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Design and Operation of Flexible Manufacturing Networks

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SUMMARY

Nowadays, the manufacturing companies are dedicated to the production of tangible objects that are high in quality, competitive in cost, meet customers' expectations for performance and are delivered in timely manner. Manufacturing companies have to face constant change and competitive pressures. Competition is marked by volatile demand, shorter product life cycles, globalization, product customization and shorter time to customer. To meet today's challenges, companies are moving away from traditional manufacturing pattern and department structures, to customer and process oriented flexible entities. Finding and achieving the appropriate balance among these criteria, quality, cost, performance, and time to market challenge all manufacturing companies.

One of the most identifiable trends in the fundamental changes that are currently transforming manufacturing industry is the vertical and horizontal integrated value-chain. While some companies are pursuing subcontracting to allow them to concentrate on their customers and core competencies, others are building their businesses by focusing on these out-sourced tasks. Original Equipment Manufacturers (OEMs) are evolving into total solution providers. OME is a company that uses product components from one or more other companies to build a product and delivers it to the customer under its own company name or brand. Collaborations between these two groups are the emergence of Flexible Manufacturing Networks (FMNs) that strongly challenge existing business models and the traditional manufacturing concepts. FMNs have more access to outside information and market contacts, and use both personal contacts and modern communication tools to maintain contacts and information flow. In addition, FMNs develop internal mechanisms needed to ensure cooperation, pooling of information, collective learning, and access to specialized services from local and outside suppliers.

Through firms' cooperation, firms gain access to markets or equipment that would have to had otherwise no access to them, or are able to achieve lower costs than they could on their own. But competition is always present, even among the firms in the network: a firm may choose to work with one firm on one network and with second firm on anther network, depending on which combination seems more likely to succeed at a particular job. FMNs are created to take advantage of market opportunities for particular products in what are often rapidly changing market niches. When market conditions change, FMNs disband and organize in different forms to take advantage of new opportunities.

This thesis seeks to explore the new phenomenon of inter-firm collaborations and to understand in more detail the design and operation of FMNs. It elaborates a conceptual framework for the FMN that consists of manufacturing, storage, transportation and service companies. The FMN is also recognized as an organizational basis for future manufacturing.

The issue is a network management wants to accomplish an order from a customer or the market by exploiting the potential of its manufacturing network. The network

management has to plan and schedule the needed tasks through a FMN composed of manufacturing, storage, and transportation firms. The objective is to deliver the order at a minimal cost within the delivery time allowed by the customer or market. This thesis presents furthermore an approach to the design and operation of the FMNs through the appropriate selection of partners, and also coordinates the tasks among these partners. Therefore, the objectives of the thesis are to:

1. Define the global manufacturing environment and its impact on the manufacturers,

2. Define FMN goals,

3. Cite FMNs design and operation,

4. Establish a configuration and coordination approach for the most appropriate selection of the manufacturing partners,

5. Plan the tasks among the partners for a specific customer's orders.

Therefore:

Chapter one analyzes the economics of manufacturing and the changes taking place in modern manufacturing structure.

Chapter two analyzes the FMNs and discusses their characteristics which are considered one of the new manufacturing trends in the 21 century and the direction of manufacture in new global manufacturing environment.

Chapter three describes the systematic evolution model of the networking, presents past and current practices of the manufacturing processes and its economical

Chapter four presents the FMNs that they are often designed using two dimensions: the configuration and the coordination of the network. The configuration dimension of the network describes the relationship between the different parties in the networks. To enable the study of FMN, there is a need to determine the number of organizations involved in network and also the number of sites that each organization controls. Another important parameter of a network's configuration is the types of organizations. The next step in this analysis is the coordination dimension. The dimension of coordination depends on four parameters, data sharing; operation within the FMN, financial commitments among the partners and the structure of the FMN. Chapter four discusses how FMNs can be designed and operated and it investigates the network strategic objectives and the procedure to establish them.

Finally, chapter five illustrates the configuration and coordination modeling of the FMNs and shows the compounded dimensions which affect the configuration and coordination model. The principle behind these FMNs and the management of their operations is that network management team organizes operations through the exploitation of the capabilities offered by existing manufacturing and logistic firms.

Partner firms are meshed into manufacturing networks mainly because they extend manufacturing capacity and technological knowledge.

Chapter five presents also the FMNs process model and its requirements and description of the steps of constructing this model. Also it explains a list of parameters defining the different planning and scheduling decision processes encountered in FMN, different manufacturing bidding mechanisms which are used to optimally configure and coordinate FMNs for the realization of an order.

This thesis concludes an approach used to formulate the FMNs configuration and coordination process. Finally, an illustrative example is presented to show how the proposed approach can be applied to configure and coordinate FMNs. This illustrative example also sketches the impact of the inter-relationship and the information sharing in FMNs using three different types of bidding processes.

KURZFASSUNG

Die Anforderungen an Produktionsunternehmen sind heutzutage mannigfaltig. Diese müssen hochqualitative Produkte zu konkurrenzfähig Preisen entsprechend den Kundenanforderungen und engen zeitlichen Rahmenbedingungen liefern. Produktionsunternehmen unterliegen im Umfeld steigender Globalisierung einem stetigen Wandel und hohem Konkurrenzdruck bei gleichzeitig schwankender Nachfrage, verkürzten Produkt-Lebenszyklen und erhöhten Anforderungen hinsichtlich Kundenwünsche. Dahingehend ergeben sich Änderungen der Fertigungs- und Abteilungsstrukturen hin zu kunden- und prozessorientierten Entitäten. Die Balance zwischen den Zielkriterien Qualität, Kosten, Leistung, „time to market“ ist für alle Produktionsunternehmen eine Herausforderung.

Einer der stärksten Trends in der Fertigungsindustrie ist die vertikale und horizontale Integration der Werteketten. Während bestimmte Firmen viele Aufgaben auslagern um sich auf ihre Kunden und Kernkompetenzen zu konzentrieren, bilden diese „outgesourceten“ Aufgaben die Basis des Geschäftes anderer Unternehmen. Sogenannte „Original Equipment Manufacturers“ (OEMs) entwickeln sich zu Lieferanten von Gesamtlösungen. Ein OEM ist eine Firma, die Produktbestandteile von einem oder mehren Firmen kombiniert, um ein Produkt zu erstellen und es an den Kunden unter seinem eigenen Firmennamen oder einer anderen Marke zu vertreiben. Diese Zusammenarbeit zwischen diesen beiden Gruppen wird „Flexible Manufacturing Networks“ (FMNs) bezeichnet und stellt eine große Herausforderung für vorhandene Geschäftsmodelle und traditionelle Fertigungskonzepte dar. FMNs haben besseren Zugang zu Informationen von außen und Marktkontakten, dabei benutzen sie sowohl persönliche Beziehungen als auch moderne Kommunikationswerkzeuge, um den Informationsfluss sicherzustellen. Zusätzlich entwickeln FMNs Mechanismen um Zusammenarbeit zu sichern, Informationen zu poolen, das kollektive Lernen und den Zugang zu fachspezifischen Serviceleistungen von lokalen und weiter entfernten Lieferanten sicherzustellen.

Durch Kooperation können die Unternehmen Zutritt zu Märkten oder bestimmten Infrastruktureinrichtungen erlangen, welche ihnen sonst insgesamt verschlossen bleiben würden und oftmals Kostenreduktionen erreichen die jeder einzelnen Firma nicht möglich wäre. Die Konkurrenz zwischen den Unternehmen ist aber immer existent, auch zwischen den Mitgliedern im Netzwerk: Ein Unternehmen kann beschließen, mit einem bestimmten Unternehmen in einem Netzwerk und mit einem zweitem Unternehmen in einem anderem Netzwerk zusammenzuarbeiten, um einen bestimmten Auftrag zu erlangen. FMNs entstehen oftmals um Nutzen aus sich häufig ändernden Marktsituationen für bestimmte Produkte zu ziehen. Wenn sich die Marktlage ändert, lösen sich bestimmte FMNs auf und organisieren sich in unterschiedlichen Formen neu, um geänderte Markchancen zu nutzen.

Diese Dissertation versucht, das neue Phänomen der interorganisationalen Kooperation zu erforschen und die Gestaltung und das Funktionieren von FMNs besser zu verstehen.

Sie erarbeitet einen konzeptionellen Rahmen für FMNs, bestehend aus Produktions-, Lagerungs- und Transportunternehmen. FMN ist auch eine neue organisatorische Grundlage für zukünftige Produktion.

