical process.

2. STRATEGY, PROCESSES, AND MEASURES

We have observed in section 2.7 that the critical business processes are identified based on the competitive strategy. Specifically, we have given examples of supply chain, order-to-delivery and new product development processes being critical for low-cost, high-delivery-reliability, and rapid introduction of new products, respectively. The process goals and measures should be consistent with the organization goals. Also, the measurement system should support the critical business process as well as the low-cost, high-delivery-reliability, rapid new-product-generation kind of strategies. In case of the new product introduction process, the most important performance measurements are the time to market (i.e., the time interval between two new product introductions), the time interval between the company's and competitor's product introductions, and cost, revenues, and profit per new product introduced. The measurements must appraise, reinforce, and reward improvements in timeliness. Process goals the function goals, and conversely, each functional measure should reflect its contribution to the overall process goals. As competitive advantage changes, core business processes change and performance measurements change. Improper performance measures–for example, those based on functional optimization–may lead to total system suboptimization and also to actions that impede the realization of the process goals. On the other hand, choice of the right performance measures that are in tune with the competitive strategy and a comparision of these measures with the best-in-class will provide a correct internal picture about both the business and the competitors, thus helping the firm adapt to the competitive external environment faster (see Figure 5.2). The performance measurement system also plays an enabling role in developing a critical business process into a core capability.

Triggers for continuous improvement should emanate from the measurement system. Typically the measurement system should have both an external focus, by measuring such things as delivery performance, defective deliveries per million, and product variety, and also an internal focus, by measuring such things as efficiency. Financial performance measures such as sales, sales growth, sales from new products, and return on assets are also important. Continuous improvement comes from targets such as cutting current defect levels to half, reducing the cycle time by 30%, etc. This is done by finding the causes of the defects or the

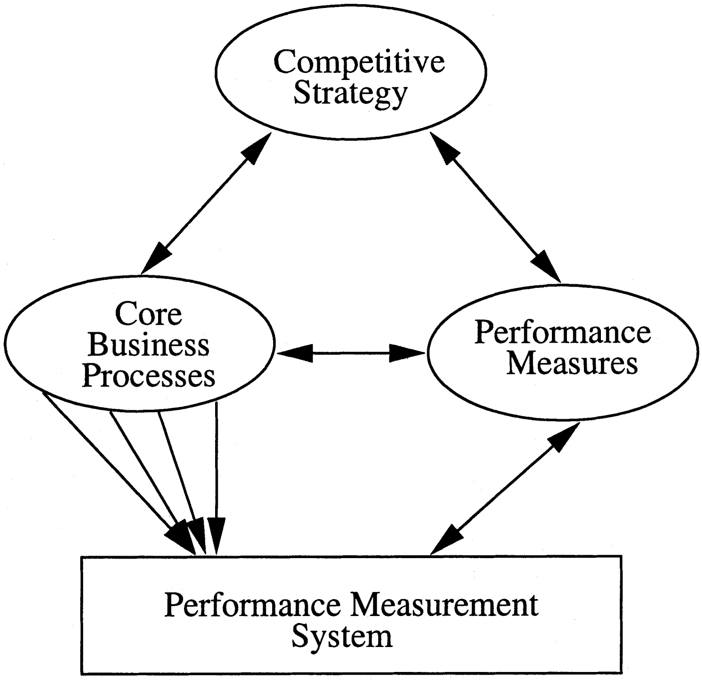

Figure 5.2. Strategy, processes, and performance measurement

non-value-adding activities contributing to lead time, eliminating them and suggesting areas for improvement. This approach could in turn lead to changes in the way business processes are executed. As improvement occurs, the frequency of certain measurements may be reduced. Once the critical processes get perfected, they will no more be critical; some other process or subprocess will become critical. The measurement system then needs to be changed to improve the new critical process.

2.1 EXAMPLES

Example 5.1: Rapid new product introduction, at low cost and faster than the competition is important for the survival of most high-technology firms. Firms in the high-fashion sector, in the microchip industry, etc., secure niches for themselves by moving faster in this area of new product introductions. The drivers for increased new product flexibility include CAD tools, groupware, better coordination and communication among design, manufacturing, and marketing, rapid prototyping tools, innovative suppliers, and distribution with competence in new product launch. The core business processes are new product development and order-to-delivery processes, as well as the supply chain process. Measurements that support new product introduction are typical lead time measures such as product development times, the interval between the two product introductions, efforts in monitoring the performance of new products and modifying them, competitor lead times, sales from new products, and defects in design, manufacturing, marketing, and logistics. Equally important are elimination of measures such as machine utilization, direct labor, reduced prices from vendors, and other function-oriented measures that impede progress.

Example 5.2: A company has recognized that promised on-time delivery is a competitive advantage. Naturally, the core business process is the order-to-delivery process. The company wants to ensure, promised service levels, even in the presence of failure of equipment on the factory floor or trucks in distribution and also demands for rush orders. The measures that support world-class on-time delivery performance under all conditions are strategic alliance relationship measurements; defects in design, manufacturing, and delivery; a flexible (trained in all functions) work force, suppliers and their performance, and excess capacity. A focus on direct cost reduction, labor efficiency, offshore manufacturing, machine utilization, etc. would be counterproductive.

Example 5.3: Suppose a company finds it a competitive advantage to maintain a breadth of product line (mix flexibility) at low cost, i.e., without high inventory and obsolescence. Then the company must have flexible equipment, flexible suppliers, low setup times, modular product designs based on commonalities of parts and manufacturing processes, a good production scheduling system, and innovative logistics that will transport small lots economically. The relevant performance measures include setup times, manufacturing lead times, number of part types, scheduler performance, and relationships with customers. Smart managements should learn more about customer requirements to precisely define the specifications for new products through customer surveys and good forecasting methods.

Example 5.4: An IC chip manufacturer for national and international customers decides to compete on quality, i.e., defect level reduction. The manufacturer has identified the delivery process as the core business process. The operational measures include time to market, on-time delivery performance, mix flexibility, defects, and lead time. The financial measures include sales, sales growth, and return on assets.

Finally, we need to point out that the competitive advantage and thus the core processes as well as the measurements change with time. If the competitive advantage changes from price (volume) to features (variety) or from standardization to customization, then there would be a big change in the core processes and measurement systems.

3. MEASURES AND MEASUREMENTS

It is clear from the above discussion that one has to define and measure both financial and non-financial or operational performance to guide a company to excellence. Previous measurement systems were only concerned with financial performance and were suitable in stable mass production markets. Financial results announced biannually or annually come very late to make any operational improvements. On the other hand, company performance ultimately should be reflected in terms of financial profits, market shares, sales per product, etc. These measures are important to higher levels of management. Growth, market penetration, and profitability are issues at this level. At lower levels such as the work process, the functional subprocess and process levels, we need measurements that would permit tuning the process variables so that the efficiency and effectiveness of the processes can be maximized.

We consider in detail the measurements at the work process level and the process level. At the work process level, we are interested in measurable quantities such as lead time, defect rate, variety, and cost. Depending on the strategy followed and the critical value delivery processes of the company, these measurements can be used to enhance the performance, i.e., to reduce the cost, defects, and lead times. From these measurements, process-level performance measures such as customer satisfaction, flexibility, productivity, asset utilization, and reliability can be computed easily.

3.1 MEASUREMENTS AT THE WORK PROCESS LEVEL

As we mentioned before, a business process consists of work processes and interface processes. The work processes are typically machining, transport, design, delivery, etc. The issue is what to actually measure and what sensors to use ? At the work process level one can measure lead time, defects, variety, and cost. We consider each of these briefly now.

Lead time: Lead time is the time from start to finish of the work process. It is a crucial measure and provides basis for measuring several important high level measures.

Generally, work processes such as design, transport, assembly, delivery, etc., are performed at facilities, that must be set up or tuned for each batch of products. These products need to be transported to and away from the facility. Also, the facilities are prone to failures. Thus lead time has several components, such as setup time, downtime, move time, processing time, and waiting time. Each of these measurements is important in the computation of different process performance measures. For example, setup time and batch processing time are important to measure flexibility, downtime is a measure of availability of the equipment, and so on. For each workpiece, all five components of time can be measured through automatic barcode readers and time stamping, and their mean and variance can thereby be obtained. Since subprocesses are a collection of work processes and interfaces, subprocess lead times can easily be obtained. Measurements at the interfaces must be carefully defined. If two work processes are processing workpieces on machines, the interface may just involve the transport of workpiece from one machine to another. If the two work processes are two clerks in an accounts payable and accounts receivable process, the interface is defined by the procedures of file transfer. Generally, measurements are not conducted at the interfaces, but our prescription for effective interface management is to treat them as work processes. Lead time at the interfaces is an indication of the quality of alliance between two work processes.

Defects: A defect is any non-conformance to requirements. A requirement represents a recipient's (user, consumer, or customers) view of the product. Specifications represent the provider's view of the product. Quality means conformance to requirements, i.e., freedom from defects. This general definition is applicable not only to products and services but also for each work process, subprocess, and any complex process. It is a definition independent of technologies, resources, standards, procedures, and specific products. It is easily measurable as long as the process of measuring conformance is defined. Thus a defect either in design, manufacturing, or logistics is a kind of universal measure, and a defect-free business process is one without any defects in its constituent work processes or at its interfaces. Conversely, a process can be made defect-free by making every work process and interface process defect-free. Thus establishing a clear (understandable, unambiguous) and complete (all the needs, price range, time table) requirement statement is fundamental to achieve total quality.

Conformance means agreement. It means that substantive, observable, and measurable attributes of two or more entities are identical. When measured for attribute data, i.e., data that can be counted (such as the presence or absence of an IC chip, the number of spelling errors in a document, the number of engineering design changes, the number of defective deliveries, etc.), conformance means zero defects or a defect-free work product. When conformance is measured in terms of quantified attributes of variables, (such as the diameter of a shaft, the lifting capacity of the fork, the weight and volume of the product, etc.), conformance means attainment of quantifiable attributes within the stated tolerance limits. Depending on the complexity of the product, service, or process, the judgment of conformance may require the installation of elaborate and coordinated inspection and test programs at the work process level, the subprocess level, and the the process level.

Variety: The number of different types of products manufactured at each work process is an indication of the mix flexibility of the process. This measurement at each work process level will give an indication of the ratio of potential flexibility to actual usage of the flexible equipment. Variety induces complexity in terms of work flow. Combined with lead time measurements, this measure will indicate the effectiveness of scheduling, supplier relationships, etc. Flexibility of the constituent work processes and interface processes is necessary for the flexibility of the entire value delivery process.

Cost: Costs are incurred everywhere along the process. Some of the obvious costs include procurement costs, inventory carrying costs, warehousing costs, manufacturing costs, design costs, transportation and delivery costs, etc. Cost of negotiation (interfaces), cost of quality, and cost of variety are also very important. At each work process, the cost incurred is noted, particularly in wasteful activities such as reworking, inventory, and machine failures, defective materials, etc. The tracking of cost figures at the work process level is important in the overall context of waste reduction.

Quality costs are divided into three major components: (1) failure or non-conformance costs: costs of not meeting the requirements which include scrap, rework, and warranty costs, (2) appraisal costs: costs incurred to detect nonconformity such as the cost of checking an insurance policy for correctness; and (3) prevention costs: cost of preventing future errors.

We discussed above the issues of measurement of lead time, defects, cost, and variety. Measurements can be taken whenever events such as completion of a part, the arrival of part, or the purchase of raw material occur. Suppose, that the work process is an assembly by a facility; then the lead time is the time interval from the arrival of a batch of components at the facility till the departure of the assembled part; defects are wrong assembly, incomplete assembly, defective components, and so on; variety is the different types of assemblies performed during a shift; and finally costs include machine time costs, waiting time costs, and inspection costs.

3.2 COMPUTATION OF PROCESS-LEVEL MEASURES

Process-level performance measures can be computed from the above data.

Customer satisfaction: For any process, customer satisfaction is defined in terms of quality, delivery, and price. Our measurements on lead time, defects, variety, and cost will enable one to measure the probability of making a defect-free product delivery at the right price. Price is often dictated by the market conditions, but cost-cutting measures along the process will allow lower pricing.

For example, in the case of the order-to-delivery process, the customer satisfaction measures are delivery on the committed date, complete product fill, and a defect-free product. All these outcomes can be inferred from the work process measurements. Further, by driving down the costs, defects, and the lead time, one can improve customer satisfaction levels. We will list below the measurements that contribute to customer satisfaction levels in terms of the four measurements that we considered above.

- Defects: design, manufacturing, delivery, shipping, billing, and packaging

- Lead time: time to market, time between new product introductions, manufacturing lead time, order-to-delivery time, and non-value-adding times, such as set up, waiting, movement, etc.

- Cost: product development cost, material cost, manufacturing cost, logistics cost, quality cost, rework cost, and scrap cost

- Variety: product breadth, volumes of each product, and new products introduced

Flexibility: A company is considered flexible if it can meet the changing demands of the customers. The variety and batch size measurements enable computation of the mix flexibility measure; the lead time and the delivery defects reveal the response-time flexibility; low setup times and lead times of the supplier indicate volume flexibility; the time interval between successive new product introductions indicates the new product flexibility; etc.

In chapter 4 we discussed , the flexibility issues in the supply chain and order-to-delivery processes. It is a good exercise to compute these flexibilities from raw measurements such as lead time and variety. How do we measure its new product flexibility or delivery time flexibility for a new product development process? The time interval between successive product introductions or the number of new product introductions in a given period will give us good metrics for flexibility.

Efficiency: This measure aims at the most cost-effective and timely way of achieving customer satisfaction. Objectives can be stated in terms of short lead times, low cost and high asset utilization.

Asset utilization: The manufacturing company has substantial assets. The metrics on assets are focused on sales levels that can be maintained with a specific asset base. Cash-to-cash cycle time, which is the average time spent from procurement to cash realization from sale of the finished product, is enhanced by fast order-to-delivery and cash collection times. Increased sales without a comparable increase in inventory will increase the inventory turns, which in turn will result in more profits without additional inventory costs. Asset performance is defined as the ratio of total sales to assets.

Delivery reliability: This is the percent of time an order is delivered perfectly, i.e., in complete quantities at the promised time. The delivery defects will indicate this measure, and lead time measurements will indicate the possible reason for the delay.

So far, we have been considering only the operational performance measures. We also mentioned in section 4.1 the importance of the financial measures and in section 2.8 learning and innovation measures. We briefly consider here an integrated performance measurement system called the *balanced scorecard* introduced by Kaplan and Norton [57] .

4. BALANCED SCORECARD

The balanced scorecard, developed by Kaplan and Norton [57], provides managers with performance measures from four important perspectives (see Figure 5.3).

Financial perspective: Financial performance measures indicate whether the company is financially sound in terms of profitability, growth, and shareholder value. Some argue that financial performance is the logical consequence of doing fundamentals well and that improvements in cycle time, quality, customer satisfaction, employee motivation, etc. must result in financial excellence. While operational excellence is necessary for achieving financial excellence, it is not enough.

The question is how we look in the eyes of our shareholders. This is important, since the bottom line for any company is profitability, growth, and shareholder value. Although financial performance is the result of operational actions and financial success is a logical consequence of doing fundamentals well, there are instances when operational excellence has not resulted in increased profitability. The reasons are as follows.

- Operational measures, customer satisfaction, business performance, and learning are derived from a company's view of the opportunity and its perspective on key success factors. But this view may not be correct.

- An electronics company, for example made orders-of-magnitude improvements in operational measures: defects dropped from 500 ppm to 50 ppm, on-time delivery improved, and yield jumped from 26% to 51%. But during the same period, stock price plummeted to one third. Slow releases of new products and failure to enlarge the customers base have prevented the company to realize the benefits.

- Quality and cycle time improvements will create excess capacity and redundant functions such as inspections, reworking, and expeditors. If this excess capacity is not put to work by expanding the customer base and sales, thus increasing the depth of service, it will become a

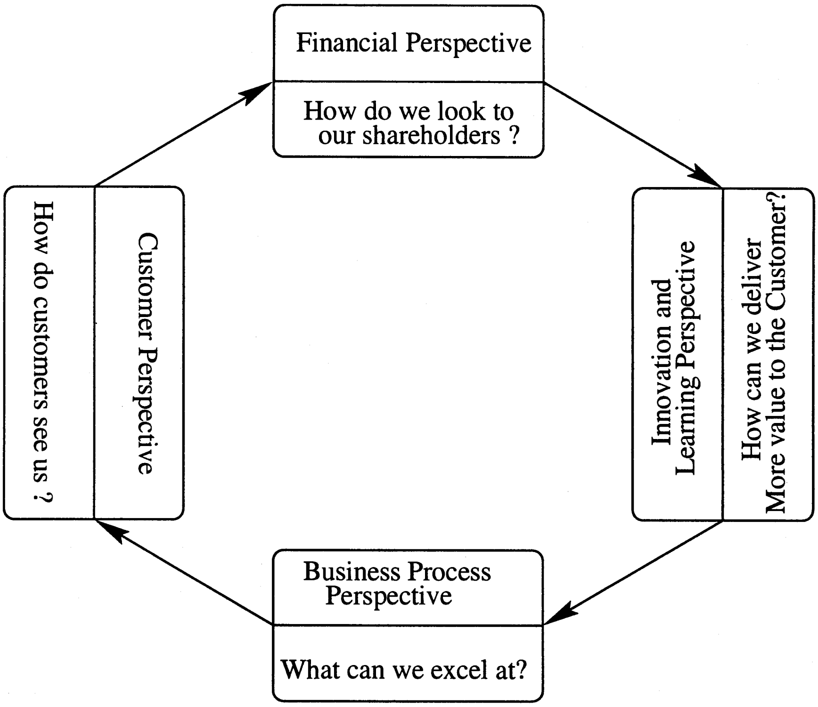

Figure 5.3. The balanced scorecard [Adapted from Kaplan and Norton]

drag on the system and will outweigh the benefits obtained through the cycle time improvements.

It is important to develop linkages between operational and financial measures, i.e., to develop cause and effect relationships that will link operational and financial measures and evaluate how improvements in quality, cycle time, delivery, and new product introduction will lead to higher market share. Also, it is essential to periodically review the link between the corporate strategy, critical business processes, and the critical success factors. Further, it is important to assess a company's performance—not in isolation, but relative to its competitors—by using such techniques as process benchmarking. Kaplan and Norton [57] provide several examples.

Customer perspective: The balanced scorecard demands that the mission statement–to be number one in delivering value to the customers–be translated in terms of lead time, quality, cost, performance, and delivery reliability. In particular, the cost of the products should include the costs of ordering, receiving, inspection, storage, scrap, reworking, obsolescence, supply of defect-free products, IT infrastructure , etc.

As we mentioned in chapter 2, customer satisfaction, customer retention, customer acquisition, and customer profitability are also important measurements. It is also clear that customer satisfaction leads to customer retention and new customer acquisition and is a result of customer profitability. The market share is positively influenced by both customer retention and new customer acquisition.

Business process perspective: As we have said several times before, the customers are served through the processes and a company can only be as good as its processes. Customer satisfaction measures must be translated into process goals, and the process goals in turn dictate the work process goals and interface management policies. Also, the core business processes are nurtured into core capabilities through the development of appropriate core competencies(see section 2.8).

Innovation and learning perspective: As we observed in chapter 2, the targets for success keep changing. Continuous improvement of existing products and processes and the ability to develop new products are of paramount importance. The company should have competencies to develop new products and new benchmarks to penetrate new markets, and to increase the revenue.

Thus, we see that core process measures combined with financial measures will give a complete picture about a company's performance.

5. PROCESS BENCHMARKING

Benchmarking is now recognized as a valuable performance measurement and evaluation technique that can make important contributions to many different areas of business endeavor. It is an ongoing investigation and learning experience to uncover best industry practices and to adopt and implement them. Benchmarking is a branch of industrial research wherein managers perform comparisons of processes, practices and performance measures with other companies in order to identify the "best of the best" and to attain competitive advantage. It is searching for ways of doing business more effectively. Searching for the best and then emulating, can often produce breakthrough results. Benchmarking concentrates on both the hard issues of performance such as market share, quality, cost, and productivity and the softer management issues, such as work force commitment, shared and common goals, teamwork, and employee communications.

According to Camp's original definition, "*Benchmarking is the continuous process of measuring products, services and practices against the company's toughest competitors or those companies renowned as industry leaders.*" In short, in the benchmarking process, you identify the benchmark, compare yourself to the benchmark, and identify the practices that will enable you to become the new best-in-class. Thus, benchmarking is about finding and implementing best practices. It is continuous because technologies and industry practices change. Measurements can be qualitative or quantitative. Qualitative measures are practices that will eventually lead to quantitative measures of performance. Benchmarking is also called an external focus of internal activities.

We follow here the more useful and process-oriented definition "*Benchmarking is the process of continuously measuring and comparing business processes against corresponding processes in leading companies to find and implement the best practices.*" This is also called process benchmarking. Here, the processes that are ultimately responsible for the operational and financial returns, are the targets of analysis and comparison. How do you select which process to benchmark? As discussed in chapter 2, the processes that will impact the critical success factors the most are selected for benchmarking. If the internal measurement system is process based, then process benchmarking is easy to conduct.

5.1 HISTORY OF BENCHMARKING

The Xerox corporation is known for its competitive benchmarking studies and demonstrated its power in manufacturing operations as early as in 1979. However, benchmarking is a part of human history, and learning by imitation is a part of life. We see this almost in every walk of life; including the way we dress, eat, and even govern ourselves. Sometimes one wonders if the world is moving towards a monolithic society where people will eat the same things, read the same books, watch the same entertainment programs, and govern themselves following the same principles.

The most successful benchmarking application in manufacturing history is by Taiichi Ohno. He applied his observations of the replenishment of American supermarkets to factory management by using shelf restocking as an analogy for the development of just-in-time (JIT) method of inventory management. Ohno also developed the Kanban system of inventory management using the above supermarket analogy. The IMV program at MIT is an international study on design, production, and distribution of automobiles in the U.S., Europe, and Japan. The concepts of lean production, supplier management, and cross-functional teams for product development were all unearthed through the MIT study [99].

Xerox refined competitive benchmarking as a science during the decade 1976-1986. Product and process comparisons with competitors have enabled Xerox to regain its competitive position in the copier market. Xerox also introduced the concept of generic benchmarking by comparing the shipment of copier products with L.L. Bean's shipping process, i.e., comparing processes with those with recognized best practices. Industries practice other business activities that have similar aims to benchmarking, including the following:

Reverse engineering: A firm tears apart a product to understand a competitor's products and processes and tries to redesign both the product and the process.

Market intelligence: This practice is the collection and analysis by a third party of data on sales, prices, customer groups, and promotions and supplying to companies.

Competitive intelligence: This practice is defined as an analytical process that transforms disaggregated competitor, industry, and market data into actionable strategic knowledge about a competitor's capabilities, intentions, performance, and position; it is one of the most important strategic tools in the corporate world today. An effective competitive intelligence program can serve as a catalyst for change.

It is clear that benchmarking is being practiced in the business world all the time. However, it was not practiced as a scientific method. Now, it is recognized as a strategic tool for uncovering best practices and implementing them.

5.2 TYPES OF BENCHMARKING

Four types of benchmarking studies are generally performed, namely internal, competitive, functional, and generic process benchmarking. Each has specific outcomes and benefits.

Internal benchmarking is done within an organization and typically between closely related divisions or similar plants or operations by using performance measures or business processes as the basis for comparison. Business practices and production processes in one part of an organization may be more effective than those in another part of the company. Internal benchmarking will determine the best business practices within a company as a starting point for external benchmarking, promotes information sharing, and encourages employee communication.

For a multinational company having operations in Asia, Europe, and North America, best practices of inventory control, customer complaints handling, etc. may have been developed by some smart manager in one of the regions for local use. Internal benchmarking will uncover such a practice so that it can be shared across the company. An outcome of internal benchmarking is documentation of internal business processes, which is useful in other contexts as well.

Competitive benchmarking is a comparision of business process with that of the best competitor. The purpose of competitive benchmarking is to gather information so that a company can use that information to manage its own processes. The comparision will reveal what performance levels must be surpassed. The gap between internal operations and the competition is assessed with a view to find the means of closing the gap. One can anticipate many difficulties in conducting competitive benchmarking. Information may be difficult to obtain for proprietary reasons. Approaching the benchmarking exercise through a third party such as a consultant may be mutually beneficial.

A comparison of inventory management structures between different companies may reveal a four-layer structure (national, regional, branch, and service centers) for a company and a two-layer structure (regional and service centers) for the competitor. Also, a comparison of flow charts of corresponding business processes may be very revealing.

Comparisons should be carefully made depending on the size of the operations. A large plant for compressors may have a fully automated operation with huge silos of inventory, but a corresponding medium-size operation may look different. Similarly, large size may mean complete automation of factory operations and rail shipment, whereas small operations may mean semiautomation and truck shipment.

Functional benchmarking is comparing one's own work process practices with those of the functional leader or with those renowned as the best at what they do. The classic example is Xerox following L.L. Bean for warehouse-picking operations. The office products at Xerox and the sports goods at Bean are diverse in size, shape, and weight and are ordered in small quantities. The diversity of products precluded the use of an automated storage and retrieval systems at both places. It was observed that Bean was "picking" packaged products three times faster than Xerox. A complete analysis of the picking process uncovered unique practices in sorting the orders to minimize the trips to the storage location, and these were adapted by Xerox. Benchmarking in this case refers to a very specific function and is not process oriented.

Generic process benchmarking is a different approach to benchmarking that has emerged in recent years. It aims to improve the generic critical business processes such as the order fulfillment process or the new product development process. Once the key business processes have been identified, best practices can be sourced from whatever company is the best, regardless of the industry type and location. This approach is therefore termed as generic benchmarking. The potential for identifying new technologies or practices that could lead to breakthroughs is highest in generic benchmarking. An excellent example is the spread of barcoding, originally used in the grocery industry, to hospitals, warehouses, and document transport. Here are some more examples of generic industry benchmarks.

- An electronic company wanting to improve the time to market and the new product development process should target the fashion houses. If the objective is to improve the time to finalize the accounts, then they should target a bank.

- A telephone company wanting to improve the billing system should benchmark itself against a credit card company.

- A home delivery pharmaceutical outlet looking for benchmarks should target a pizza home delivery process.

5.3 WHAT TO BENCHMARK?

It is possible to compare the product performance, the process performance, or the entire process: its flow chart, technology, practices, procedures, measurement system, etc. In performance benchmarking, a chosen metric or variable is compared against the best-in-class. The metric could be lead time, defect rate, product variety, etc. In process benchmarking, critical business processes are identified and compared with the best-in-class firm in terms of methods, techniques, and practices.

Focus: Benchmarking may have a strategic or operational focus. If the focus is on strategic issues, benchmarking is concerned with competitive strengths and weaknesses. Core competencies that will help to build competitive advantage, new products, new markets, alliances or acquisitions, new businesses, etc. are issues of a strategic nature. In the operational scenario, benchmarking is used to understand the best practices to achieve customer satisfaction and to become the choice supplier to the customers.

Best practices: One of the greatest benefits of benchmarking is the awareness and the learning experience it brings regarding superior practices used by others. These may be used directly, adapted, or used to modify current practices in order to improve process efficiency and effectiveness. Benchmarking is a process of learning from other's experience rather than reinventing the wheel.

Some practices are clearly benchmarks if one encounters them over and over again. One good example is package weighing which confirms that the order is picked and packed as per the order. The weighing is done automatically as the package travels on the conveyer. Also, storing in the computers the weight, volume, and dimensions of all items in inventory is a common practice. It involves much data maintenance and collection, but the advantages are also substantial. Also, interface management practices could be benchmarked, and many benefits could result from such an exercise.

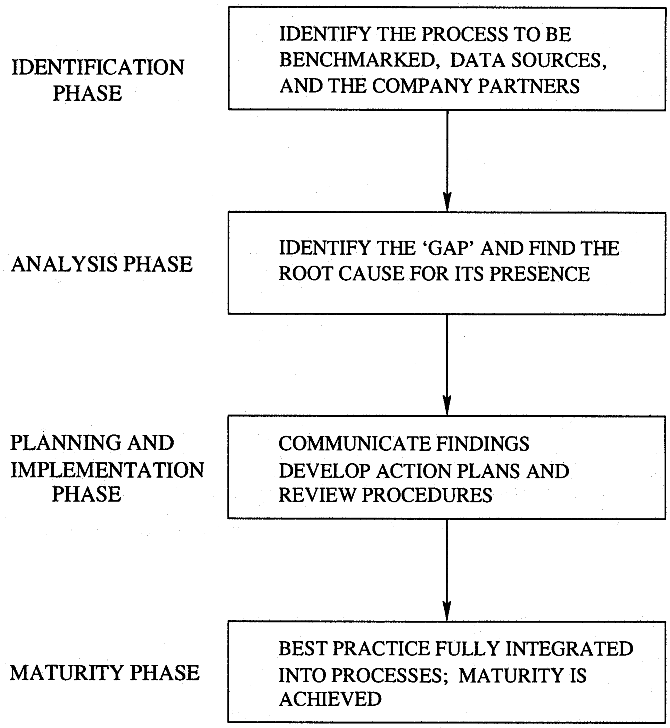

Figure 5.4. The benchmarking process

5.4 A BENCHMARKING PROCESS

There are several benchmarking procedures that are available from various companies. The best known, with a well-documented methodology and wide application is the one from Xerox. Other companies like AT & T and Price Waterhouse have their own benchmarking process descriptions. Here, we present one typical benchmarking process (see Figure 5.4). It has four phases: identification, analysis, planning and implementation, and maturity.

1. **Identification phase:** The objective in this phase is to plan for the investigation by choosing the process to be benchmarked, identifying the data sources, and identifying the companies to benchmark.

2. **Analysis phase:** The benchmarking process is a comparative analysis. The analysis phase involves a careful understanding of current process enablers, practices, strengths, and weaknesses as well as those of the benchmarking partners. The fundamental issue is to measure the "gap" that is the difference in performance. It could be positive, negative, or in parity. The gap provides an objective basis for con-

ducting root-cause analysis to determine why the gap exists. The benchmarking partner may have fewer inventory echelons between factory and customer, which is a positive gap. If the order entry systems of both companies are telephone based, then both are at parity. Suppose the distribution of the company using an alliance partner is working better than that of the benchmarking partner; then the gap is negative. Business practices such as employee communications, operational efficiency in equipment use, performance measurement, incentives, and facilities location are all factors to be taken into account while conducting a root-cause analysis.

3. **Planning and implementation phase:** In this phase, one plans for possible change. Communicating the benchmarking findings, i.e. the gaps, to the management and employees is an important activity. Developing action plans, implementing them and monitoring the progress by assigning responsibility for implementation to the teams is also done. Specific implementation plans and periodic review procedures are also put in place in this phase.

4. **Maturity phase:** Maturity is achieved when the best practices are incorporated in all business processes and benchmarking becomes a way of life for continuous improvement.

Benchmarking has now become an important business process of all big companies. There are several books on this subject. Our aim here had been to highlight the principles of benchmarking and its relevance in performance measurement.

6. PROCESS RATING AND IMPROVEMENT

In earlier chapters, we have defined and described several processes and subprocesses such as new product development, supply chain, order-to-delivery, and production. We have also defined the performance measures for these processes, such as lead time, quality, cost, flexibility, capacity, and asset utilization. We have also often said that the implementation of these processes in an enterprise determines its competitive strength and position. The way these processes are implemented in various organizations varies widely. For the purpose of comparison and to provide a basis for improvement, it is essential to categorize the processes into various levels based on important attributes such as technology, equipment, manpower, quality control, defects, and cycle time specifications. In essence, it would be useful to characterize a given process in terms of various attributes and best practices in order to determine its level of performance and the missing elements. This approach would enable one to develop a road map for improvement. There are considerable costs involved in making the improvements and becoming the best. Decisions on process improvement are also economic.

Following several of our predecessors, such as Harrington [45] and Melan [66], we would like to classify business processes into various levels depending on their capability to generate the output of quality expected from it and also its repeatability, effectiveness, and efficiency. For the entire process to satisfy these requirements, it is essential that all the work processes such as billing, transport, and customer service also be predictable, repeatable, effective, and efficient.

In software development, the SEI has defined the capability maturity model (CMM). With the ultimate goal of achieving level 5 on the SEI scale, individual software organizations around the world follow this model and characterize their software development processes. The process maturity of an organization characterizes the repeatability, effectiveness, and efficiency of its processes and its capability to manage changes. SEI recognizes five levels of process maturity in software development: initial process, repeatable process, defined process, managed process, and optimized process. The characteristics of these five processes were described in [18, 84] and the methodology for transition from one level to the next level is also well documented. It is not very difficult to adapt the same levels to the new product development process since generic new product development has several parallels to software development. Other processes such as supply chain and order-to-delivery could also be rated into different levels. Continuous improvement of these processes essentially involves transition from one level to another. At this point of time, there is no single universal characterization that is followed for business processes. Our attempt in this section is to propose one such characterization.

6.1 RATING CRITERIA

Here, we rate business processes into five levels from chaotic to world class (see Figure 5.5). A level 5 process is a world-class, highly effective, efficient, and defect-free process and can remain so even under changing conditions. Level 1 processes are chaotic in the sense that the value delivery processes do not have consistency and repeatability. An enterprise has to choose the right level for each of its critical business processes. The returns on the investment made to achieve higher levels of process performance have to be commensurate with the benefits that result from the improvement.

The criteria that we use in rating the processes are as follows:

Level 5: World-class	Recognized as best of the breed, flexible, nurtures core competencies and has learning capability
Level 4: Best-in-class	All processes are effective, efficient, benchmarked,and defect free.
Level 3: Effective and efficient	Well-defined, cost-effective processes that accomplish end user satisfaction efficiently
Level 2: Effective	Processes are well defined and customer requirements are met, but may not be met efficiently
Level 1: Chaotic	Processes are not well defined and not well managed. Run by traditions and experiences; no consistency or repeatability

Figure 5.5. Levels of business processes

1. Process definition and management
   - Performance monitoring and control system (PMCS)
   - Organization structure and management of interfaces
2. Human resource capabilities and management
3. Learning and strategy development capabilities

The first two criteria are operational in nature and the third one has strategic focus. These criteria are based on the 1997 Malcolm Baldridge National (U.S.) quality award requirements [24].

Process definition and management: Process definition and process management constitute a key issue in all manufacturing and service industries. The management should be effective and efficient. Customer orientation, root-cause analysis and defect prevention, performance measurement and evaluation, continuous improvement, productivity, and interface management, particularly with suppliers and distribution, are all issues to be considered in process improvement. We can describe levels 1–5 from the process management point of view. Recall that in Table 2.2, we presented typical core, support, and managerial processes in a manufacturing enterprise. The fundamental issue is identification of core, support, and management processes for the system on hand. Then for each of these processes, we need to define a measurement and control system and an organizational structure with emphasis on the management of interfaces.

- **Core processes:** The new product development, supply chain and order to delivery processes are very important core processes and we have dealt with the interaction between them in chapter 2. Interface management is critical in all three processes. Defining critical performance variables, measuring them, comparing them with the best in the breed, and taking appropriate corrective action when process deviations occur are all very important to achieve level 5 status.

- **Support processes:** Identifying and redesigning key support processes are other important activities. Companies have to strive to improve these processes by instituting a measurement system and performing corrective actions. One of the key support processes is the creation of IT infrastructure and the redesign of the core, support, and managerial processes using it.

- **Management processes:** Perhaps the most important management process is the supplier management process. The design of interface management schemes such as audits, reviews, certification, testing, and rating to evaluate and improve supplier and partnering processes is an important attribute of good process management. Actions to improve the capability of suppliers and partners by joint planning, rapid information exchange, benchmarking customer-supplier teams, alliances, agreements, incentives, etc. are also considered important.

We have in chapter 2 defined the characteristics of a well-managed process. Here we define levels 1–5 from the process definition and management point of view.

Human resource management comprises human resource practices directed towards the creation of a high-performance workplace and towards training the employees in skills and knowledge that can give them the abilities to manage change. Employee education, training and development, satisfaction, well-being, and motivation need to be addressed. The design and delivery of the education and training programs and the emphasis these programs place on imparting knowledge and skills are an important consideration.

Learning and strategy development capabilities address the view of the future and the strategy for remaining excellent. It is essential to focus on future markets and products and also to allocate resources for product development, human resource development skills and knowledge, development of future markets, etc. The purpose of these projections and preparation is to detect and reduce competitive threats, to shorten reaction time, and to identify opportunities.

6.2 PROCESS LEVELS

Now we present a description of levels 1–5 of a business process. This classification can be used for transition from a given level to the next.

Level 1 (Chaotic): In a level 1 process, there are no process definition, no process management teams, no measurement system, and no documentation of the process or the procedures to be followed. Such processes are typical when work travels through several functions and organizations. While you can find some one incharge of the inside functions of each individual work process, the interfaces between functions are in no-man's lands. Interoffice transfer of paper is done manually and increases the cycle time enormously. The ratio of cycle time (total time the customer's order spends in the process) to processing time (total time required for performing the value-adding operations) is generally very high. Level 1 organizations are run more by common sense, the experience of staff, and traditions than by sound procedures. No process performance management or measurement systems may exist in such systems.

In level 1 organizations, human resource management is not taken seriously. Managers and heads of the departments are chosen on the basis of seniority or experience, not on people management skills. not believed by the Managers of level 1 organizations do not believe that development of talent is their responsibility. Basically, recruitment is done on the basis of vacancies rather than skills. Skills available in the organization may not grow over time. Most functionally organized manufacturing plants determine the suppliers by calling for bids and supply the customers by maintaining inventories. They are representative of level 1 organizations.

Level 2 (Effective): Level 2 processes are in stable operation; the procedures are well documented, and the employees are well trained. The management structure is in place with an identified process owner. A performance monitoring and control system is in existence. Critical variables are measured from the point of view of the end user, and statistical control methods and root-cause analysis and other defect-prevention methodologies are used for both process and product. The deficiencies of the process such as large cycle times, defects in designs of processes, and product and other non-value-adding activities are identified. Suppliers and customers are identified following good management criteria, and the interfaces are smoothed. Basically, in level 2 processes the first two criteria have been addressed, and the processes are effective in meeting customer requirements. Most processes in manufacturing organizations are at this level.

In level 2 organizations, policies, procedures, and practices exist that commit the organization to implementing and performing consistent and established management of its people. Managers take responsibility for recruitment and selection, performance management, training and career development, compensation and reward, etc. of their employees.

Level 3 (Efficient and effective) : Processes at level 3 are by definition effective and efficient in the sense that a performance measurement and control system is operational and customer expectations are met. Improvement plans towards level 4 are in place. Supplier and partnership management are well defined. Regular meetings are held with suppliers regarding delivery specifications and input quality.

In level 3 organizations, human resource practices such as performance measurement, placement of the right people in the right places, and a reward system support the efficiency of the business process. In companies operating at this level, the competitive strategy, the performance measurement system that supports it, and the critical business processes that deliver value to the customers are all identified. Plans for making these processes defect-free are also made.

Level 4 (Best–in–class): Processes at this level are classified as six sigma and are effective, efficient, and defect-free. Processes are optimized by removing the non-value-adding activities and are benchmarked for best practices. Level 4 processes are operationally excellent, i.e., customer, supplier relationships are smooth, performance measurement system shows that customer requirements are met, and processes are efficient and follow the best practices. People-management practices are defined in terms of the business process hierarchy. This process decomposition is used to define the skills and knowledge needed to perform the work processes and to manage the interfaces. Organizational management rewards core competencies and improving the processes through application of skills and knowledge.

Competitive advantage is identified, and the skills and knowledge required to keep ahead in various possible scenarios are listed. Accordingly, methods to develop critical business processes into core capabilities and plans to develop the human resources are discussed and documented.

Level 5 (World–class): A level 5 process is one of the few best in the world. These processes are often targets for benchmarking by other organizations. Level 5 processes have both strategic focus and operational excellence. Delivery of products or services to the customers is defect-free and is on-time, every time. Further, the focus is in terms of staying ahead by nurturing core competencies, restructuring to achieve operational excellence and to develop business processes into core capabilities, and hiring employees based on their competencies and their place in the organization.

Level 5 organizations are perpetually improving themselves and their people management skills. Team building, improving skills and knowledge, improving the overall organization performance, and innovating new people-management structures are all practices in level 5 processes. Goals and plans are developed to increase the organization's ability to attract, develop, motivate, and retain talented staff. In level 5 processes, strategic plans to move ahead in time and maintain the same level are in place and are like living organisms, quickly adapting to changing circumstances and always keeping ahead. It may not be necessary and may be impossible to develop every business process into a level 5 process. One needs first to identify those processes that are critical or which provide the competitive advantage and then to develop them into level 5 processes.

The above descriptions of levels and the basis for their determination in terms of the three criteria represent a particular way of classifying processes. One can add several more criteria, such as financial performance. As SEI has done for the software development process, it is very important that manufacturing companies, at least sectorwise (i.e. automobile, electronic, pharmaceutical, food, etc.), define the critical business processes and levels and establish criteria for certification at each level. Much effort is needed in this direction.

7. PROCESS REDESIGN

Here, we outline a systematic procedure for transforming a given process into a level 5 (world-class) value delivery process. To do so, we must first identify the current level of the process in terms of the rating criteria mentioned in section 5.6.1. We must then devise the steps necessary for migrating towards the higher process levels. The five steps for the transition include:

1. Identify the core value delivery process that gives the competitive advantage

2. Analyze the existing process for performance using the rating criteria

3. Develop the plans for resource acquisition and building a performance measurement system

4. Define the new process architecture

5. Devise a project plan to transit to the next process level

There is a fundamental difference between the process redesign suggested here and business process reengineering (BPR) or total quality management exercises. Fundamentally, here we are dealing with interorganizational processes of global manufacturing networks rather than interfunctional processes in reengineering exercises. For example, in a supply chain process, we concentrate on interorganizational interfaces and the methods for smoothing them. Issues such as number of suppliers, co-makership, sharing of design and point of sale information, co-location, co-design, partnership with customers and distributors, and vendor managed inventories need attention. These are not typically considered in BPR exercises. Also, we consider a resource-driven viewpoint of the entire enterprise—to leverage resources to become best of the breed, rather than concentrating only on streamlining an existing process in an organization. Thus, level 5 process design is strategy driven and resource based and is more fundamental than narrowly defined BPR exercises.

At first glance, it might look impossible to implement a level 5 process design. Some leading companies have planned and achieved results seemingly far beyond their resources and capabilities. Strategic intent [41] is a management process that includes creating a winning obsession within the organization and achieving it over time through competitor focus–to be the best and remain the best through sustained yet flexible efforts. Strategic intent by design creates a chasm between resources and ambition and is a long-term plan implemented incrementally step by step. One cannot achieve what one did not seek to achieve. Strategic intent is a well-considered aspiration, and all resources should be efficiently directed towards it. Successful examples in history include "putting a man on the moon," Coca–cola's "putting Coke at arm's length of everyone", Cannon's "beat Xerox," and Kodak's "world leadership in imaging," etc. To win with this kind of goals, companies have to develop competitor focus at every level throughout the enterprise, follow the level 5 human resource development skills, ensure employee involvement, and establish clear milestones and review mechanisms, taking into account patterns of industrial, technological, cultural, social, and economic, evolutions. This process is like chasing a moving target in an uncertain marketplace, effectively and efficiently acquiring and leveraging resources.

Strategic architecture [73] is the road map to realize the strategic intent. It provides the framework for resource leveraging and competency building, the essence of the corporation's long–run competitiveness. This framework involves developing core competencies and forming strategic alliances and thus developing critical business processes into core capabilities. Now we consider each of the steps given above.

Identify the core value delivery process: The core process that is strategically aligned with the competitive strategy is selected for redesign. We have discussed this issue in sections 7 and 8 of chapter 2 , and section 2 of this chapter. Redesign of a business process that transits several organizations and functions provides opportunities for streamlining the functional and organizational interfaces.

Analyze the existing process: In this step, the process is mapped either as a flow chart or some other model, and the performance measures are determined. A performance measurement system and feedback control mechanism for improvement are also considered. The interface processes are given special attention. At the organizational level, the management structure (roles and responsibilities), the interfaces, and human resource and technology management practices are also examined. As part of the analysis, these practices are evaluated using appropriate performance measures. Apart from the performance issues mentioned above, we also look at interface management, organization structure, human resource management, product design, facility location, staged manufacturing, customer service issues, and total cost of delivery.

Discrete event simulation is a useful tool for performance analysis, although building a simulator may take a long time. Once built, this model would be useful in subsequent steps as well. Tools such as fishbone charts, Pareto diagrams, and others are useful in conducting root-cause analysis. It may be instructive sometimes to collect and analyze data from the existing process in order to understand, for example, issues such as the supplier–manufacturer interface, the most-profitable product, or the most-valued customer, etc. The analysis also can identify non-value-adding activities. At the end of the analysis phase, one should be able to identify the level of each of the core processes.

Control is essential for any well-managed process. As we have shown in Figure 1.1, the manufacturing enterprise is subject to several external and internal disturbances that tend to make the process outputs deviate from their optimal values. Feedback regulation is essential at the work process, subprocess, and process levels to bring the process outputs to their optimal operating values. A schematic is shown in Figure 5.6. In the context of manufacturing enterprises, continuous improvement using the process measurements is in principle the same as in continuous process control systems, but the tools used are entirely different. As we said before, the measurements made are the cost, time, defects, and variety. Improvements in the process performance must be obtained through technology to speed up the value-adding activities, eliminate the non-value-adding activities, and reduce the defects using root-cause

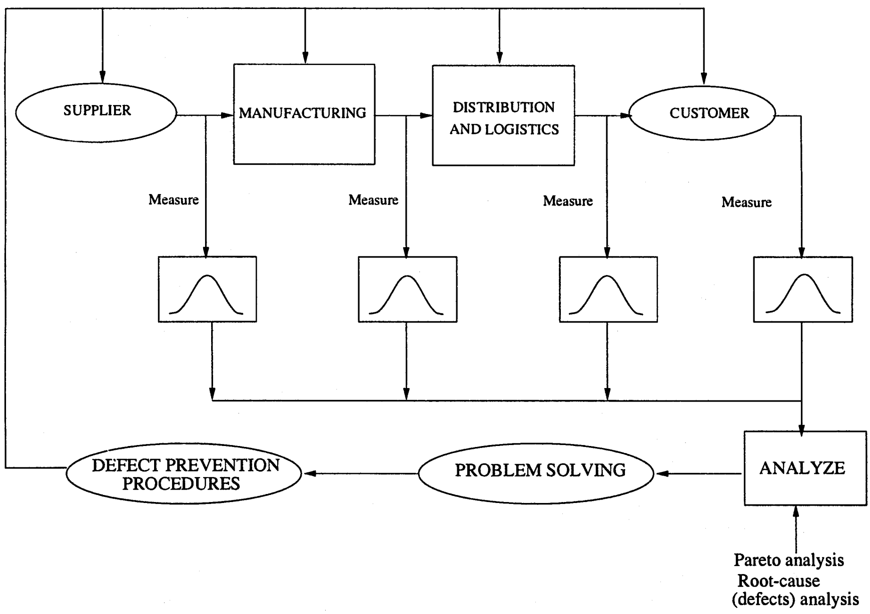

Figure 5.6. Continuous improvement using measurement feedback

analysis and defect-prevention strategies. We use tools such as Pareto analysis, fishbone charts, control charts, etc. for this purpose.

At the work process level, the monitoring is done by using statistical control charts or other equivalent mechanisms. If the work process uses an NC machine, the chart measures the tolerance of the parts manufactured. If the work process involves delivery of an order, then the variables monitored are average delay time or the number of defects in the delivery. The upper and lower control limits for the statistical process control (SPC) charts are set depending on the total allowable error for the entire business process. Once the defects are identified, root-cause analysis is done and actions are taken to prevent occurrence of defects. Figure 5.7 shows the SPC chart for delivery time performance and errors in purchase orders. Figure 5.8 presents a sample root-cause analysis using a fishbone diagram for a late delivery from a supplier.

At the subprocess level, the response time, cost and defects are measured. Deviations from targets of cost and response time are also treated as defects and are investigated. Removal of causes responsible for defects may often require changes in operational and human resource practices and in technology. Equipment or machines causing defects may require upgrading or redesign. If the defect is a non-conformance to scheduled delivery commitments, resource and capacity enhancements may

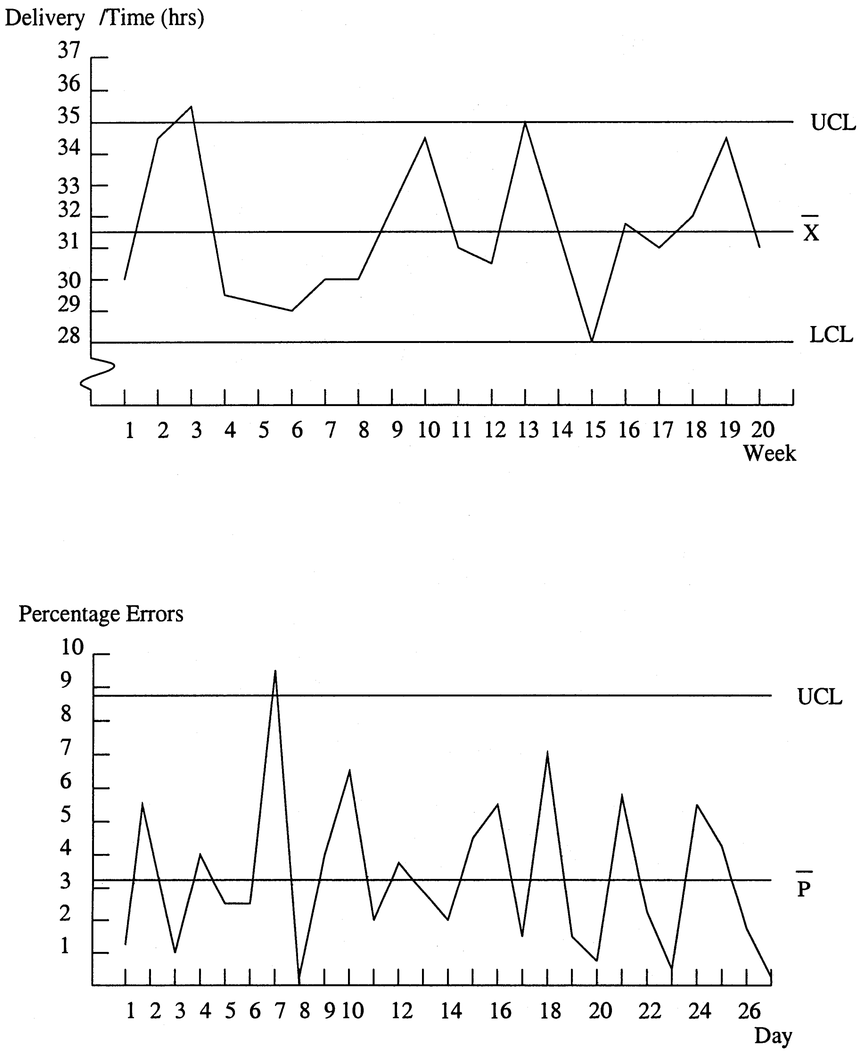

Figure 5.7. Control charts for delivery time performance and errors in purchase orders

be needed or streamlined procedures may be required. The prime result of all these corrective actions should be the removal of all identified causes of defects.

Thus we see that developing core capabilities involves several minor and major decisions. It could be as simple as putting up an EDI connection with suppliers and customers, or relocating the design and sales office in a country of residence of major customers, or instituting a per-

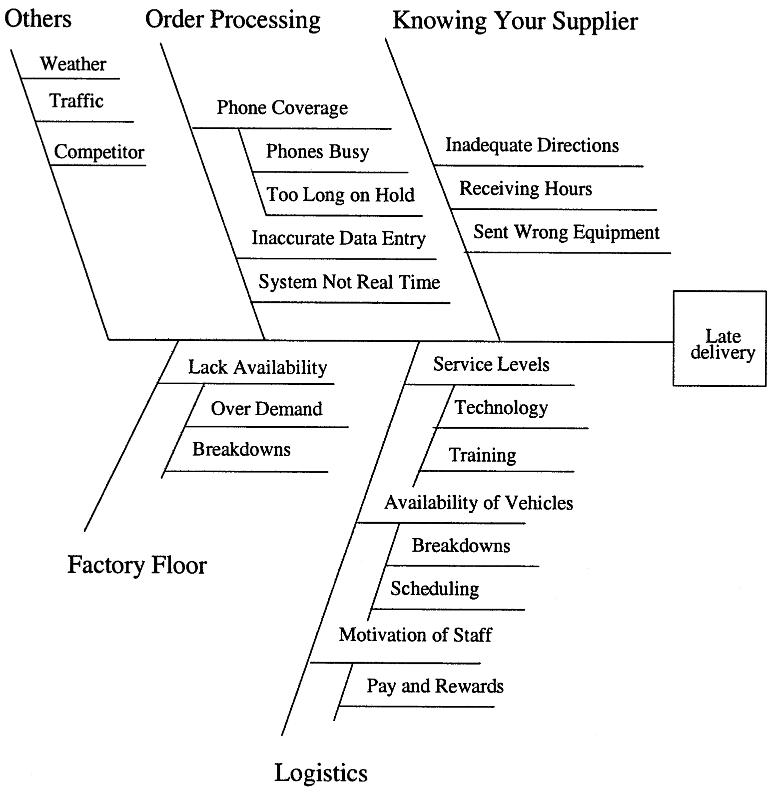

Figure 5.8. Fishbone diagram for late delivery from a supplier

formance control system, or incorporating a best practice into the critical business process.

Develop technologies and resources: In step 2 above, we analyzed the process. Here we identify the core competencies, technologies, and best practices that are needed to make the target process a core capability and also the best of the breed. Information, material, and biotechnologies, the appropriate human resources, and industry best practices need to be identified. Plans are made to develop these resources. In the case of the supply chain process, issues such as electronic commerce, logistics, multicultural teams, and new Internet products for business-to-business commerce are some of the issues. Software development and data mining skills, and high-speed communications infrastructure are needed.

Develop new process architecture: Here, we are seeking a radical redesign of the entire process, its organization structure, and the performance measurement and control system. In other words, we are not seeking to speed up a subprocess or a work process using IT tools such as databases or EDI-based ordering systems. We are looking for a process with learning loops built into it. We want to create a capability-based process that will support the company's competitive advantage on an enduring basis.

If one is redesigning a supply chain process, apart from looking at e-commerce tools, one may want to look at the product design and assembly and location of the subassembly manufacturers relative to the customer locations and logistics costs. The interactions of the SCP with the NPDP and ODP needs attentions (see Figures 2.11 and 2.12). The ODP influences very strongly the interface processes, and the NPDP influences the logistics costs.

Transit to the next level: The company needs to communicate its plans to all stakeholders, make action plans, find resources, and make a road map for phased implementation. Obviously, the initial phases should concentrate on high-impact no-man's lands such as organizational and functional interfaces and finally converge towards efficiency improvement using disruptive technologies.

We have outlined a systematic procedure for process redesign in the above paragraphs. Much work is needed to standardize these steps. We illustrate the design procedure using a generic order-to-delivery process.

7.1 A PROCESS REDESIGN EXAMPLE

We would like to illustrate the process levels and process redesign using a global order-to-delivery process between the distribution and the end user. This example is a typical one and arises in a number of companies. We are sure that this ODP has been mapped and reengineered by several companies. In most cases, a solution is attempted by using better inventory policies or providing better information and communication tools such as extranets, expert systems, and databases. All these need to be done in any case. We will view this as a demand management problem and will try to illustrate the principles of redesign that we presented previously.

Problem Description:

A firm manufactures and inventories a number of products in its Southeast Asian (SE) division and ships to its European distribution (ED) center, from where the European customers are served. If stocks are available, a customer order originating in the European division can be filled in 2 days; otherwise, the customer order is relayed to its SE division. The current ODP subprocess at the SE division consists of several work processes.

1. The order is processed for the usual credit checks and is scheduled for picking and packing.

2. All European shipments are consolidated for air freight. The order receipt and processing takes an average of 7 days with a standard deviation of of 1.2 days. The consolidation of shipments, cargo handling and waiting takes 2.0 days on the average, with a standard deviation of 0.5 days.
3. The product is then sent by air freight to the Eurodivision. This activity is highly deterministic, thanks to efficient airline freight operators. It takes 2 days.
4. The customs clearance process in Europe is highly variable and takes about 8 days with a standard deviation of 2 days. This means that it can take anywhere between 2 and 14 days. This subprocess can be simplified and speeded up. This simplification process can start by locating brokers at the air freight terminal with facilities for sending and receiving EDI messages. The SE division can send the package lists and invoices directly to the broker. Also, the customs inspectors could be informed of the products and the shipments in advance. Further, care could be taken to avoid errors in package lists and invoices. Since the process is a repetitive one, the items that require more review by customs and those that are routine should be separately packaged.
5. After clearance from customs, the product is shipped from the port of entry to the distribution center. On average, this takes 2 days, with a standard deviation of 0.5 days.
6. At the distribution center, the goods are repacked and sent to the customer. This takes 2 days, with a standard deviation of 0.6 days. The customer order fulfillment time is 2 days if the stocks are available in the Eurodivision.

If the shipping has to arrive from SE, then the order fulfillment time under suitable probabilistics assumptions, has

$$\text{Mean} = 7+2+2+8+2+2 = 23 \text{ days}$$
$$\text{Variance} = 1.44+0.25+0+4+0.25+0.36 = 6.30$$

This example illustrates a typical situation in global supply chains. Customers are frequently frustrated by the lengthy lead time and more often by the variability. They have to keep inventory and safety stocks to maintain good service levels. If cycle times are reduced, it is possible to leverage more orders from customers. Thus it is very important to reduce the cycle time. We present a discussion on possible approaches to cycle time reduction, rather than providing a solution.

Possible solutions: The above process can be characterized as a level 2 process. It is an effective process, with procedures and management in place. But it is not efficient because it has to maintain two warehouses and inventories at both despite use of air freight. The lead times are long and the variabilities are high, which will result in further inventories in terms of safety stocks. The industry benchmark for an order-to-delivery process is amazon.com or Dell computers. The performance and defect tracking and monitoring systems of Federal Express may be borrowed. We present below three possible solutions.

Best inventory management: A classical solution to this problem is to define the reorder point and reorder quantity strategies for the EU division for 99% service levels and also to provide visibility to EU division inventory using IT tools. In effect, the SE division can manage the EU division inventory using vendor-managed inventory types of concepts. IT tools such as EDI, the Internet, and extranets can be used for quick, accurate, and secure delivery of information.

Third-party logistics: An attractive proposition is to enter into a strategic alliance with a logistics provider for direct delivery to the EU customer. This approach would avoid the EU division warehouse. The logistics provider will have a good interface with the customs and be aware of the procedures to be followed for quick and easy clearance. Also, the logistics provider has the network within Europe to route the shipment directly to the customer. One can make 3-4 day delivery a contractual condition. This alternative provides a single-window delivery process. The process will be as good as the logistics provider and the strength of the alliance.

Postponement strategy: Both the above approaches may work well, but, they do not incorporate the learning aspects into the solution. A solution that assumes a standard product and a constant demand and then devises means of shipping the product to the customer may not be efficient. The method does not give any feedback on customer preferences or on changes in the demand.

One can look at the demand management problem, rather than trying to redesign the ODP. To proceed, we need more information regarding the customer and the product. The customer could be another company if the product is an intermediate product such as a disk drive or a keyboard or a monitor. The customer could be retail outlets selling to end users. In both cases, we also need to know the product shelf life as well as the customization needed. In Europe, with different countries and different languages, one needs to produce a variety of products from the same platform.

We assume that the product is an electronic product and needs to be customized for each country. The current practice is to assemble the entire product in the SE division and ship it to the EU division. Based on the country forecasts, one needs to maintain an inventory of finished items at both distribution centers for all varieties. It is known that the forecast for the entire European region will be more accurate than the itemwise and countrywise forecasts. The suggestion is to redesign the product and produce a modular structure that would be an assembly of a common standard part and a country specific add-on that would give the necessary variety. Also, it is suggested to redesign the EU distribution center with facilities for product customization.

The ODP now is redesigned as follows. Based on the total forecast for the base product, the standard module is produced at the SE division and is shipped to the EU division. The SE division operates on a push system. At the Euro division, however the system operates as a make-to-order or pull system. The assembly and delivery can all be done in 3-4 days. In this solution, the system is in contact with the customer and products are made to order. Customer vagaries are immediately spotted and addressed.

The above example illustrates that solutions for high quality product delivery are available beyond conventional inventory management. We have presented a range of solutions and there could be many more using newer technologies.

8. CONCLUSIONS

In this chapter, we have dealt with very important subjects including performance measurement, benchmarking, and control of business processes. We have also brought out the fact that the measurements and control should have both a process and a strategic focus. Traditional measures are financial and function based. We have pointed out the disadvantages of such an approach. We have also identified five levels for the business processes. These are fundamental for improving business processes and developing them into core capabilities

We have postulated that four measurements–cost, time, defects, and variety– are fundamental and that all process or subprocess measures such as lead time, quality, flexibility, and asset utilization can be computed using some or all of these quantities. In terms of actual measurements, we need to have sensors such as barcode readers to measure time, mechanisms for recording defects in the delivery process, cost incurred in various activities, etc. These measurements and measures can be used to improve the process performance. Since the decision variables in our context are best practices, the feedback control has to follow a different methodology. Monitoring of errors is done by installing control charts at various critical points along the process. Any abnormal behavior is immediately analyzed using tools such as fishbone diagrams, and the problems are removed. The indices C_p and C_{pk} also aid in process control. Setting the upper and lower control limits in the control charts, as well as in the control of variation using C_p and C_{pk}, is an important issue. Location of measurement points for monitoring and control is another important problem. We have only touched the fundamental problem here, and its resolution requires practices involving human, organizational, cultural and technological elements.

It is important first to identify the critical business processes and their health status in terms of their performance and also the process and human resource practices. We have identified five different levels of process and have mentioned the guidelines for transiting from one level to the upper level. We have also considered the process redesign issues. We have illustrated the method using an example of an order-to-delivery process in an international supply chain.

9. BIBLIOGRAPHIC NOTES

During the mass production era, financial measures such as profit, sales, return on investment, and productivity were emphasized. During and after the decade of the 1980s, companies started emphasizing low costs, lower lead times, dependable delivery, and more variety. Kaplan and Norton [57], Eccles [27], and a number of other authors have pointed out the fact that financial measures are lagging indicators and have emphasized the need to supplement them with operational measures.

There are several articles on integrated performance measurement [33, 34, 36]. All these basically emphasize the point that measurement should be process based and also should be used for continuous improvement. Dixon et al. [26] have developed a tool for checking the consistency between strategic objectives and performance measurement.

Three integrated performance measurement systems have been developed to guard against suboptimization and also to provide an overview of company performance. Wang Laboratories developed the Strategic Measurement technique (SMART) consisting of four-level pyramid of objectives. Dixon et al. [26] developed a performance measurement questionnaire (PMQ) to help managers identify the improvement needs of the organizations and to determine the extent to which the existing performance measures support improvements. Kaplan and Nortan [57] developed the balanced scorecard approach to integrate strategic, operational, and financial measures. Since these do not support improvement and are monitoring and control tools Ghalayini et al. [33, 34] developed the Integrated Dynamic Performance Measurement System (IDPMS) system which supports operational as well as managerial performance improvement and alignment. Our approach here was to concentrate on physically measurable quantities and use them for performance improvement, as is done in continuous feedback systems. Our approach is closely related to the SMART approach described above.

Satisfactory external performance of an enterprise is as much a function of competitors' capabilities as of customer expectations. Benchmarking has become very popular for this reason [8] and was pioneered by the Xerox corporation. Several books and handbooks are available on this subject. Several books on supply chain management [11, 61] suggested the kind of process control presented by us here.

There are several books [45, 66, 67] on reengineering of processes within an organization. Our presentation here follows the SEI methodology [18, 84], for improving software development processes. Vollmann [95] presents a procedure to develop core business processes into core capabilities. Hart [46] also presents a systematic procedure identical to ours. Neither Vollmann and nor Hart identify process levels and rating criteria. Melan [66], Harrington [45], and De Toro and Mecabe [23] identify the process levels but do not integrate the rating criteria into the design procedure. Kodak [73] has redesigned its processes by redefining its vision to be the "best in imaging" rather than best in chemical imaging. Fast cycle time designs [67] also resemble our description here.

Chapter 6

THE PRODUCT DEVELOPMENT PROCESS

Learning objectives

1 Outline different product development strategies.

2 Describe the new product creation process.

3 Describe the stage gate process and compute its reliability by defining type I and type II errors.

4 Describe the alternative organization structures for NPDP.

5 Discuss the lead time and lead time reduction strategies.

1. INTRODUCTION

In a global, intense, and dynamically competitive environment, developing new products and processes is increasing the focal point of competition. Firms that get to the market faster with products that are well matched to the needs and expectations of the target customers have significant leverage. In a highly dynamic environment, excelling at the product and process development can provide a sustainable competitive advantage.

The importance of product development is not limited to high-technology industries such as electronics and computers but applies equally well to established industries with historically long product life cycles, mature technologies, and stable demands. In the auto industry, for example, exploding product variety, intense global competition, and diversity in technologies have created a turbulent environment.

There are a number of reasons why companies have to create, produce, and deliver customer-desired products faster. Competition is now more intense, demanding, and rigorous, since businesses competing at the world-class level have sprung up all over the globe. Today's customers expect product performance and reliability unheard of yesterday and want orders-of-magnitude improvement tomorrow. The variety of products has increased dramatically, since new technologies now make available a variety of possible solutions. Material, bio, electronic, and information technologies are making possible the creation of products that will change the nature of business and competition. For example, information technology has made possible the linking of supplier, production, and distribution networks with the retail outlets, creating a capability to respond quickly to customer demands.

In the hard disk drive industry, for example, the market for hard disks has expanded from its base in mainframe computers to applications in laptop and palmtop computers and supercomputers. Even within each applications segment, the number of form factors, capacities, access times, and features has increased sharply. In addition to the explosion in variety, firms in the hard disk drive industry have to meet demands for a tenfold increase in reliability and a fivefold increase in cost. Another example is the diaper industry, where the days of one generic diaper are over. Now Proctor & Gamble offers diapers for boys, for girls, for infants up to 6 months, for babies older than 6 months, for thin babies, for heavy babies, etc.

For any company to survive, it should be fast acting, be responsive to customer demands and competitor moves, and efficiently create several generations of the products that deliver value to the customer. A stream of successful product introductions will lead to rapid sales and profit growth. As with any other process, the new product development process (NPDP) should also be judged for its effectiveness: how well it meets the needs of the company's stakeholders—owners, employees, customers, suppliers and regulators. Also, customer satisfaction must be achieved at low cost, i.e., efficiently with minimal amount of time and money. Sales of new products is a measure of process efficiency and effectiveness. Succeeding with new products will not happen by accident. It is possible for an organization to come up with a good product that will do well in the market for a while. If this did not happen because of a well-articulated vision of the company and efficiently and effectively run processes, chances are that competitors will overtake soon.

1.1 WHAT IS A NEW PRODUCT?

It is essential to define a new product, or what the newness is in a new product. There are a variety of definitions of new products. Here we refer to new-to-the-world or innovative products. It is known that this kind of product accounts for 10% at maximum of all "new" products. In recent years, several products such as Netscape, Internet, mobile phones, and fax machines, which have essentially emerged from the computer and communication fields, have created a revolution. The Sony Walkman and 3M's Post-It notes are also considered to be new products. Similarly, in the biotechnology field, clones of sheep, rats, and mice are real new products to the world.

One also finds that several products that already existed have been reintroduced–with a tremendous amount of improvements. Digital computers have been around for over 50 years, but there have been changes in size, shape, capabilities, and performance. Do we call a PC a new product or a variant of the mainframe? Do we say a 3.5 inch disk drive is new compared to a 5.25 inch disk drive? Do we say that the Honda Accord is different from earlier Honda cars? Products known to the world but with orders-of-magnitude higher performance form a good percentage of so-called new products. Indeed, most new-to-the-world products with a medium performance level are improved and reintroduced into the market by the same or other companies. Discontinuities in technologies, such as those that happened in the computer and semiconductor industries, also enable the creation of new, high-performance products. The cost also comes down as the product matures. In short, as the product matures and demand declines, the product takes a new incarnation, and continuous improvements are made to deliver value to the customers.

Types of new products

There are different classifications of the new products. we discuss three of them below [90].

Technology-push products: In developing technology-push products, the firm begins with a new proprietary technology and looks for an appropriate market in which this technology applies. Gore-Tex, an expanded Teflon sheet manufactured by W.L. Gore Associates, is a striking example of technology push. The company has developed dozens of products incorporating Gore-Tex, including artificial veins for vascular surgery, insulation for high-performance electric cables, fabric for outerwear, and dental floss.

Platform products: A platform product is built around a preexisting technological subsystem (a technology *platform*). Examples of such platform products include the tape transport mechanism in the Sony Walkman, the Apple Macintosh operating system, and the instant film used in Polaroid cameras. Huge investments were made in developing these platforms, and therefore every attempt is made to incorporate them into several different products.

Process-intensive products: Examples of process-intensive products include semiconductors, foods, chemicals, and paper. For these products, the production process places strict constraints on the properties of the product, so that the product design cannot be separated, even at the concept phase, from the production process design. In some situations, a new product and new process are developed simultaneously.

2. PRODUCT DEVELOPMENT STRATEGIES

There are many ways to provide value to the customers beyond the traditional cost or differentiation approaches in new product development. Companies can compete by providing product variety, speedy introduction of generations of products, and by value-added services. Companies with a few platform products can provide differentiation via speed, flexibility, and after-sales service. We briefly enumerate different product development strategies below [25].

Product variety as strategy: General Motors pioneered product variety as a weapon to battle Ford's Model T monoproduct culture. Even today, providing a variety with marginal increase in cost may be a way for companies to dominate the market. Flexibility–the capability to produce a variety of products without penalty on cost, quality or cycle time–is certainly a desirable attribute. Flexibility management is a capability that firms must develop to compete with product variety. An aggressive proliferation strategy is one of the most effective ways to nudge competitors out and also to defend a leading position. Honda in motorcycles, Sony in portable audio equipment, Hewlett-Packard in printers, and Rubbermaid in plastic houseware have maintained their leadership positions by providing product variety to the customers. Management of variety is a difficult subject and involves providing variety economically without much overhead.

Design as a strategy: Design has always served as a competitive strategy for a number of consumer goods industries, such as apparel, furniture, house furnishing, consumer electronics etc. In these products, aesthetic appeal, safety, easy operation, ease of installation and maintenance, and value for money are important criteria. Image building for life-style-conscious customers is possible with competence in design. Companies competing through design must nurture world-class design teams, consider all aspects of design (see Figure 2.11), and enforce design consistency over time.

Innovation as strategy: Several companies compete with new products: 3M in adhesive and film-based products, Sony and Philips in consumer electronics, Apple in user-friendly computers, and Cannon in office management products are some of the striking examples. Innovations create a new market: compact discs, cellular phones, fax machines, intranets, and search engines are all recent examples. Innovation requires a management with vision, a strong culture, and human capabilities to develop new technologies–and more importantly, the ability to convert innovations into core products.

Service as strategy: For most customers, service and product are two sides of the same coin. Customer service is an opportunity for differentiation. Loyal customers are an asset. Customer defections cost a great deal more than lost sales. Service has become a winning strategy for many companies, such as those selling elevators and farm equipment. Value added services topping core products could easily be a winning solution.

Speed as a strategy: Fast cycle times provide several advantages. The fast rate of technological progress makes products rapidly obsolete. Being first or second with a new chip or new device makes all the difference between winning and losing. With smaller life cycles, the market window is small. By introducing several generations of products first into the market, a company gets what is called the *first-mover advantage.* A late entrant into the market faces a declining market; even if he gets a major piece of the action, it may not mean very much.

Speed also reduces the risk. With long lead times, features and designs have to be frozen long before market launch. The ability to make changes is maximum at the beginning of the project and diminishes thereafter. If the product creation time is low, the ability to respond to market needs is greater.

3. THE NEW PRODUCT CREATION PROCESS

A product creation process consists of a sequence of activities involving conception, design, prototype, test and commercialization of a product. Many of these steps or activities are intellectual and organizational rather than routine. A product creation process consists of several mutually reinforcing subprocesses. A well defined product creation process is essential to create products that delight the customers and propel the manufacturers to market leadership and wealth. Here we describe a level 5 new product development process.

There are four main subprocesses in the product creation process [25]. They include:

- Technology and resource development process
- Product strategy development
- Product development process
- Review process

3.1 TECHNOLOGY AND RESOURCE DEVELOPMENT PROCESS

Top-notch product development requires unique skills, competencies and capabilities within the company and its partners. In the technology and resource development sub-process, the focus will be on the development of core technologies and competencies rather than products. Each of the technologies will in turn lead to a number of core products, as shown in Figure 2.14. The range of activities involved in building technical competencies include selection and development of the right technological skills for in-house development through implementation of advanced development projects, and supply-base development involving selection of a network of partners for development of component technologies. This process has to be developed over time and involves smoothing the organizational interfaces between the new product development teams of the suppliers and the manufacturer and also the functional interfaces between their research and development and the marketing departments. This process is still not as well defined and well developed as the NPDP.