Die Zielsetzung ist es, den Auftrag zu minimalen Kosten innerhalb der Lieferfrist zu liefern, die durch den Kunden oder den Markt gefordert wird. Diese Dissertation stellt ausserdem einen Ansatz für das Design und das Betreiben von FMNs durch die passende Auswahl der Partner sowie die Koordinierung der Aufgaben zwischen diesen Partnern, dar. Die Zielsetzungen der Dissertation sind daher folgende:

1 Definition des globalen Umfeldes von Produktionsunternehmen und deren Auswirkungen

2 Definition der Ziele von FMNs

3 Entwicklung eines Rahmens für Design und Betrieb von FMNs

4 Erstellung eines Ansatzes zur Konfiguration und Koordination von FMNs sowie für die Auswahl von Netzwerk Partnern

5 Planung der Aufgaben zwischen Partnern für spezifische Kundenaufträge.

Kapitel 1 stellt die wirtschaftlichen Rahmenbedingungen und die strukturellen Änderungen des Produktionssektors vor.

Kapitel 2 präsentiert und analysiert FMN und diskutiert ihre Eigenschaften, welche den produktiven Sektor des 21. Jahrhundert im globalen Umfeld prägen wird.

Kapitel 3 beschreibt das systematische Entwicklungsmodell der Netzwerkbildung. Weiters stellt dieses Kapitel vergangene und gegenwärtige Praktiken der flexiblen Herstellung und seiner ökonomischen Effekte dar.

Kapitel 4 stellt die zwei Gestaltungsdimensionen von FMN, die Konfiguration und die Koordination des Netzes vor. Die Konfiguration des Netzes beschreibt die Beziehungen zwischen den unterschiedlichen Akteuren in den Netzen. Um das Studium von FMN zu ermöglichen, sind Parameter über die Anzahl der Organisationen, welche in ein Netz miteinbezogen werden und die Anzahl von Standorten, die jede Organisation steuert, nötig.

Ein weiterer wichtiger Parameter einer Netzkonfiguration ist die Art der beteiligten Organisationen. Der nächste Schritt in dieser Analyse ist die Dimension der Koordination. Das Ausmaß der Koordination ist von vier Parametern abhängig: dem Grad der Informationsweitergabe, die Bearbeitung innerhalb des FMN, die finanziellen Verpflichtungen zwischen den Partnern und die Struktur des FMN. Schließlich präsentiert Kapitel 4, wie FMN entworfen und betrieben werden können und erforscht die strategischen Zielsetzungen und das Vorgehen beim Aufbau derartiger Netze.

Schließlich veranschaulicht Kapitel 5 einen Modellierungs-Ansatz für die Konfiguration und Koordination von FMN und beschreibt die Effekte auf das Konfigurations- und Koordinations-Modell einwirken. Die Grundlage hinter diesen FMN und des Managements des Betriebs ist das Netzwerkmanagement-Team, welches die Geschäfte durch die Ausnutzung der Fähigkeiten der vorhandene Produktions- und Logistikunternehmen organisiert. Partnerunternehmen werden in FMN aufgrund erweiterter Fertigungskapazität und technologischem Wissen aufgenommen.

Kapitel 5 präsentiert auch ein FMN Prozessmodell und entsprechende Anforderungen hinsichtlich des Aufbaues dieses Modells. Anschließend wird eine Liste der Parameter, für die Ablauf- und Terminplanung in FMN, unterschiedliche Angebotsverfahren dargestellt um optimale Konfiguration- und Konfigurationsbedingungen zur Realisierung eines Auftrages zu schaffen. Weiters versucht die Dissertation einen Ansatz zur Beschreibung des Konfigurations- und Koordinationsprozess zu liefern. Schließlich wird in einem illustrativen Beispiel dargestellt, wie der vorgeschlagene Ansatz angewendet werden kann, um das FMN aufzubauen und zu koordinieren. Dieses Beispiel zeigt auch die Auswirkung der Beziehungen und Informationen auf, die in dem FMN bei drei unterschiedlichen Arten von Angebotsprozessen auftreten.

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INTRODUCTION

1.1 Background

There are many factors which accelerate the shift in manufacturing structure during the 1970s. This shift was away from a mode of traditional industrial structure which had been in a dominant existence since the early part of the century. There was essentially a revolution by workers against the assembly line mentality of work and production. Concurrently, there was a rise in the price of raw inputs that increased the cost of manufacturing significantly for many businesses. The formerly dominant mode of manufacture structure for at least half a century was the mass or volume production **[9]**. It was introduced by Henry Ford through his development of the first moving assembly lines at the beginning of the twentieth century. Mass production served to displace the craft based type of production which had been the leading manufacturing structure at the end of the nineteenth century.

There was a clear change taking place in modern manufacturing arrangement by the end of the 1970s. Mass markets had begun to break up as consumers became of standardized products; industries met inherent technical barriers, such as production line problems and the system was too rigid to cope with the uncertainty of the decline. In addition, the world realized, they had reached a point where all the economies had become inherently joined. The new global economy presented many opportunities and dilemmas to the major countries around the world. The trading systems were now on a global scale, and out of the control of one national government. The economies of countries are now in complex manner tied together. The decisions of one nation greatly influence the options available to another.

1.2 The evolution of the economics of manufacturing

Change is ever present in manufacturing. New technologies brought to the marketplace in the form of products and capabilities become part of the platform that manufacturers use to create the next generation of products. New economic conditions, new knowledge about how to organize the manufacturing effort, new consumer preferences, and new manufacturing techniques constantly alter the manufacturing front. In a few decades, manufacturing has undergone a major change with respect to the environment in which it operates, the methods through which it conducts business, and the technologies that support it.

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INTRODUCTION

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The economics of manufacturing is driven by the desire to produce salable finished products at as a low cost as possible while still maintaining acceptable standards of quality, functionality, and timeliness. Fig. 1-1 describes in broad the relationship between unit cost and production volume for three paradigms of production: manual, mass, and flexible. Flexible production has been the focus of recent efforts to apply modern technology in manufacturing **[18]**.

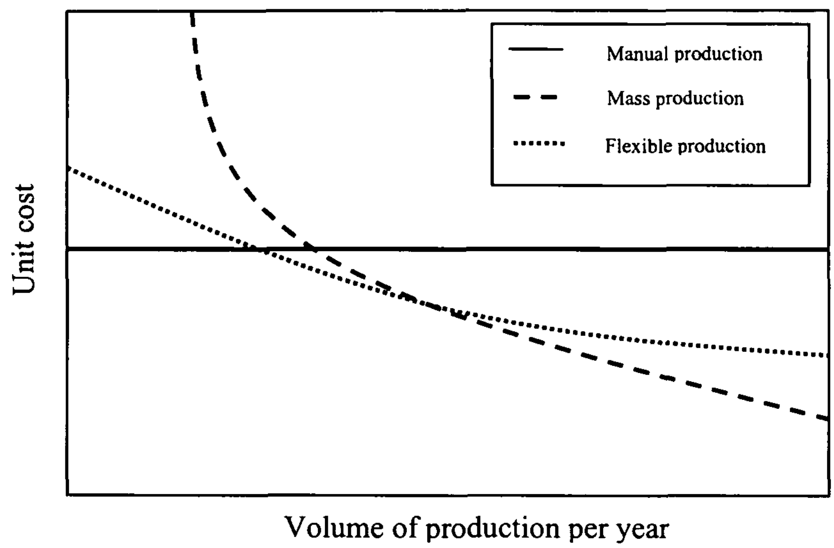

Figure 1.1 Unit cost versus production volume per year

Manual production: Manual production is the earliest paradigm; the transformation from raw material or subassemblies into more valuable final product was carried out by skilled and crafts persons, people who had practiced under expert supervision until they achieved proficiency. These workers performed the entire task of transformation, from raw material to final assembly mostly by hand. In manual production, the cost of production of an item is independent of the production volume, since the dominant cost of production is worker's time in producing the item.

Mass production: During the industrial revolution, economic wealth was determined largely by the capital equipment available to transform raw materials into finished goods. The latter part of the industrial revolution introduced mass production methodology. Specialists performed repetitive tasks in one specific activity, substantially decreasing the cost of finished products. In mass production, a substantial amount of capital is invested in a production line. However, once the facility has been built, the incremental cost of producting an additional unit is that of material and labor, which is small compared to the initial cost of the facility. When the production facility is fully utilized, unit cost is minimized. However, such facilities by assumption produce a single product require long lead times to deploy, and tie up large amounts of capital.

Flexible production: Flexible production is still a goal for all the manufacturing firms. If successful, flexible production lowers both the capital and the time required to arrange the factory for the new product. Indeed, for certain types of products, a new production facility is obtained from a present facility simply by making changes to the software that controls the production processes.

As Fig. 1-1 suggests, manual production is superior to other types of production for those cases in which highly customized product is needed in small volume for which the non-manual production of the product in a factory would require an expensive facility. When sufficiently large numbers of identical products are needed, mass production is generally superior. But the flexible production paradigm seems to be the most economical for medium size quantities of moderately customized products that are needed in a timely manner.

1.3 The new manufacturing orientation

Product quality, more rapid delivery, better asset control and utilization, and the ability to execute more complex manufacturing tasks and build increasingly complex products have come to characterize excellent manufacturers. Manufacturers are now linked directly to their suppliers and consumers. Many retailers collect worldwide sales data every day and modify their suppliers' schedules in response. Products are designed to suit regional styles and needs, even if they are made in other regions. International payments are made in a variety of currencies as materials are purchased, labor is obtained, ships are laden, and products are transported. These business and marketing issues are not usually associated with the more technical concerns of manufacturing, but in fact they are central to its success and enlarge the very definition of manufacturing **[14]**. More importantly, they are very information intensive. Without information-driven links to financial markets, logistics services, and market knowledge, manufacturing businesses would operate in a vacuum or seek blindly to force their output on unwilling customers and ultimately fail.

One of the most identifiable trend in the fundamental changes that are currently transforming manufacturing industry is the both vertical and horizontal integrated value-chain. While some companies are pursuing subcontracting to allow them to concentrate on their customers and core competences, others are building their businesses by focusing on these out-sourced tasks. Original Equipment Manufacturers (OEMs) are evolving into total solution providers, a company that uses product components from one or more companies to build a product and delivers it to the customer under its own company name or brand. Collaboration between these two groups is the emergence of Flexible Manufacturing Networks (FMNs) that strongly challenge existing business models and the traditional manufacturing concepts. FMNs have more access to outside information and market contacts, and use both personal contacts and modern communication tools to maintain contacts and information flow. In addition, FMNs develop internal mechanisms needed to ensure cooperation, exchanging of information, and access to specialized services from local and outside suppliers.

1.4 The importance of flexibility in manufacturing

Flexibility is an attribute not only of the network, but also of the firms and their manufacturing styles as well. Neither firms nor networks are unchangeable, and neither will necessarily exist in one particular form indefinitely, even when successful. The goals and components of the network or a firm will evolve flexibility over time, if allowed. They need to be flexible in trying new response to the customer needs **[8]**. The networks most responsive to the customer needs are those composed of firms that implement flexible manufacturing techniques. Flexible manufacturing is a one way to modernize production, and also the ability to shift from one product to another new product following changing demand, and to adjust or quickly switch between products.

1.5 The emergence of FMNs

It is an appropriate to short with general description of the concept FMNs. A network is a form of s strategic alliance, a form of "partnering". A firm can be a member of many networks at the same time, regardless of whether the potential for the networks to complement or compete against one another. A network may be configured in response to certain objective and then dissolve again as soon as the objective is achieved. Occasionally they may be re-configured, perhaps with new partners or a new objective. Some networks may be formed among those who share a common need for a service or piece of equipment. These networks may be considered primarily horizontal, vertical network or both. A horizontal network includes several manufacturers at the same point in the value-adding chain collaborating on filling an order for a final producer or producing a finished product. Vertical networks may be considered primarily in the sense of a chain of value-adding manufacturers. Those Original Equipment Manufacturers (OMEs) or final producers who certify vendors and then work only with those vendors may be considered an example of this type of network.

FMNs are means toward increasing the competitiveness of firms, particularly Small and Medium-sized Enterprises (SMEs). FMNs increase the competitive ability of SMEs by providing cost efficiencies through group services and greater flexibility by combining resources and capabilities in various tasks of manufacturing.

The concept of FMNs is based on the following:

1. Product and process diversification will continue to proliferate at a high rate. There will be a practically unlimited ability to create increasingly customized products, equipment and related applications and new kinds of service industries.

2. To increase their productivity and flexibility, partners will continue their disintegration process, decentralizing their operations as well as globally out-source their component and service needs to well flexible shops.

3. Facing increasing global competition, partners will increasingly benefit from participating in the growth of potentially enormous emerging markets by means

of FMNs and by the use of latest technologies and know-how and production sharing.

1.6 Thesis objectives

This thesis seeks to explore the new phenomenon of FMNs and understand in more detail the design and operation of FMNs. It proposes a conceptual framework for FMNs that consists of manufacturing, storage, transportation and service companies. The FMN is also recognized as an organizational basis for future manufacturing.

The issue is a network management wants to accomplish an order from a customer or the market by exploiting the potential of its manufacturing network. This network management has to plan and schedule the needed tasks through a FMN composed of manufacturing, storage, and transportation firms. The objective is to deliver the order at a minimal cost within the delivery time allowed by the customer or market.

This thesis presents furthermore an approach to the design and operating FMN through the appropriate selection of partners, and coordinates the manufacturing tasks among these partners. Therefore, the objectives of the thesis are to:

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CHAPTER 2

GLOBAL MANUFACTURING ENVIRONMENT

2.1 The change in the manufacturing environment

The manufacturing companies are dedicated to the production of tangible objects that are high in quality, competitive in cost, meet customers' expectations for performance and are delivered in timely manner. Manufacturing companies have to face constant change and permanent competition. Competition is marked by volatile demand, shorter product life cycles, globalization, product customization, and short time to customers. To meet today's challenges, companies are moving away from traditional pattern and department structures, to customer and process oriented flexible entities. Finding and achieving the appropriate balance among these criteria: quality, cost, performance, and time to market challenge all manufacturing businesses. Those companies that are successful in meeting the challenge remain in business; those that not usually disappear. In the manufacturing environment that is changing more rapidly now than in any time before, competing successfully requires manufacturers provide customers with increasingly shorter times between order and delivery and between product conceptualization and realization, greater product customization, and higher product quality and performance, while meeting more stringent environment constraints **[17]**.

Technology has been driving the world toward a converging commonality. It has leveled communications, transport, and travel, making them readily accessible to the world's most isolated places. No place and no one is insulated from the attraction of modern goods. The world has become a global village. For one reason, television and other media have helped to create globally standardized consumer demand. For another, companies can improve processes and products by drawing on talents from different cultures and traditions. The result is the explosive emergence of extremely large global markets for globally standardized goods.

Everywhere consumers want products that are rich in feature, high in quality, low in cost, and independent of who makes them. With increasing "globalization" of manufacturing, strategic manufacturing takes on a new meaning **[34]**. The ability to rapidly manufacture the right thing at the right time and at the right place has become a requirement for survival in a global market where high quality and low price have become mandatory and where new technologies allow for doing things which only yesterday were impossible to achieve.

Since lowest cost and highest quality are not always found under the same roof, or in the same country, more and more companies manufacture in two, three, or more countries, and treat the whole world as their shop floor and market place **[10]**. Like the global village consumers, these businesses are an increasingly powerful constituency for the free flow of goods and services. This creates competition that puts an increasing premium on continues innovation, flexible production runs, and rapid entry in global markets with improved and new products.

These new perspectives require new understandings of the nature of manufacturing environment and the ways in which the required performance can be achieved. Accomplishing these goals will require major changes in current manufacturing practices; such changes include the use of the new and/or more complex manufacturing processes, more of information about these new perspectives to reduce waste and defects and more flexible manufacturing styles.

In general, these new driving forces, global market opportunity, and the new trends of global competition, require a new generation of manufacturing networks beyond the classical physical transformation. The networking characteristics of the new manufacturing system must involve a wide perspective covering interdependent configuration and coordination techniques rather than the traditional focus on separated manufacturing sites.

2.2 The evolution of the manufacturing strategies

Manufacturing strategies may be evolved four evolutionary stages, as shown in Table 2-1. This expresses that different aspects have received attention at different times.

	Stage 1	Stage 2	Stage 3	Stage 4
Manufacturing strategy criteria	Cost	Quality	Flexibility	Time

Table 2-1 Evolution of the manufacturing strategies

In the following sections, the four stages of manufacturing strategy are analyzed in terms of the strategy stages' background, concept and methods.

2.2.1 Cost orientation

Background: The concept of continuous production was introduced in the 1920s; manufacturing entered the cost orientation age **[4]**. At that time, the market for products showed that demand was greater than supply. Therefore, for a company, the most important issue was to try as much as possible to expand its production volumes. In this situation, all a company's products could be sold as long as it could produce them. Because of the customers' unsatisfied demands, the mass production concept eventually occupied a leading position.

Concept: The main purpose of mass production is to reduce cost. Ford established the assembly line for production. He used the concept of standardization and specialization to create a continuous production system, in which the company or plant could achieve managerial and financial economies of scale. The major concept of production, which occupied the production engineer's mind, was economies of scale. If a production system could expand its capacity and could produce mass volume product, it would reduce production costs.