3.2 PRODUCT STRATEGY

Every company that develops and sells products has, by necessity, some product strategy. The product strategy statement is very important for success in a highly competitive environment. It consists of several issues, which we briefly outline here.

Strategic product architecture: Developing a product architecture is the act of transforming a product function into a product form. For example, the function of a screwdriver is to turn screws, so the screwdriver generally has two components: the handle and the blade. The functions of the product are implemented using the components. The architecture of the product generally influences the performance, cost, and variety. There are two types of architectures: modular and integrated. Both have their advantages and weaknesses. In modular architecture, the product is an assembly of components, and several varieties of products can be made quickly using the same components. Variety and speed of new product introduction are advantages cited for modular products. However, there are several disadvantages of modular designs. These include reduced product performance due to the pressure to make a product out of existing components rather than making a wholly optimized product, increased product cost due to suboptimal design using standard components, products that are easy for competitors to copy, etc.

The other alternative architecture is the integrated architecture. Here the product functions are performed by a few components that are assembled into the product. Integrated architecture certainly yields higher performance and low cost and also is not easily imitable. But the design lead time will be very high, and also the variety of products that can be produced is limited.

One should first define the core products that can be built from in-house capabilities leading to the primary products. One should also define the secondary (applications) and tertiary (support, service) products. Some of these are outsourced and others are co-developed. This strategic architecture will guide all future efforts. Often this plan also includes future product offerings i.e., components/subsystems that add extra value to the product. In the case of the PC industry, for example, the core product is the hardware with the processor; software and applications are the secondary products, and technical life cycle support is the tertiary product.

Competitive thrust: This issue is very important in product strategy and defines the basic parameters of the firm's competitive posture. The geographic coverage, product line width, and general or specialist focus are some of the issues that will determine the boundaries for competition. In the case of certain pharmaceutical products, where R & D is expensive, global introduction of products may be necessary to recover costs as well as to avoid substitutes. With certain consumer products, a large product width may be mandatory to cover the tastes of all customers.

Identifying the competitors and their products will help focus the company's energy to shape a competitive product line. Also, in these days of cooperative competition, the company should also identify competitors for joint ventures, strategic alliances, etc. Needless to say, the targeted competitor should be a market or technology leader in current and future products.

The basis for competition is another issue that will determine the product architecture. It could be price, performance, variety, after-sales service, or frequent model changes. Answers should be obtained for questions such as "Where do we want to be best-in-class?" or " In which technical area do we innovate and lead?". If one is competing on variety and model upgrades, then the frequency of model changes and cycle times need to be determined in advance.

Competitive intelligence: It is obvious that intelligence and insights are critical to developing a product strategy. Market intelligence provides the current and future needs, as well as the preferences of customers and markets. Competitive intelligence is needed to gain detailed knowledge about new technologies, new products, and new competitors in the industry. Technology intelligence is vital in dynamic industries to know about expected discontinuities in technology and the resulting opportunities and threats.

3.3 NEW PRODUCT DEVELOPMENT PROCESS

We describe below, the five steps in the product development process.

1. Concept development: In the concept development phase, the needs of the target market are identified, alternative product concepts are generated and evaluated, and a single concept is selected for further attention. On the technical side, the focus is on demonstrating technical feasibility and exploring alternative product formulations or architectures. On the marketing side, the emphasis is on evaluating market opportunities, assessing competitor's products, and preparing a preliminary market plan. On the economic side, the team builds an economic model for the new product.

2. Product design: In this phase, customer needs are translated into a technically and economically feasible solution. The product structure is defined as a modular assembly of subsystems and components. A product structure task graph is generated in this phase, along with the functional specification of each component. The main issues of manufacturability, manufacturing in stages in the case of international manufacturing, and cost of manufacture are all investigated. Assessments regarding meeting regulatory standards, political and market risk analyses, and a competitive analysis are also done during this stage. This stage ends with the approval of the final product design, submission of the prototype, and the business plan. This is the final stage for planning and for determining options. Changes are difficult beyond this stage.

3. Product engineering: This phase involves a complete specification of the geometry and materials of all parts of the product, deciding on suppliers, establishing a process plan, designing the tooling, developing the part programs, etc. The activities could be iterative, with prototype building, testing, customer assessment, and feedback. The investment plan is also submitted for approval.

4. Manufacturing engineering: This phase is executed concurrently and in close cooperation with product engineering . It focuses on manufacturing facilities planning and on the issues of the location of manufacturing plants, their capacities, and their impact on supply chain costs.

5. Market launch and full production: This step is very important . Promotions for market launch, withdrawal of the old products the new product is supposed to replace, and production and distribution ramp-up are some of the important issues. Training of the work force, briefing the sales force, distributions and retailers are also included here.

3.4 REVIEW PROCESS

A review process is essential and should cover technical, commercial, and economic aspects as well as market, competitive and technical intelligence. The review process should be constructive and should consider both the product design and the project schedules. At the end of each stage of the product development process, reviews are conducted. The outcome of the reviews is a go/no-go decision and resource allocation. A go-ahead signal may be given even if the project is not on target, and the project may be killed even if project is on target but a competitor product is already in the market. Here, we consider the typical decisions at each of the reviews/gates.

Review 1: This is conducted at the end of the concept development stage. It is assumed that, for all products coming for reviews, technical feasibility is established and company has core competence in vital product technologies. At this review, apart from the standard project milestone review, questions concerning market attractiveness, competitive advantage, payback period, and existence of a champion are considered. Availability of cooperative suppliers for component sourcing is another criterion. A weighted rating is obtained and a go/no-go decision is taken. The review committee should use the collected information in a constructive manner to help project execution.

Review 2: At the end of the product design stage—probably the last point at which the project can be aborted without much resource expenditure—review 2 is conducted and it is thorough. Apart from project and design reviews, financial analysis is an important part of this review. A full project team is designated and empowered at this review. The product development, marketing, and manufacturing process development plans are all reviewed here.

Review 3: The product design is throughly tested in the environment in which it is supposed to function, using simulation, electronic prototyping, etc., and the results are reviewed by the committee. The suppliers chosen and their capabilities and updated financial analyses are also reviewed by the committee at this stage.
Review 4: This review is conducted after the manufacturing engineering phase is complete. The entire production and marketing activities are reviewed here. The market launch, expected financial returns, marketing channels, etc. are also considered. This is the final point at which the product can be abandoned, although with substantial financial impact on the company.
Review 5: This review is conducted about six months after the product is launched. The data on revenues, costs, expenditure, profits, and timing are all analyzed. The product performance, customer reports, strengths and weaknesses, and project execution are all reviewed, and the lessons learnt are documented.

4. DESIGN OF THE STAGE-GATE SYSTEM

The management of new products can be perceived as the management of risks. In line with this insight, state-gate systems are designed to manage risks. Risks consist of two key elements, namely, the amounts at stake and the probability of failure. New product development is highly plagued with risks because the amounts at stake can be enormous and the probability of failure is high as a result of the level of uncertainty and the complexity of the multifunctional operations, which lead to ambiguity in decision making. The single key question in new product development is: "Should the product concept be developed and marketed as a new product?" The decision to this question is an "all-or-nothing" decision. The risk involved might be too high if only one decision is required to provide the answer. The stage-gate system, as proposed by Cooper [16], breaks the "all-or-nothing" decision into a "multigate" decision (multiple steps and multiple decision points), where the strategy is to spend money and time to buy more information about the new product project.

It sounds logical that the stage-gate system will be able to reduce the risks involved in new product projects. Intuitively, we know that by adding more screening controls (gates) to the new product development process, the chances of committing an evaluation error of rejecting a good project can be reduced. This will however, increase the process lead time. Also, how can one explain on a more theoretical basis that the stage-gate system can improve the reliability of a new product decision making?

THREE-STATE DECISION MODEL

Null hypothesis H_0:

The new product development project should be aborted

Proper Course of action \ Decision	STOP	PROCEED
STOP	Correct Decision	TYPE I ERROR
PROCEED	TYPE II ERROR	Correct Decision

Figure 6.1. Three-state model for NPD decisions

To answer the above question, we use the three-state decision model as a conceptual framework to study and analyze the reliability of the stage-gate system, where it is conceptualized as a serial decision system. So far, no theory exists to allow formal analysis of the reliability of the stage-gate system in implementing a new product launch. A conceptual framework, in the absence of theory, is helpful in organizing and understanding a subject such as complex as the reliability of new product launch.

4.1 THREE-STATE DECISION MODEL

Consider the null hypothesis for new product decision making to be that the new product development project should be aborted. Therefore, if the gatekeepers decided to proceed to the next stage when it is improper to do so, a type I error has been committed. Similarly, if the gatekeepers decide to terminate the project when it shows good merits and potential, then a type II error has been committed. The possible outcomes for a three-state decision model and the null hypothesis are shown in Figure 6.2. We made three assumptions in the model:

1. Probability of failure for each decision gate in the system is given.

2. Reliability of the system is assumed to be static.

3. The states of all decision gates are assumed to be statistically independent.

Reliability against type I errors: The stage-gate model of the NPDP is shown in Figure 6.3. As a serial decision system, the stage-gate framework is more effective in preventing type I errors from propagating through the decision system. Following the null hypothesis, NPD gatekeepers should not allow the project to proceed to the next stage unless the information delivered to the gate satisfies the gate criteria. At any decision gate, the gatekeepers are rejecting the null hypothesis when they make the decision to proceed to the next stage. If the decision to reject the null hypothesis is wrong, then a type I error has been committed. For the stage-gate system to fail, all decision components must commit type I errors. In structuring a new product decision making process as a serial network of decision gates, the stage-gate system provides multiple checkpoints to stop type I errors from advancing through the system. This improves the reliability of the system with regard to type I errors.

We consider a numerical example (hypothetical) to illustrate the improvement in the reliability of the system. Assume the probability of failure of a decision gate with regard to type I errors to be 0.8, and also assume that this probability is the same for all the decision units. This figure translates to the implication that there is a 80% chance of making a type I error at each decision unit. If a total of five decision units (gates) are used, the probability of failure with regard to type I errors (at the system level) would be 0.328. There is a large improvement in the reliability of the decision-making process when a series network of five gates is used instead of a single decision unit.

Reliability against type II errors: However, a serial system and hence stage-gate system is less effective against prevention of type II errors. This is because when one decision unit (NPD decision gate) accepts the null hypothesis of aborting the project, the project will be terminated immediately. If the decision to abort the project is incorrect, then a type II error has been committed, and the whole serial system will fail. It only requires a single component to commit a type II error for the whole system to fail. The more components added in series, the greater the probability that a component will commit a type II error, causing failure of the whole system.

Therefore, the increase in the reliability of the stage-gate system (serial system) against type I errors is achieved by compromising the reliability of the system against type II errors. To get a better insight of the trade-offs encountered here, the nature of type I and type II errors must be understood. This will be discussed in the next section.

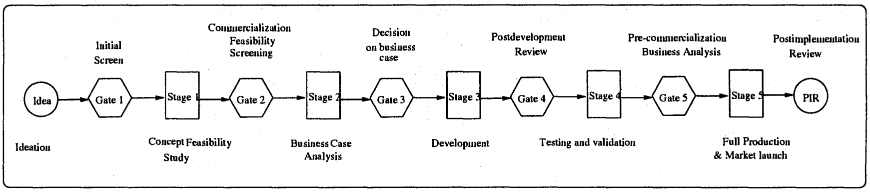

Figure 6.2. Stage-gate model for the NPDP

4.2 TYPE I AND TYPE II ERRORS IN THE STAGE-GATE SYSTEM

We consider below five causes of the two types of errors.

Deficiencies in the decision-making capabilities of gatekeepers: New product decisions are tough decisions that require good decision makers to be the gate-keepers. However, in real-life situations, the gatekeepers are not properly trained to handle decision-making requirements of new product development. Thus there are deficiencies in the decision-making capacities of gatekeepers.

Deficiencies in the collection and management of vital information: Information or intelligence is critical to new product decision making. Lack of vital information or mismanagement of vital information has a direct impact on the reliability of NPD decision gates. The quality of the information supplied to the gates is affected by the capabilities and competencies of the organization and the amount of resource committed to new product development. Lack of resources would compromise the effectiveness of the decision making at the gates.

Organizational culture: Organizational culture relates to the propensity of the organization to take calculated risks. New product development is a risky business. For example, if the company's culture is not supportive of risk-taking and is intolerant of failures, then the product development team will be more conservative (to the adverse effect of even denying meritorious projects) in making their critical product development decisions, especially when the decisions involve high cost and resource (i.e., higher risks). This implies a higher probability of committing type II errors. The reverse is true for type I errors.

Decision criteria at gates: The inability to select the right criteria for decision gates to assess the merits of projects could lead to the abortion of projects with good potential or to the continuation of bad projects. This cause may seem trivial, but the reliability of the decision process is highly dependent on the correct selection of the key gate criteria. An overly strict criteria could lead to type II error being committed while the reverse is true for type I error. Absence of a key criterion that can make or break a new product project at a gate implies compromising of the reliability of the decision gate and hence the reliability of the system.

Chance elements: No matter how well a system is perfected, there is always a chance that it will fail. In new product development, no matter how effective and capable the decision gatekeepers are, the decision process may still fail. So the reliability of the product development team in making critical decisions (with regards to type I and type II errors) must be objectively assessed. Chance elements in the dynamic business environment (external) may include:

- Customer needs and preferences
- Technological breakthroughs
- Competitors' strategic moves and
- Economic and social trends

Examples of type I errors in NPD decision making: Type I errors can be easily observed in the reported cases of new product failures, whereas type II errors are less obvious because they are not reported in the open literature. An example of a type II error is that of a wrong prioritization decision being made by NPD gatekeepers whereby valuable resources are allocated to other inferior projects, resulting in a meritorious project being terminated or put on hold. Such a project might not maintain its merits forever because the window of opportunity can be short and limited. Table 6.1 tabulates a number of type I errors that can occur at the various gates of the stage-gate system used to implement new product development.

The three-state decision model provides a conceptual framework to study the reliability of NPD decision making that recognizes both types of errors and the consequences associated with them.

4.3 DECISION TREE FOR THE STAGE-GATE SYSTEM

An event tree diagram can be obtained for the stage-gate system under the three-state decision model (see Figure 6.4). Event tree analysis is an inductive method used for identifying the possible outcomes of a given initiating event. The initiating event in this context is the arrival of the first new product decision at the first gate of the stage-gate system. For simplicity, the initial gate (initial screen) of the stage-gate system has been combined with the second gate (commercialization feasibility screening) to form a single decision gate.

From the initiating event, the tree then branches into the possible success and failure states of all the subsequent decision gates in the stage-

Table 6.1. Examples of type I errors at the respective gates

Decision Gates	Examples of type I Errors
Gate 1: Initial screen	• Competitive strategy and new product ideas are not aligned • Impending changes in the legislation and regulations and a new emerging technology ignored
Gate 2: Commercialization feasibility screening	• Competitive differentiation ignored; Products with no unique benefits to customers; *me-too* products • Synergistic fit with company resources; competencies not considered
Gate 3: Decision on business case	• Incorrect identification of customers' needs, wants, and preferences • Incorrect translation of customers's needs into product concept and specifications • Indequate competitive intelligence • Wrong assessment of market situation • Inadequate predevelopment work • Premature project go-ahead when the technical development plan is not properly formulated
Gate 4: Postdevelopment review	• Failure to realize that customers' needs have ceased to exist. • Poor quality of development work ignored, i.e., prototype does not meet design specifications • Cost of developing the product far outweighs the returns
Gate 5: Precommercialization business analysis	• Approval of a new product launch whose window of market opportunity has been lost • Approval of a hasty product launch.

gate system. At the initial gate, there are four possible outcomes: correct decision to proceed (branch G), correct decision to stop (branch N), type I error (branch I), and type II error (branch II). The state represented by any branch is conditional upon the occurrence of all the preceding events, up to the initiating event. From the second gate onwards, the event tree is separated into two arms. One arm propagates the correct decision to continue with the new product project while the arm is driving the type I errors through the stage-gate system, causing an eventual failure of the entire system. Hence, at a particular branch, the overall probability of

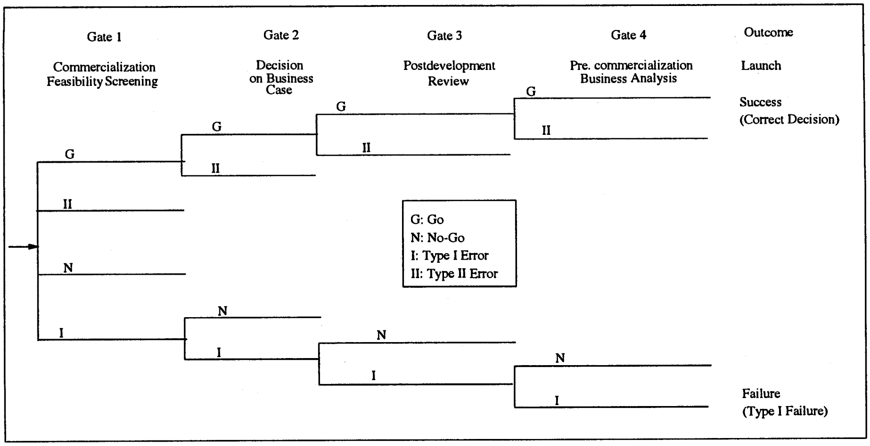

Figure 6.3. Event tree for an NPD stage-gate system

occurrence is given by the product of the probabilities of occurrence of all the preceding branches, the chosen branch inclusive.

4.4 WHY DO NEW PRODUCTS FAIL?

We have seen from the above analysis how a stage-gate model can predict product launch failures. We now quote the results of a survey by Cooper [16]. If a product is designed and manufactured to suit a customer or a group of customers, why should it fail? It is very important to know the reasons why products generally fail and to take care to see that one's own product does not fail. Cooper has conducted extensive studies to investigate this issue [16]. According to one study, for every 4 new product ideas, 2 enter development, 1.3 are launched and 1 is a commercial success. More than half the money spent on new product development process is a waste because the products are canceled or fail. The reasons are very simple: companies do not conduct detailed marketing studies, i.e., products are developed and launched based on mostly hunches , as imitations of the competitor's product. Also, new product development process is generally deficient in detailed financial analysis, product strategy, product launch efforts, test marketing, and so on. The analysis by Cooper shows that one fourth of products made are those that nobody wanted, and me-too products account for another one fourth. In the first case, a company starts the product development without market analysis, and in the second case, projects are initiated with the thought that their product gets a fair share of the market. The other 50% of the product failures relate to competition, cost, and performance. In most cases, either the product performance is not up to the mark or the price is too high. These failures could be avoided by having an effective and efficient new product development process. Competition is another important factor: competitors drop prices and initiate a sales promotion at the time of your launch. In such cases, the launch should come with a counterstrategy as well.

5. ORGANIZATION STRUCTURE

Successful firms organize their product development teams effectively. Project teams monitoring and participating in the development of new products exist in every company. It is also true that most of these teams have members drawn from several functions such as marketing, manufacturing, sales, etc. and also from suppliers and distributors. These teams are usually co-located, and if not they are linked by communication networks with facilities for almost instantaneous transfer of information. Project management exists in many forms in different companies, and the level of empowerment given to the team leader differs from company to company. A wide spectrum of choices exists between a functional organization without a project manager and an autonomous process-owner-based new product development process. The organization structure is important because its ability to influence the outcome of the NPDP. We now consider some typical structures.

Functional teams: The project is divided into functional segments that are assigned to functional bosses. The functional boss is responsible for coordinating her portions of the project, and she gets it done via her staff. She also coordinates with the next function to which she passes the baton. This model of product development is sequential and is not suitable in areas where cross-functional knowledge is essential and short lead times are expected.

Coordinated functional teams: This is also called *lightweight project organization.* The coordinator is responsible for smooth transfer of work across functions and does not have any authority.

Matrix project structure: Once a new product development project is approved, a cross-functional team is formed with a coordinator. The employees in functions are assigned to the project, as discussed in chapter 3. This model is widely used in aerospace and electronics companies. It is also called a *lightweight project structure* if the functions are powerful and a *heavyweight project structure* if the project boss is powerful. The heavyweight project structure, where the project manager is fully responsible for the project, is followed in consumer electronics, automobiles, and other high-volume product industries to meet the pressure of lead times.

Process-based organization structure: Here a cross functional team, selected from various functions and headed by a process owner, manages the NPDP. As we mentioned in chapter 3, the team and the process owner are permanent and are not dissolved as soon a particular product is completed, as in the above cases. The primary benefit of identifying a process owner is to ensure both a smooth launch and continuous maintenance. Also, implementation of the review process mentioned in section 6.3.4 could be the responsibility of the process owner. Monitoring the metrics of the process, such as time to market, cost of development, etc., and comparing them with previous products as well as with the best-in-class is also the responsibility of the process owner. Needless to say, continuous improvements based on metric information are also the responsibility of the process owner.

A good process owner can make a difference in developing generations of products rapidly. The learning effect from project (product) to project (product), already-established interfaces between functions, knowledge about the expertise available both inside and outside the organization, and the continuous improvement possible from earlier experiences will all cut the lead time as well as the cost. The process team generally consists of members of the suppliers, distributors, and perhaps preferred customers. Since the concept-to-market-launch process and maintenance are the responsibilities of the team, this cross-organizational team would be more effective than other structures.

6. PERFORMANCE MEASURES

As with any process, defining and measuring a few vital measures that reflect the process performance is very important for the NPDP also. The measures should be standard and acceptable in similar organizations, capture the progress towards the objective and also guide improvements. The three important measures for NPDP are cycle time, ie., the concept-to-market-launch time which is a principal product development metric for many companies with short product life cycles; quality, ie., customer satisfaction with the product design and performance and match between the launched product and the product that sells; and cost, ie., the total cost of product development from concept to launch. We have earlier considered the issue of the reliability of product launch. We consider the cycle time below in more detail.

6.1 CYCLE TIME

Cycle time is the elapsed time from concept to some important milestone in the product development process, such as market launch, profits

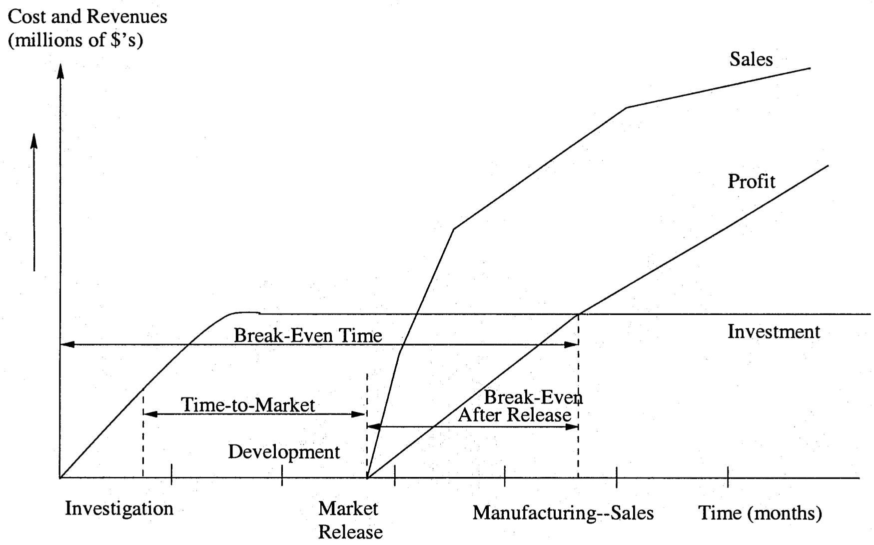

Figure 6.4. Hewlett–Packard's time–cost break-even diagram

exceeding the investments, etc. Short lead times allow a company to develop a market advantage either by launching a new product first or by following up with a better product. Also, a shorter product life cycle narrows the window of market opportunity; speed is essential to enter the window before competitive preemption. Also, market share and margins are generally won in the early part of the product life cycle. Further, short lead times allow a company to start later, i.e., closer to the market entry, thus reducing the uncertainty and risk. As we mentioned several times before, short lead times result in low costs and a smaller number of defects. We now define three important cycle time measures for NPDPs.

Time to market: Time to market is the actual project duration time from start to finish. It characterizes the speed of product development purely from an internal and operational perspective. It is also important to have the market and financial viewpoint. This speed is influenced by technology used and at times by the company strategy for leapfrogging to keep competitors at bay.

Break-even time: This is the time elapsed between the start of the project (concept) to the moment cumulative profits exceed the investments. While computing this time, one can also compute the percentage of sales from new products. The break-even time, developed by Hewlett Packard, measures the market penetration and not just the development speed as illustrated in Figure 6.5.

Product cycle time: This is the time interval between two successive product introductions. The inverse of the product cycle time is the frequency of new product introductions. Product cycle time compression increases the barrier for competitors. There are two attitudes in the introduction of new generations of products, namely, the Japanese incremental but rapid-improvement model, and the European model in which each product represents a quantum jump in performance.

Cutting cycle times has immense advantages. Companies have to decide, based on the capabilities of the teams and the resources available as well as on internal and external benchmarking information, the amount of cycle time reduction. In the following, we consider some important methods available for lead cycle reduction.

6.2 CYCLE TIME REDUCTION

There are several possible ways to reduce cycle times. The key issues, namely, avoiding waste and tracking down non-value-adding activities and eliminating them, take away dead time from the lead time.

Do not make late changes: Design changes create disruptions and time-consuming iterations. Changes at the beginning of the project are normal, but the later the changes particularly—after freezing the specifications—the costlier they are in terms of wasted time and money. Changes are painful if they are done after prototypes have been tested and molds and dies have already been ordered. Most functional departments argue that changes are unavoidable, based on probably very valid arguments such as fast-changing market conditions, unexpected changes in environmental regulations, introduction of a new product by a competitor, availability of a new technology, and similar easily defensible arguments. They argue that these changes are needed to add value and or to be competitive in the market.

A number of measures can be taken to reduce the number of changes and also to manage the changes effectively should they become necessary. These include

1. Improving market, customer, and competitor intelligence.

2. Building products on available and mature technologies. Developing new technologies for new products results in uncertain research and development times and in waste.

3. Management by cross-functional teams, improved communication between the design team and other stakeholders, root-cause analysis of late changes, learning experience from previous product creation exercises, etc. can reduce the number of changes.

4. Despite the best planning and use of various types of intelligences, sometimes changes cannot be avoided. The process team should develop the ability to handle changes effectively. Frequent product introductions are the best way to incorporate changes that would improve competitiveness of a product.

Avoid errors: Another cause for lead time increases is errors committed at various stages. Errors in the conception of the product are very costly and may lead to abandonment the project. Errors may result from poor understanding of the customer and market requirements or lack of proper communication between various functions. Rekeying errors may occur due to lack of uniform tools and connectivity between computer systems. First-time-right product developers use modern documentation systems, encourage team work and frequent communications, use faster prototyping tools and engineering simulation approaches to validate designs, and implement rigorous design reviews.

Reduce product variety: A broad product line, in the name of flexibility, could be a waste particularly when many products are not needed from the market point of view and are not appreciated by the customers. A broad product line increases both design and production complexity. It is important to keep complexity to a minimum while supplying products to customers that are tailored to their needs. A modular product structure with a standard base and a large number of common parts and customized add-ons will keep flexibility skin deep. Pareto analysis of variety-cost and variety-market share allows one to determine realistic product diversity targets.

Work concurrently: Once all wasteful activities are removed, the product flow graph can be rewritten to show the concurrency between various activities. Concurrent engineering is a big subject and requires accurate and complete information sharing among its partners.

Work faster and smarter: Here is an area that requires much thought. Working in teams, sharing designs with suppliers, automating work flow and communications, and outsourcing part of the development are some of the means to cut lead times. Building capabilities within the company; developing a modern infrastructure, such as CAD/CAM/CAE, rapid prototyping tools, and flexible manufacturing systems; and partnering with suppliers and customers are all long-term measures that would enable faster product development.

6.3 EXAMPLE 6.1: MODELING SOFTWARE DEVELOPMENT

The basic activities to be performed for developing a software product include:

1. **Requirements analysis:** This analysis is done to understand the problem that the software product is supposed to solve. Two major activities are involved here–problem understanding and requirements specification. The output of this phase is a software specification document, which specifies the formats of inputs, outputs, design constraints, and functional and performance requirements. This phase ends with validation of the requirements by the customer.

2. **Software design:** This activity often consists of two subactivities: system design and detailed design. In system design, one identifies the modules and their specifications and in detailed design their internal logic. Two separate documents are produced–one for system design and another for total design–and this phase ends with design verification.

3. **Coding:** In this phase, the design, is translated into code in a given programming language in an easy-to-read and understand format. The code is controlled to reduce the testing and maintenance effort. The output of this phase is the verified and tested code of different modules.

4. **Testing:** This is a major quality control measure and its rigor depends on the criticality of the application. The basic function here is to detect errors in requirement, design, and coding. The final output is a test report containing the results of executing the cases for specified test cases.

5. **Installation:** This may be a simple activity or a complex gradual process involving handing over user's manuals, installation and jumpstarting of the system, and training of personnel.

6. **Maintenance:** This is generally not a part of development cycle but is an important activity.

A typical software product may take a few months to a few years to develop, and its life is generally 5–10 years. While the exact numbers differ from application to application, typically, of the total cost, 10% is incurred in requirements, 20% in design, 20% in coding, and 50% in testing. There are several models available to study software development, including the waterfall model, the spiral model, and prototyping. The interested reader can refer to [101].

Our problem here is to compute the lead time. Suppose the requirement phase takes 10 weeks, the design phase 6 weeks, coding 6 weeks, testing 15 weeks, and installation 4 weeks; then the total lead time is 41 weeks. If one assumes that each of these activity times is normally distributed, it is possible to compute the probability of completing the project in a given time for a dedicated team.

6.4 EXAMPLE 6.2: MODELING A PRODUCT DEVELOPMENT ORGANIZATION

Here we consider a typical organization in which several product development processes are concurrently executed. The issue is scheduling the various product development activities onto the limited resources.

We now describe briefly the product development organization (PDO) studied by Adler, Mandelbaum, Nguyen, and Schwerer [1], which serves as a typical example of a multiproject PDO. This particular PDO is involved in the development of plastics products that are either *new products* or *reformulations*. Since much of the effort is spent on new products, we shall only consider these for our modeling study here.

The main resources in the PDO are the product and process engineers and technicians. Other resources are application engineers, product management personnel, manufacturing engineers, marketing and sales personnel, etc.

The activities in this organization can be broadly categorized into five phases: phase 1 (Concept/Feasibility); phase 2 (Project Plan/ Team Formation); phase 3 (Product Development); phase 4 (Manufacturing Standardization/Product Launch), and phase 5 (Continuous Improvement). Phase 5 is not considered here as in [1], since very few data can be collected on this issue. Phase 3 of the process contains the bulk of the work and again, as in [1], is chosen for a detailed study here. Phase 3 involves 15 main activities. These activities are as follows:

1. Review Patent
2. Manufacturing Process Development: Determine process methods and equipment for all stages of production
3. Market Position: Determine competitiveness of the product and establish market position
4. Make Slabs: Create samples in the form of slabs
5. Test Slabs: Test slab prototype for conformance to material requirements
6. Make Product: Make sample products from prototype materials
7. Test Product: Test product prototype for conformance to product requirements
8. Make Product-Mfg: Make product prototype in plant to uncover any manufacturing issues
9. Test Product-Mfg: Test manufacturing prototype for conformance to product requirements
10. Sales Strategy: Formulate sales strategy
11. Lead Customer: Identify lead customers and determine their needs
12. Product Specs: Identify product requirements and testing procedures
13. Field Trials: Test product with lead customers
14. Agency Specs: Determine whether product is subject to government regulations
15. Quality Testing: Test product for conformance to all specifications

Of the above 15 activities, many are concurrent. For example, prototyping, manufacturing process development, marketing, and sales strategy can all progress at the same time. Also, for each activity, several different types of resources may be required simultaneously. For example, for the manufacturing process development activity, the following resources are required: product engineers, product technicians, process engineers, and process technicians. The precedence constraints and sequencing among these 15 tasks are shown in Figure 6.6. In this figure, CF indicates phase 1 (Concept/Feasibility); PP indicates phase 2 (Project Plan), and ML indicates phase 4 (Manufacturing and Product Launch).

In the PDO under study, at any given time, many new product development projects are in progress in different phases. This causes contention for engineering/human resources and results in delays at various points. We would like to model the resulting congestion. Oftentimes, different phases of the same NPD project could be contending for a given resource. For example, product engineers are required

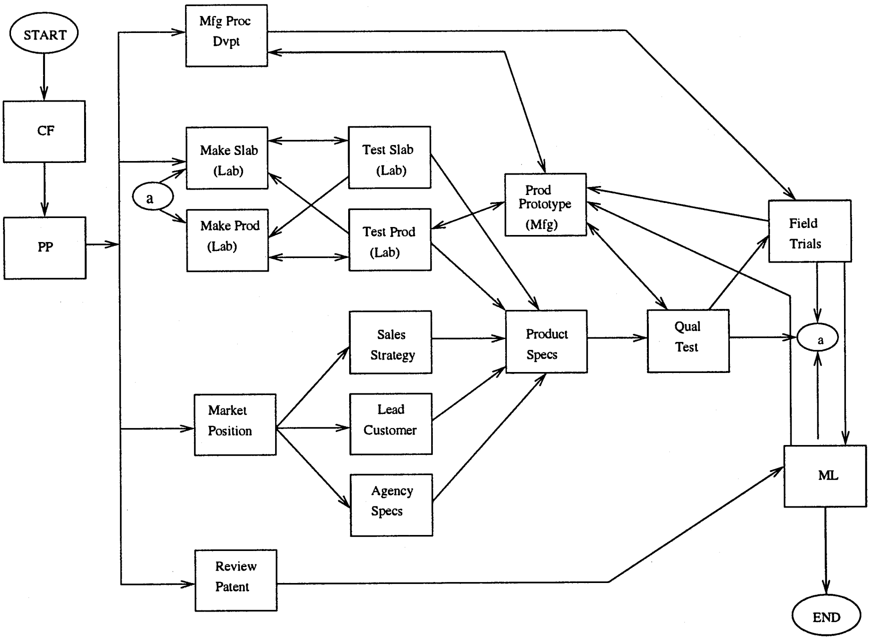

Figure 6.5. Process flow diagram for the product development process

for slab prototyping, product prototyping, manufacturing process development, and quality testing activities of the same project.

An important aspect of a typical PDO is the need for feedback and reworking at most stages of the process. This is necessitated because design/manufacturability and other such problems can get unearthed at various stages, and this calls for repeating a subset of PDP activities all over again. One can characterize this iteration structure using feedback probabilities. Figure 6.7 shows the iteration structure of typical NPD projects. This diagram is derived from the data available in [1]. In this diagram, phase 3 of the NPDP is aggregated into eight activities: MPD1 (Manufacturing Process Development-1); MPT (Material Prototype and Testing); PPTL (Product Prototype and Testing in Laboratory); PPTM (Product Prototype Testing and Manufacturing); MPD2 (Manufacturing Process Development -2); Sales; Specs; and FT (Field Trials).

From Figures 6.6 and 6.7 one can easily develop mathematical models for lead time calculation. Graph models [77], Petri-net models [92], and queuing network models [92], are commonly used in analytical studies. In complex situations, as in the case of the above examples, discrete event simulation techniques are utilized.

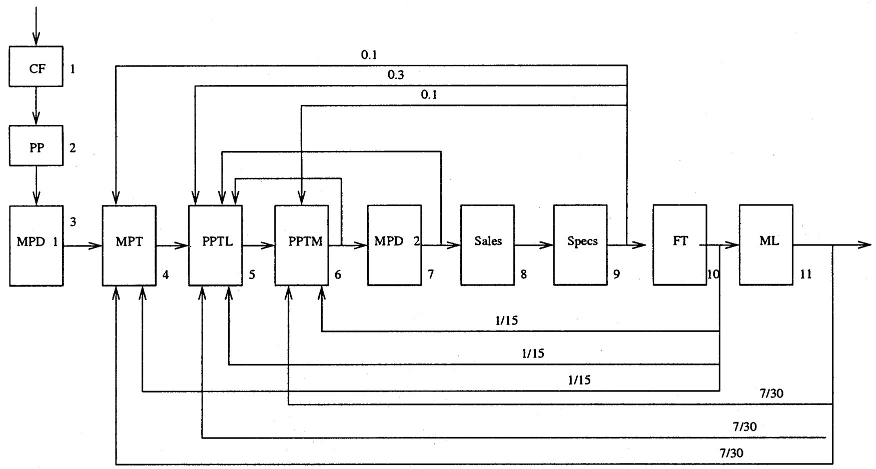

Figure 6.6. Iteration structure for the new product development process

7. BENCHMARKING IN THE NPDP

A major study was undertaken by the International Motor Vehicles Program at MIT in trying to understand and compare the automobile production in Japan, the U.S. and Europe. As a part of the study, several comparisons were made between practices followed by auto manufacturers in Europe, Japan, and the U.S. Performance, best practice, and generic benchmarking studies were conducted on the new product development process. The MIT study compared the organization structure and the product development process: communication and information transfer, performance measures such as lead time, design changes, etc. These results are documented in two well-known books [12, 99]. We do not attempt to repeat these findings here. We summarize some interesting results, however.

Performance benchmarking: By conducting these studies, the MIT team was able to isolate the miracle behind Japanese successes. They found that the average engineering hours spent per new car was 1.7 million hours by the Japanese car makers as against 3.1 million hours by the Americans. Similarly, they found that Japanese development time was 4 years as against 5 years by American automakers. They also found that Japanese car makers employ half the number of engineers and spend much less time on engineering changes in comparison with Americans. The MIT team also compared the number of models introduced between 1982-1990. Japan has manufactured and sold twice the variety of cars. These studies had profound implications. Several research studies were instituted to close the performance gap.

Generic benchmarking in the NPDP: The MIT team also compared the best practices in manufacturing and new product development. In manufacturing, for example, small batch production, group technology layouts, close coordination with suppliers, process simplification and automation, and short lead times were followed by tremendous success. By following similar methodologies, such as transfer of information in small batches by constant communication among all stakeholders, project team groupings for creation of similar products, high involvement of suppliers in the design of components and choice of technologies, automation of design by using CAD/CAM/CAE methodologies, and short development times in the new product development process, companies were able to gain tremendous advantages. A close interaction between marketing and product development teams follows the pull system of the manufacturing practice. All the activities of the NPDP are scheduled to meet the market introduction date. Reduction of lead times forces frequent communication and transfer of information across various stages of problem solving. The new product development process is made flexible to design changes, cost targets, and varying schedules. Thus, transfer of best practice from manufacturing to the NPDP has resulted in tremendous gains.

The manufacturing process of a product is a structured process, with standard decisions or almost no decisions made on the factory floor. Decisions regarding scheduling and planning are supported by a great amount of software. In contrast, the new product development process is believed to be unstructured, with lots of high-risk decisions regarding the product structure, technologies, choice of partners, etc. There is almost no software support to aid decision making. Companies use project management techniques, but monitoring and coordination is almost never present. The reason for this is that earlier product life cycles were very long and standard models were acceptable to the customers. When the need is mass customerization, not mass production, the need for churning out generations of products became evident. Companies started thinking of reducing the product development lead times. The aim was then to make the product development a structured process by benchmarking it with the manufacturing process.

Competitive benchmarking: The literature is full of examples of learning by companies, particularly from their competitors. In the auto industries, maintaining a close relationship with the suppliers through financial involvement is a Japanese tradition. The rest of the world followed this approach even in the NPDP by involving the suppliers, customers, distributors, etc. The organization structure of the NPDP is another item that is frequently benchmarked.

8. CONCLUSIONS

The new product development process is a very important value delivery process of a manufacturing enterprise. As we mentioned in chapter 5, depending on the competitive strategy the NPDP can be a core business process. As mentioned in chapter 2, the NPDP is very closely coupled to the supply chain process and requires attention.

In this chapter, we have presented a description of the NPDP and the stage-gate process. We introduced the concept of reliability of the NPDP and outlined the causes for wrong decision making at various decision points in the NPDP. We discussed various organization structures currently in practice. We discussed the performance measures of the NPDP. Finally, we present the influence of benchmarking: learning from direct competitors and also from manufacturing organizations, the best practices and implementing them in the NPDP.

9. BIBLIOGRAPHIC NOTES

There are a large number of books on product development, and some of them are very famous, containing case studies (see [98]and [12]) Boothroyd [4] has published extensively on design for assembly and manufacture. The most recent valuable addition to this list is by Ulrich and Eppinger [90]. The book on product juggernauts [25] presents a combination of theory and practical examples. Their presentation is also process oriented like ours. Several case studies have been presented by Cooper [16] who also provides very valuable survey results. Our description of the stage-gate system is from Cooper, and the type I and II analysis is our own [80] and follows Heimann [52]. The cycle time reduction methods and the break-even analysis are taken from literature. Benchmarking of the NPDP is from the books by Clark et al. [12] and Womack et al. [99]. There are several recent articles and books on cycle time reduction in the NPDP; see, for example, Meyer [67], Kole [58], Griffin [37], and Cohen et al. [14]. The example on product development is from [1] and [100].

Chapter 7

ORDER-TO-DELIVERY PROCESS

Learning objectives

1 Introduce and describe the order-to-delivery process.

2 Bring out the importance of logistics in the delivery process.

3 Emphasize the value of information in ODP and describe the best practices in industry.

4 Study important ODP performance measures: customer service, lead time, cost, and flexibility.

5 Describe the controller to monitor the ODP.

1. INTRODUCTION

The order-to-delivery process (ODP) is the principal means by which buyers or customers communicate with sellers, the final sale transaction is made, and cash is generated for the seller. The ODP, also known as the OCP (order-to-cash process), is an extremely important core business process in a manufacturing enterprise. It is a customer-facing process and is key to operational efficiency and customer satisfaction. Can the order processing process create differentiation and competitive advantage? Most certainly yes. Companies should strive to create an ODP that is world class and that results in customer delight.

N. Viswanadham, *Analysis of Manufacturing Enterprises*

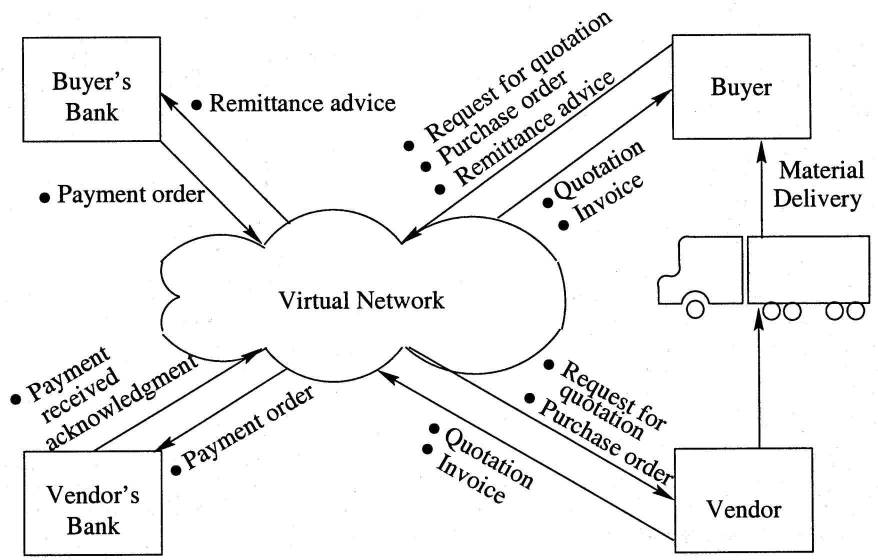

Figure 7.1. Buyer—vendor activity under electronic commerce

We now very briefly describe a typical ODP between a buyer and a vendor in the electronic world(see Figure 7.1). All the communications and transactions between the two parties and their agents such as banks and logistics providers happen electronically. The only physical activity is the delivery of the product to the customer and possibly installing the same at his or her site.

The ODP is thus the main beneficiary of the recent advances in information technology. The Internet, electronic commerce, electronic funds transfer (EFT) are the three most important technologies that affect the ODP. Companies should leverage these technologies for achieving competitive advantage. Business-to-business commerce deals with transactions between two companies, whereas business-to-customer commerce deals with the transactions between a company and the end user. These are similar, but there are several fundamental differences. In business-to-business commerce:

1. The volume of goods and money transacted is very large
2. The buyer could be very powerful and larger than the seller
3. The seller should be able to meet the requirements of rapid changes in product design
4. The transactions happen directly without intermediate marketing channels.

5. Information transfer is more critical and rewarding upstream of the supply chain; purchasing or procurement is a common process that occurs between businesses

6. Logistics is an important subprocess and consists of a set of activities to acquire goods and services.

Cost reductions in the ODP will have a tremendous impact on the profitability of both businesses

There is a rich body of literature on procurement practices in industries in general and in the auto industry in particular. Womack [99] identifies two kinds of relationships between suppliers and manufacturers in the auto industry. The Western practice is an arm's-length adversial relationship, whereas the Japanese OEMs work together with their suppliers and share design, production scheduling, and quality information with them. The recent global trend is to deal with fewer numbers of suppliers and work together with them towards a common goal of giving higher levels of service to the end users. The ODP and procurement are now recognized as a very important interorganizational interface processes. Smoothing these interfaces will give benefit to the entire supply chain. The performance measures–total cost, lead time, delivery reliability, defect rates– play a big role in determining the supply chain competitiveness. The material in this chapter is a typical way of studying the interorganizational interface processes.

Fundamentally, one should distinguish between the supply chain process (SCP) and the ODP. We study the SCP in chapter 8. The SCP is formed out of an ordered chain of interactions among several organizations. The ODP receives the customer orders, negotiates a price, procures the products, and delivers to the end users and collects money. One can classify ODPs into three types:

1. An ODP between two businesses. An SCP has several such ODPs as interorganizational subprocesses embedded within.

2. An ODP between the supply chain and the end user. Here, orders generated by the distributors or retailers are filled by the supply chain network. The SCP follows either make-to-order, make-to-stock, or assemble-to-order, depending on the velocity of product movements and the requirements of the customers. The ODP between mail-order stores such as amazon.com or Dell computers and the end user is also of this category. These stores either maintain inventory or have an arrangement with several distributors and manufacturers to supply the items.

3. There are special type of products such as aircraft, guns, and other warfare equipment, which are directly negotiated, ordered, and supplied to the end-user customer. In this case, the SCP and ODP are not independent but highly interacting.

Now we provide a description of a typical ODP.

2. DESCRIPTION OF AN ODP

In this section, first we provide a description of the ODP, and then bring out some issues involved in its monitoring and control. The ODP consists of six steps, starting from accepting the orders through order configuration, sourcing the order, monitoring the order, and finally billing and cashing. It cuts across several organizations, such as credit bureaus, logistics, distributors, the order processing organization and its finance accounts, sales and marketing functions. We will describe below a generic ODP [35]. The flow chart for an ODP is given in Figure 7.2.

1. Accept orders: Customers choose many ordering methods. Most companies accept orders through traditional means such as sales representatives, fax, mail, the Internet, direct market, EDI, or telemarketing channels. The order information should be visible to all stakeholders. One important issue in this step is order selection and prioritization. All orders need not be accepted, and not all customers are equal. We note that generally 80% of the orders come from 20% of the customers for 20% of the products. These customers should be treated as "sweet spots" and given priority. In this step, we have four tasks:

- Order receipt: The order is received, documented, acknowledged and transmitted for further processing.

- Order selection: The orders are prioritized for delivery based on factors such as the special nature of a relationship with a customer, as in the case of vendor managed inventories; premium price paid by the customer; and the availability of the input components and materials.

- Credit check: In this step, past customers are checked for default and new customers are checked for credit rating. A rule-based expert system can suggest credit limits, and any exceptions that arise can be handled manually.

- Order confirmation: In this step, the customer is informed of the time and place of delivery as well as the price. He is also informed of the schedule of delivery. This involves

- Checking warehouse inventory and its allocation to orders and back orders in all locations and determining if the current order can be met from nearby warehouses
- Checking the production orders in various plants
- Making a decision on how the items in the order are shipped to the customer
- Estimating the cost and time
- Interacting with the customer on cost, delivery date and site planning if it involves equipment installation, etc.
- Confirming the order, price, and delivery date and time to the customer

Depending on the type of business, the above process may take a few minutes (see Figure 7.1), as in the case of ordering books from amazon.com or a PC from Dell computers, to a few days where information has to be obtained and integrated from several sources, as illustrated in Figure 7.2.

2. **Configure order:** This step consists of

- Identifying the complete list of products and services that are contained in the order
- Planning and sourcing each product and service in the order
- Scheduling synchronized delivery of each of the items with availability of service personnel and transport as well as the convenience of the customer (see Figure 7.2).

3. **Source the order:** Here, the most effective way to satisfy the customer order is worked out. If the order can be met from a nearby warehouse, then all activities relating to picking and packing are initiated. If the delivery time allows, orders may be sourced from a nearby manufacturing assembly plant, bypassing the local distribution. In this case, the order is included in the production schedule. If the plant doesn't have preassembled subassemblies, then these are sourced from suppliers, assembled, and sent directly to the customer. If the order requires some design changes, then the product design and engineering departments are contacted. Figure 7.3 shows these four options and the time frames entailed. Quick response manufacturing, partnership with suppliers, and safety stocks are the key to effective and efficient delivery schedules.

4. **Order delivery:** This final step in the ODP involves

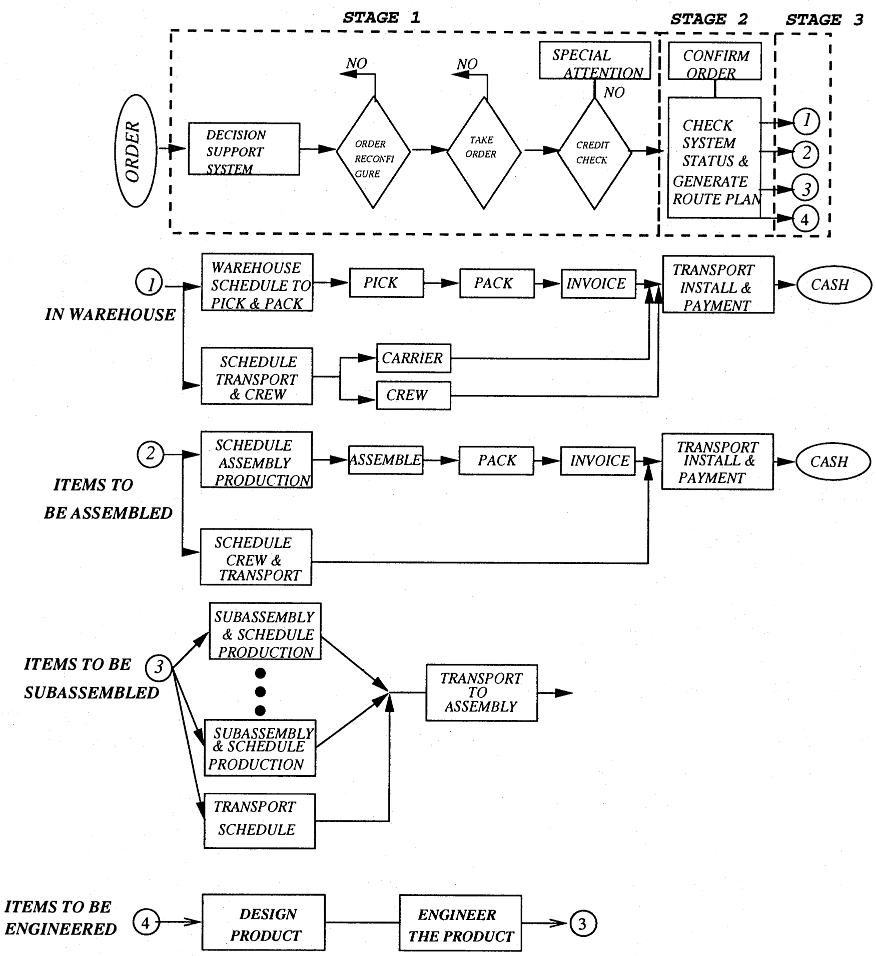

Figure 7.2. Order-to-delivery flow

- Making plans for a coordinated delivery process of the product to the customer
- Communicating the customer's order execution plan to all stakeholders responsible for shipping a product or providing a service such as transportation, installation or customer training. (planning for transportation can start before shipment is ready)
- Removing traditional interfaces, if possible, will reduce lead time.
  - Order management can directly initiate the picking and packing operation, bypassing order entry

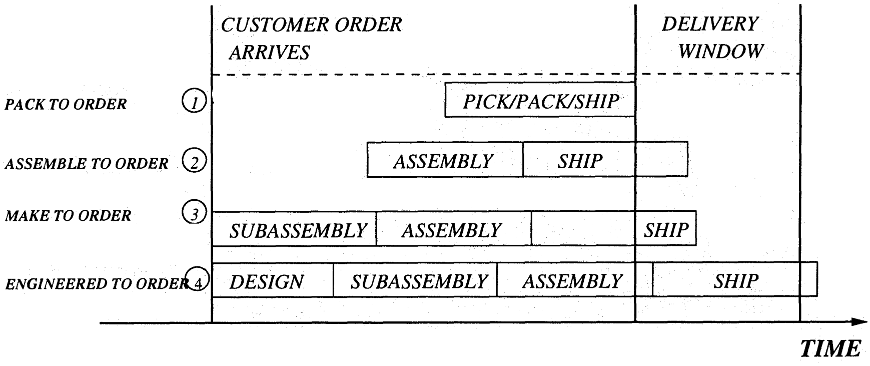

Figure 7.3. Time windows for the four options

- A product can be directly shipped to a customer from the dock, bypassing stocking and picking

- Transportation and service operations can be scheduled directly

5. Order monitoring: As in project management, the progress of the order is monitored and the actual progress is compared with the anticipated progress. The signals of completion or failure are sent at each stage to appropriate entities, which automatically assess the progress of delivery to the customer.

If the delivery to the customer runs into problems, the impact of these problems can be assessed and new actions can be planned. Also, since ODP management tracks all paper, message, and product movements, root-cause analysis of failures can be conducted and sources of problems can be removed.

6. Billing and cashing: Invoices are certified after installation of equipment and after payment has been authorized to the customer's accounts payable, which transfer funds via EFT to the company's accounts receivable.

We have described above the ODP in a typical manufacturing enterprise. Our description includes intelligent decision making by converting available raw data into information (by analyzing the orders to conduct the root-cause analysis of defects in the ODP, etc.) This kind of analysis would help in achieving an integrated order processing process of six-sigma quality.

2.1 MONITORING AND CONTROL OF THE ODP

The description of the ODP in Figure 7.2 can be automated in order to achieve rapid cycle times and highly reliable delivery to the customer. For the purpose of our description here, we assume that all stakeholders are under computer control and are all connected for placing and processing of the orders. We propose here that the ODP controller monitor, control, and track orders. This controller has adequate information processing capabilities and is equipped with decision support tools. We assume that the document transfer is through EDI and that funds transfer is done through EFT.

ODP controller: The following are typical functions of a generic ODP controller starting from the arrival of an order (Figure 7.4).

1. The order arrives at the ODP controller and is checked for customer status, creditworthiness, configurability, delivery deadline, customer status etc. The idea is to accept only high-yielding orders and to prioritize them.

2. The controller decision support system has status information on the availability of the items in the warehouse, the production scheduling of the assembly and subassemblies, and also the pick and pack schedule at the warehouse. The order route plan is made and cost and time are estimated. The cost, delivery time, and date are confirmed to the customer.

3. If the item is in the warehouse, the warehouse controller is signaled to schedule, pick, and pack and also inform the relevant controllers of the schedule. An invoice is transmitted to the service crew to deliver to the customer along with the goods. At each stage, warehouse, transport, and other involved controllers update the event in their computers and communicate to the ODP controller.

4. If the item has to be assembled, the assembly is signaled to schedule assembly based on due-date and customer priority. Transport and service crew are simultaneously scheduled. The order is packed and delivered as in (3). The warehouse is bypassed in this case. Similarly, if the order has to be met by ordering the subassemblies, then the process follows as shown in the flow graph (Figure 7.2).

Figure 7.3 shows the delivery time under four availability conditions: (1) item available in the warehouse, (2) item to be assembled, (3) item made to order, and (4) item engineered to order.

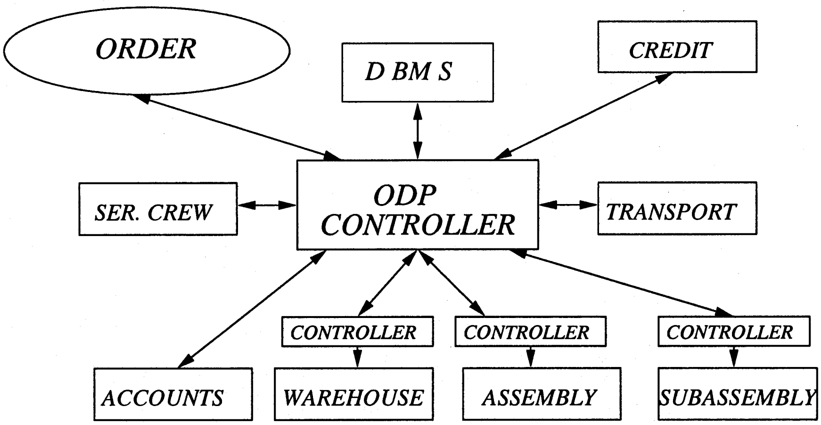

Figure 7.4. ODP controller

3. LOGISTICS

We see from Figure 7.1 that every transaction in an ODP, except the final delivery, happens electronically. In the case of digital products such as software, text, audio, music, and video products, all transactions including the product delivery could be electronic. Thus, logistics is important in the final delivery to the customer in the case of physical products and physically packaged digital products. This involves packaging, warehousing, transporting, installing, and maintenance of the semifinished and finished products. Several companies around the world use logistics to their strategic advantage. Wal-Mart is one well-known examples. Logistics companies such as Federal Express and UPS are taking over the procurement, warehousing, and retailing functions, apart from product delivery.

The Council of Logistical Management defines *logistics* as the broad range of activities concerned with effective movement of finished products from the end of the production line to the consumer and in some cases to include the movement of raw materials from the source of supply to the beginning of the production line. These activities include freight transportation, warehousing, material handling, protective packaging, inventory control, plant and warehouse location, order processing, marketing, forecasting, and customer service.

Logistical activities are generally dispersed throughout the firm: order processing and facilities planning under finance; purchasing, warehousing of raw materials and finished goods, and production scheduling under manufacturing; forecasting and customer service under marketing; etc. The main goal of the logistics function is to ensure the availability of the right product at the right place, in the right quantities and the right condition at the right time and the right cost for the right customer. It is important to note that coordination of a chain of activities across different organizations and functions is needed to integrate the material flow. Advances in the information technology area are helping this process of integration, as we discussed earlier.

Logistics could be provided by either the seller or the buyer or by a third party. More specifically, a tier I supplier may have a contract to deliver components directly to the factory floor of the manufacturer, or a manufacturer may have a contract to have a batch of parts ready for pickup. Alternatively, a third-party logistics provider may supply the interface and transport the parts from suppliers to the manufacturer.

Third-party logistics: Third-party logistics is the use of an outside company, a transportation carrier, a warehouse, or a third-party freight manager to perform all or part of a company's material management or product distribution functions. There are several reasons for this trend, the principal ones being

- globalization of sourcing, manufacturing, and distribution leading to global manufacturing and the consequent increase in the complexity of material movement

- competition that forced companies towards more product offerings, more responsiveness, a reduction in inventories and safety stock, and the increased need for small but frequent shipments with 100% reliability, requiring core competence in logistics management

- resource constraints that enable companies to concentrate only on their core manufacturing or new product development activities.

Many firms are now entering into alliance with logistics providers, as is the case with vendors and customers. This change has led many firms to greatly reduce the number of carriers they do business with and to increase the involvement of the carriers in planning shipments by sharing information.

3.1 INFORMATION SYSTEMS IN LOGISTICS

Information is pivotal in a relationship. The logistics contractor needs information about future product flows, capacity and special equipment needed, and likely destinations. The distribution or manufacturer needs information as to how the product is handled, performance measurements such as delivery reliability, process deviations, and root causes. Use of barcode and EDI technologies, computerized order processing, and appropriate data communication methods has made possible information sharing in a secure way.

Logistics companies are using IT to gain competitive advantage. They enhance the quality of service offered through broad applications of several information-based technologies.

1. Barcoding and scanning allow companies to selectively track and report on shipment status 24 hours a day, seven days per week, simply by calling a toll-free number.

2. Truck drivers carry computer clipboards that utilize digital pen-based technology to sequence routes and collect delivery information. The clipboard allows the driver to digitally record the shipment recipient's signature to provide receipt verification. The computerized clipboard coordinates driver information, reduces errors, and speeds up delivery.

3. The national wireless communication network and the cellular phone technology allows drivers to transmit real-time tracking information from their trucks to the company central computers. Wireless mobile technology and system support from company data center enable the company to provide electronic data storage and retrieval to track the company's millions of daily deliveries around the globe.

3.2 ECONOMIC ISSUES

Compared to all forms of surface transport, the outstanding benefits of air freighting goods include faster and reliable transit time. Because of its high cost, air freight has found favor with only high-value goods. The introduction of containers meeting the requirements of both air and surface transport has given impetus to true intermodal freight transport. The automated loading and unloading facilities, customs clearance procedures, and procedures in the freight delivery process ultimately decide the door-to-door delivery time.

While evaluating the mode of transport, attention is generally focused on pure transport cost only. As we have said several times before, a realistic evaluation of the alternatives should be based on total process cost, including packaging, handling, transportation, insurance, and import duties. The biggest cost reduction comes from reduced leadtime, which reduces the stock in transit as well as inventory and safety stocks at the seller's and buyer's end. Furthermore, interest on the capital (which is invested in the stock), opportunity cost, and costs of obsolescence and deterioration are also reduced.

In most logistics systems, a considerable amount of goods will be moving in transport vehicles, flowing through terminals and distribution centers. For example, in a pipeline, oil flows through thousands of miles of four-foot-diameter pipes all the time. In a similar way, the logistics pipeline should be full before the first product is available at the end of the logistics channel. Suppose in a distribution system, raw material transport to the factory takes 14 days; transport from the factory to its warehouse takes 2 days; consolidation within the warehouse takes 4 days; transport from the factory warehouse to distribution takes 7 days ; consolidation within the distribution warehouse takes another 2 days; transit to and consolidation in the retailer warehouse takes 7 days; transit to retailer shops and consolidation in shops takes 3 days. Then the total pipe length is 39 days. The stock-in-transit as described above exists in all industries, and this is called inventory-in-motion.

One can develop a relationship between the savings in inventory costs and the excess cost of airfreight. Let T_i = Transportation unit cost for mode i (\$/ton); V = Annual Volume shipped (\$/year); I_i = Average inventory cost when mode i is used; and C = cost of carrying unit inventory; then we have $(T_F - T_S)V = (I_S - I_F)C$, where F and S represent the fast and slow modes, respectively.This would give a linear relationship between $(T_F - T_S)$ and $(I_S - I_F)$. One can also try to find the mix of fast and slow modes that gives the total cost and minimum cost.

The average inventory carried is the sum of three components: pipeline inventory and inventory holdings at the buyers' end and at the sellers' end. Suppose the mean lead time of the sea transport of an item is 12 weeks, with a variability of 3 weeks. Suppose the company switches to a multimodal (land + sea) system, whereby the mean and variability dropped to 7 weeks, with a variability of 1 week. How many days inventory is saved? At the buyers' end, for a more than 98% service level, the inventory kept is [mean lead time + 2 x (standard deviation of lead time)]. The same amount of inventory will also be present in transit. The seller keeps psychologically as much as he ships. Thus one can approximately assume that the inventory at the buyers' end = 12 + 2 x 2 = 14 days. Further, the total inventory is 42 days. However, in case of the (sea + land) mode alternative, only 27 days of inventory need to be kept. Thus 15 days inventory is saved by switching to the multimodal alternative.

4. INFORMATION SHARING IN AN ODP AND BEST PRACTICES

In any industry, information is actually the vital commodity for exchange between partners, and it also represents a large percentage of the cost structure. In the health care industry, for example, the patient records, diagnostic test results, physician notes, and insurance claims form 30% of the total health care costs. There is a tremendous amount of information flow between the stakeholders of every process, whether it is the supply chain, new product development, or the order-to-delivery or strategy formulation. If one can reduce the information asymmetry between manufacturers and suppliers in the automobile, telecommunication, food, etc. industry segments then substantial cost reductions are possible.

In today's global business arena, competition is marked by volatile demand, decreased customer loyalty, shorter product life cycles, and mass customization. It is important for businesses to gather vital information and to act quickly on it. When a number of companies are in alliance, as in a manufacturing enterprise, there is a need for collecting accurate, comprehensive and timely information and sharing with the partners. This will enable the partners to make decisions based on global information that benefits the entire process. More fundamentally, information is the glue that binds together all the businesses in the enterprise, and it must be shared appropriately. Trust is very crucial in a networked organization, as we mentioned in chapter 3. And we assume that trust exists among the stakeholders. A variety of information-sharing patterns are practiced in the industry. These vary between the two extremes of sharing no information and sharing all relevant information. These patterns are marketed as best practices in the industry circles and include vendor-managed inventories, quick response manufacturing, supplier scheduling, JIT purchasing, JIT II, and efficient consumer response. Basically, these are information-sharing patterns among two or more partners in a value delivery process. In this section, we basically describe the best practices as well as the information systems that enable these best practices. Accordingly, this section is organized as follows:

1. Vendor managed inventories

2. Supplier scheduling

3. JIT purchasing and JIT II

4. Interorganizational information systems

4.1 VENDOR-MANAGED INVENTORIES

In the competitive manufacturing world today, tremendous competitive advantage is available to companies who think radically, particularly in networking, partnerships, and information sharing. The new technologies such as the intranets, extranets, and the Internet offer speed advantages and remarkable opportunities for organizational synthesis and working together. In business-to-business commerce, the customer company is the reason for the existence of the supplier. Similarly, the end user is the ultimate reason for the existence of the entire supply chain. Thus, realization of common purpose and shared destiny is the prime motivation for businesses to link their information systems that contain the forecasts and schedules for mutual advantage. Exchange of information provides both companies with visibility into the future activities of all the stakeholders, enabling planning of economic production of the goods. This vision makes it possible to avoid large inventories, rush orders, expediting, rescheduling, and supplier switching, which normally result in a lot of waste. Initiatives such as quick response, efficient customer response, and vendor-managed inventories are such cyberlinking strategies between organizations.

Generally sellers make a forecast of the buyer's requirements. This prediction is based on a history of the customer's previous orders. But the buyer has more information on hand: balance of inventory, possible design changes in the offing, planned new products, and finally, the history of its own customer-ordering patterns and the anticipated demand. Some buyer companies may have weekly requirements of the subassemblies from each supplier. How wonderful it would be if all this information were shared with the seller company. With such information, the seller can make more accurate forecasts and can make predictable deliveries at possibly lower cost. The buyer company is certainly running a risk in sharing this information. A quantitative assessment of the risk and benefits of information sharing is needed prior to the partnership agreement.

In vendor-managed replenishment, the seller (supplier) manages the sales forecast and the replenishment functions for the buyer. In many cases, the buyer is a distributor or retailer or a manufacturer. The buyer transmits each day an EDI transaction that contains the current balance for each stockkeeping unit on hand and the total shipment quantity from the seller. The shipment quantity is the amount predicted by the forecasting software to meet future demands. The seller company does a forecast updating for each stockkeeping unit at each VMI location, taking into account any promotional events, unexpected demands/downturns, etc. A replenishment calculation is made and released to the order inventory system. The orders are picked, packed, and shipped to the buyer. An EDI transaction is sent to the customer that tells him or her what is coming. The buyer, upon receiving the order confirmation, creates his or her own purchase order against which goods are received. What is described above is a VMI system operating a reorder point system that triggers a replenishment order based on forecast and on-hand stock. The VMI based on a reorder point system has no visibility beyond the current order cycle and automates only the ordering system. VMI planning systems, on the other hand, provide visibility into the future, typically into a planning horizon of several weeks. If a supplier is catering to the needs of a number of manufacturers, then the pooled forecast for an item is more accurate than the accuracy of individual forecasts. If one can see the customer's demand pattern, then one can plan for it. Thus, the VMI planning system can reduce the total cost of procurement.

Vendor-managed inventories are also called *continuous replenishment programs* (CRPs), where the product flows at the buyer and seller ends are matched. This means that the inflow should equal outflow. One has to be careful not to ignore the increased logistics cost due to frequent delivery schedules. Most sellers will be servicing both VMI customers and traditional purchase orders. In case of conflict, the sellers should realize that VMI customers need the replenishment, whereas traditional customers order to stock up the inventory.

Customer-managed replenishment (CMR): Here the customer, instead of supplying only the raw data, shares the forecasting and schedule information with the seller. The seller collects similar information from other customer companies and determines the planned replenishments using the distribution resource planning logic.

Future companies, whether buyers or sellers, have to cope with multiple information-sharing patterns to make the production forecasts. These include (1) raw sales data from point of sale terminals of customers with whom VMI agreements are in operation, (2) forecast and replenishment data supplied by CMR customers, and (3) traditional purchase orders. Demand management is crucial for survival and customer retention.

4.2 SUPPLIER SCHEDULING

An important aspect of partnership between the buyer and the seller is the sharing of the scheduling information. The supplier schedule is a document that gives the suppliers the information about what the buyers need and when, where, and how much. This schedule provides itemwise weekly requirements for several weeks into the future. These are typically valid schedules generated by the MRP of the buyer. This seems straightforward at first, but what is actually done in practice is to give the supplier the replenishment dates to stock up the inventory [78].

The buyer is generally a manufacturing company and is expected to have its own schedule for various products. The material requirements generated by MRP are used for building up inventories for a 3—4-week production. The suppliers are often asked to supply just-in-time to replenish the inventory. The suppliers have their own forecasting regarding the requirements of the buyers (see Figure 2.12). By providing a valid material plan to the suppliers, buyers can insist on reliable deliveries of quality products to their factory floor. Basically, the buyer shares his production schedules for the next several weeks, and sometimes months into the future, with his suppliers. With this information, the supplier is in a better position to plan, and the buyer need not issue purchase orders. The supplier schedules are updated periodically as the target delivery date approaches. Typically, the commitment from the buyer is divided into three phases. There is a committed zone of 3—4 weeks before delivery, where details of the product and delivery times are frozen. The next zone, the agreement zone, is a window where the supplier allows some changes in the delivery quantities and in the product mix. Here the supplier can procure raw material and also make capacity acquisitions. Beyond the agreement zone is the planning zone, where information is supplied with no commitment.

The benefits of supplier scheduling include low inventories, low prices, shorter lead times, and less freight costs. These result from the information and visibility into the buyer's actions. Also, there is a possible freight cost reduction. In a typical purchase process, the unbound freight cost can run up to one fifth of the total costs. With supplier scheduling, the carriers can be given visibility into the freight, and rates can be negotiated based on future plans. The buyer can pool the shipments from various suppliers in the region and negotiate a pooled freight rate.

Since the buyer is now telling the supplier the need dates, not the due dates, the performance of the supplier is critical for the continuance of production at the customer's end. It is important to have a performance monitoring system in place to monitor the supplier scheduling process. Two measures–delivery reliability and quality– need to be monitored effectively.

Delivery: If the supplier does not deliver on time, the production will stop. Some buyers even tell the time of day the shipment is wanted. Reliable delivery is critical to MRP II. Since the supplier schedule is based on need dates, almost 100% reliability should be guaranteed. The delivery time is monitored using control charts, as in Figure 5.7.

Quality: Out-of-specification components actually stop production, and hence it is important that the supplier's process generates products of acceptable quality. It does not do the buyer any good if bad components are delivered on time or good components are supplied late. The buyer should write down well-defined specifications of each component and effectively communicate them to the suppliers. Also, an audit of the production process of the supplier by the buyer's team and suggestions for changes would prevent low-quality deliveries.

4.3 JIT PURCHASING

JIT purchasing involves the purchase of materials such that the delivery precedes demand or use. In the extreme case, no inventories are held. Arguments in favor of JIT purchasing include inventory and obsolescence costs. Some organizations follow daily delivery practices for as many products as possible. In the disk drive industry, for example, the PCBs are delivered to the assembly floor directly by the supplier, and other items procured globally arrive by air freight. The assembled and tested disk drives leave for customer destinations the day they are certified by inspection. The justification for JIT purchasing comes from the total cost of procurement rather than unit price, as we have illustrated using several examples in chapter 4.

JIT II: JIT production and inventory control systems were invented and perfected by Toyota Motors. The concept of JIT II [78] was developed by Bose Corporation as a time-saving, cost-cutting approach. It is a partnership based on high trust. The supplier representative is present at Bose, participates in product design meetings, and is even empowered to fill in purchase orders on behalf of Bose. Coupled with EDI and other IT tools, JIT II offers significant cost advantages. The advantage for suppliers is that they get an ever green contract with no bidding. Such optimal and mutually beneficial systems can be put in practice only when organizations first develop mutual trust.