Method: The means of a production technology to achieve mass production is to construct a continuous production line. Mass production was supported by a standardized production flow, standardized parts and specialized production functions. Depending on their success in maximizing these factors, companies could reduce their production costs, set lower prices and thus become highly competitive. The production of the Ford Model involved standard design, special-purpose automation, standardized parts and a flow-type assembly system. It reduced production throughput time and thus was able to increase production volume. Therefore, production costs fell dramatically. This cost orientation manufacturing strategy, although developed in the 1920s, still has a dramatic effect on industry. The concept of mass production or continuous production is still one of the major aims of current manufacturing systems.

2.2.2 Quality orientation

Background: In the demand-over-supply market situation, there is no effective competition. However, after the 1930s, more and more factories or plants were built. The supply of products increased gradually in the market place, and, from the 1950s, because of the progress of production technology on the one hand, and the increase of the supplies of products, on the other, the competitive era increased **[4]**. For competitive reasons, products produced by different factories might have some differentiation to attract customers. The major way to attract customers was quality. If a producer wanted his products to be sold, his products had to be of higher quality.

Concept: The concept of quality grew with the increase in functions and performance requirements, for example, specifications of dimensions and operating characteristics, life and reliability of objectives, safety requirements and relevant standards. Quality has always been considered as a trade-off with cost. In some respects, quality may achieve a competitive advantage over and above cost. Quality could not only reduce cost, for example, by eliminating defects, scrap, reworking and inspections, but could also overcome price competition. The firms with higher quality were able to charge higher price. Consequently, companies began to believe that quality leadership could defeat their competitors in the market, and increase their sales and market share.

Method: There were many quality control methods which were developed by using a control process plan. There was also a statistical method, namely Statistical Process Control (SPC)[1] to control the quality of the production processes. When it had been

[1] Statistical Process Control (SPC) is a method of monitoring, controlling and, ideally, improving a process through statistical analysis. Its four basic steps include measuring the process, eliminating

successfully developed, more and more companies adopted quality improvement programs, such as Total Quality Control (TQC)[2] to improve their product quality.

2.2.3 Flexibility orientation

Background: Since the 1980s, the manufacturing environment has changed tremendously. Mass production, which was induced by standardization and specialization, has retired backstage. A stable environment has been replaced by unpredictable changes of customer preferences and intensive competition in the worldwide marketplace. Due to the change in customers' demands, products have to be renewed continuously, market demand fluctuates and the product life cycle is reduced. Because of greater market segmentation, more kinds of product specification are needed. Because of the progress in production technology, attention has been paid to the application of new production techniques, the changed rate of specifications of parts, the precision of equipment, the velocity of equipment, and the introduction of new materials. Market changes and technological revolution are connected with and affect each other. Technological development follows on market change and tries to meet its new demands, while in turn; it also creates new customer demands, meaning that technology sometimes generates new markets. Companies, therefore, need some measures other than cost based competitive orientation in order to assess their performance.

Concept: The manufacturing system calls for flexibility in order to cope with different kinds of environment variations and the needs of manufacturing process capabilities. Flexibility means the quick production changeover from one part or product to another. Manufacturing flexibility is defined as having the following three aspects:

(1) Product changes: Meaning different kinds of modifications or innovations of part configurations;

(2) Production system changes: Meaning new machines, new production methods, new systems (e.g. computerization); and new operators added to the system;

(3) Demand changes: meaning fluctuations and unexpected variations of demand.

Manufacturing flexibility is a system, when faced with environmental uncertainty, can adapt and respond quickly. Flexibility, therefore, refers to the ability to adapt and respond. Specifically, manufacturing flexibility means the adaptability and response of

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variances in the process to make it consistent, monitoring the process, and improving the process to its best target value.

[2] Total Quality Control (TQC) is quality control in which designing quality into the product or service during its development phase (prevention of defects) is emphasized, rather than inspection and subsequent control of a problem. All departments in an organization which affect the quality of a product or service are involved in TQC.

the system under the restriction of cost, quality and time to ensure the changes of the business environment.

Method: In order to cope with environmental uncertainty, a new competitive model in manufacturing strategies was necessary:

(1) Reduction in delivery time: market competition has become stronger than ever before. The factor of time has become a major issue in manufacturing management.

(2) Product differentiation: Due to the variety of customer requirements, products require a variety of customized specifications.

(3) Increased introduction of new products: product design and process design have become more important, and concurrent engineering has improved co-operation between design engineers and manufacturing engineers.

(4) Increased equipment availability time: For a highly efficient operation of the system and to avoid equipment breakdown, a company should concentrate on the planning and carrying out of total productive maintenance[3].

By using advanced manufacturing techniques to construct a flexible factory, a company can obtain efficiency and flexibility at the same time as it can reduce production lead time, develop new processes, and reduce set-up times. It can therefore produce a wide variety of products at low cost.

2.2.4 Time orientation

Background: Due to the unpredictable turbulence and more and more strong competition in the market place, manufacturing engineers and researchers have had to place increasing emphasis on the time factor. This aspect may be divided into two areas: just-in-time and new products development.

➔ Just-in time (JIT): Since many companies have successfully applied the JIT technique in the late 1980s, not only manufacturing companies but also service companies are paying attention to the time factor in their operations. In manufacturing companies, the main points of JIT manufacturing are that materials, parts and products should be moved to the right places in the right volume and at certified quality at the right time. This concept is summarized as to meet demand instantaneously, with perfect quality and no waste.

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[3] Total productive maintenance is all about preserving the functions of physical assets and carrying out tasks that serve the central purpose of ensuring that the machines are capable of doing what the users want them to do, when they want them to do it. The possible maintenance policies can be grouped under, "corrective" restoring the asset to productive capability) as quickly as possible, "preventive" by a regular maintenance, and "predictive" looking at a calendar and assessing what attention the equipment needs.

→ New product development: In a fast-changing market place, companies are forced to develop new products quickly, because of competitive pressure. If they can develop new products fast enough, they can keep up with the turbulence and shifts in the market place. Companies around the globe are discovering that rapid product development is a huge, untapped source of competitive gain.

Concept: Speed is becoming increasingly essential. Firstly, because of technological progress, companies will have great opportunities to improve in terms of time. Secondly, speed does not always replace other objectives, for example quality or cost, but often supplements them. Therefore, if a company can reduce the time needed, it may obtain other advantages simultaneously, for example in cost, flexibility, dependability, productivity and so on.

Method: By eliminating all kinds of waste, overproduction, waiting time, transport, storage time, and defective goods, a company may be able to meet its customers' needs. Regarding the reduction of product development time, company can adopt computerized aids (e.g. computer aided design/computer aided manufacturing CAD/CAM) and computer integrated manufacturing (CIM) etc. to improve its development potential.

2.3 New paradigm

In the past age of mass or volume production, the relatively small internal markets have been inhibiting industrial diversification and economic growth. There simply was not sufficient demand for most modern products to justify the investment in new local production facilities, special machinery, special tooling and special processes required for any given article.

Presently, adapting to the new paradigm of global manufacturing is by applying high technology with the objective of accelerating industrial diversification and economic growth. The use of Flexible Manufacturing Systems (FMS) makes it possible to produce growing varieties of new products in small batches and thereby overcome the bottleneck problem of small markets **[13]**.

One of the manufacturing paradigms is the manufacturing networking. The basic idea is that the manufacturing of a certain product is organized in a network of partners and these partners form temporary and timely limited collaborative forms. These forms are product oriented and existing and lasting according to the product life cycle. Therefore the partner has two different modes of existence in the network: logical one and physical one. Logically it exists in the sense of time and connectivity: the specific connections and partnerships exist only for certain products and this partner can be a part of several logical production lines. Physically it exists in the sense of real production: the production, of course, is always done at physical sites and by physical machines.

on one hand, if companies expect to gain a core competence, they must take good use of the manufacturing network platform to meet the market needs, and they must take full advantage of the resources in existence. Nowadays companies should share in the manufacturing networks with their own resources (which include information, capital, material and knowledge). They should make global accelerated flow and collocation of manufacture factors into realization. Therefore if customers send out their demand information, the meshed partners in the manufacturing network should corresponding answer to the needs rapidly, and they may design and manufacture the products in a short time. In this way they can strengthen the competence of the whole network.

On the other hand, customers have various requirements such as asking for customizing products, asking for short delivery, and asking for global customized service. Under these conditions a manufacturing network may shorten the design and production period to meet customers' various needs. As a result, the partners in the network can gain high competence by respond to customer requirements quickly. Moreover competition in the manufacturing network under new manufacturing environment may help partners to cooperate with each other closely, and the win-lose relationship of partners is replaced by win-win relationship, in some cases it is replaced by multi-win relationships **[38]**. This relationship of partners can make the best of global resources, global capital, global technology, global market and global service to meet customers' various requirement.