4.4 INTERORGANIZATIONAL INFORMATION SYSTEMS

Interorganizational information systems (IOISs) are computer communication networks for sharing data and information between partners in an enterprise. Traditionally, proprietary IOISs have provided a competitive advantage in applications such as airline reservations and hospital inventory management. Recent developments in the Internet, intranets, extranets, and the World-Wide-Web have immense possibilities for sharing information reliably and securely among partners. It is now possible to transfer funds securely over the network. Netscape and IBM are two companies devoted to e-business, which is trading over the Internet.

The Internet is a network of computer networks that provides global access to organizations, individuals, and information sources. An Internet connection, using a relatively inexpensive PC, will enable the user to communicate with others on the network and also to conduct organized searches on specific topics. The Internet offers a cost-effective and secure way of sharing information among partners in a supply chain. Intranets are networks internal to an organization that use web browsers, system software and protocols. Intranets are a cost-effective means for sharing information within an organization. Extranets are interconnections of networks of intranets of stakeholders.

Electronic Data Interchange (EDI) is a tool to exchange business data between organizations in a machine-processable format. A purchase order is generated on the buyer's machine and is transmitted to the seller's order processing system. Postal delays and data rekeying errors are all eliminated. EDI standards have evolved over time. The communication is either through dedicated lines or through a third-party valued network (VAN). In the latter case, the seller or buyer sends electronic messages to the VAN, which sorts the messages and stores them in a designated mail box periodically accessed by the user. All participating parties are connected to the VAN in a star network. Encryption and authentication are also provided by the VANs. Encryption is a method of coding data to ensure secrecy as the data moves between the trading partners. Authentication is a method of identifying the sender and ensuring that the data are not changed during the transmission. Several companies have adopted EDI, but for small companies cost is the major issue–the EDI audit cost, setup cost, and then the operating cost. Internet-based EDI is becoming very popular since it is relatively cheaper than the VAN-based EDI.

The Automotive Network eXchange (ANX), the most visible of the new wave of business-to-business virtual private networks (VPNs) running over the Internet, promises to provide the network infrastructure to cut costs by billions of dollars and change the way the automotive supply chain does business. In most cases, suppliers typically must maintain multiple connections, based on different underlying communications protocols in support of particular application needs. This places a heavy burden on trading partners because each protocol and every connection adds incremental support tasks for systems personnel.

There is clearly a growing need for trading partners to move towards a generic, permanent network infrastructure service that supports all applications. For example, for EDI to function, there must be a network for transporting the information among trading partners or the automotive enterprise. ANX does just that. It provides a common, standards-based global TCP/IP network service to meet the datacommunications needs of the automotive industry's applications. Using the ANX, each automotive supplier and OEM will need only a single TCP/IP data transport connection to communicate globally with all trading partners. The goal is to provide a level of performance, reliability, and security and management that is not available on the public Internet. Similarly, grocery companies are trying to form food exchanges, and textile manufacturers have formed AMTEX, the American textile partnership.

Information systems enable the process orientation and process-based control systems. They are essential to smooth the interfaces, cut down the costs and improve delivery reliability. They provide all the stakeholders with the information needed for effective decision making. For example, a supply chain process derives its competitive advantage because of sharing of information with its partners on demand forecasts, point of sale data, production schedules, logistics plans, market trends, etc. Thus the only uncertainty is the market uncertainty, which is beyond the control of the supply chain owners. At the ultimate level of process integration, all decision makers (see Figure 2.7) at the organization level, functional level, and the work process level are provided with the information they need at the time they need it and in a readily usable format. For example, as we noted earlier in the case of the procurement process or ODP, the exchange of point of sale data and production schedules has led to industry best practices of VMI, ECR, and so on. Figure 7.6 shows a typical information-sharing pattern between suppliers and manufacturers.

Benefits of information sharing: Vast amount of data are generated in the business environment, and it would be desirable to identify and share relevant information among the partners. Seidmann and Sundararajan [28] identified four levels of information exchange.

1. Order information exchange: Companies exchange the reorder point and the order quantities, inventory levels, sales data, and prices using EDI. This approach is supposed to reduce the inventory levels.

2. Operational information sharing: This kind of information exchange happens in VMI. The buyer shares the aggregate inventory position with the seller, and this enables the seller to better manage the inventory of his or her products at the buyer's site. Cost savings are likely

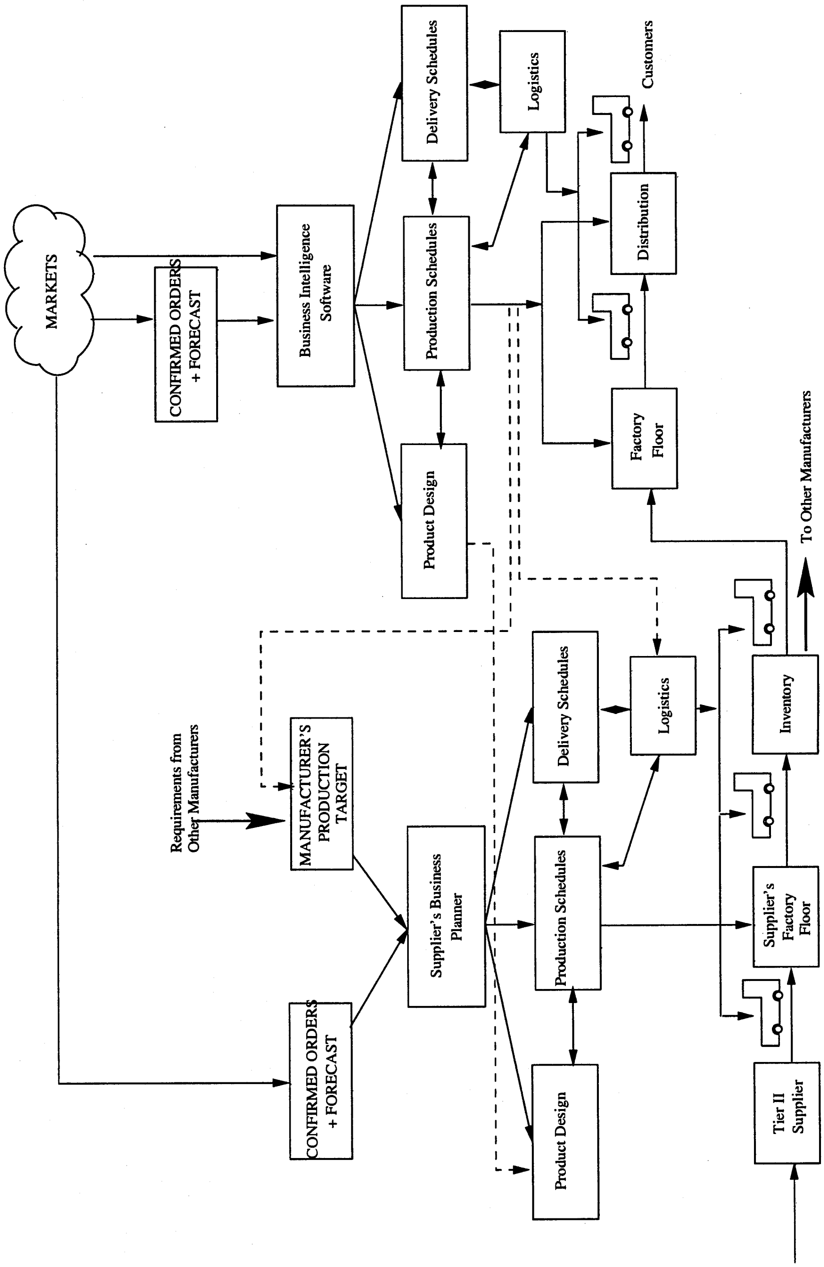

Figure 7.5. Interorganizational information system

to occur because the seller (1) has experience in managing the inventory of the product he manufactures, (2) has knowledge and control of the production schedules for the product, and (3) can exploit the economies of scale by having VMI arrangements with a number of buyers.

3. Strategic information sharing: A supplier can make a superior demand forecast by analyzing point of sale information from a number of retailers. A manufacturer can share the production scheduling information with his first-tier suppliers. This kind of information sharing is done extensively in efficient consumer response and quick response initiatives. Since inventory position can be easily derived from the point of sale data, the VMI type of operational information sharing is included as a special case. With point of sale data, the supplier has the price and the customer information and this puts the buyer at a disadvantage while negotiating the price terms of supply.
4. Competitive information: Here one supplier is given by the buyer access to all information regarding all the products, including those manufactured by the rival suppliers. This information provides competitive benefits to the suppliers.

Whenever information is shared between two parties, the party supplying information is running a risk. When a retailer provides point of sale data to the supplier, then the retailer is running a risk of a shift in bargaining power. In addition, the supplier gains strategically from better forecasts. The retailer has to evaluate the gains of the suppliers and get price advantages through appropriate contracts.

5. PERFORMANCE MEASURES OF AN ODP

As we mentioned before, the ODP is the most important customer-facing process, and to that extent, all issues connected with customer satisfaction are important. These include customer service, lead time, cost, and flexibility.

5.1 CUSTOMER SERVICE

The power of customer service as a potential means of differentiation is increasingly being recognized. Increasing competition and easy availability of substitutes have diminished the power of the brand name. Differences between competing products are difficult to perceive, and customers are influenced by price and ready availability. This can be seen in the PC and the consumer electronics markets. Customers are more demanding than they were earlier. In industrial purchasing situations, customers expect vendors to be on an intranet, use sophisticated IT and electronic commerce tools, possess factory floors with automated machine tools, obtain ISO certification and follow variability reduction techniques, and have logistical capabilities to supply the right quantities directly to the factory floor on a daily basis. No product or service has value unless the customer is able to use it in the way he or she was expecting to use it and to benefit from it.

Definition: *Customer service* is defined as the set of activities involved in timely and accurate delivery of products, invoices, and any other items necessary to use the product in a fashion perceived as excellent.

The important elements of customer service include

- Delivery reliability and consistency
- Delivery service frequency
- Single point of contact
- Price and quality
- After-sales service

The objective of a customer service strategy is to enhance customer retention by creating such a high-level of customer satisfaction that the customer would not even think of switching to another supplier. Suppliers should see that all transactions are profitable to the customer: on-time deliveries will reduce customer's safety stocks, frequent deliveries will reduce the inventory levels, EDI will reduce paperwork and lead time, and so on. Thus it is clear that an effective supply chain is vital for creating competitive advantage.

There is a cost–benefit trade-off for service. Improved levels of service could cost more, and this increase should be justified by increasing returns on sales. A typical cost–service trade-off curve looks like the one shown in Figure 7.7. Minimum levels of service are expected for a sale, and profits are maximum for certain service levels.

Some of the primary costs involved are material, packaging, marketing and sales, overhead and indirect costs, and costs of transportation, warehousing, inventory, and after-sales servicing. Increased incremental customer service levels typically result in increased sales through goodwill, convenience, and product availability, but at rising costs. Optimum service levels therefore balance the cost of increased service levels with increased sales revenues.

Prioritizing the customers: While all customers should receive the level of service they desire, it is important to prioritize them. Not all customers are equally profitable, and also not all products are equally

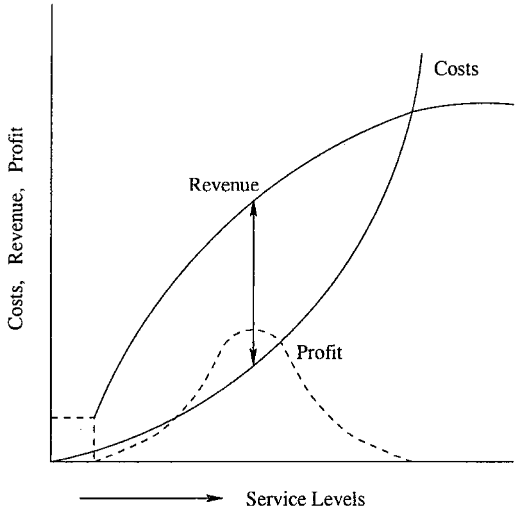

Figure 7.6. Trade-off between service levels and costs

profitable. The 80/20 rule (Pareto rule) can be applied to get a general idea of where to spend the money. The Pareto rule says that 80% of the orders come from 20% of the customers and for 20% of the products. Thus 64% of the business comes from 20% of customer orders for 20% of products, i.e., 4% of all customer–product transactions. Key customers ordering key products should get superior levels of service. One should review the less profitable customers and less profitable orders. Some low-profit items may have to be supported to provide full-line service to core customers (See [11].

Measures of customer service: The goal of an ODP is to supply to the customer with the right product, at the right time, at the right price, in right quantities. Some customer service measures could be defined to determine whether this goal is effectively met. These include

Order cycle time: Elapsed time from ODP is the order cycle time. It is directly related to the inventory and its location: at the customer site or at the manufacturer's site or at the logistics partner's headquarters. Maintaining inventory at the customer's factory in anticipation of demand is an expensive way to do business.

Delivery reliability: The proportion of orders delivered on time (as per the customer's definition of on-time; next hour, day, week, etc.) is termed *delivery reliability.*

Order completeness: The proportion of orders supplied as per the purchase order, with no part shipments or back orders.

Order fill rate: The proportion of orders delivered accurately on time. One can see that the order fill rate is the product of delivery reliability and order completeness. A company can identify products that are critical and identify fill rates based on customer requirements.

Frequency of delivery: Number of deliveries within a specified time window.

Order-size constraints: The flexibility to cope with small orders or, equivalently, with a large number of deliveries in small quantities.

It is clear that delivery reliability and order completeness have to be carefully monitored. Any deviations from targeted values should be investigated for probable causes using cause–effect diagrams.

The importance of customer service can be better studied by looking at the impact of service failure on the customer. Non-availability of a specific component may force a plant to shut down, and the profit impact of such a failure could be significant. At times, a week's delay in replenishing a particular product in a warehouse may not have any impact at all. In either case, speedy and consistent delivery of items is expected by the customer. In fact, customers want consistency first and then improvement in delivery speed. Also, customers expect the supply chain to be flexible in accommodating unexpected requests such as rush orders, changes in the order, etc. Besides this, consistency in deliveries has to be maintained despite malfunctions in supply chain constituents: inaccurate documentation, incorrect assortments, damaged products, supplier failures, manufacturer's problems on his shop floor, etc. An analysis of the failures using fish bone diagrams, fault trees, etc. and finding mechanisms to create fault-tolerance in the supply chain are an active area of concern.

5.2 ODP LEAD TIME

The time interval from the instant a customer places an order until the instant the product is delivered is the lead time of an ODP. It is a very important factor to gain competitive advantage. It is also well known that low lead times will result in low costs, high quality, and customer delight. This is because lead time reduction is obtained by removing all non-value-adding activities and improving the variability of the value-adding activities. The lead time depends on the state of the system when the order reaches it. We see in Figure 7.3.that the system can be in four states: pack to order, assemble to order, make to order, and design to order. The lead time is the shortest in the first case and longest in the fourth case. There is a lead time–cost trade-off of inventory and obsolescence in keeping items in stock. One way companies overcome this problem is to divide their products into three types of orders: orders with customization, where the lead time is bound to be greater; standard orders for repetitive products for alliance partners; and standard products that are assembled to order with little customization. In the case of alliance partners, the agreements spell out when and where the product is to be supplied. Depending on the mix of order types, companies have to tune the ODP.

It is important to keep the lead time minimum while maintaining low cost and high quality in the presence of demand uncertainties and competition. Also, errors in order processing, product design, production, delivery, and installation need to be kept to a minimum. All these errors eventually show up as defects in the ODP. To minimize the lead time, the steps to be taken are essentially the same as for lead time reduction in the NPDP. These include

- Following error-free procedures for order taking and also for product configuration: use of EDI and product configuration expert systems are steps in this direction
- Developing good rapport with customers and understanding their requirements to reduce the late changes in orders as well as rush orders
- Use of information technology tools such as EDI, EFT, decision support systems, secure intranets, and the Internet to reduce paper-processing delays and errors and also to speed up the operations
- Forming strategic alliances and following best practices such as VMI

Logistics is a very important part of the delivery process. Error-free packing, transport, delivery, installation and billing are important. Wrong deliveries, partial deliveries, and damaged or delayed deliveries create enormous amount of customer dissatisfaction. Companies generally prefer third-party logistics providers that have facilities such as inventory management, Internet goods tracking, wireless communications, and a world-wide presence.

There are many examples of world-class ODPs. Dell computers and amazon.com use Internet ordering and credit card services to sell PCs and books. Their ODP is very similar to the one shown in Figure 7.1.

In earlier chapters we presented numerical examples to compute the mean lead time and also its variability. One can develop discrete event models such as Markov chains, Petri nets, and queuing networks to study performance and also to compute the lead time.

5.3 ODP COSTS

An ODP described above includes all activities from the instant customer places an order until the product is delivered to the customer. The ODP costs include

- Order processing costs: Accepting, configuring, and sourcing the customer order takes time and effort.
- Logistics costs: These are basically the costs involved in delivering the product to the customer and installing it for use. Transportation, installation, damage insurance, site preparation, and after-sales service are all included here.
- Infrastructure costs: The ODP management requires manpower, computer and communication equipment, databases, expert systems software, etc. Warehousing of finished goods and maintenance are additional infrastructure costs.
- Stock-out costs: A stock-out arises when a customer demand is not met immediately. A company may respond by expediting the order with associated costs. Alternatively, the company may lose the sale, generating customer ill-will.
- Quality costs: These are the costs of conformance with preannounced standards for the product, such as warranties, maintenance, etc.

Companies that have embraced just-in-time manufacturing and total quality control realize that suppliers should be chosen not on the basis of quoted price but rather on the basis of total cost, which includes the above costs. We deal with supplier rating and other cost-related issues in the next few examples.

5.4 EXAMPLES

Example 7.1: The economic order quantity (EOQ) model in its simplest form minimizes the total relevant cost (cost of ordering and carrying cost). It assumes that the same fixed quantity is ordered in each period and that the order lead time is constant and known. Let

EOQ = economic order quantity
D = Demand for a specific time period
C_e = Cost of carrying one unit over the specific time period
C_o = Ordering cost per purchase order

TRC = Total relevant costs

Then

$$TRC = \frac{DC_o}{Q} + \frac{QC_e}{2} \quad (7.1)$$

One can find the EOQ from the above expression as

$$EOQ = \sqrt{\frac{2DC_o}{C_e}} \quad (7.2)$$

Suppose D = 10000, C_o = 40, and C_e = 5; then we have EOQ = 400. Also TRC = 2000. The number of deliveries is given by 10000/400 = 25.

This model can be extended to include several features, such as bulk discounts, transportation costs, and distances.

Example 7.2: Suppose unit cost and carrying costs are not affected by the ordering quantity Q. One can ask that the order quantity be delivered in installments. Then the order costs remain the same at DC_o/Q, but the inventory holding costs are reduced by a factor n. Thus,

$$TRC = \frac{DC_o}{Q} + \frac{QC_e}{2n} \quad (7.3)$$

One can find the new EOQ, $Q^* = \sqrt{n}Q$. Also, $TRC^* = TRC/n$. Suppose in the above problem, the order quantity of 400 is delivered in 4 installments. Then we have Q^* = 800, which is split into 4 equal deliveries of 200 each. Total cost is now $1000.

Example 7.3: Suppose the purchase price of an integrated circuit (IC) is $2.50. The total overhead costs (warehousing, inspection, insurance, handling and transportation) is $0.67. Testing and warranty costs sum up to $0.53, and after-sale maintenance is $1.06. Then the total cost of ownership of the product is $4.76.

The above example says that if the IC is in good condition, then its cost is $2.50, but if it is in bad condition, then the cost is $4.76.

Example 7.4 : Some companies define a supplier performance index as the ratio of the sum of nonconformance costs and purchase price to the purchase price. Suppose the purchase price of goods purchased per month is $25,000. Three types of nonconformance costs are identified: cost of returns, cost of undershipment, and cost of late deliveries. On average, there are 2 returns, 5 undershipments, and 3 late deliveries in a month. The returns cost $300 per item, each undershipment costs $1750, and each late delivery costs $500. Thus on the average

Non-conformance costs = 2 x 300 + 5 x 350 + 3 x 500 = $ 3850

The supplier performance index (SPI) is given by SPI = 28,850/25,000= 1.154. The SPI is used to rank order the bids received from the suppliers. The quoted unit price is multiplied by SPI, and that amount is treated as the total cost of procurement.

Example 7.5: A company has an annual demand of 10,000 units of a particular component. It is considering two suppliers, A and B, to procure these components. The details are as follows:

Company A: The quoted cost per unit is $21. The cost of stock-out is $4 per unit which is essentially the cost of rush ordering. The company on average experiences about 5 stock-outs in a month. Annual stock-out cost = 5 x 12 x 4 = $240.

Company B: The quoted cost per unit is $20. The company is new, the production schedule is not stabilized, and quality control procedures are not yet in place. The components are to be inspected. The cost of inspection is $0.05 per unit and there could be as many as 25 stock-outs per month. On average, each stock-out costs about $10 per unit. A poor-quality unit may also result in the return of the final product by the customer. Each return costs $100 for handling and repair. Customers are likely to return 1% of the sold products. Thus we have

Annual stock-out cost = 25 x 12 x 10 = $3000
Customer return cost = 10,000 x 100 x 0.01 = $ 10,000

The carrying costs are $2 per unit per year for both companies A and B. An average inventory of 500 units is carried throughout the year by both companies.
We find that the total cost of company A is $ 2,11,240 and that of company B is $ 2,14,500 although company B's unit price is higher.

5.5 ODP FLEXIBILITY

We have seen in chapter 4 that volume, mix, and routing flexibilities are important in the context of process flexibility. We now consider the flexibilities connected with the ODP.

Definition: An ODP is *volume flexible* if a number of customer orders with different product mixes and volume levels can be simultaneously processed for rapid delivery.

Mix, routing, and delivery time flexibilities of an ODP can be similarly defined. Notice that volume flexibility of the ODP requires flexible order processing and a flexible SCP with flexible manufacturing, logistics chain, marketing channels, etc. Also all these subsystems need not be within the boundary of a single firm; they could be a part of a supplier–manufacturer–distributor value chain. For example, a catalog store has an ODP that is mix and volume flexible if it can reliably coordinate with the supply chains of its supplier companies. Similarly a car dealer is mix flexible if he or she can arrange for delivery of any customer-desired car as quickly as possible. An ODP is routing flexible if it has redundant suppliers, manufacturers, distribution, etc. in various locations. Table 7.2 gives some measures of the flexibility for an ODP.

6. CONCLUSIONS

In this chapter, we have considered the order-to-delivery process and its characteristics. We also have brought out very clearly the influence of information technology on both business-to-business commerce and the business-to-customer commerce. We have discussed current practices such as vendor-managed inventories, continuous replenishment, JIT II, and supplier scheduling. There are several radical developments in this area with the exploding use of the the Internet for marketing, business communications, order processing and for funds and document trans-

Table 7.1. Flexibility measures for an ODP

Type	**Measures**
Mix flexibility	• Number of different products that can be supplied • Optimistic changeover times and costs among different products (function of scheduling)
Volume flexibility	• Stability of cost of delivery over varying levels of production volumes • Smallest profitable volumes of operation
Routing flexibility	• Average number of ways in which a product can be ordered, manufactured, and delivered • Average delay due to subsystem failures

fer. One can expect very exciting developments in this area in the very near future. We have also discussed performance measures, particularly customer service and lead time. The lead time and its variability will determine the amount of inventory in the system. A customer is also interested in reliable delivery. Developing mathematical models for ODPs is a good area for future research.

7. BIBLIOGRAPHIC NOTES

Our presentation on the ODP does not have a single source in the literature. The logistics discussion in section 7.3 is a coherent presentation from various sources. There are several textbooks on logistics including [5], [11], and [61]. Section 7.4 on best practices in ODP is collected from Internet and textbook sources [65],[97]. The performance measures section follows chapter 4 with an emphasis on lead time, cost, and flexibility.

Chapter 8

SUPPLY CHAIN PROCESS MANAGEMENT

Learning objectives

1 Describe the supply chain process (SCP) and bring out important issues such as hierarchy, product flow, and integration.

2 Discuss the configuration of the SCP, location of facilities and identify automation and IT issues in the SCP.

3 Discover effective means of supply chain management in partnering, combined product–SCP design, and information system design.

4 Discuss important performance measures: customer service, cost, lead time, variation, flexibility, and asset utilization.

5 Discuss performance measurement and benchmarking in supply chains.

6 Discuss the organization structure suitable for supply chain management.

1. INTRODUCTION

The integrated supply chain is one of the primary interfunctional, interorganizational processes of a manufacturing company. The mission of a supply chain is to deliver customer-desired products at the right time and place, in right quantities, at the lowest cost, and faster than the competition. It is no longer enough to produce good products; they

N. Viswanadham, *Analysis of Manufacturing Enterprises*

need to be delivered to the customers with other benefits that add value to the product.

Traditionally, supply chain management is considered equivalent to inventory management at various places along the chain: suppliers, manufacturing, distributors, and retailers. But with shorter product life cycles (now measured in months instead of years) and consequent proliferation of new products, the rate and costs of obsolescence have become very high. Further, customers expect small-lot deliveries at greater frequencies at point of use, packaged for ease of use. These changes have left companies no option other than to manufacture products at high speed and to make them available at the time the customer needs them.

Recent advances in information and manufacturing process technologies have significantly influenced the way supply chains function. The stakeholders of the supply chain are connected electronically via intranets and extranets and have linked databases. Customer orders are received and processed electronically, and funds are also transferred electronically. Automated material handling systems, storage-retrieval systems, and other computer-controlled equipment make possible quicker deliveries. Advances in telecommunications have made possible virtual co-location of suppliers, manufacturers, distributors, and other partners in the supply chain.

The proximity to the customer has put enormous power into distribution channels, and there is a definite shift of balance of power towards the distributors. Also, a global supply chain can span several countries, and logistics plays an important role in various stages of the supply chain. Overall, there are multiple stakeholders in the supply chain, and all of them have to work together to make the chain competitive. Supply chain management means managing the entire chain of activities—purchasing, production, distribution, marketing, and sales—as though it were one entity. All decisions of the functions are made for the effective and efficient functioning of the chain, rather than from an individual function perspective. In this chapter, we provide an overview of the various business processes in the supply chain, study the performance measures and consider the organization structure with regard to effective management. There are a large variety of supply chain configurations depending on the product structure, local or global sourcing, manufacturing, and marketing strategies. There are food supply chains, chains for electronic goods, networks for make-to-order supply of aircrafts or high-rise buildings, and pipeline structures (e.g. the production and distribution of petroleum products).

We organize this chapter as follows. In section 8.2, we define and describe the supply chain process (SCP) and also consider issues such as

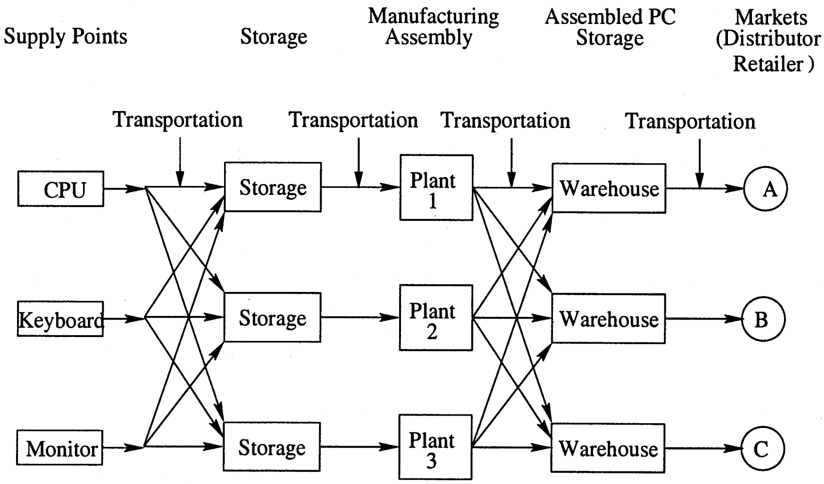

Figure 8.1. The supply chain as an integrated network of suppliers, manufacturers, and distributors

product flow, virtual integration, and streamlining in supply chains. We briefly consider the strategic, tactical, and operational issues in supply chains in section 8.3. In section 8.4, we describe the subprocesses of the SCP such as manufacturing, logistics, etc. Effective management of SCPs is an important issue. We discuss four important topics in section 8.5 , namely, production control policies, interfaces between supply chain partners, integrated product–SCP design, and the information systems. In section 8.6, we deal with the important performance measures of a SCP. sections 8.7 and 8.8 deal with benchmarking and organization structures, respectively.

2. SUPPLY CHAIN FUNDAMENTALS

Figure 8.1 shows the constituents of the supply chain network of a personal computer. The SCP integrates several organizational subprocesses of a company: supplier, assembler, distribution, retailer, and customer delivery. In many companies, each of these facilities is located in a different geographical location. In many others, two or more of them are co-located.

Definition: A supply chain process (SCP) is an integrated or coordinated network of value delivery processes that procure raw materials, transform them into final products and deliver the products, to the customers.

As we mentioned before, an SCP encompasses the full range of intracompany and intercompany activities, including raw materials procure-

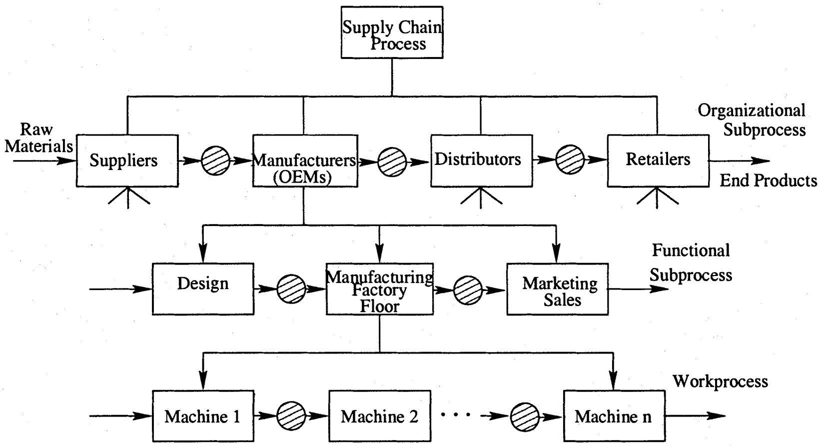

Figure 8.2. The supply chain process hierarchy

ment from suppliers, manufacturing, distribution, and after-sales service. For example, a manufacturer of shirts is a part of the supply chain that extends upstream through weavers of fabrics to the fiber manufacturers and downstream through distributors and retailers and finally to the customer. Similarly, a disk drive manufacturer in Singapore is a part of the supply chain that extends from manufacture of ICs, small motors, and PCBs to the delivery of PCs to customers in Europe. Virtually all high-tech products have international or global supply chains. Also most companies are members of multiple supply chains. Each company procures from several suppliers and sells multiple products to multiple customers.

In Figure 8.2, we decompose an SCP into its constituent organizational subprocesses, functional subprocesses, and work processes. We have also highlighted the interfaces between various subprocesses in this figure.

The second row in Figure 8.2 shows various organizations in the supply chain and the interfaces between them. These interface processes basically include the procurement process of the upstream member, the delivery process of the downstream member, and the logistical processes. The third row shows the decomposition of each organization into its functions, divisions, etc. The next row shows further decomposition of the functions into work processes, and the second and third levels together represent the internal supply chains of an organization. These could themselves be very large and complex, with the ubiquitous problems of turf wars and limited communication.

Figure 8.2 has a very interesting interpretation in terms of the interfaces. At the lowest workprocess level, the interfaces are well structured and understood. Factory automation and office automation are used to streamline these interfaces. Automated material handling and local area networks provide the material flow and information flow integration. At the functional subprocess level, the interfaces between design, manufacturing, and marketing are smoothed out using the principles of design for manufacturing (DFM), design for assembly (DFA), and marketing–manufacturing cross-functional teams. At the highest level, i.e. the organization subprocess level, the principles of supplier management and partnering are used to smooth the interfaces between suppliers and OEMs and between manufacturing and distributors respectively. Thus Figure 8.2 succinctly describes the interface smoothing practices in manufacturing enterprises. We note that the suppliers and distribution can be similarly partitioned into functional and work process levels.

The recent developments in the supply chain management area are a natural outgrowth of process improvement efforts such as total quality management, quick response manufacturing, time-based competition, and business process reengineering. Developments in electronic data interchange, electronic funds transfer, and barcode technology have helped to streamline SCPs as well as cash management functions.

One can view Figure 8.2 as a descriptive hierarchical model of the SCP. Basically, each organization has three components: the input interface process (called the procurement process), the production process, and the output interface process (called the delivery process). With this interpretation, the analysis of the SCP can be conducted. For example, the lead time of the SCP, is sum of the lead times for each organization and the interface elements. This is shown in Figure 8.3.

A well-managed SCP need not be vertically integrated. Vertically integrated firms own suppliers, transport systems, distribution, and retail channels. Although such ownership was considered desirable in previous decades, now increasingly organizations are focusing on their core businesses, outsourcing everything else. In an SCP, the integration and coordination of information and material flows from a multitude of suppliers (often offshore), manufacturers, and distribution channels is managed through virtual integration. The goal of an SCP however, is to achieve the economy and efficiency of vertical integration.

2.1 PRODUCT FLOW IN A TYPICAL SUPPLY CHAIN

A typical supply chain functions in the following way. As shown in Figure 2.12, the distribution centers (DCs) collect customer demands

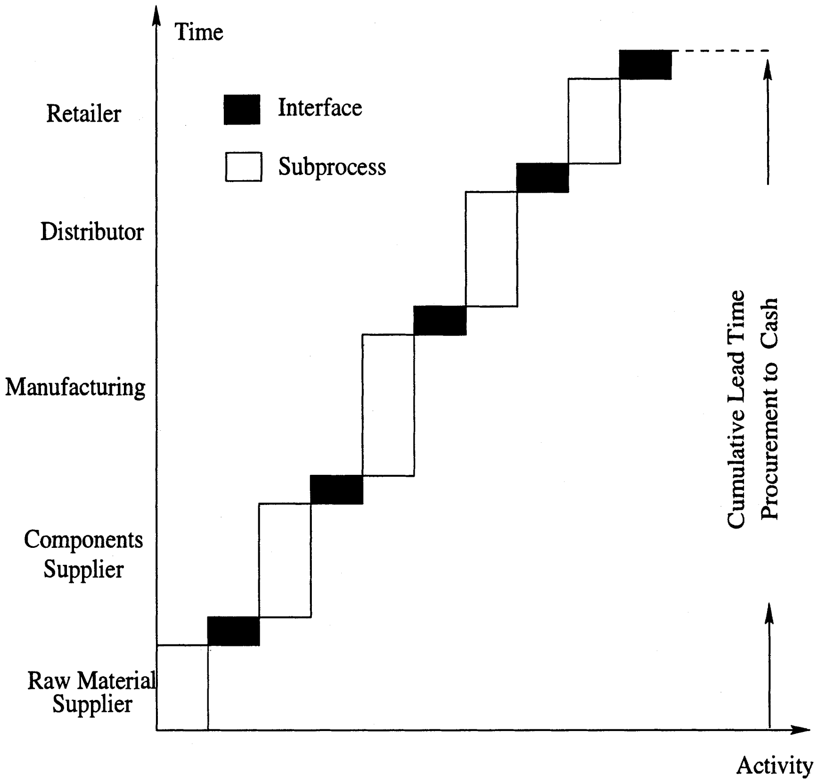

Figure 8.3. Lead time in the supply chain process

and forecast plans and use this information to project the replenishments needed from the manufacturing plants for several time periods into the future. The manufacturers consolidate the projections from several DCs and schedule their production during the next few periods of time. Once the master production schedule (MPS) is developed, time schedules for receiving the raw materials and components are developed. Dates for receipt of materials, logistics requirements, and dates for shipping out of materials are also worked out based on the lead times and inventory levels.

Inventories exist throughout the network in the form of raw materials, components, work-in-process, and finished goods. They exist as in-transit or pipeline inventories or in distribution centers. The reasons for holding inventories are uncertainties in demand; batching and balancing economics; the time required for processing a batch, for transportation, and for line balancing in the presence of bottlenecks and varying lead times; speculative stocks for promotions; unexpected demands; etc. The right amount of inventory at each place acts as a lubricant, but excess inventory could get the supply chain into trouble. In a fully integrated supply chain, the causes that create the need for inventories are eliminated. Opportunities lie at the interorganizational and interfunctional interfaces, and by smoothing them, much can be gained. Information sharing, combined forecasting and scheduling, and low setup times in production and transportation are some of the practices followed by leading companies to achieve the integration.

2.2 VIRTUAL INTEGRATION

In an integrated supply chain, the partner company sees itself as a part of a seamless pipe that achieves customer satisfaction while maximizing supply chain profits and minimizing the cycle time. World-class companies do not seek to achieve cost reductions or profit improvements by transferring costs (particularly inventory costs) upstream or downstream. They are aware that ultimately all costs make their way to the end user. Real competition in the years to come, will not be one particular company against another but will be process based, i.e., it will be one value delivery process against a similar process. For example, it will be one SCP vs. another SCP, one NPD vs. another NPD,etc.

Figure 4.9 shows the margins (price–cost) and interface costs at each stage of the supply chain. Some elements of the supply chain give higher margins than others. This analysis could also be used for integrating forward or backward along the SCP to increase the margins available to the company. This figure also illustrates the simple fact that to be a low-cost producer, costs must be cut all along the chain. Pushing the costs upstream or downstream will not alter the final cost to the customer. Figure 8.4 shows the cumulative lead time from procurement to cash in a supply chain network. Integration across the supply chain reduces an individual firm's risk by spreading the investment, leveraging information against inventory, and pooling expertise. The investment can take the form of manufacturing capabilities, product transportation, marketing, and handling of the products. Members can pool expertise and information to drive the costs down. The process can be formed by selecting retailers with access to new markets, communicating point-of-sale and production information to reduce inventory levels, etc. Further, each member of the process can concentrate and contribute to a specific area of its own core competence.

2.3 STREAMLINING THE SUPPLY CHAIN

There is tremendous scope for taking both time and cost out of the SCP. Eliminating the interface times spent in negotiations, inspection, packing, repacking, reconciliation, etc., one can reduce the total lead time and hence the cost. Use of EDI and barcode technologies will speed up the document transfer, eliminate data rekeying and improve processing accuracy. Further, a comprehensive costing methodology will enable supply chain members to understand the costing patterns and to identify areas for cost reduction.

By now it should be clear that the SCP which spans different organizations and their functional departments, is a fertile ground for process improvement by targeting interface issues and non-value-adding activities. Transport subprocesses are another black hole in the supply chain. Goods normally disappear at the factory site and reappear at customs. In the meantime, no one knows whether they are on the truck, at the warehouse, or on a dock. EDI can improve this situation dramatically. EDI messages indicate when the vehicle left the supplier, when it arrived at the port and cleared customs, and any unexpected delay. There are other means of updating information, including GPS, wireless networks, intranets, and so on. Material transfer between the vendor and buyer is the only time-consuming activity; all others can happen at electronic speeds. The transfer of all documents and cash can be done electronically using the communications network (see Figure 7.1).

2.4 COMPETITIVE ADVANTAGE

Successful companies seek both productivity and value advantages through a well-managed SCP. Productivity enhancement occurs through better capacity utilization, inventory reduction, closer integration with suppliers and distributors, removal of non-value-adding activities, and performance measurement and control. Superior customer service could be achieved through effective supply chain practices such as on-time deliveries, financial packages, technical support, and after-sales support. Thus twin peaks of excellence, the cost and value advantages, could both be achieved through effective management of the SCP.

The SCP management traditionally has been efficient inventory management. Perfect customer service is considered expensive. This traditional outlook has changed, and now supply chains are well coordinated and integrated across organizations and their functional areas. The notion of perfect order [17] is gaining ground in industries wherein the SCP is managed so as to have zero defects. Also, value-added services, which differentiate one SCP from another, are different from a zero-defect SCP.

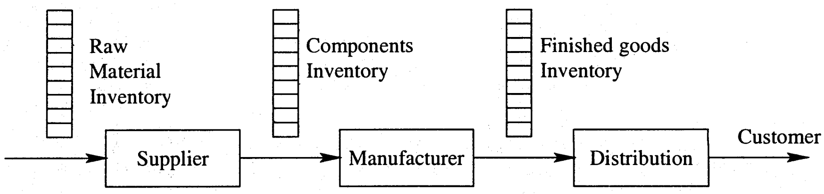

Figure 8.4a. Functions acting as silos separated by inventories

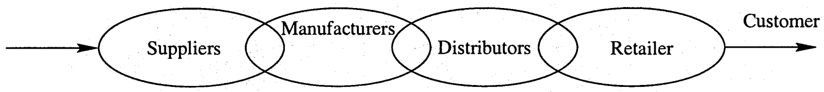

Figure 8.4b. Fully integrated supply chain

A zero-defect SCP basically delivers the right product, at the right time, at the right place, in right quantities, to the right customer. Value-added services are provided in addition to the basic product (including zero defect delivery) to delight customers. Such services include price marking, special packaging, home delivery, frequent deliveries, maintaining an inventory of spare parts, etc. These will create value uniqueness and distinctiveness of service, thus helping to differentiate the product from that of the competitors.

Further, most companies are functionally organized and optimized. Integration of all relevant functions as an end-to-end value delivery process and further integration of this process with the appropriate business processes of the suppliers and distribution will lead to an integrated SCP. Achieving total supply chain integration requires a lot of hard work in terms of simplifying the network process by removing all non-value-adding activities, using the new technologies, smoothing out the interfaces with the suppliers and customers, and a host of other challenges. Figures 8.4a and 8.4b show the extremes.

3. DECISION MAKING IN THE SUPPLY CHAIN WORLD

Decision making in the SCP is very complex because a large number of organizations are involved and several alternative routes are possible to fulfill an order. A supply chain has several facilities in different geographic locations, producing different products and serving different customers by supplying them with the required variety and lot sizes at the time and place they specify. Thus modern-day supply chains need to solve a five-dimensional decision problem: *When, Where, What and How Much to produce, and for Whom.* This problem is in contrast to the one dimensional decision problem of mass production systems: how to keep the production going. The supply chain problem is further complicated because all the stakeholders are autonomous and may not share the information, whereas most mass production enterprises are vertically integrated and information is centralized. In chapter 7, we have discussed several possible information-sharing patterns among the supply chain partners.

Here, we are concerned with identifying the strategic, tactical, and operational decisions in supply chain networks. The strategic decisions are long-term and are often one-time decisions. They determine the competitiveness of the supply chain. These include partner selection, strategic alliances, location of facilities, technology choices and outsourcing decisions. Which products to produce and for what markets are also strategic issues. At the tactical level, the time horizon is weeks or months. Demand forecasting, resource allocation, routing of the orders along the supply chain, subcontracting, scheduling production onto the supply chain facilities, load leveling, and bottleneck scheduling are all issues at this level. The operational-level decisions include order processing, production matters, fleet scheduling, inspection, and delivery, to mention a few. These are basically day-to-day decisions. The questions that are addressed at this level include which customer order is to be filled, how to react to breakdown of a truck carrying items to a customer, the disruption of the supply of subassemblies from a supplier due to labor problems, etc. Effective supply chain management involves addressing issues at all the three levels simultaneously.

Sources of uncertainty: Basically, all decisions made in the supply chain world have to counter some kind of uncertainty. It is known that retail product stock-outs in the industry occur at an average rate of 8%. In other words, for every 100 customers going to a store to buy a specific product, about 8 will not find the item they wish to purchase because it is not in stock. The traditional answer to customer service problems has been to increase inventories. Unfortunately, inventory bears a high cost in terms of capital consumption and expense: it is known that inventory costs form one third of total sales. To understand the opportunities for dramatically reducing inventories, it is worthwhile to examine the drivers of inventory.

The inventory is more significantly impacted by the uncertain demand. The more unpredictable the demand is, the more inventory is required to manage the risk. Another potential source of problems for inventory management is the uncertainty of supply processes. Supply variability drives inventory at both the beginning and the end of supply chain nodes. There can be several reasons for its occurrence at each node of the supply chain. One of the most common reasons at the input stage of a supply chain node is suppliers failing to deliver what is ordered. At the output stage of a supply chain node, inventory depends on production cycle time. It is fairly common for output inventories to be equal to the node process cycle times multiplied by the supply chain throughput. Coordinated planning of supply processes reduces multiple sources of supply variability and the inventory it drives.

Planning and forecasting have made steady and significant improvements over the last several years. Data content and quality have improved, and the understanding of their importance and value has also increased. The use of collaborative planning, forecasting and replenishment can minimize inventories, and supply chain participants can focus on value-added process activities. By focusing on the flow of supply to consumers, without the clouding effect of inventory, participants can discover previously hidden bottlenecks in the flow and address them. In turn, taking care of these now-visible inefficiencies can reduce process costs. Collaborative relationships across the supply chain can be more efficient, more cost-effective, and more successful in satisfying consumers than adversarial practices.

4. CONFIGURATION OF THE SUPPLY CHAIN PROCESS

As discussed earlier, the SCP is an ordered collection of activities performed at facilities geographically dispersed (across continents in the case of global manufacturing networks), each performing a value-added function to the product in its journey towards the customer. Proper coordination of all the subprocesses performed at these facilities will ensure a smooth flow of material and information along the supply chain. Coordination includes organization structure and decision making and performance measurement and control.

Configuration of the SCP (see Figure 8.5), particularly the location of various facilities, is an important strategic decision. Locating manufacturing facilities offshore is a common strategy followed by most companies, the main consideration being cheap labor costs. It is, however, important to take into account the impact of such decisions on product delivery times, logistics costs, and cross-functional integration such as that between design and manufacturing, etc. In this section, we consider some of these issues.

Partnering considerations: The enterprise integrator frequently has to decide whether to make a product or perform a service internally or partner with another company. This is the classic make-versus-buy decision. Historically, the trade-off centered around economic issues.

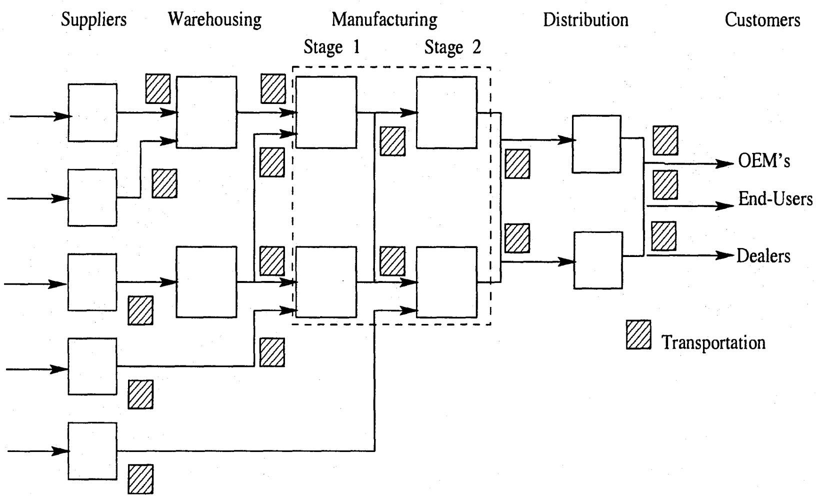

Figure 8.5. Supply chain configuration: facilities

Recently, however, attention has also focused on strategic issues. For example, when an enterprise evaluates the alternatives of establishing a private trucking fleet or outsourcing to for-hire carriers, cost is not the only consideration. Strategic vision and long-term trends need to be considered. Some service providers may have special capabilities that differentiate them from their competitors. Examples include the parcel tracking capabilities of Federal Express, and the satellite tracking service of Schneider National Inc., which can locate any truck; these are difficult-to-duplicate capabilities developed by these companies over the years. The outsourcing or partnering decision must center around capabilities provided or achieved. If the capabilities achieved by performing activities internally does not extend an enterprise's core capabilities, then such activities should be outsourced.

4.1 FACILITY LOCATION

Here, we are concerned with the location, size, and organization of various supply chain facilities, such as manufacturing plants, distribution centers, and procurement and service offices. It is necessary to design the supply chain network while taking into account such tangible factors as total cost, closeness to the customer, and delivery times, as well as intangible factors such as synergy between design and manufacturing, complexity in planning and scheduling, information lag, etc. Figure 8.6 shows the factors that need consideration in determining the capacity of

Suppliers	Logistics	Manufacturing	Distribution
• Number of vendors per product • Capacity allocated • Location	• Number, location, size, and capacity of warehouses • In-house fleet/ contract carriers • Modes of transportation	• Plant location(s) • Single flexible plant or staged mfg or several dedicated mfg plants • Capacities	• Location, size, and capacity of distribution centers and architecture • Retailer's locations

Figure 8.6. Structural features in the supply chain process

the supply chain: manufacturing, suppliers, transport, and warehousing. We also show in Figure 8.7 the information, material handling, and automation technologies useful for the SCP.

Some of the location decisions are straightforward. Computer companies locate assembly plants in the Far East because major suppliers of terminals, printed circuit boards, computer chips, and keyboards are located there. Several manufacturers locate manufacturing plants in Ireland and distribution centers in Germany, Belgium, and Netherlands because of the proximity to key European customers. Sometimes it is cheaper to ship components and subassemblies over long distances than to ship finished products. This fact is made use of in the facility location decisions.

Location of facilities in several countries will certainly increase the complexity of coordination, scheduling, transportation, and in-transit inventory. Uncertain lead times will increase the inventory levels. Political uncertainties and differences in culture further exacerbate the problems. Separation of design, manufacturing, and marketing will increase the time to market and will increase the costs of making design, demand, and order changes. These comments are true even though advances in information technology such as video conferencing have greatly improved matters. But such tools, as of today, present opportunities for only structured interaction. A factory worker in Singapore cannot have an informal interaction with a counterpart in Germany.

International supply chains carry with them two additional risks: political and exchange rate risks. Political risk requires close appraisal and can range from minimal to extreme. Exchange rates have become volatile. People are following multiple site manufacturing strategies, but

Suppliers	Logistics	Manufacturing	Distribution
• EDI links • Equipment capabilities • Point-of-sale information tracking • Raw material cost control, quality control and delivery charges	• Carrier tracking • Automated storage systems • Communications : Intranet/ Internet • Loading/ unloading technologies • Material handling technologies • Raw material and in-transit inventory tracking • Freight monitoring • Warehouse management systems • Information management • Distribution resource planning (DRP) • EDI links • Freight monitoring	• Materials technology • CAD • FMS/FMC technologies • Material handling • Group technology • Manufacturing, planning, and control systems (MRP II) • Shop floor control • Information and communication technologies	• EDI links • Distribution management systems • IT • Integration of distribution centers with plants and customer • Returns and root-cause analysis • Order processing • Customer tracking • Order entry and order-taking technologies

Figure 8.7. Automation and information technologies in the supply chain process

there is a trade-off between loss of economies of scale in small plants and the exchange risk hedging through multiple locations.

Manufacturing facilities: The supply chain architecture depends on the product and process technologies, customer location, and the size of customer orders. There are several reasons to locate of manufacturing facilities in various countries, including taking advantage of cheap labor and infrastructure facilities, government subsidies, tax relief, etc., and also to gain access to local markets (thus meeting government regulations) and technologies.

Manufacturing facilities could be organized as several small focused factories dispersed geographically or as one large flexible factory producing several products. Also, manufacturing could be done in a single stage from raw materials to components to subassemblies to assemblies. It could also be done in multiple stages by locating various factories for various stages in various countries. Multistage manufacturing is common in PC and semiconductor manufacturing.

The ability of the SCP to serve several product markets through a single network is an example of economies of scope. The main contributor to variety production is the manufacturing plant. A collection of small production facilities producing a limited variety of products and distributing locally is an example of decentralized or focused supply chains. Large production networks catering to international markets are another extreme.

Several important decisions regarding the number of stages of the manufacturing activity and the customization stage at which the product is earmarked for the customer (at the labeling stage, packaging stage, assembly stage, subassembly stage, etc.) can profoundly influence the supply chain architecture. To analyze these decisions, one can build cost and cycle time models for various stages along the supply chain and determine the total cost and cycle time. Such an analysis would also help to identify strategic issues, such as a number of focused factories vs. one large flexible factory, at What stages in the product life cycle to split the manufacturing activity, trade-offs associated with postponing the order penetration point to later stages in manufacturing, etc.

Distribution: Distribution often implies inventories of finished products delivered from a factory to the distribution center and then to the customers. The distribution centers could be of several types: one consolidated center with full service for order taking and inventory holding, several regional centers interconnected by high-speed transport and communication facilities, or a center with several satellites. Some distribution centers act as final customization points where the final assembly of such things as power supplies and power cards is done, thus efficiently managing the product variety.

An emerging trend is to couple very closely all supply chain elements, in particular the production and distribution. Some companies use the data from the cash registers in a chain store to drive the production schedule of the manufacturer.

Transportation: The facilities for international, long-distance, and short-distance transport and their capacities must be determined. Air, rail, truck, water, and pipeline are different modes of transport with different economic characteristics. Loading and unloading facilities; communication facilities onboard vehicles to receive telephone, fax, Internet, and EDI messages; and alliances between transport, distribution, and production partners are important issues. Further, changes in production strategies are driving major changes in transportation.

- The emergence of production methods such as JIT and FMS has created need for a flexible, fast, individually tailored transport systems that can economically perform large shipments of small sizes with high delivery reliability. Frequently, the delivery is to the next customer, where the next operation on the product takes place.

- There is a shift towards international sourcing of materials which has created a need for international transport systems.

- The drive for increased customization, modular designs of production, and staged manufacturing has increased the need for high-speed transportation of small quantities. There is a shift towards air and road transportation from rail and water transportation.

- Environmental consciousness is growing all overeverywhere.

- Garment manufacturers and also certain superstores allot floor space to product manufacturers for managing the inventory. Here the distinction between different companies and different functions within a company disappears and the objectives of supply chain effectiveness and customer service take priority.

Delivery within the window of time specified by the customer is rated as the most important service quality. Some manufacturers locate suppliers close to final assembly, simplifying the logistics process. Other solutions include

- Pooling services so that a truck picks up subassemblies from various suppliers and delivers to the customer

- Suppliers shipping to a central point subassemblies destined for several customers, which are then collected by the manufacturer

- Using buffer inventories located near the manufacturer

- Using small shipment carriers

Transit time determines pipeline inventory, and its variability determines the buffer or safety stock necessary. Large transit times also reduce the ability to respond quickly to the market and thus the effectiveness of the SCP. Flexibility options of choosing air, sea, rail, and road transport, direct supply, or distribution are often used to reduce lead times.

5. EFFECTIVE SUPPLY CHAIN MANAGEMENT

As we have said before, the supply chain cuts across several organizations, each of which has multiple functional units that need to be coordinated for faster delivery. Most SCPs are not systematically designed and have evolved over time through additions and alterations. To that extent, there exists a tremendous opportunity for orders-of-magnitude gains if the SCP is streamlined by removing all non-value-adding links, by redesigning intra- and interorganizational processes using new technologies such as EDI, and EFT, and finally by redefining the interorganizational relationships as a shared destiny of all collaborators. We consider all these issues in this section.

5.1 PRODUCTION CONTROL POLICIES

An important ingredient of supply chain specification is the supply chain planning and control methodology . Any order for an end product triggers a series of work processes in the supply chain that must be completed so that the end customer order is satisfied. The flow of information and material in the supply chain is controlled by the this planning and control system and generally falls into three broad categories:

1. **Make-to-stock**: Here, the end-customer products are satisfied from stacks of inventory of finished goods that are kept at various retail points of the SCP. The decisions regarding the amount of finished goods inventory and the component inventories that are held at various intermediate stocking locations, are made according to an integrated plan for the SCP. The plan specifies who has to build (manufacture) which subassembly or components, and at what point of time. Here, the manufacturer pushes the product into markets without direct regard for the customer orders. Forecasting is a crucial step in such an approach. Make-to-stock control requires that there be a feedback of demand information from the customer to his immediate supplier. Thus, there is a possibility of information distortion when the customer wants to hedge against risk and *forward buys*, resulting in what is known in the literature as the bullwhip effect or the Forrester effect.

   In the context of the supply chain, it is possible that while the manufacturer produces goods to stock, his supplier may be following, say, a make-to-order policy (see below). Thus alliances and information sharing become crucial drivers of supply chain performance in terms of the performance measures discussed earlier. Practices like vendor-managed inventories are increasingly being embraced by health care and other industries, in order to reduce inventory costs.

2. **Make-to-order**: In this planning and control method, it is the *confirmed* customer orders that trigger the flow of materials and information in the supply chain. Each customer order may be unique in terms of manufacturing, procuring, packaging, or logistics requirements. There is very little or no inventory maintained of finished

goods or components. This technique requires that the facilities of the SCP should be mix flexible in order to reduce the setup costs when that facility switches from one product type to another. Important issues in such a SCP include setting due dates and release dates for orders, scheduling various orders so as to minimize the variance or mean of order flow times in the SCP, and effective allocation of resources and order-tracking mechanisms for efficient customer response.

3. **Build-to-order**: This is a mix of the above two methods. A part of the SCP is engaged in manufacturing and moving materials made to stock, and the remainder of the SCP exerts its resources on making end products to order. Issues crucial in this method are the location of the customer order decoupling point, forecasting of subassembly requirements, etc. Typical examples include supply chains for automobiles, machine tools, etc.

We observe that the configuration of the manufacturing units of the SCP, for any of the above types of planning and control, could be job shop, transfer lines, flexible manufacturing systems, and the like. We are not concerned with these; our emphasis is on the aggregated and higher level view of the SCP itself, instead of the constituent facilities.

5.1.1 INPUT CONTROL

Another component of the supply chain specification is the input control mechanism. We draw upon the analogy from literature on queueing systems to define these. Defined with respect to the admission control of orders into the SCP, this is of three types: open, closed, and mixed.

1. In an open supply chains, fresh orders are allowed into the SCP irrespective of the status of the system in terms of congestion at various facilities and capacity available. This is common in make-to-order kind of SCPs.

2. In a closed supply chains, the flow of fresh orders is regulated. Say the exit of a batch of orders triggers the release of a fresh batch into the SCP. This is similar in spirit to the JIT method and the CONWIP method, where every echelon of the supply chain initiates an order to its supplier once its inventory gets depleted.

3. In a mixed mode supply chains, while some facilities work on open control, others work on closed loop control.

The input control and planning and control policies followed are dependent on the market demand for the product, variety and customization needed. These are very important decisions and have to be carefully made.

5.2 INTERFACES BETWEEN SUPPLY CHAIN PARTNERS

From the business process hierarchy of a supply chain (see Figure 8.2) we can define interfaces between

- suppliers and manufacturing
- suppliers and logistics
- manufacturing and distribution
- manufacturing and logistics
- distribution and logistics

Basically, there are two extreme relationships between various organizations: one based on the American mass production paradigm and the other based on the Japanese lean production model.

The relationships in the mass production model are adversarial, based on mistrust, threats, and counterthreats between the so-called seller and buyer. The relationship between the various elements of the supply chain is stressed in this case. Also, contracts are awarded for short time spans creating a transitory perception with the result that renegotiations consume time. Further, each function in an organization defends its own turf or empire, and interaction is impersonal, cold, and distant. Measurements of performance are narrowly defined to minimize cost or maximize performance within the function. This narrow focus leads to suboptimization (see Examples 4.1 and 4.2). The results of such a model include procedural delays, frequent reworking and redesign of products, and inventory buildup.

In the lean production model, the interface problems between the supply chain elements are first attacked. Collaborative partnership among all elements is encouraged, which will lead to long-term contractual arrangements, information sharing, co-design of products based on trust, and an overall relationship focused on effectiveness and improvement. The relationship is established based on the capabilities, infrastructure, people, and practices of the constituent partners. Thus, multiple inspections are avoided. The performance measurements are made on the entire supply chain network on such measures as delivery performance, cost, flexibility, defects, and lead time. Thus, the major contribution to time compression come from good management of the interfaces. Once this is done, the other redesign exercises can be done by removing redundant activities, concentrating on core competencies, and using IT tools. The benefits of such an exercise will be shorter delivery times, reliable delivery, low inventory, low costs, low setup costs, and high flexibility.

Partnership sourcing: Partnership in supply chain relationships is clearly a powerful strategy. It encourages a cooperative approach to problem solving and leads to cost reductions, quality improvements, and time compression. The traditional view of supply chain management assumes the existence of the owner of the supply chain network, called the OEM or customer, and this company retains most of the control of the supply chain. The suppliers work in cooperation with the OEM. The lean supply chain model goes beyond this concept towards a networked organization of autonomous companies cooperating towards a joint objective. Some members of the network will add more value to the process than other and will thus take a leadership role, but the sharing of technical, logistical, and commercial responsibilities will be based on value/cost calculations and a mutually beneficial collaboration.

What partnership means is a trust that both parties will do what they have to do with a high level of clear and candid communication that leaves neither party in doubt about the feelings on relationship. High levels of trust affect transaction costs in any relationship, potentially reducing these costs. This avoids the need to monitor and also reduces the supply chain wastes of inventory and overproduction. Vertical integration is the opposite of partnering; in this case, all activities in the supply chain are done and controlled by one company, as was done by Western automobile companies prior to the early 1970s. Although vertical integration has many virtues, its inertia makes it inflexible and slow in response to changes in the environment and in technologies. Experience has shown that a network organization structure built through partnering has the potential to deliver the benefits of vertical integration without the need to own each of the supply chain elements. This kind of partnering is also called *virtual integration*. The strategic alliance with partners will enable a company to create a major barrier to market entry for other suppliers, a feeling of local participation in case of foreign owners, and access to core technologies of the supplier.

Supplier management is a process of selecting the supplier or customer and establishing a relationship managed by a cross-functional team as in TQM programs. The performance measures of the relationship are quality, delivery, cost, and innovation. The supplier's capability to deliver products and services of high quality is assessed. The skill level of the work force, the capabilities of the business processes, the capacity, quality management processes, the level of technology, the capability for innovation, and supplier management are some of the parameters assessed before selection. The information that needs to flow from customer to supplier and from supplier to customer is determined. This includes sharing of internal cost information, availability of resources/lead times, and so on. Going through a systematic process of interface management certainly helps in developing effective partnership sourcing relationship with suppliers.

Reaction in case of potential threat to the relationship: A relationship characterized by mutual dependency and a high level of trust is always vulnerable. Both parties should be aware of the potential threats and should work together to neutralize them. Some of the external threats include the emergence of a new supplier at a lower price or with an advanced technology, changes in the product specification, reduced orders from the market, and need for cost cutting due to competition. Such issues have to be addressed while keeping the long-term relationship in mind. Benchmarking suppliers with new ones in terms of best practices, cost, quality, etc. will keep the customer alert to the threats mentioned above. A feeling of shared destiny is a powerful factor for sustaining the commitment in a collaborative relationship.

Thus, during partnership sourcing meetings, all issues concerning daily operations are discussed and sorted out. With the active involvement of all customers, the resource base of the supplier is audited, including management practices, and issues such as delivery practices, variabilities in delivery volumes and times due to procedural and organizational interfaces, price changes, new product development, and the flexibility to deal with volume and variety changes.

Single, dual, and multisourcing: The principle of a supplier contributing to product technology by collaborating with the assembler is now well accepted. Multisourcing is suggested to avoid risk (not having all eggs in one basket) but is expensive due to the administrative costs associated with monitoring and maintaining the relationship. Also, it is difficult to maintain quality consistency with multiple suppliers. Dual sourcing seems to be a possible alternative.

The trend toward single sourcing is global: it is vertical integration without ownership. Total single sourcing is risk prone but has the great benefit of quality consistency. Dual sourcing within the same commodity group is followed by some Japanese companies: they deliberately split the volume demands between two suppliers, and then the demand requested can be modified at short intervals. The suppliers themselves are not in direct competition, and each is expected to share with the other any improvements that have been made.

Risks associated with alliances: A degree of risk is associated with disclosure of sensitive proprietary information. Alliance arrangements create a dependency that would be detrimental if the partner fails. Smaller organizations are vulnerable to manipulation by a stronger one. The strength of the alliance—being locked into a relationship—is also its weakness. Companies lose their autonomy and flexibility. Further, active participation in an alliance means focusing resources and efforts for mutual gain. One should make sure that the rewards are more than sufficient to compensate for all the above risks.

5.3 INTEGRATED PRODUCT–SCP DESIGN

Product planning is an activity involving decisions about the product lines and markets that shape the direction of a business. The time required for development of product families and for manufacturing, the transit time to markets, and the costs of manufacturing, inventory, and transportation all determine the ability of the company to compete in world markets. Like the other issues, such as design for manufacturing, design for assembly, etc., design for effective supply chain management is also important. Ultimately, the competitiveness of the product is determined by how it is delivered to the market by the supply chain. The product design should take into account, among other things , the cost and time of transportation as well as the interface costs and times.

The design of products requires visualization of the entire chain of actions to move the product to market, including several stages of transportation and handling through distribution centers with a variety of carrier and material-handling equipment.

Design considerations: The characteristics of the product that make it transportable with ease of handling are considered here. In packing, issues include the degree of protection needed given the product fragility and dimensional considerations for fitting unitized loads such as warehouse pallets, and labeling identification for automated scanning. The monetary density, which is the monetary value per unit of weight (e.g. dollars per kilogram), determines the mode of transport and the cost of storage. The physical density, which is the ratio of cubic volume to weight, determines the costs of transportation and storage. Products with high volume-to-weight ratios are costly to transport and store are best produced locally to minimize the logistics costs.

Product design affects the costs of handling and shipping. Sometimes disassembled units could be shipped with less damage and lower transportation cost. Modular product design to minimize total supply chain cost is an important issue.

Global marketing requires wide diversity in product offerings to match the local demands. Manufacturing different products ordinarily adds to the complexity of product scheduling. The wider the product range, the more time and capacity must be allowed for production. At the same time, an increase in service levels requires holding the finished product inventory close to the market. There is, however, an alternative. When markets demand product variety, products can be designed for local customization. This reduces the variety necessary in basic production and intermediate inventories, resulting in greater potential for variety at the point of use.

Product structure: The product structure defines the set of component modules or elements for a product or a family of products. Product structure influences production time because it allows the production process to be separated into stages. It influences production flexibility when components are interchangeable. It influences distribution because it reduces inventory requirements. A product family can be designed as a product group with standardized components that can then can be assembled into a broader range of final products. The number of combinations can exceed the number of components, creating mushroom products.

Components can be held in inventory and assembled after the order arrives. This stage of production at the last possible moment is an application of the postponement principle and can be performed at the factory or distribution center or within the distribution channel. Product structure can compress the time between order and shipment because part of the production process has been undertaken in advance in anticipation of actual orders. Only final assembly and matching to specific customer requirements must be performed after the order arrives. Manufacturing and marketing jointly determine how much product variety is to be incorporated into the design.

Focusing on component structure promotes efficiency in that the production inventory is lower in value than finished products. It also makes possible supply chains in which products can be made directly to the customer order, eliminating the need for any inventory other than that directly in transit between factory and customer. It shifts forecasting requirements from individual finished product units, where the accurate estimation of demand is extremely difficult, to component demands. Component demands can be more stable, particularly if they are combined in larger product families.

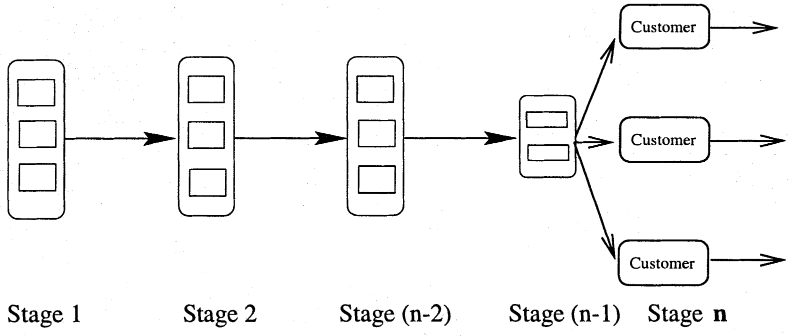

Figure 8.8. Product–process structure with late customization

5.4 SCP TYPES

The performance issues in supply chains are intimately related to the product structure and also to the supply chain network configuration. Modular designs, with customization occurring as late as possible in the production, are preferred. Also, manufacturing facilities are staged with the customization occurring with the help of local suppliers in order to meet local language, power, and communication standards. The combined product and SCP design yields the following structures.

Pipeline structure: The first case is a straight-line interconnection of plants, each adding modules to the semifinished product sent by the previous plant and passing it to the successor. The product variety is limited, the material flow is unidirectional, and the decisions are infrequently made as to when to stop the line for switchover to another product type and how large the batch size should be. Mass production and continuous manufacturing are examples of this type. Batch sizes are large in this case.

Late customization: The second case is when customization occurs in later stages of manufacturing . During the initial stages, production is of standard items that are customized to give variety either at the customer end or in a local manufacturing plant or distribution. The structure of the plant looks similar to that shown in Figure 8.8. Personal computers, IC chips, disk drives, laser printers, and other electronic equipment follow this pattern. Here product variety can be obtained through dedicated plants that perform the last stages of manufacturing. Also, modular design of the product (keeping in view the logistic costs will reduce the total logistic costs) as well as help in effective supply chain management. Individual customer demands may highly variable, but the total semifinished product demand variability is low. Thus it makes sense to maintain inventories at the subassembly level that are

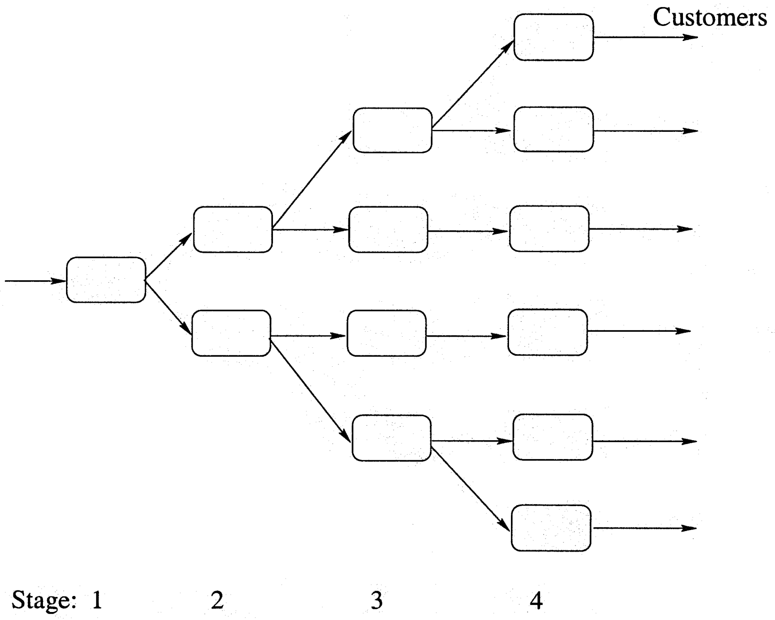

Figure 8.9. Product–process structure with early customization

customized based on individual demands and thus to maintain low lead times.

The various stages of manufacturing may be dispersed across continents, and often transportation is on the high seas. Thus the economic transportation batch size is larger than in plants located near to each other. The transportation batch size dictates that the production batch size of the predecessor plants also be high. Thus batch sizes and inventories are high and product variety is low in all the first $(n - 1)$ stages. The final stage, however, has dedicated low-volume plants.

In the plant structure shown in Figure 8.8, uncertainties in customer demands and long transportation times are basically met through staged manufacturing plants with dedicated technology, inventories, and large to medium batch sizes. Supplier management, partnership with logistics agents, and modular product designs are some of the enablers for good flexibility management in this case.

Diverging structure: We now consider a third case, in which customization starts early in the production stages and the plants have a diverging architecture (see Figure 8.9). Starting with a limited number of raw materials, a wide variety of finished products are produced. Examples can be found in electromechanical systems such as motors, textiles, metal fabrication, and chemicals. In this case, the enterprise

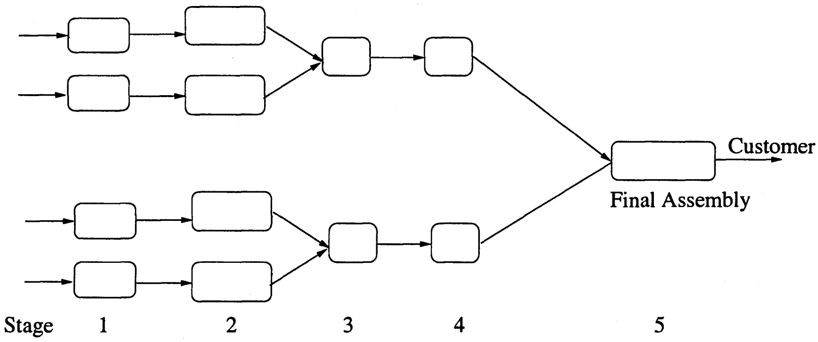

Figure 8.10. Converging product–process structure

is very complex from a managerial viewpoint. Several plants with similar manufacturing capabilities have to be managed and must maintain partnership relations with several suppliers, distributors, and customers. The plants can be staged or can be centrally located; they are made flexible through use of automated technologies. Batch sizes are typically low, and lead times must be small. Low inventories are to be maintained for cost competitiveness. Integration using EDI and barcoding and scheduling of customer orders using point-of-sale information will increase the effectiveness of the supply chain.

Converging structure: The final architecture is assembly oriented with a converging architecture. One finds such patterns in the manufacture of aircrafts and in construction. Numerous raw materials are transformed into subassemblies and finally into a huge assembly (See Figure 8.10). Large numbers of midvolume components are produced at various stages of manufacturing. Components are globally sourced from a variety of suppliers. The management is complex. Here again, supplier management, flexible manufacturing, and information integration will enhance the enterprise's performance. Small batch sizes, sometimes one of a kind, and low inventories are typical here.