Recently special attention is focused on the high technical industries. The manufacturing networks are important for the growth of high technical industries, and it is important to manage fast product life-cycles (time to market), short delivery times (time to customer) and product variety (flexibility). For example, in the automobile and consumer electronics industries especially, one of the competitive advantages is to cope with relatively fast model changes and customization (beside cost and quality, of course). To manage this economically it is necessary to distinguish the product and production technology life cycles from each other. The manufacturing networking, modern information technology and manufacturing automation (CAD system, flexible manufacturing systems) make it feasible.

2.3.1 The emergence of the network era

The manufacturing environment seems to be entering a new era where traditional manufacturing are being replaced by manufacturing networks of interrelated firms and other actors. This development is made obvious in several ways, which are briefly discussed with the help of Fig. 2-1, describing the different business relationships forming the network concept of a focal manufacturing firm. The vertical and horizontal relationships are obviously interrelated forming complex networks of organizations. This is reflected in the figure through the double-headed arrows connecting various vertical and horizontal actors. The major driving forces of the network are positioned at the outer corners of the framework.

2.3.1.1 Suppliers partnership

The first look at Fig. 2-1 is at the supplier side of a manufacturing firm. Manufacturing firms are increasingly outsourcing their business activities, except those related to core competencies. This externalization of value activities is dependent on creating strong supplier partnerships in those activities that have high strategic relevance for the customer. The externalization process is well documented and lead to hierarchical structures consisting of several tiers of suppliers forming supply chain networks. This process is driven by several factors. The global competition is enhanced by the removal of regulative barriers, forcing firms to increase their operational efficiency. Customers are demanding shorter and more flexible delivery times at very competitive prices. Quality is taken for granted after a decade of total quality management. In response to these demands, firms are creating streamlined supplier networks where each member specializes in the activities (components, parts, and services) where it has a strong core competence. With the help of efficient logistics, enhanced by information and communications technology (ICT), this kind of concerted action leads to shorter lead times. Combined with a Total Quality Management approach (TQM), covering the whole supplier system, these value creating networks can offer better products and services cost-efficiently and with shorter delivery terms.

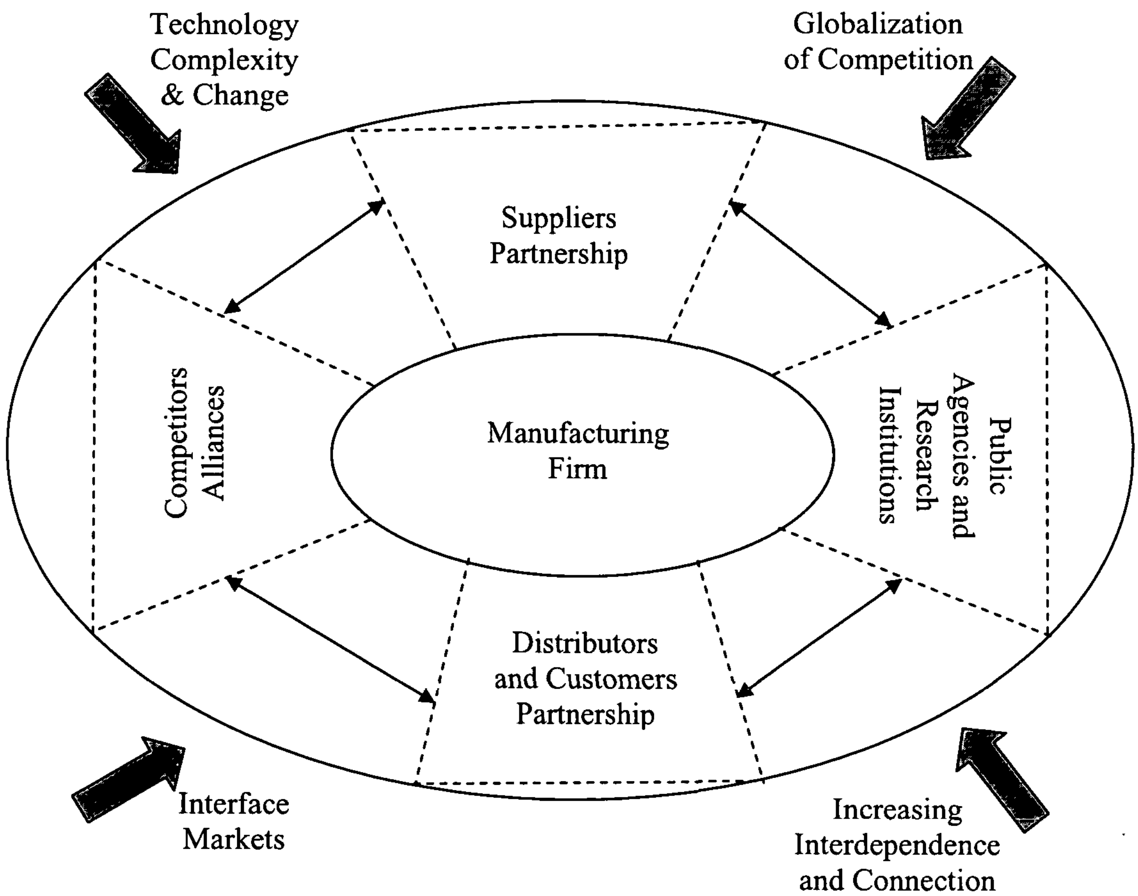


Figure 2.1 Business relationships and networks

2.3.1.2 Distributors and customers partnership

Another aspect of the network era is the changing character of distributor and customer relationships. The globalization of competition increases the difficulty of getting access to end customers. This enhances the position of distributors, who have rapidly organized themselves into powerful chains. The distributors' role is strengthened further by the evolution of customer database management, efficient customer response, and customer loyalty programs, giving the distributors a gatekeeper position between the producers and end customers. To reach the global customers, marketers are increasingly trying to build distributor partnerships where the access and information about the end customers are shared between the marketer and the distribution network.

A new factor in this struggle over the access and management of end customer relationships is the Internet. The Internet can be used to establish direct contact over a widely dispersed set of customers. In this sense, the Internet and the emerging e-commerce solutions may rapidly change the power position between current distributors and marketers and facilitate the appearance of virtual companies that have externalized all value activities (product development, production, and logistics) except branding, customer creation, and customer portfolio management through data-bases. And the standard aspects of the competencies of the virtual company probably will be handled through supplier partnerships when there are competitive service providers.

2.3.1.3 Competitors alliances

The previous discussion has addressed the emerging network character of the management of supplier relationships and distributor and customer relationships. Besides these vertical relations, several types of horizontal relationships are becoming increasingly important. A specific type of horizontal relationship is the alliance between competitors. There are several reasons for the increase of alliances, in spite of their difficulties. The globalization of competition requires a strong presence in the global market. This demands very high investments in marketing and distribution. Another aspect increasing the cost of operation is the advancing technological complexity. Most industries are becoming more knowledge-intensive. Multiple technological platforms are needed to master the development. These pressures on resources and capabilities lead companies to seek strategic alliances with such competitors with whom they have joint interests in some markets and/or product fields, and such goals and competence profiles which are mutually compatible.

2.3.1.4 Public agencies and research institutions

When companies search for learning new competencies and getting access to markets and resources, companies increase the development of horizontal relationships to non-commercial actors such as governmental agencies, universities, and research and social institutions. Some of these are targeted for R&D purposes, as the collaboration with universities and other research agencies, some to influence legislation for the norms and guidelines regulating industrial and commercial action, and some for getting access to regulated markets or industries.

The above discussion presented separately the various vertical and horizontal relationships indicated in Fig. 2-1. In reality, however, companies form complicated webs of relationships that form networks containing suppliers, customers, competitors, and non-commercial actors

The described emergence of the network era is rapidly transforming view of a company. The global scale of operations, enhancing competition, and the complexity of technology is increased even the resource linkages between multinational companies. The electronic channels, together with powerful databases, have facilitated the management of organizational communications. No firm can afford to be a self-contained "island" anymore; learning through relationships is crucial for the fight over the future.

According to the above analysis, a conclusion can be drawn that manufacturing companies face global manufacturing environment. Therefore manufacturing companies should apply manufacturing networks to meet market needs. In this way they can strengthen their competence.