5.5 POSTPONEMENT

Postponement offers a strategy to reduce the anticipatory risk of the supply chain process. As we mentioned before, it offers an alternative to inventory and forecast of the final product. To some extent, the commitment of a batch of products to the customer can be postponed until receipt of the customer order. Two types of postponement are possible [5].

Manufacturing postponement: Here the product designs are modular so that a variety of products can be manufactured from certain platform components. Using flexible manufacturing technologies, which allow economic production of small lot sizes, one can manufacture the standard base products and attempt customization later. Economy of scope is introduced into the SCP by modular design of the product and a treelike product structure. The final product is made to the customer order, thus avoiding the risk associated with stock-piling finished inventory. Since the intermediate products are in inventory, the supply chain lead time is substantially reduced.

Several examples are given in the literature. One of them is postponing mixing color into paint until the customer's order arrives. Perfecting the in-store mixing process has reduced the inventory. There are many examples in semiconductor and PC industry.

This kind of postponement strategy also leads to what is called *staged manufacturing.* The standard and base products are manufactured at one location, and the final customized assembly is done nearer to the customer using some of the local components. This approach saves supply chain costs as well. This type of manufacturing is done in the PC industry, wherein all the components– disk drives, mother boards, monitors, etc.– are procured from different international sources. Power supplies, the chasis, and communication interfaces, etc. are locally procured.

Staged manufacturing and postponement reduce inventory as well as supply chain costs. An inventory of standard or base units is maintained in order to support a broad product line. The lead time is also reduced, since what needs to be done is the final assembly and shipment to the customer. Sometimes the final customization is done at the distribution site.

Logistics postponement: Here the final products are manufactured to forecast, and the inventory is maintained at a few strategic locations. When a customer order arrives, the order is filled from the inventory, i.e., the product goes from the warehouse to the customer directly. The location of the inventory could be nearer the manufacturer, or nearer a logistics operator (in a place like Memphis). In either of these cases, there are cost and time advantages. This does not mean that manufacturing is not responsive or flexible. It may well be that a product shipped to the customer today was on the factory floor yesterday.

One should understand that electronic commerce facilitates the movement of orders and money almost instantaneously. Only the movement of goods needs time. Both types of postponement focus on reduction in lead time and costs. In manufacturing postponement, the product differentiation occurs after the arrival of the customer order and takes more time for assembly and shipment. In logistics postponement, differentiated products are made to stock and are shipped directly to the customer once the order arrives. In some cases, both types of postponement can be combined into a good supply chain strategy.

5.6 INFORMATION SYSTEMS

Competitive challenges and changing customer service requirements are driving leading firms to use information capabilities to a gain faster, higher-quality response and closer relationship with their trading partners. As we mentioned several times before, advances in information technology have brought tremendous changes in the SCP operation, monitoring, and control and management. IT can be used for communication and more importantly in transforming data from disparate sources into vital strategic information. In chapter 7 we have seen use of IT in nourishing partnerships such as VMI and others.

In the automobile and electronics industries, manufacturers and suppliers use EDI to exchange drawings, programs, and other CAD/CAM data. This exchange will integrate all functions and organizations of the SCP such as engineering, procurement, production, and marketing, leading to international competitiveness. EDI is also critical in international supply chains because of the volume and complexity of transactions.

EDI originated in transportation because of the large volume of documentation regularly exchanged between shippers and carriers. Several companies use EDI for processing freight bills. EDI combined with barcoding has led to a new initiative called the quick response manufacturing (QRM) by DuPont.

Quick response manufacturing (QRM): QRM [88] is a strategy of time compression all along the supply chain pioneered by DuPont in the mid-1980s. The characteristics of QRM are the following:

- Its primary objective is to provide customers with products and services in the precise quantities, variety, and time frames desired.
- Tighter linkages between raw material suppliers, manufacturers, distributors, and retailers reduce waiting time, inventory, and duplication of efforts. They form a networked organization with vertical integration benefits.
- Retailers and department stores collect information on sale volume, merchandise returns, and customer reaction to sales using barcode and point-of-sale terminals.
- The idea is to manufacture and replenish the fast-moving items, to avoid selling at discounts, and to respond to customer demands more accurately.

Information processing: As is often said, the more you know about your process, the better you can operate it. This is true for supply chains as well. In the supply chain, there is an enormous amount of information available that has been collected by various subsystem computers. Can we use this information to operate the supply chain better, i.e., to make better decisions? The answer is a big yes. But the problems are (1) the information is collected by independent organizations in their own formats and is stored in a manner useful to them, (2) strategic alliances involve only the sharing of agreed-upon information, and (3) formats for integrated information storage are only evolving now. We have already seen that

- Point-of-sale information at the retail outlet can be used for scheduling of the product by the manufacturer, with a consequent reduction in inventory and markdowns.
- Performance measurements can be used to tightly control the process deviations and to operate the SCP as a near six-sigma process.
- Data can be used to identify the 20% of customers that make up the 80% of the orders for 80% of products.

Basically, we are saying that by using IT one can have instantaneous reliable and secure information transfer among various constituents of the supply chain. This information can be used to counter the uncertainties of demand and to increase the velocity of the supply chain.

6. PERFORMANCE MEASURES

World-class companies recognize the importance of defining and measuring performance metrics that summarize their operational, financial, and learning capabilities and suggest procedures for improvement. Generally, performance measures and measurement systems are confined to single organization or a function within the organization. Companies generally measure the manufacturing lead time, defects in the manufactured product, etc. Here we consider the performance measures as applicable to the SCP.

The fundamental operational performance measures of a SCP include the following:

- Lead time
- Quality management
- Supply chain process costs
- Flexibility

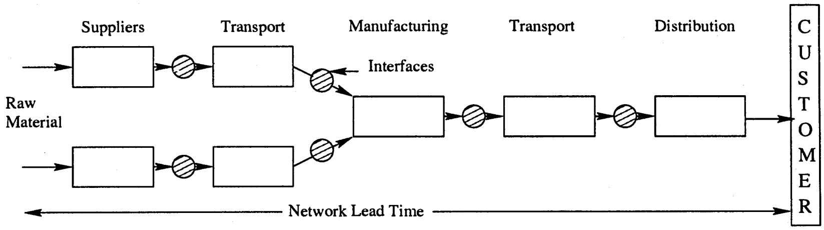

Figure 8.11. Supply chain lead time

- Asset utilization

We believe these are comprehensive measures through which the health of a process can be assessed and improvements suggested.

6.1 LEAD TIME

Lead time is a very important measure. Actually, two lead times can be defined: one for the SCP and the other for the ODP process. The ODP lead time, is the time elapsed between the instant customer places an order till the instant he or she is delivered the product. We studied this lead time in chapter 7. The other lead time, which is also very important, is the the SCP lead time. It is the clock time spent by the supply chain to convert the raw materials into the final products and to place them in the hands of the distributor or customer. It thus includes (see Figure 8.3) supplier lead time, manufacturing lead time, distribution lead time, and the logistics time for transport of raw materials, semi-finished and finished products.

Clearly, lead time must be reduced, since it is directly proportional to the inventory at various points of the network. Also, the setup times in assembly, subassembly, transportation, and storage contribute to lead time; the flow through the network is smooth if there are no inventories, machine breakdowns, transport breakdowns etc. The interface management time also contributes a large percentage to the cycle times. Partnership arrangements between the organizations will remove all uncertainties involved in negotiation, procedures, etc. We assume that all the partners in the supply chain have a good understanding of the process and act as though they are under single ownership. This structure is shown in Figure 8.11.

The supplier's lead time has five components: move time, waiting time, setup time, queue time, and processing time. Except for the last one, these are non-value-adding times and should be reduced. The key to reducing the lead time is to reduce setup times and inventories by processing small batches. The transport lead time (in both the supplier-to-manufacturer case and the manufacturer-to-distribution case) consists again of setup time, load–unload time, and move time. In this case, setup time is defined as the waiting time for the batch before it is loaded on to the truck. Several techniques are used for small batch transport, including pooling, milk van type of routing, hub and spoke service, etc. The manufacturer's lead time also has five components like those of the supplier. Distribution lead time is basically composed of interstorehouse transport, transport logistics to the retailer, time required to store an item in a locatable address, and so on.

One can see that each of these lead times is huge and involves several machines, methods, and people. There is scope for time compression in all these activities. The mean and variance of the lead time are very important. The variance indeed determines the amount of *safety stock* one needs to carry for a *given service level.* Time compression actually reduces the forecasting error, allowing the entire system to move to a make-to-order type of situation. To reduce the cycle time, companies have tried several time-saving methods, including

- *Stockless distribution*: The product arrives in consolidated shipments for several customers, and distribution routes the product to individual customers
- *Final assembly points*: Distribution facilities act as the final customization points for the assembly process
- *Cross-docking*: The distribution facility serves as a point of transfer from one type of transport (long-haul full truckload) to another (local delivery trucks)
- *Customer logistics centers*: Distribution takes over inventory management of customers
- *Electronic data interchange*: Document transport takes place by electronic means

The lead-time gap: The gap is the time difference between the time it takes to procure, make, and deliver the finished product to a customer and the time the customer is prepared to wait(see Figure 8.12). In a conventional organization, inventory is carried at various levels, in order to fill the gap. This involves long-term forecasting, which is inaccurate. Improving the forecast is a desirable goal. Another way is to reduce the supply chain lead time and to increase the customer lead time, thus reducing the gap. The lead time in the supply chain process can be reduced by

- Process view: Supply chain processes can be viewed as a collection of interlinked activities with well managed interfaces
- Visibility of the process: All the activities of the SCP are visible to all stakeholders, who can then realize their role in the process.
- Process owner architecture: A process owner is responsible for the process performance and improvement; he manages with the help of a cross-functional team

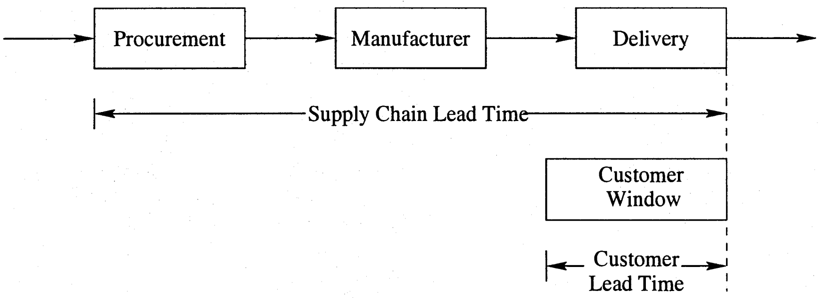

Figure 8.12. Lead time gap

It is very desirable to extend the customer's order cycle time. This can be done through

- Early warnings about the order through customer surveys and by making customer order information visible throughout the network
- Using the order penetration point as a decision variable. As we mentioned before upstream of this point is driven by forecast and downstream is driven by customer orders. A key issue is how far back we can push the order penetration point; it can be at the final assembly, at semifinished parts, etc.

6.2 EXAMPLES

In chapter 4, we have presented several numerical examples illustrating the computation of lead times in supply chains. Here we assume that the laed times are random variables and present methods of computing the distribution of the lead time. The analysis is similar to computing lead time distributions in PERT networks and for acyclic graphs [56], [79] and [13].

Example 8.1: Consider a pipeline supply chain with a single supplier, single manufacturer and a single distributor with logistical operations in between. Let X_i be the random variable representing the corresponding lead times. Assume that they are independently and identically distributed. Then the distribution of supply chain lead time $F_{\mathrm{LT}}(t)$ is given by

$$F_{\mathrm{LT}}(t) = F_{X_1}(t) \otimes F_{X_2}(t) \otimes F_{X_3}(t) \otimes F_{X_4}(t) \otimes F_{X_5}(t)$$

where $\otimes$ is the convolution operation. For a given distribution of X_i, the mean and variance of LT can be numerically computed.

Example 8.2: A manufacturer sources three subassemblies from three independent suppliers, who deliver to the factory floor. Let X_i be the random variable denoting the delivery time from supplier i, and let $F_{X_i}(t)$ be its distribution function. Let T be the random variable denoting the max (X_1, X_2, X_3). Then T is the time after which all the subassemblies are available at the manufacturer. Also,
$F_T(t) = F_{X_1}(t).F_{X_2}(t).F_{X_3}(t)$
If A is the random variable signifying the assembly time at the manufacturer, let $F_A(t)$ be its distribution function. Then the distribution of the supply chain lead time LT is given by

$$F_{\mathrm{LT}}(t) = F_T(t) \otimes F_A(t)$$

where $\otimes$ represents the convolution operator. The mean and variance of LT can easily be computed. For given distributions of X_i and A, one can numerically compute $F_{\mathrm{LT}}(t)$. Also , the probability of delivering an order within a specified time limit can be easily computed.

Example 8.3: A manufacturer sources a particular subassembly from three independent suppliers for reliability reasons. This is called multisourcing. The delivery times of the three suppliers are identically distributed and are denoted by X_i. Suppose we rearrange the X_i to get an ordered sample in the increasing order $X_{(1)} \leq X_{(2)} \leq X_{(3)}$ where X_i is the delivery time of the ith arrival. The probability density function of the lead time of the first arrival $X_{(1)}$ is given by [2]

$$f_{X_{(1)}}(t) = 3[1 - F_X(t)]^2 f_X(t)$$

Let Y_{ij} represent the time between two successive arrivals, i.e., $Y_{ij} = X_j - X_i;\ \ i < j$. Then the density function of $Y_{ij}(t)$ can be obtained. Several authors (see for example [38])have studied this problem for exponential, Weibull, normal, and uniform distributions. They have established the obvious fact that the more the number of suppliers, the less is the variance of the first lead time $X_{(i)}$.

6.3 QUALITY MANAGEMENT

Quality is a moving target, and what is regarded as excellent today may be a pedestrian feature tomorrow. For the SCP, there are several dimensions of quality. Under the customer service dimension, we have seen that the customer-perceived quality is in terms of lead time, delivery reliability, and order fill rate. In this section, we concentrate on variability reduction mechanisms in the SCP. We have discussed variations in general business processes in chapter 4. Here we treat variation in SCPs

As shown in Figure 8.2, the supply chain is an interorganizational process touching several organizations and several functions within each organization. These include suppliers, manufacturing, distribution, and retailers. For effective supply chain management, one has to (1) manage the interfaces across boundaries, and (2) reduce the variations in the work process lead times, defects, changeover times, and costs along the supply chain.

A concept that is gaining ground is that of the perfect order [17] or perfect delivery. It is the ultimate measure of quality of an SCP. It meets all the requirements of delivery of all items requested, on time with all supporting documentation and installation of the equipment in a form directly usable by the customer. A perfect delivery means all subprocesses in the SCP—purchasing, suppliers, logistics, manufacturing, and distribution— act in cohesion without errors or defects from one end to the other. There are several hurdles to achieve this mostly because of variations, errors, and delays.

Variation: Quality management emphasizes understanding, stabilizing, and continuously reducing variation. Process variation is common and is the tendency of the process to produce different results under the same given set of conditions. For example, a truck takes different times between two destinations. An assembly station may take different times to assemble parts. Each machined part will have different dimensions. In all the above cases, the process is unable to produce output consistently to a single target value. If one defines acceptable specification limits around the target value, the traditional view has been that a product is good if it is within the specification limits.

Impact of variability: Variability in the cycle time can have a significant impact on the level of safety stock that needs to be carried by the receiving organization, such as a distributor. As the variability increases, the safety stocks needed to obtain a certain customer service level also increase. Suppose a distributor gets shipments from a far-off factory and wants to maintain a service level of 95%. Suppose that 95% of his shipments take 20 days or less; then the distributor has to maintain 20 days worth of stock as inventory. If the variability could be reduced, then the safety stock could also be reduced.

Statistically capable supply chain process: Just as inventory is evil in cycle time management, variation is evil in quality assurance. First of all, due to variations, there will be scrap, rework, and repair to get a unit within specifications. Second, there will be customer dissatisfaction and defections.

In chapter 4, we defined process capability as the ability of the process to produce results whose variations are within customer specifications and centered on the design target value. We also defined the C_p index as the ratio of customer specification width to natural width of the process (6σ). The customer specification width is the difference between the upper and lower specification limits. If the specification limits are $\pm 6\sigma$, then $C_p = 2$; $C_p = 1$ if specification limits are $\pm 3\sigma$. The mean varies over time from batch to batch in manufacturing or from one transport company to another company. A variation of about $\pm 1.5\sigma$ in the mean is commonly considered. A second capability index C_{p_k} tracks batch-to-batch or company-to-company shift in the mean. We have defined C_{pk} in chapter 4.

The variation in the supply chain: The SCP consists of several activities, each with its own variation characteristics. All the individual variabilities contribute to the overall delivery time variability. Figure 8.15 shows the variability in a supply chain example. This illustrates the point that for variability reduction, all subprocesses and work processes must be improved. For purposes of analysis, we are treating interfaces of all types as work processes, and hence their variability has to be controlled to improve the total SCP variability.

Normally, the specification limits for delivery time will be from 1 to 7 days (1 day to 1 week). All the subprocesses need tremendous improvement, and the allowed time range around the mean should probably be reduced to ± 0.5 day. This can be done by monitoring the subprocesses and each of the work processes. Use of C_p and C_{pk} indices, control charts, and fishbone charts is very useful. Root-cause analysis of variation would reveal the cause that needs to be eliminated.

Quality management in a world-class company emphasizes understanding, stabilizing, and continuously reducing variation. This variation must be controlled, however, and ultimately reduced to allow the supply chain to operate as a stable and reliable system that consistently delivers products meeting design quality targets. The variation reduction strategy shown in Figure 8.13 builds a very high confidence level into the supply chain so that the system consistently meets customers' expectations.

Example 8.4 : Consider a supply chain with a pipeline structure. The variance of the raw material supplier is 4 days, transportation 2 days, manufacturing 1 day, and distribution 2 days. The total variation thus is 9 days and the standard deviation 3 days. The natural width of the supply chain is 18 days. If $USL - LSL = 24$ days, then we can have a C_p of 1.33. Even if we make the variation and the standard deviation 1 day, we need a specification width of 8 days to get a C_p of 1.33.

The above example illustrates the tight control one needs to exercise in supply chains to keep the variation at low levels.

How to reduce variation: In chapter 5, we discussed the performance measurement and control system for general business processes. The

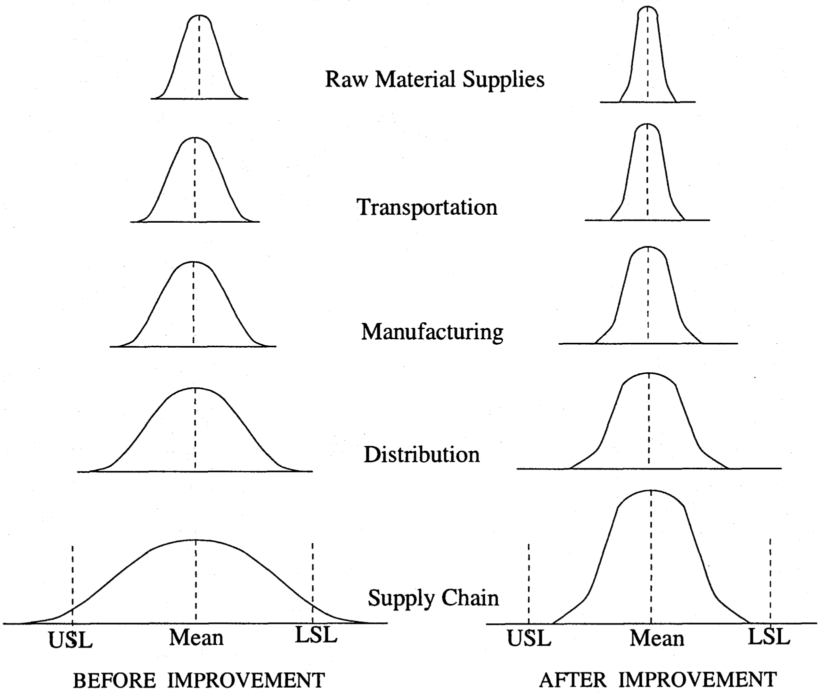

Figure 8.13. Control of variation in a supply chain process

same is applicable to SCPs. It is very important to analyze each of the supply chain activities, such as production, logistics, etc. and to list down all the errors that can occur or can be made by the humans involved. In Table 8.1, we have shown as an example, the kind of errors that can occur in a warehouse. A performance measurement system should be designed for all subsystems as well as for their interfaces. Figure 5.7 shows the control charts for delivery time performance and also for purchase order errors. One can use all the methods available in TQM, such as control charts, fishbone charts, and Pareto charts, to identify the causes of variation and to remove them. Figure 5.8 shows a fishbone diagram analyzing late delivery by a supplier.

6.4 SUPPLY CHAIN PROCESS COSTS

A SCP has a large number of facilities connected by transportation and communication operations through which the products move. Each firm in the supply network may have multiple vendors, multiple manufacturing facilities, several distribution centers, and multiple customers. There are several fixed and operational costs associated with the supply

Table 8.1. Errors in warehouse activities

Receiving and Put-Away Errors • Receipt of incorrect product: Errors can be detected by reading the barcode label of the product and the subsequent identification of incorrect entry or by physical inventory stock checking. • Put-away in wrong bin or storage location: These errors can be detected at the time of put-away and recording of storage location or by the operator when he or she notices the wrong product in the bin.
Order Picking and Replenishment Errors. • Wrong item picked, incorrect quantity pulled, or erroneous consolidation of orders.
Packing and Shipping Errors : • Lack of proper dunnage, wrong carton, no packing list, or incorrect address.

chain network. We enumerate the important costs below. It is necessary to streamline the supply chain to keep the costs low.

Inventory costs: Basically, inventories are buffers against demand uncertainties and are safety stocks to avoid shortages. The economics of manufacture dictates batch production creating cyclic stocks. The time required in transportation and manufacturing gives rise to in-transit and work-in-process stocks. Variations in processing rates due to a variety of factors such as breakdowns will lead to maintenance of stocks to improve the delivery reliability. Thus, inventory costs include storage, material, insurance, damage, and other costs to maintain work-in-process, finished goods at warehouses and customer sites, and in-transit inventories.

Transportation costs: Costs involved in inbound, outbound, interplant and interdistribution center transportation.

Facilities costs: Costs incurred in building and operating manufacturing and distribution facilities.

Operating costs: Costs for material movement and handling, storage, order processing and expediting.

IT costs: Cost of providing information technology connectivity and facilities such as EDI, E-mail, EFT, etc.

It is very important to keep the costs to a minimum in order to gain a low cost advantage with the customers. Reduction of inventories; removal of redundant activities by merging value chains of suppliers, manufacturers and distributors; and supplier development are some of the methods used for cost reduction.

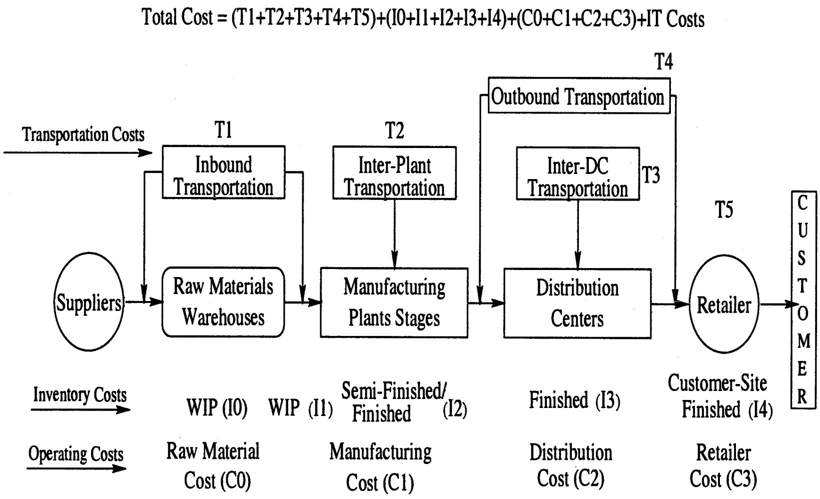

Figure 8.14. Total cost analysis for supply chains

Total cost analysis: Total cost (see Figure 8.14) includes all the supply chain costs, including material, transport, inventory, and facility costs. It is seen that these costs are dependent on one another. For example, air freight reduces the in-transit inventory and facility costs. In addition, the customer may be willing to pay a premium price for speedy delivery for items such as beer, flowers, fruits, meat, etc. if they are of assured freshness. With the use of new technologies and techniques such as intranets, EDI, responsive manufacturing systems, and good forecasting techniques, lead times and inventories are kept low. The major costs are transportation, facility operation, and in-transit inventory costs. These need to be balanced with the choice of mode of transport.

Several examples exist in the literature where companies have chosen direct factory-to-customer air transport, since the extra costs of transportation are more than offset by reductions in inventory and field warehouse costs. Some IC chip makers centralize inventory in one warehouse and make deliveries using courier service providers. Another interesting case cited in the literature is a US brewery exporting fresh beer to Japan. The brewery uses an express service provider which takes delivery of the beer at JFK International Airport and hands it over to a Trading Company in Tokyo after customs clearance. The freshness of the beer allows it to be priced at a premium, almost five times higher than that shipped by sea.

Managers often focus on minimizing functional costs such as transportation, with the belief that such an effort will achieve the lowest combined cost. The total cost concept is a radical departure from the conventional practice but is in line with the process orientation of a manufacturing enterprise. However, the implementation of effective SCP costing remains a challenge.

The appropriate level of supply chain costs must be related to the desired service performance. The simultaneous attainment of high availability, operational performance, and delivery reliability is very expensive and may not be what customers need, expect, or even want. The key to supply chain management is in matching competency with customer expectations and requirements.

6.5 ASSET UTILIZATION

Assets are facilities, vehicles, equipment, and working capital. Better supply chain management has the power to improve productivity in each area. Cash and receivables are critical assets to the businesses. Order cycle time directly influences the cash flow. Shorter delivery time and accurate invoicing will shorten the order-to-cash time. Inventories tie up a company's assets. A quick response SCP will reduce the inventory levels along the supply chain and increase the asset utilization.

Plants, depots, warehouses, vehicles, and material-handling equipment are all fixed assets. Lots of capital is sunk into these if they are owned. Nowadays, everything is outsourced from manufacturing and R & D to transport, and one should attempt critical analyses to find effective ways of deploying the investment. We have seen in chapter 4 that the capacity of the asset has to be carefully determined to avoid bottlenecks along the supply chain.

The asset metrics include cash-to-cash cycle time, inventory days of supply, and asset performance. The cash-to-cash cycle time is enhanced by quick acquisition of raw material, responsive manufacturing, speedy transport, quick delivery and accurate billing and cash collection. Inventory days-of-supply can measure inventory velocity or turnover. The asset utilization is the ratio of current capacity utilization and the achievable output in a 24-hour 7-day-week operation.

6.6 FLEXIBILITY

During the late 1970s and early 1980s, flexible manufacturing systems have emerged a key technology for gaining competitive advantage. There were several studies on the flexibility of manufacturing systems. These studies are important in the SCP context, since manufacturing is involved at the level of the suppliers, and assemblers. Here we would like to define the concept of flexibility for the SCP.

The importance of flexibility in the SCP context depends on the variety of products to be handled by the SCP. In continuous flow SCPs, such as in cement, steel, chemicals, glass, etc., the processes are highly automated. These produce and supply to the customers a few grades of standard types. In flow line supply chains, various input components are assembled through dedicated and optimized operations to produce high volumes of a particular product. The variety could be obtained by changing the line to produce the same product with different specifications. Intermediate products for big industries, such as disk drives and automobile components, fall under this category. In section 5.4 of this chapter , we studied the SCP–product structure interaction. We also saw in diverging and late customization product structures how product diversity can be obtained from the SCP.

Definition: A flexible supply chain process is one that responds effectively to changes in volume, product mix, delivery times, and delivery routes without deterioration in cost, quality, and lead time.

It is essential that all subsystems be flexible for the SCP to be flexible. Flexibility management is a capability that has to be built up over time through use of a skilled work force, automated equipment, IT tools, computer control systems, benchmarking, implementing the best practice, etc.

We will first discuss the various types of flexibilities for the supply chain. Essentially, flexible supply chains accommodate special customer requirements, provide customized service, allow product modification while the order is in process, introduce new design features, and so on.

Volume flexibility: A supply chain is volume flexible if a customer order with different product mixes and volume levels can be processed for rapid delivery.

It is essential that small batches of products are produced and delivered for a system to be volume flexible. This implies that setup times are small all along the process. This is because the economic batch size in any work process (manufacturing or transport) is an integral multiple of its predecessor.

Mix flexibility: A supply chain is mix flexible if the system can produce a number of products simultaneously and deliver them to the customers.

This capability indicates the breadth of the product line and ability for quick changeovers. The suppliers are either mix flexible or there is a larger number of suppliers. Also, warehousing and transportation should be able to handle different sizes, shapes, and installation procedures (multiskilled labor).

Excessive product variety induces several problems in both performance and management. The system complexity increases with more suppliers (at least two or more for each component); Establishing partnerships, sharing information, helping in quality control, reducing changeover times, etc., all consume time and effort . Thus variety means more design, more production planning and control, more forecasting and more leftovers. While no one can disagree that one should have variety, it is necessary to find and manufacture the 20% of the products that win in the market.

Routing flexibility: This is the ability of the supply chain to produce and deliver to the customer through alternate routes, equivalently, each function or some of the functions (manufacturing, warehousing, transporting) could be performed in more than one location.

Routes to supply equipment or to fill the order are ordinarily fixed but can be changed in the event of problems, such as a breakdown. Routing flexibility is generally obtained by duplication of each function in various locations, overcapacity and redundancy in transportation, and efficient scheduling and control software. The average number of possible ways in which an order can be filled could be used as a possible routing flexibility measure. For example, an order for a workstation from an Indian customer can be filled either from Singapore, Europe, or the U.S. alomg a variety of routes. Depending on the time available, the product is sent by air freight or by ship.

Delivery time flexibility: A supply chain process is delivery time flexible if it can reduce or expand the delivery time as per customer requirements.

Here again, rush orders and delayed shipment requests are common from customers. The ability to reschedule the orders all along the supply chain, low variation of the lead times of all the work processes, quick changeover times, and excess capacity in all resources are some of the requirements for delivery time flexibility (see Table 8.2).

7. PERFORMANCE MEASUREMENT AND BENCHMARKING

7.1 INTERNAL PERFORMANCE MEASUREMENT

In chapter 5 we saw, the objectives of performance measurement. In the SCP, both financial and nonfinancial measures are used for controlling and monitoring purposes. As shown in Figure 8.2, each of the supply chain elements, such as suppliers, manufacturers, and distributors, has several functions and work processes, such as supplier's assembly station

Table 8.2. Flexibility measures for an SCP

Type	Measures
Mix flexibility	• Number of different products that can be handled • Flexible equipment of suppliers • Change over times and costs among different products (function of scheduling)
Volume flexibility	• Stability of cost of delivery over varying levels of production volumes • Volume flexibility of suppliers/ logistics • Smallest profitable volumes of operation by the SCP
Routing flexibility	• Average number of ways in which a product can be manufactured and delivered • Multisourcing and multiple logistic channels • Average delay due to subsystem failures

or distribution's picking and packing in its warehouse, etc. At the work process level, the measures are defects, lead times, variety, and cost. At the process level, the measures include customer satisfaction, flexibility, productivity, asset utilization, and delivery reliability.

Cost: Supply chain costs are not easily obtainable, since several organizations are involved. But as shown in Figure 4.9, the final cost to the customer is an indication of costs at the level of the supply chain constituents. Also, each organization measures on a monthly or quarterly basis the transportation, warehouse, direct labor, administrative, and manufacturing costs, as appropriate. These cost figures generally are not used in monitoring and control. When the introduction of new technology or buying of equipment needs to be justified, the task teams go through the usual before-and-after cost analysis. Since an organization structure to manage the entire SCP is generally not present, total supply chain cost analysis is not done except in vertically integrated firms.

Customer satisfaction: This measure is very important in order to maintain competitive advantage. On-time deliveries, fill rates, shipping errors, cycle time, design and material defects are generally obtained from the enduser viewpoint. Customer dissatisfaction is generally used to trigger benchmarking on reengineering exercises.

Asset utilization: A SCP has many assets, although these are owned by several different organizations. Since in an SCP, we look at total cost to the customers, it is important that all the assets along the chain are efficiently utilized. Inventory turnover and return on investment

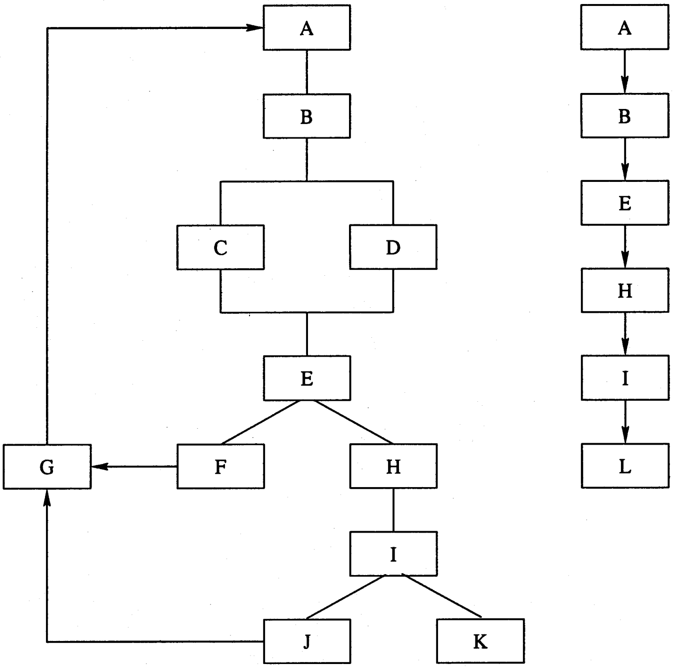

Figure 8.15. Supply chain process maps of two different companies

for fixed assets are good performance measures. Managements must typically decide whether to fully own an asset, or to rent it, or to put it up for rent on order to improve its utilization.

Delivery reliability: This measure is very important, since if delivery reliability is low, the inventory along the chain increases enormously. Delivery of the so-called perfect order involves delivery of all ordered items on time at the customer site, with accurate documentation and equipment installation for ready use by the customer. It is very easy to miss delivery targets. Every defect along the supply chain contributes to the unreliability of the chain. Hence delivery reliability could be very low if it is not properly monitored and controlled.

Productivity: Here, measures such as units shipped per employee, orders booked per sales representative, and items manufactured per day are generally monitored by most companies.

While internal measures are important, external performance measures are also necessary to monitor, understand, and maintain a focused customer perspective and to gain insights into best practices of other industries. This is done via benchmarking, which is the subject of the next section.

7.2 BENCHMARKING SUPPLY CHAINS

We introduced a discussion on benchmarking in chapter 5. Here we are concerned about benchmarking with special reference to the SCP. In Figure 8.2, we have a decomposition of the SCP into (1) work processes, (2) work process interfaces, (3) functional interfaces, and (4) organizational interfaces. We see that in a SCP we have several different kinds of facilities, activities, tasks, technologies, interfaces, and human resources involved. Benchmarking this megaprocess will certainly be rewarding. There are several ways in which this comparison between several supply chain processes could be done. These include

- comparing the process architectures (see Figure 8.15)
- best practice benchmarking
- comparison of individual facilities management such as warehouses, factory floors, etc.
- comparison of the quality of relationships (interfaces) between functions and between organizations
- comparison of the performance measures

As can be seen this is a big subject and we briefly consider here only two important issues.

Benchmarking the interface management:

The quality of the relationships between suppliers and manufacturers and distributors and retailers, and between all these organizations and the enduser, plays a key role in determining the performance of the SCP. We have seen in section 6.4 that the cost to the customer is the cumulative effect of all the costs and margins along the supply chain. Interface management is key to high productivity of supply chains and is crucial to gain competitive advantage. One useful benchmarking study could be of interface management with best-in-class companies. When comparing interface management across companies, one may note the following:

- *Communication mechanisms:* This includes communication of orders, quality problems in the supplied items, reliability of deliveries, and other financial and operational issues. Both horizontal and vertical employee communication is also important.
- *Integrated schedules:* The ways that the production schedules of various companies involved in the SCP are integrated is important.