Many researchers may advance their own opinion on the new manufacturing mode to adapt the changing manufacturing environment facing with. For example, some researchers gave an agile network manufacturing mode to sustain the case that quickly research and develop new product and then produce it in a short time **[19]**. They argued that the key factor to determine whether the competence is strength is the ability of new product expeditious development. Some researchers believed virtual company would be widely applied **[20]**. Some researchers studied global supply chain management that can support optimum function in dynamic alliance **[22]**. Some researchers advanced virtual demonstrated factory that included virtual design, manufacture, inspection and some other aspects. They also demonstrated and validated feasibility of virtual manufacturing technique **[36]**. Other researchers researched global manufacturing virtual network system **[15]**. All the researchers argued their own opinion on trend of manufacture in 21 century. They studied new manufacturing mode to enhance competence and adapt to economic environment.

This thesis will analyze the Flexible Manufacturing networks (FMNs) and discuss the characteristics of which are considered one of the new manufacturing trends in the 21 century and the direction of manufacturing in the new global manufacturing environment.

2.3.2 Characteristics of the FMNs

From the above analysis, Flexible Manufacturing Networks (FMNs) are characterized with rapidity and flexibility. FMN is advanced according to its fast response. It sets up dynamic alliance with high efficiency partners and benefits each partner in the network. So it can recombine resources of research, design, production and distribution efficiently. FMNs may combine all the different relationships in it (i.e. the vertical and horizontal relationships). Moreover it can strengthen the partners' ability to reply to customer needs and competence. Today, manufacturing should apply with FMNs and take good use of advanced network technology to share resources of information, capital, technology, knowledge and so on. FMNs may reflect to market requirements quickly and enhance their core competence with short design and production period. However, it is difficult to the manufacturer to meet customers' needs individually with proper cost when outside a FMNs.

The partners in the same FMN may be distributed in different places; they can get orders at the same time from the management of the FMN. They can reflect to the orders as soon as they get it. Then they design and produce the received products or orders and finally deliver at the exact time, and then go to produce the next one in the network. Hence it is rapidity with less design and production period. With the information technology, customers require products with the character of diversification and customization. For example, a customer orders a computer with customized specifications form a computer company. In this condition the company should have flexibility to meet customer's special needs quickly if the company produces computers by itself. However the company may pay high cost to get the flexibility. This high cost must apportion among the computers that customers want to buy. As a result the price of the computer may be very high. If the company is member in a manufacturing network it can take good use of advantages in different places (such as technology, human resources, and geographical location). The company can let different partners in the network produce different accessories and components at the same time. After that the company who owns the trademark of the computer takes charge of assembling the accessories and components, and then finds a partner to distribute the computers. Hence the company may produce computers with high quality, proper cost and short produce period. Computer Company can cooperate with manufacturers who have strength and advantages when the market is changing. Consequently the company can share the needed flexibility to its partners to reduce the production time. In this way the company can provide satisfied products to customers with proper price and short delivery time.

FMNs are created to take advantage of market opportunities for particular products in what are often rapidly changing market. When market conditions change, flexible manufacturing networks disband and organize in different forms to take advantage of new opportunities. A typical procedure to establish a flexible manufacturing network includes the following steps. This will further be explained in detail in the following chapters:

1. An emerging market and/or product idea is identified.

2. A set of firms form a flexible manufacturing network quickly to design and produce this product.

3. Flexible manufacturing network partners communicate frequently and clearly during the process.

4. The flexible manufacturing network determines when the product is no longer profitable.

5. The flexible manufacturing network disbands when this is the case.

6. The firms in the disbanded flexible manufacturing network use what they have learned about partners and processes to form new, even more successful flexible manufacturing networks.

FMNs have the following advantages:

→ More flexible forms of industrial organization seem to be a key to competitiveness in the changing manufacturing environment.

→ Flexible manufacturing networks could lead to new favorable forms of industrial relations that can benefit the region where the networks are located.

→ Each individual firm can focus on their core competency but link with other member firms to produce as much of the final product or service as the customer needs.

→ Member firms establish relationships with each other, facilitating ease of joint project work, and are not locked into rigid structures.

From the above analysis, FMNs present the trend of manufacturing in the new global manufacturing environment. Table 2-2 outlines the general characteristics of FMNs.

Attributes	FMNs
Goals	• Establish new product or enter new market • Geographic dispersion • Business opportunity orientation • Value-adding chain position
Structures	• Order based temporary relation • Dynamic re-configuration • Stable partners • ICT platform and teamwork
Operations (Dynamics)	• Temporary cooperation • Shorter term business deal • Operations coordination • Fast engagement and work • Responsiveness and flexibility • Global out-sourcing

Table 2-2 FMNs characteristics

2.3.3 The competence of FMNs

Small and Medium Enterprises SMEs embedded in various overlapping networks are particularly well suitable for the necessary flexibility and learning provided by FMNs to respond to rapidly changing markets and technologies **[27]**. In fact, the networks of

SMEs make up an information and rich relationship form of organization that contains many degrees of diversity because they have no rigid boundaries [6]. In addition, the specialization of firms in specific aspects of an industry as well as the accumulation of individual and collective know-how concerning the organization of a particular production cycle leads to external economies and creates the basis for on-going technological dynamism. Table 2-3 shows the SWOT analysis of the SMEs which explains that the SMEs are suitable competence cells for the FMNs.

The concept of flexibility can be identified by two distinct sets of capabilities [25]. Flexibility breaks into flexibility within firms and flexibility within the network as a whole. FMNs have two different types of configurations, Intrafirm (one organization with multiple sites) and Interfirm (multiple organizations with multiple sites per one organization). Intrafirm flexibility means that the partners within a region can, on one hand, scan the market continually to identify rapid changes in demand or the sudden appearance of new opportunities and, on the other hand, adjust the manufacturing processes to take advantage of these market changes as quickly as they arise. The partners achieve internal flexibility by using more general-purpose machines, broadly skilled workers, and close links between conception and execution. The market consequence is a product customized to meet the needs of each individual customer. Although the flexing is essentially internal to the firm, networks can support manufacturing flexibility by allowing timely exchanges of information about processes and management tactics.

Interfirm flexibility is the ability of FMNs to allow a regional manufacturing system as a whole to respond quickly to changing markets and competitive contexts. Such flexibility is a question of building rich partnerships among the partners. Flexibility in the network is augmented through frequent rearrangement of the contracting agreements to meet changing final product demands. A network can adjust to achieve optimal scales of manufacturing by adding or subtracting partners. When the network is built on social trust and fluid flows of information, the added costs due to manufacturing partnership are low and more than offset by the gains due to adjusting the scale and content of output.

SWOT analysis of SMEs	
Strengths	→ Flexibility, SMEs can easily absorb new technology, new design, and new processes. The cost of such change is minimal. → Quick decision making, due to minimal layers in management, decision making could be faster. → Favorable capital output ratio, by properly utilizing the local reserves, SMEs can keep low level of capital investment per unit of output. → Cooperation from employees, managers can keep personal contact with employees to ensure full cooperation from them.
Weaknesses	→ Lacks of technical superiority, SMEs are somewhat less oriented to advance their technological capabilities due to lack of funds. → Lack of infrastructural facilities, in a developing economy, SMEs are generally set up at remote places to take advantage of government subsidies and to satisfy local demands and so face problems of infrastructure such as power and transport. → Lacks of financial strength, SMEs depend largely on the banks for finance. They do not have good corporate/brand image. Without this, they cannot get money from the equity market.
Opportunities	→ SMEs can act as an excellent supplementary unit for a large company (OEM). → Due to globalization, SMEs can interact and have the networking strategy with global companies.
Threats	→ Acquisition and mergers of large companies may affect their business. → Government policies, and open competition may threaten their very existence.

Table 2-3 SWOT analysis of SMEs

CHAPTER 3

CONCEPTUAL FRAMEWORK OF FLEXIBLE MANUFACTURING NETWORKS (FMNs)

3.1 Systematic evolution model of networking

The traditional view of the evolution of networking largely reflects sequential view of technological innovation. First, the potential entrepreneur develops a technology based idea that is supposed to have commercial potential. Then the entrepreneur gathers resources and possibly a management team and establishes a firm to exploit the idea. If the business idea of the firm is viable, the firm becomes commercially successful. The success is supposed as rapid natural growth.

However, rapidly growing new technology firms are exceptions. The majority of firms seem to be technologically and/or manufacturing embedded in value-creating systems. The system sets the opportunities and constraints for the survival and possible growth of the firms. Table 3-1 illustrates the view of the systemic evolution of networking **[16]**.

The model illustrates the evolution of the firms as part of innovation and/or manufacturing networks. Firstly, a firm is founded as a private venture. The firm's technology, application area, and the capabilities of the management team determine, whether the firm has potential to reach stand-alone growth. Instead, they become embedded in a manufacturing network.

As the network is established, in stage 2, the firm becomes embedded in it, by developing relationships with customers, suppliers, research institutions, financing institutions, and other possible actors in the environment. Some of the linkages become intensive and continuous in nature. Resource leveraging starts to take place, and the firm establishes itself in the network.

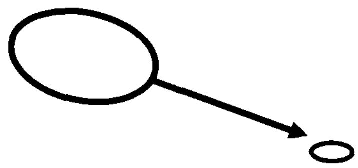
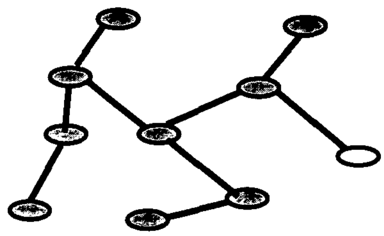
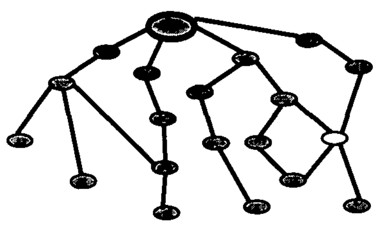
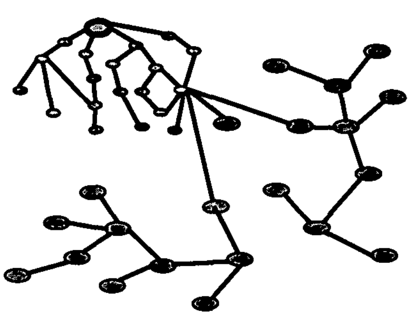
	**1. The firm is founded as a private venture** ▪ The firm is founded as a private venture to exploit new solutions
	**2. The firm is linked to a network or chain** ▪ the firm develops initial customer and other connections ▪ some of these connections become intensive ▪ the firm starts to become embedded in an innovation network or a manufacturing chain
	**3. Cluster development** ▪ positive externalities develop in the network; development and growth start to feed itself ▪ many technology firms are founded ▪ locomotive effect takes place ▪ looking-in into paradigmatic technological stage ▪ the firm is manufacturing and/or technologically embedded
	**4. The firm is able to link with other networks and clusters** ▪ the firm has developed firm-specific distinctive competencies ▪ the firm has reached critical mass necessary for moving into new networks ▪ it is possible for the firm to link with other networks and clusters and become less dependent on the initial cluster

Table 3-1 Systemic evolution model of networking

At the system level, the whole network starts to develop. There are usually many competing new technologies in this pre-paradigmatic stage. Gradually, the system shifts to the third stage of the evolution model. Many firms are founded in the network, often but not always in proximity. At some point, a locking-in into the systematic evolution takes place.

The development of the cluster is often driven by a big firm [3]. This big firm benefits from the technological network externalities, gaining competitive advantage over its competitors. It may expand through direct natural growth and by acquiring other firms. Dynamic complementarities are exploited between the constituent firms of the network.

Thus for individual firms there is the opportunity to grow with the network, in this third phase of the model. External complementary resources are available, with which the firms can increase its specific resources. The firms can establish a continuous resource generation process.

In such a synergistic value-creating system, the firm can develop distinctive competencies, to create value for its customers in the network. At this point, the firm is often very dependent on the big firm and the development of the network.

To decrease its dependence on the development of the network, the firm may seek to establish linkages to other networks in new geographical or application areas. At this stage, the firm may be able to carry out this expansion, through a growth reinforcement process, having developed its distinctive competencies in the initial network. These firm-specific competencies make the firm valuable to firms in other networks. Also, with the growth of the initial network, the firm has reached the critical mass necessary for moving into new networks.

The systemic evolution process described above is not a linear sequential one: one stage does not necessarily lead to another. The evolution takes place spontaneously, as a result of the actions of the actors in the network. The firms are often born directly into the developing cluster, that is, the third stage in the model.

3.2 Manufacturing processes: Past and current practices

Conventionally it was thought that in order to be economically efficient in production it was necessary to be of a certain scale. Fig. 3-1 depicts the evolution of the production paradigms. The manual production was the existing view when products were individual products (single product production in the horizontal axis). At the same time production volumes were low (vertical axis). Ford' application can be regarded as a shift from the manual production to mass production, where there was simultaneously a considerable jump in the size of the series, the efficiency and volume of production. Later the application of the Lean production approach brought small improvements in production efficiency (shift along the vertical axis) and increased prevalence of more customized products (shift along the horizontal axis). Lean production practices attempt to increase productivity/efficiency through continuous improvement (improved inventory systems and elimination of wasted time and motion, also it visualizes elimination of unnecessary steps in the manufacturing process, and aligning all steps in the value-chain in continuous flow). The network structure and the related business logic can be seen as facilitating a rise in efficiency and increase in volume (shift along the vertical axis from lean production to network), but it also fosters a shift toward more flexible manufacturing and supply of unique products (shift in the horizontal axis from lean production to network). For the time being the speed of production and flexibility aspects are of key importance. Many companies have to use the network structures to upgrade their unique products and develop their production and business approach.

The key elements of the new production technology, based on information technology, were various Computer Integrated Manufacturing (CIM) technologies, like Computer Aided Design (CAD) and Flexible manufacturing System (FMS). These were especially important in providing flexibility in terms of product variety and in managing time to market and time to customer. It was in the '80s long thought that FMSs were mid-range systems providing rationality between small batch, semi-manual production and highly efficient transfer lines of volume production. Table 3-2 summarizes the key findings concerning the different ways of implementing systems **[21]**.

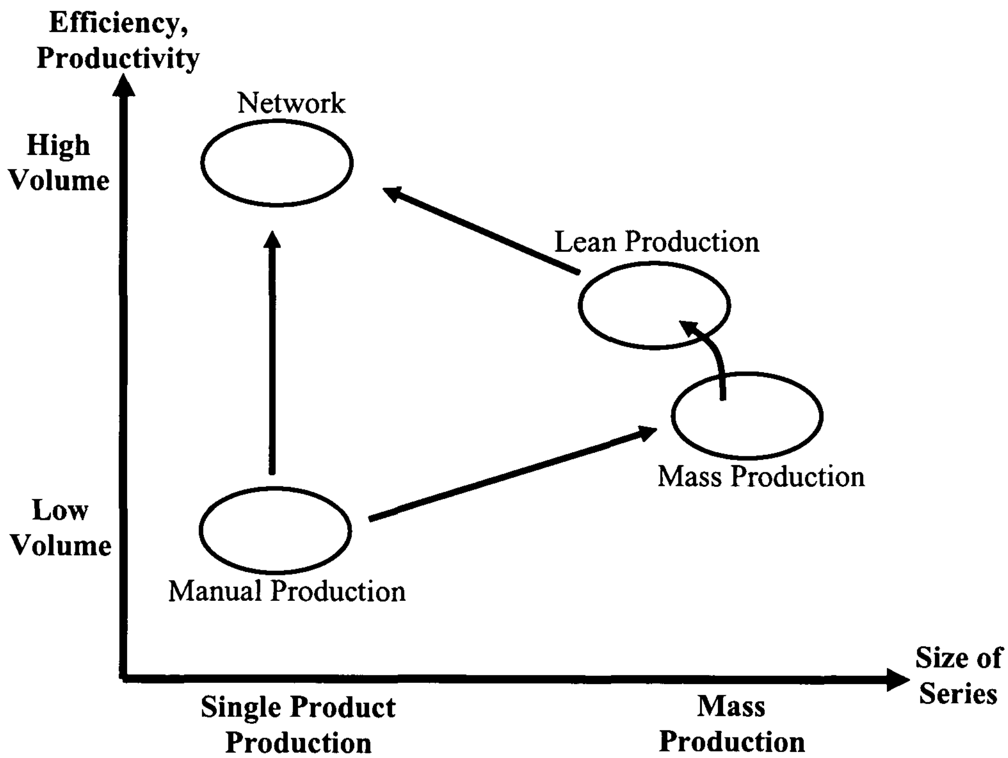


Figure 3.1 The evolution of the production paradigms

Successful and economically beneficial applications could be found in all types of production: from mass production to small batch production. However, the rationality and benefit mechanism in these various applications were quite different.

The starting point in Table 3-2 of ***strategy A*** was usually semi-automatic or even manual production in small or medium-scale companies. Usually there was a high product variety, which was manufactured by small batch production systems. The products were customized or specialized products. The strategy was a simple capacity increase and quality improvement strategy, while sustaining existing flexibility. Capacity could be increased without major investment in new buildings and also without increasing labor. The productivity increase, in both capital and labor productivity, was usually quite remarkable. The key aspects were capacity increase without investment in new factory buildings and to increase labor.