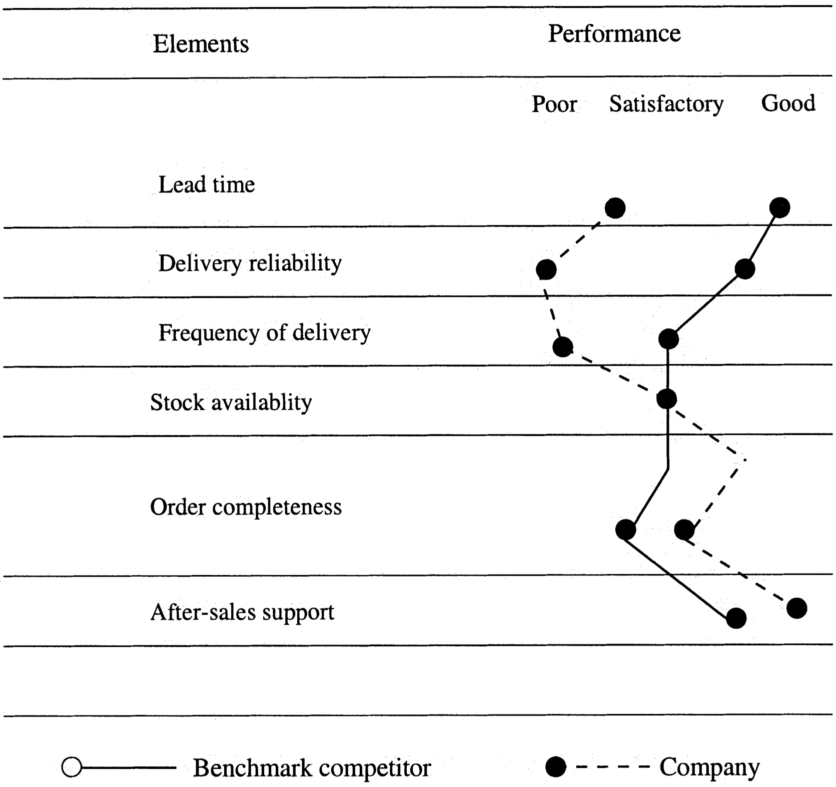

Figure 8.16. Customer service benchmarking

- *Information sharing:* The ways in which information on new product designs, human resource training programs, future products, product performance (defect rates, costs), and new facilities are generally shared between organizations is important.

- *Audit:* A review of partnership at periodic intervals should be conducted.

Comparison of performance measures: We have already discussed the supply chain performance measures. We only point out here that the measures should be in tune with the importance that the enduser gives to the issue. Supplying high-reliability products when failure of equipment is not a big issue, making faster deliveries to a customer whose schedules are erratic, and emphasizing testing and quality when the customer wants low cost are examples of out-of-tune situations. Figure 8.16 shows the performance measure comparisons.

8. ORGANIZATION STRUCTURE

As we discussed in chapter 3, an organization structure defines the roles and responsibilities necessary to effectively manage the SCP. Supply chain activities are geographically dispersed, and the operations of the supply chain often span more than one business. As of now, no organization structure exists to manage the entire supply chain process. The best known organization structure closest to the ideal, is to have supplier representatives at the manufacturing plant and to involve them actively in planning, scheduling, and order processing, as was done in the much-cited Bose Corporation. The same practice is followed in several disk drive companies in Singapore. Organization structures generally evolve in each firm and rapidly change to accommodate new opportunities. From the physics of an SCP, it is easy to infer that the network structure is most suitable. We briefly trace the evolution of organization structure in SCPs.

8.1 FUNCTIONAL ORGANIZATION STRUCTURE

Various activities of the SCP have been traditionally viewed as support activities in functional organizations. These activities are fragmented, are relegated to lower organization levels, and include jobs such as warehouse managers, purchase managers, and material managers, all operating independently in an "over the wall" fashion. In other words, these supply chain activities were performed without coordination, often resulting in waste and delays. In this case, the relationship with suppliers is strictly cost based, and the intention of all players in the supply chain is to minimize their own cost without worrying about the cost to the customer. Interfaces between the involved organizations are managed without careful attention.

In the 1980s, organizations realized the importance of logistics. Some organizations created a vice president of logistics, under whom purchasing, distribution, transportation, and field operation activities were maintained by managers. Others followed a matrix organization, treating the logistics activity as a project cutting across all functions. Rapid advances in information technology have provided, an impetus for the development of integrated logistics systems. Grouping logistical functions under same authority resulted in improved efficiency and customer service.

In the organizations of the 1990s, the emphasis has shifted from function to process. Traditional changes in organizations shift the balance between centralization and decentralization or realign the operating structures between products, customers, and territories without any redesign of the work flow. With process orientation, the effort is focused on the value-added to the customer.

We discussed the process-based organization structure in chapter3.We briefly consider below the network structure which is most suitable candidates for managing an SCP.

8.2 NETWORK MANAGEMENT

Except in a few vertically integrated enterprises, organizations involved in the SCP are geographically dispersed and are under separate owners. The network organization structure is eminently suitable for supply chain management across organizations. Process management is well suited for management within an organization. The integrator of the SCP is generally the original equipment manufacturer, and he or she will control the movement of material and information throughout the process. In some cases, such as grocery chains and electronic goods, the distributors act as integrators. The organization structure is generally customized to suit the geography of the operation, the cultural traits of the people, and the demographics of the countries involved. The use of information technology to coordinate and orchestrate integrated performance allows work to be distributed across various organizations. Using EDI, electronic kanbans, software agents, and other technologies, one can schedule, coordinate, and monitor work in different organizations, as though the organizations were geographically co-located. A virtual network architecture is best suited to this case. As we mentioned in chapter 3, each of the organizations involved concentrates on its core competence, and the rest of the network supplies other capabilities through alliance partnerships. Different networks can be formed for different products. It is not unusual to find an organization concentrating on its area of competence, and yet being a member of several virtual networks. In this way, the networks will be very flexible and will be able to deliver the customized products demanded by the customers. This structure is essentially an electronic *Keritsu*, a coordinated network of firms that cooperate to deliver quality products to customers. Co-destiny, mutual trust, and information and resource sharing are characteristics that keep all the companies together.

An SCP has several alliances. There are alliances between manufacturer and service provider, between two manufacturers, between two service providers and suppliers and manufacturers, etc. Manufacturers enter into strategic alliance with logistics partners to handle all inbound logistics. Cooperation between airlines, railways, waterways, and trucking companies and their smooth relationship with customs authorities at various ports, airports, and entry points are musts for competitive trade. Railways perform point-to-point long-haul service, and trucks are used for pickup from and delivery to the customer sites.

The crucial point in network-based supply chain management is the alliance partnership. Having clear policies for implementing an alliance and measuring the performance of the alliance are necessary for success. Fuzzy goals, human incompatibility, and an inadequate operating framework, are some of the reasons identified for the failure of alliances. Also, three key activities are vital for long-term stability of the alliance: strategic and operational compatibility, periodic review of the alliance, and two-way performance measurements. The measurements and the frequency at which they are measured is jointly determined. Also, measures such as total inventory, total cost, gains to both partners should be used rather than OEM-biased cost, delivery, reliability, and quality.

9. CONCLUSIONS

The SCP is a very important megaprocess in a manufacturing enterprise. The whole practice of integrated manufacturing, involving interface management between suppliers, distributors, and manufacturers on one hand and the design, manufacturing, and marketing teams on the other, and factory floor material, and information flow integration, is very nicely captured in Figure 8.2. One can derive strategic and operational issues connected with the supply chain network from this diagram.

Facility location in supply chains is a very important problem. We have presented only qualitative descriptions of this problem here. Very interesting mathematical programming and network flow formulations exist to determine the optimal locations for various facilities [3]. Similarly the automation and information technologies, that are useful in streamlining supply chains have been given in this chapter. We have brought out the role of information systems, partnering, and product structure in SCP design and management. Our emphasis in this book has been on measures, measurements, and continuous improvement. Accordingly, we have defined and presented an in-depth discussion on performance measures, benchmarking, and organizational structure.

Several research issues present themselves from our description. Scheduling of supply chains is an important subject. One can use Lagrangian relaxation [74] to obtain rough schedules over a given planning horizon. Determination of performance measures is an important subject. Approximate analysis using queueing networks would be a fruitful area of research [74]. Quick calculations could be made to find the lead time and other measures using series–parallel graphs [77]. A network organization structure seems to be best for supply chain management. Information sharing among the partners is a big issue and needs further research.

In chapter 5, we have identified five levels of a business process. More studies—both conceptual and real world case studies—are needed to identify the five levels for the SCP and develop methodologies for transiting from one level to the next higher level. Also, there is a tremendous need for developing methodologies for the design of SCPs themselves.

10. BIBLIOGRAPHIC NOTES

Several books have been written about supply chain management—for example those by Christopher [11], Bowersox and Clos [5], Poirier and Reiter [70], Copacino [17],Handfield and Nicholos [43]. Our emphasis here has been on on performance measures and measurement systems. A treatment of performance measures is also available in [5, 11]. Bowersox and Clos [5] also deal with the emergence of new organization structures in the supply chain and logistics context. The research issues detailed above in the conclusions are treated in a number of papers by the author and his co-workers. Electronic commerce is an exploding field. Several companies have sprung up in various countries for business-to-business commerce or business-to-consumer commerce. One can find lots of up-to-date information by searching the Internet using appropriate key words. The collaborative planning, forecasting, and replenishment (CPFR) initiative is designed to bring full-blown, network-enabled data sharing to warehouses, suppliers, manufacturers, and retailers. It is the vision of DAMA (demand activated manufacturing architecture) to connect all stakeholders of U.S. textile industry through use of e-commerce tools. References and information can be obtained easily from the Web.

Chapter 9

EPILOGUE

We would like to conclude this book with a description of problems for future research and possibly material for another book.

Starting with the definition of a manufacturing enterprise in chapter 2, we went on to dwell on the principal issues of organization structure, performance measures and measurement, and enterprise design in chapters 3—5. In chapters 6—9, we discussed in detail three important value delivery processes of a manufacturing enterprise: the new product development process, the supply chain process and the order-to-delivery process. Wherever possible, we cited real-world examples and also presented abstractions of the real world using flow charts or block diagrams. We also presented numerical examples. This is an important first step towards the development of mathematical models and the analytical tools based on them. We also introduced several topics with a research flavor. The business process decomposition in chapter 2; the network organization structure in chapter 3; the lead time, variability, and flexibility issues of business processes developed in chapter 4; the performance measurement and control system, the five process levels and the enterprise design of chapter 5; and the event tree analysis of new product development process, the performance measures for the supply chain process, and the control system for the order-to-delivery process are a few of those topics. We expect the reader to be confident about the physics and the rough-cut analysis of manufacturing enterprises and ready to embark on analytical and simulation modeling studies. Further, we hope that this book will provide an analytical foundation for the business process-based analysis of manufacturing enterprises. This is important because of the widespread acceptance of process-oriented organization structures, process-oriented enterprise re-

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source planning systems such as SAP, BAAN, PeopleSoft, and Oracle, etc.

1. MODELING MANUFACTURING ENTERPRISES

A manufacturing enterprise is a complex interconnection of independent organizations that have come together towards the common goal of delivering value to the customers. There is the information flow among the constituents as dictated by the organization structure and the end-to-end material flow as dictated by the product structure. The enterprise has facilities that are highly capital intensive, and some subsystems are also human intensive. For the enterprise to be competitive, its critical value delivery processes have to be effective, efficient, and optimal in cost, lead time, and quality. Mathematical modeling provides a systematic foundation for decision making at strategic, tactical and operational levels. This book provides the background physics that serves as a prelude to mathematical modeling. The mathematical models can then be used to compute the performance measures and also to determine the effectiveness of various control and scheduling policies.

There are several levels at which decisions are made for all business processes: at the strategic level, the tactical level, and the operational level. For example, in the case of a supply chain process, the strategic-level decisions include facilities location, facilities creation and their capacities, policy regarding customization and service levels, introduction of new technologies, customer acquisition, supplier partnerships, etc. At the tactical level, the issues include customer identification, scheduling production onto supply chain facilities, load leveling, etc. The operational-level decisions include which order should be processed at each of the facilities, which facility the order should visit for next operation, how to react to breakdowns of facilities and logistics, how many orders to accept, etc. Effective supply chain management involves addressing issues at all three levels simultaneously. We discussed this issue very briefly chapter 8.

The models useful at the strategic level—for example, for supply chain facility location—are nonlinear integer programming models [3]. Similarly, capacity planning models are also nonlinear integer programming models and are solvable using Lagrangian relaxation [74]. Several other optimization problems can be posed and solved. Operational-level decision making and optimization are conducted using discrete event models.

Manufacturing enterprises are discrete event dynamical systems (DEDS) in which the evolution of the system depends on the complex interaction of the timing of various discrete events such as the arrival of components at the supplier, the departure of the truck from the supplier, the start of an assembly at the manufacturer, the arrival of the finished goods at the customer, payment approval by the seller, etc. The state of the system changes only at discrete events in time. Over the last two decades, there has been a tremendous amount of research interest in this area. There are several classes of models that are useful in this context. These models can be used for either qualitative or quantitative analysis. Qualitative analysis yields results on stability [59], deadlock analysis [92], etc. There are several methods available for this kind of analysis using Petri nets, queueing networks, etc. While these are fairly well developed in the manufacturing context, in the supply chain context the research is nascent. Reliability of information transfer and security aspects of communications are very important since they can cause system breakdowns, stability problems, and deadlocks. Quantitative methods, on the other hand, highlight the determination of system performance measures such as throughput and lead time. Markov chains are fundamental models for DEDS. Petri nets and queueing networks are higher-level models. Discrete event simulation is a very general method and is widely followed.

1.1 PERFORMANCE MEASURES

There are certain generic measures using which the performance of an enterprise can be described. These are financial and operational measures. The operational measures include lead time, quality, flexibility, asset utilization, capacity, reliability, and cost. These measures are interrelated, and their importance is dependent on the type of the business process and also the competitive advantage. We pose below some typical performance questions useful in the enterprise context for each of the three important value delivery processes.

Supply chain process: We have dealt with this process in chapter 8. Some of the important operational questions that can be answered using either simulation or analytical models include the following:

1. What is the probability of delivery of a product to the warehouse?

2. What is the demand allocation to suppliers and logistical partners so that variations in lead time and product performance are minimal?

3. Which orders and how many to accept?

4. What route should be chosen to fulfill the order?

5. How should orders be onto facilities, taking into account the capacity of the facilities?

6. What is the effect of sudden spikes in customer demand on upstream flow rates and inventories? How does this vary with the information-sharing pattern?

7. What is the effect of closing or opening a warehouse or changing the distribution architecture or directly supplying the customer?

8. What is the cost–benefit analysis of outsourcing the logistics to a third party?

A host of other questions can be raised and answered. We are also interested in studying the effects of the interface dynamics, such as the effects of vendor-managed inventories, concurrent engineering practices, automated material handling, joint inspection of product by suppliers and manufacturers, etc. As we mentioned in the text, the supply chain process is a megaprocess, and there are hundreds of questions concerning work processes, interface processes, technologies, and best practices that can be posed, modeled, and answered.
Order-to-delivery process: In this case also, we can resolve several performance related questions such as;

1. What is the probability of complete order-fill of a typical order?

2. What is the delivery reliability?

3. What is the probability of delivering a rush order, and what is its influence on lead times of other orders?

4. What is the impact on performance if one becomes a partner in an extranet?

5. What is the effect of logistics on delivery performance?

Here also one can write down a ODP hierarchy and pose questions relating to interfaces and work processes such as warehouse picking and packing or the use of EDI for order communication.
New product development: This process is more long term and is also more intellectual than routine. We have defined the lead time, flexibility, and other measures for this process in chapter 6. Here the issues of simulation could be more concerned with project management and resource sharing. One can pose questions such as the following:

1. What is the influence of cross-functional team management on the lead time of the NPDP?

2. What is the influence on the lead time of scheduling projects at resource centers?

3. How does one reduce the variability of the NPDP and its constituent subprocesses?

4. What is the total cost of the NPDP, taking into account supply chain costs?

5. What is the influence of iteration probabilities on the lead time?

It is instructive to develop the NPDP hierarchy diagram (similar to Figure 2.5) and the use Figure 2.11 to write down other performance questions.

1.2 MODELS OF VALUE DELIVERY PROCESSES

Performance evaluation of value delivery processes is concerned with the determination of the performance measures from mathematical models. As we mentioned before, the value delivery processes are DEDS, and the tools for performance evaluation vary from series–parallel graphs to complex queueing networks. In general, the value delivery processes have a number of facilities or service centers that deliver work in the form of components, subassemblies, assemblies, transport, storage, etc. Thus, a typical value delivery process is a generalized queueing network with forks and joins. The facilities or service centers act as delay elements before which work queues up, gets processed, departs to the next facility and finally goes out of the system. In the supply chain context, the primitive work-flow elements include (1) serial or causal flow, (2) iteration, (3) AND join, (4) OR join, (5) AND split, and (6) OR split. Figure 9.1 depicts these, using Petri net notation (see [96]).

1. **Causal or serial flow:** The work flows according to a precedence relationship.

2. **Iteration:** The work reenters the same facility several times either for reworking after inspection or for next-stage processing, as in the case of semiconductor manufacturing.

3. **AND join:** This is basically an assembly kind of operation where an event is triggered by the availability of two or more subassemblies. In the Petri net notation, the assembly operation starts only when all subassemblies are available, i.e., the transition fires only when there are tokens in all input places.

4. **OR join:** A manufacturer sourcing a component from two independent suppliers is an example of an OR join.

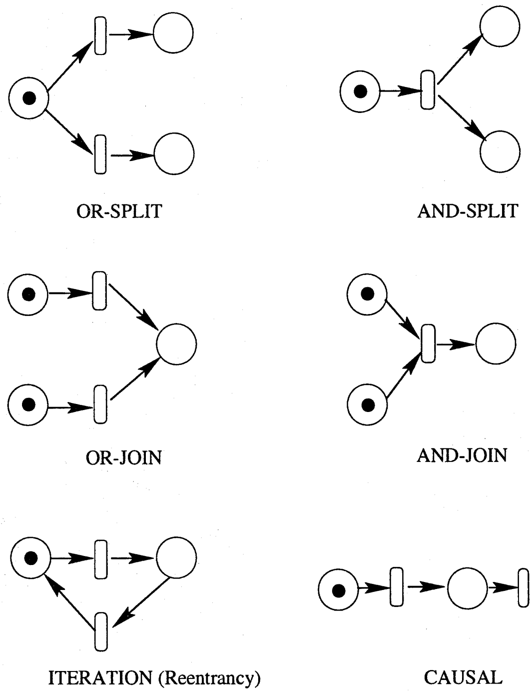

Figure 9.1. Petri net primitives for supply chain modeling

5. **AND split:** The same product being supplied by a manufacturer to two different distributors can be modeled as an AND split.

6. **OR split:** A standard product supplied to two or more distributors who customize and sell it is a typical OR split situation.

The above six primitives arise in information flow modeling as well. For example, an AND split models the situation in which a manufacturer orders subassemblies from different manufacturers. It would be a good exercise to represent some typical value delivery processes using the above primitives. By using these primitives, one can construct either simulation models or analytical models for conducting performance analysis.

1.3 SIMULATION MODELS

Very attractive higher-level general-purpose simulation packages are now available that can faithfully model the value delivery processes of a manufacturing enterprise. These include SIMPROCESS, PROMODEL, and TAYLOR II, to name a few. In a typical value delivery process simulation, synthetic random inputs are used, and the simulation generates corresponding outputs. Several output samples are collected for statistical analysis. Most of the commercial packages have statistical output analysis routines.

The simulation of a value delivery process involves developing a simulation model, coding it, validating it, designing the experiments, and finally conducting a statistical analysis to obtain the performance measures. The simulation model for a supply chain, for example, should contain the submodels of all organizations and their functions, including all the interfaces between the work processes, functions and organizations. The supply chain decomposition diagram of Figure 8.2 would be very helpful in this context. Most simulation models ignore the interfaces, primarily because of the vagueness involved in their modeling management. It is very important to develop a model for the interfaces, however crude it may be. Another issue that is not frequently addressed is the effect of the organization structure on the performance of a value delivery process.

The systems analyst has to first decide the objectives of the simulation experiment. This would determine which organization/facility/interface has to be modeled in detail and which in an aggregate manner. Modeling the entire supply chain process and all its constituents at the same level of detail may not be warranted and would be highly expensive. Hence a library of submodels of various organizations, functions, work processes and interfaces would be useful for the analyst to choose from, in order to build an appropriate model depending on the performance issues to be addressed. Hence simulation analysis of value delivery processes is not a homework assignment but has to be carefully planned and executed. There is a tremendous need to build a library of submodels, as mentioned above, for all the important value delivery processes.

1.4 ANALYTICAL MODELS

The models that we have shown in Figure 2.5 and Figure 8.2 are acyclic graphs. The other three modeling techniques useful for analyzing business processes are Markov chains, queueing networks, and Petri nets, or a combination of them. Our aim here is to show feasibility and summarize various techniques.

Series parallel graphs: Series parallel graphs can model any value delivery process by assigning probability distributions to the lead time of the activities in the graphs. These are graphs, showing the precedence and concurrency of the activities of the material and information flow. Their nodes represent the activities and the edges the precedence relationships [77]. Assuming that all the activities are statistically independent, one can determine the mean and variance of the lead times, throughputs, etc.

Markov chains: The use of Markov models in the study of performance of manufacturing systems [92] is well known. Smith and Eppinger [83] have studied design iteration in NPDPs using Markov models. Direct modeling of any value delivery process as a Markov chain would be very difficult and expensive.

Petri nets: It is easy to write down a Petri net model for the value delivery processes. These are similar to modeling work flow management systems. Vander Aalst [96] presents higher-level Petri net models for logistic system modeling. Faithful modeling of iteration synchronization, forks, and joins that arise in value delivery processes is possible using Petri nets. Numerical solution, however, may turn out to be a nightmare. Aggregation of Petri nets and hierarchical modeling may provide a tractable way of handling largeness here.

Queueing networks: The most general situation in a value delivery process can be modeled as a fork-join queueing network model with iteration or reentrancy. An analytical solution of these general models is not available, and approximations are available in only special cases. Some solutions can be found in [74]. This is an area of active research. Several preliminary results on quantitative evaluation of reengineering methods are available in [6].

2. WORK LOAD MODELING

A topic of tremendous importance is the modeling of work load in terms of the probability distributions of various arrival processes of final products, components, and subassemblies. Generally, Poisson arrivals of orders is assumed in most simulation exercises. Most advanced countries have computer-controlled enterprises, stores with facilities for monitoring the point of sale information, logistics operators tracking customer orders on the internet,etc. Data warehousing and data mining are important issues. We saw in chapter 8 that the forecasting of the demand is the most important issue in the business world. Improving the accuracy of forecasting by using the most recently collected data as well as other economic indicators is an important research issue.

3. CASE STUDIES

Manufacturing enterprises are very common, and they exist worldwide. We tried to address issues relating to the physics of enterprises. There are several case studies available on supply chain management, order processing, reengineering, and new product development from leading business schools. It would be very instructive to identify and develop case studies for each region in the world to study the functioning of the enterprises with respect to cultural, currency, and technology variabilities. This information can be used to develop mathematical models for scheduling and so on. This is a tall order but needs to be done.

4. CONCLUSIONS

In conclusion, we would like to point out that rapid advances in technology, shrinking of product life cycles, emergence of demanding and knowledgeable customers, and the lifting of barriers between countries are making global manufacturing the only strategy for survival. To cope with the complexity of the enterprise, modeling and decision aids are a necessity to make informed and sound decisions. As a prelude, one needs to understand the physics and undertake the mathematical modeling. Our book is written precisely to fulfill this need.

Chapter 10

EXERCISES

Chapter 1

1. Map the manufacturing enterprises for the PC, TV, and furniture industries. Also, identify what constitutes the competitive advantage for each industry..

2. Enumerate the difference between data integration and enterprise integration that we outlined in Figure 1.2 of chapter 1. Visit the websites of SAP, BAAN, Oracle and other ERP vendors to explore this topic further.

3. Describe the information flow in a functional organization for a typical procurement process in a company.

4. Several advances must have taken place in auto, food, and apparel exchanges. Our description is very sketchy. Collect information on these and other exchanges.

5. Identify the information technologies suitable for business-to-business and business-to-customer communications (see Figure 1.2)

Chapter 2

1. We have traced the history of manufacturing by focusing on the type of competition. Search the literature to write the history of manufacturing based on technology innovations.

2. A customer goes to a formal dining place with valet parking and reservation facility. Write a flow chart beginning at the time the customer calls for reservation and ending when he/she leaves the

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restaurant. Can you identify the processing time and cycle time of each of the activities?

3. Identify the core business processes in (a) a hotel, (b) a hospital, (c) a restaurant, and (d) a superstore such as K-mart or Wal-Mart.

4. Identify the core business processes for an automobile manufacturer and a software company.

5. The hard disk drive industry is an intermediate product industry with big customers. The customers insist on customization, cost cutting, and on-time deliveries. Most companies are not virtually integrated, so they outsource the head, disc, electronics, and motor. The suppliers are almost always on a different continent. Identify the critical business processes, given that the industry goes through tremendous technology changes.

6. The value chain of Porter [71] is very similar to the supply chain process. Compare the value chain and the supply chain process for an aerospace industry such as Boeing.

7. Write down the flow chart for the order-to-delivery process of a mail order PC dealer such as Dell computers and a mail order bookstore such as amazon.com.

8. A pizza place has a home delivery facility. It has several varieties of pizzas with a wide variety of toppings. Draw a flow chart for the delivery process. Can you comment on the concurrency of the activities?

9. Categorize the supply chain process into various types. There are serial processes as in the process industry, wherein all activities proceed sequentially through the participating functions and organizations. There are assembly processes as in the aircraft industry, and there are divergent processes where a large number of products are manufactured from a few raw materials, as in small motors. Develop the flow charts for all these processes.

10. Develop the product business process matrix for a new product development process in an automobile industry and for a IC chip manufacturer.

11. Identify the core, support, and managerial processes for an insurance company and an electric utility.

12. An order-to-delivery process system consists of an order processing subsystem, a retailer, a distributor, and a manufacturer and his or

her suppliers. The orders arrive at the order processing system, which does a credit check and passes it on to the retailer, who fulfills the order if he or she has stock on hand. Otherwise, the order goes to the distributor. If the distributor has stock ready on hand, then the order is processed. Otherwise, the order goes for manufacturing. Assume that the manufacturer has two suppliers, who supply the subassemblies. Assume that the orders are processed on a first-come-first-served basis. Draw a flow chart describing the activities of the order-to-delivery process.

13. A local pizza restaurant wants to reengineer its home delivery process to meet competition. The aim is to deliver a great-tasting hot pizza to customers in half the time as competitors, i.e., 10 minutes. Currently, customer orders are taken by phone, the chef assembles and bakes, and the driver delivers. This takes about 30 minutes, even for the best competitors. In a brainstorming session, it was decided to use a van with a freezer containing preassembled pizzas and an oven. This would cut the delivery time. Describe the new process of delivery and flow chart the process. Identify the process measures and new organization structure.

14. Describe the interface process between manufacturers and suppliers in a typical enterprise. Note that typically the process must include the procurement process of the manufacturing company, the delivery process of the supplier, and the logistics. Identify the issues at the strategic, tactical, and the operational levels.

15. Describe the interface process between OEM and other stakeholders in a new product development process.

Chapter 3

1. Explain the difference between mechanistic and organic management systems.

2. Communication is an important issue in organization design. Discuss how information technology influences the organization structure.

3. A greeting card company produces 50,000 different varieties of cards. It has on its payroll many several creative staff: 700 writers, artists, and designers. The Internet provides sites for mailing personalized greeting cards with animation. What organization structure would you suggest: functional, product, customer group, geographic area, or some other structure?

4. Hybrid structures are common in large corporations. Why?

5. Which is more responsive in decision making: tall structure or flat structure? Why? Consider two organizations, each having 15 members, with the tall structure having four levels and the flat structure having two levels. The organizations have to decide on the shipment of goods to be ordered from its suppliers. The organization members have to estimate demand, analyze inventories and back orders, etc. For the tall structure, the decisions have to pass through several levels, whereas the flat structure requires more coordination time. Do you think the tall structure permits a more orderly communication process? Suppose the task is changed to innovative product development. Which structure would be better?

6. Search the literature and the Internet for Benetton, IKEA, Mark and Spencer, and Wal-Mart. In each case, what is the kind of organizational structure in terms of supplier relationships?

7. Every industry has a supply chain process, a sequence of work processes that transform raw materials to end products. A virtual corporation consists of independent companies that perform activities along an industry's supply chain with an integrator. What type of communication pattern among partners promotes effective functioning?

8. Discuss a suitable network organization structure for an Internet service provider, the banking industry, a software company and the construction industry.

9. Using decision tree analysis, find the right organization structure for a software company. (See Robert Duncan, What is the right organization structure? *Organizational Dynamics*, Winter 1979, p 429.)

10. Using queueing network theory, develop models for each of the organization structures discussed in this chapter (see Malone [64, 63, 62]).

11. It is known that redundancy increases reliability and cost. Discuss this in the context of organizations. Identify the type I and type II errors in new product development and supply chain processes (see [52]).

Chapter 4

1. It is often said that low lead time leads to higher quality and higher levels of customer service. Can you put forward an argument in favor of this idea. See [86].

2. Little's law states that lead time multiplied by the order arrival rate will give the total average inventory in a supply chain. Using the supply chain diagram Figure 2.9, can you argue the implications of this law for a make-to-order supply chain process?

3. Compute the lead time in the following supply chain. In a company, an order goes through on average six stages. The average batch size accepted is 25. The first stage (order processing) and last stage (transportation to the customer) are independent of the batch size. On average, order processing per order takes about 4 hours, and the transportation to the customer takes about 8 hours. In the second, third, fourth, and fifth stages, the processing time per item is 36 minutes. In all six stages, each order has an administrative delay of 2 days to determine who should handle it, 4 days waiting to be processed, and about 8 days for inspection and moving to the next stage. Determine the cycle time per batch. Also determine the ratio of cycle time to processing time.

4. The PC is a product that is being bought by several homes. A survey of the PCs available in the market generally looks at the storage capacity, speed, brand name, etc. What costs do you consider significant in making a PC purchase decision? In other words, what is the total cost of ownership?

5. Discuss the following statements:

   a. Substituting information for inventory is the best way to create lean supply chains.

   b. The competition is between supply chains but not companies. Hence, attention should be given to total process lead time and total cost.

   c. The real focus in a supply chain should be to minimize the non-value-adding activities.

6. A perfect order is delivered on-time, complete, and error free. Thus the perfect order achievement is measured as the product of probabilities of on-time delivery, complete order fill and defect-free delivery. Discuss this with reference to the order-to-delivery process.

7. Sketch the capacity diagram for a paper mill or a steel plant. Discuss the bottleneck issues.

8. An interface process between two organizations generally consists of the delivery process of the seller, the procurement process of the

buyer, and third-party logistics. Map these three subprocesses and define the lead time of this interface process. How do things change when the three stakeholders are in alliance?

Chapter 5

1. Discuss the changes to be made in core business processes and performance measurements in the following cases:

   a. An electronics company makes large batches of electronic components to customer specification with an emphasis on cost. The mission statement changed to JIT shipments of greater variety of parts, with emphasis on delivery and variety and customer-oriented thinking.

   b. A ball-bearing manufacturer changed its mission statement to "providing trouble-free operations" for the customers–instead of selling them bearings.

2. The final work process in a package delivery process is delivering the package from the local office to the customer. Define the performance measures, lead times, defects, variety and cost for this subprocess.

3. Develop the balanced score card for an airline. Note that revenues and cash flow are crucial for success. Customer measures include the ability to attract and retain passengers, which is dependent on punctuality. The key business processes for maintenance of punctuality include turnaround time for unloading, refueling, loading, and maintenance checks. Learning measures include reduction of turnaround time, etc. (see Hazell and Morrow [51]).

4. A logistics provider picks up a batch of parts from a supplier and delivers it to an assembler, and after assembly picks up the batch and delivers it to another plant. Compute the lead time. Note that the lead time generally consists of waiting time, setup time, processing time, move time, down time, and repair time of the resources. The lead time for each part is to be measured. Suppose it is decided to charge the manufacture of each product in terms of the resources it uses. Can you suggest a measurement system for measuring lead time, cost, and defects.

5. Consider a supply chain process. There are interfaces between the manufacturer and suppliers. Can you suggest a measurement system to compute the effectiveness of the relationship in terms of delivery reliability and flexibility? These are the derived measures. Indicate how

you can compute these from the four fundamental measures;leadtime, cost, variety, and defects.

6. The procurement process is important in a supply chain. A typical manufacturer sources 10–15 subassemblies from suppliers. Describe the five capability levels for this process.

Chapter 6

1. The concept of heavyweight and lightweight project organizations is articulated in [50]. Discuss these structures with reference to the organization structures presented in chapters 3 and 6.

2. Wheelwright and Clark [98] describe a funnel model for product development. (see also [90]). Can you interpret funnel model as a stage–gate model.

3. Identify the business process hierarchy for an NPDP? (see Figure 2.5).

4. Quality function deployment is a methodology to translate customer needs into a set of technical specifications [48]. Through an example, illustrate how QFD acts a methodology to smoothen the organization–customer interface.

5. Design for assembly and design for manufacturing are very important methodologies. These will ensure that the designs lead to a manufacturable, low-cost, high-quality product. This is well illustrated in Figures 2.5 and 8.2. Basically, these methodologies provide techniques for interface management. Can you then write down some general principles to be followed in managing functional and/or organizational interfaces? (see[4, 25, 90]).

6. There are two ways of modeling software development: the waterfall model and the spiral model [55, 101]. Can you flow chart these processes and find the cycle time?

7. Develop the five levels for the product development process.

Chapter 7

1. Write down the business process hierarchy diagram for an ODP between two businesses. Identify the organizations and the interfaces.

2. Write down the flow chart of a pizza delivery process. What performance measures do you suggest?

3. Describe the business to consumer ODP of a mail order store such as Dell computers or amazon.com bookstore. Design a process-owner based organization structure for the ODP of a catalog store.

4. Suggest a performance monitoring system for a hard-disk-drive manufacturer and a software developer.

5. Decisions for offshore manufacturing are often done with cheap labor in mind. If you want to make these decisions based on ODP and SCP costs, what are the dominant considerations for the location of various facilities? Take currency value into account.

6. Describe the five levels of ODPs . Identify the methods useful for transiting from one level to another.

7. Identify the benchmark in ODP. Collect two case studies of ODP (one each) for a manufacturing company and a service organization.

8. Identify the technologies that can be used in each of the ODP activities.

9. A company wants to make ODP a core capability. Identify the core competencies in each of the work processes, and describe how you can make ODP a core capability.

10. Identify enablers and best practices in ODP.

11. Draw a fishbone diagram for failure to deliver on time, assuming four causes: carrier performance, stock-out, quality problems, and poor SCM. The poor carrier performance could be due to inefficient scheduling or poor communications. Stock-outs could be due to capacity constraints, and poor production scheduling. Quality problems could be due to poor process control and supplier management. Finally, poor SCM could be due to poor forecasting and poor interface management. Draw the fishbone digram. Discuss the critical performance measures to be monitored.

Chapter 8

1. Classify the supply chain process into the five levels we discussed in chapter 5(see Figure 5.5).

2. Determine the lead time for the following supply chain networks:

   a. A pipeline chain

   b. Assembly structure (see Figure 8.10)

c. Diverging structure (see Figure 8.9)

d. Network structure

Assume that the lead time of each of the activities is normally distributed.

3. In supply chains, as in manufacturing, show that the following relationships hold:

   - Low lead time ⇒ greater flexibility
   - Low lead time ⇒ low cost
   - Low lead time ⇒ high quality ⇒ high reliability
   - Low lead time ⇒ low capital assets or high asset utilization
   - Low lead time ⇒ high profitability

4. In the manufacturing strategy context, Hayes and Wheelwright have developed the process–product matrix. A corresponding notion also exists for the business processes and their outputs. Develop a business process–product matrix and the volume–variety diagrams for important business processes such as NPD and the SC.

5. Develop the business process–product matrix for a supply chain processes in the case of (a) the disk drive industry (b) the car industry and (c) the PCB industry.

6. In a pipeline supply chain, inventory can be maintained at the supplier end, at the manufacturer end, or at the logistics provider. Discuss the cost–time issues for each of the alternatives.

7. Map the supply chain for a paper mill. Transportation generally is said to be a bottleneck in this industry. Can you justify why?

8. Consider the pipeline supply chain. Let s, m, and d represent the processing times at the supplier, manufacturer, and the distributor respectively. Also, let f and g denote the delivery times between the supplier and manufacturer and between the manufacturer and distributor. Find the inventory along the supply chain.

9. A supply chain has one assembler, two subassembly suppliers, and two component suppliers for each of the subassembly suppliers. Represent the supply chain by an acyclic graph. Find the supply chain lead time, assuming 2 weeks delivery time between all members of the chain. Suppose all lead times are random; write down an expression for the distribution of the total lead time.

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