The starting point of ***strategy B*** was a transfer line of typical mass production, usually in a large company. Typically these applications were found in automobile and consumer electronics industries or in their component and part production. The main goal was to increase the flexibility, save capital, decrease lead times and most importantly to cope with the changing environment and new product demand in the future. Thus, the major benefits were really coming from potential flexibility: the product could be modified and redesigned or new products could be introduced without expensive changes to the parts manufacturing and product assembly process.

Strategy C presents a modernization strategy. Old fashioned, functional manufacturing was transferred to a modern, medium capacity and flexible workshop. This transformation was associated with many benefits and took place in an environment where the flexible manufacturing was thought to be. However, it was also a very challenging change, because it was usually connected to a turnover process in the company.

Strategy	Existing system	Characteristics for new system	Required technology	Benefits
A	▪ Small scale semi-manual batch-production	▪ FMS, high product variety, medium capacity ▪ Increased capacity and efficiency ▪ No need for shop floor expansion	▪ Compact control structure ▪ Closed systems architecture and difficult to expand	▪ Increase of the capital productivity ▪ increase of the labor productivity ▪ Decreased WIP and lead times
B	▪ High capacity dedicated automation ▪ Mass production	▪ FMS, high capacity, medium flexibility ▪ Less machines needed	▪ Complex control structure ▪ Network (LAN) based, open systems	▪ Increase of the capital productivity ▪ Potential for future changes ▪ Decreased WIP and lead times
C	▪ Conventional, functional ▪ Medium scale	▪ FMS, medium capacity	▪ Complex control structure	▪ Increase of the capital productivity ▪ increase of the labor productivity ▪ Quality improvements

Table 3-2 FMS benefits and different implementation strategies

The most interesting cases are the strategies *A* and *B*. Strategy *B* was really about competing with time, to cope both with the time to market and the time to customer. The important issue of strategy *B* was that it made possible to distinguish between the production technology life cycle and the product life cycle. And, this was the key to managing the fast product life cycles in an economically feasible way and made it possible to introduce new products quickly without major investments in production. Because the FMS application was associated with the lead-time reduction, delivery times or the time to customer could be shortened, the second aspect of time-based competition.

One may call this type of application menu-type customization, because the operative flexibility or product variety and customization were not so high. Although it was possible to a certain extent to cope with product variations and increase customer service also in this way, it was not the key point; it was important, but not strategically decisive. Strategic importance was really in the product life-cycle management.

Strategy *A* made it possible to improve efficiency and quality in small-scale flexible shops. This laid the cornerstone for networking. It is important to note that these applications were a route to the efficiency of conventional mass production without the necessity of having the same volume as well as by keeping the existing scope and flexibility. However, a more important long term impact was that those companies who applied strategy A grew to be reliable, high quality partners in the manufacturing networks. It was the high actual or operative flexibility, which made it (economically) feasible to be a partner in several networks. It was also the basis for specialization and knowledge based work sharing. Fig. 3-2 demonstrates the dynamics introduced by the flexible production technologies **[21]**.

The transformation introduced strategies *A* and *B* was later described to be mass-customization. Although the phenomena were well documented and described in the late 80s, it was not at that time called mass customization. Mass customization is to some extent a good description of what has happened, if one takes the product variety and actual customization point of view **[23]**. The more important part of the story is the capability in managing fast product generations and the route to the manufacturing networks. Moreover, there was another aspect. The transformation can be called mass customization or menu-type customization indicating that operative flexibility is not that high and from the customers point of view the flexibility related more to look and design.

The objective of presenting these strategies is to show the economics reason and rationality of the FMN. For example, the high-tech industries, such as PC's or mobile communication, are in a very dynamic phase. They are expanding in both the geographical and technological sense. The technology is developing at a very fast pace with the impact that the product generations are very short. This means that it is necessary to manage fast and overlapping product life cycles. Moreover, because of growing and expanding markets many of the high-tech industries are operating as mass and volume producers and because of market segmentation applying mass customization. Summarizing all these aspects means that high tech industries facing real time based competition must be best and the forerunners in time to market, excellent in time to customer and provide customized solutions. Because of the fast pace these industries are requiring a lot of capital and high risks. A lot of resources are needed in product development, manufacturing, distribution and marketing. These industries are resource intensive growth and technological change which drive high tech industries to collaborative forms and networking. New organizational solutions are needed and it is more necessary than ever to distinguish the product and production technology life-cycles from each other. The FMNs play a special role in this respect.

There are other rationalities as well. The production organized in the network forms flexible manufacturing and assembly on a network of factories (parallel processing). This leads to shorter delivery and lead times and makes it possible to compete with the time to customer. Therefore, the joint technology development in the networks is possible, which means parallel development activities and again shorter time to market and greater advantages in time based competition.

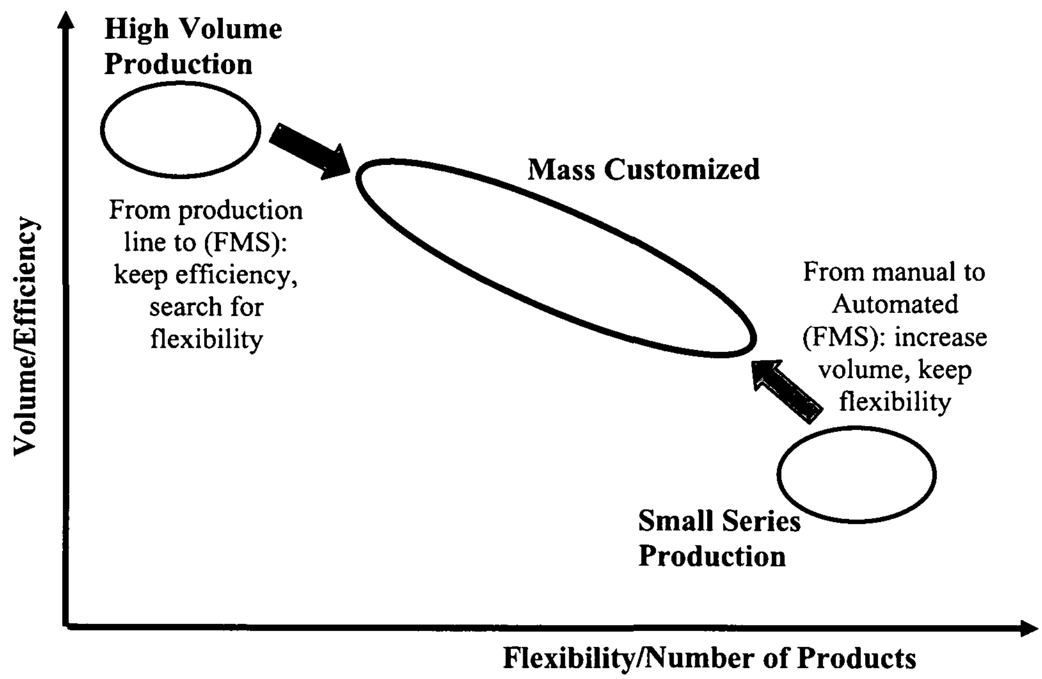


Figure 3.2 The dynamics introduced by flexible production technologies

3.3 Framework of the cooperative relationships in FMNs

The FMN allows different types of cooperation to be developed for different customers or market segments in order to optimize the mix of partner resources and achieve a competitive advantage. FMNs are the cooperation relationship among SMEs, which have demonstrated the ability to retain the advantages of speed and flexibility of the smaller companies and still attain the advantages of size and resources that the larger firms are afforded.

FMN is a group of two or more partners, which have banded together to carry out some new business activity that the members of the network could not pursue independently. The FMNs can involve similar partners which band together to share the costs of developing a new product or market, and/or dissimilar but complementary partners. Typically the nature of the cooperation within the network is carefully defined so as to preserve each partner's independence and original lines of business **[19]**. The duration of the cooperation may be very short and limited to a particular customer orders. A new FMN may then be assembled with the best configuration to meet the needs of the next customer. Nature of the cooperation tends to be deeper in a FMN, and one form of cooperative relationship tends to lead to others. FMNs generally link several partners so that one partner's weakness is improved by another's strength **[8]**.

The cooperative relationships between the partners in the FMNs are very critical to the overall performance of the FMN. Table 3-3 provides some of the main generic aspects of an efficient cooperation within FMNs. The FMNs address these aspects by providing a generic framework of the cooperative relationship that describes the day-to-day interactions and behaviours of partners. This framework defines cooperation mechanisms respecting three basic principles:

1. Organization and structure: Each partner is responsible and self-managed within a FMN for satisfying its customer' needs and fulfilling its cooperative agreements.

2. Communication: Each partner uses Information and Communication Technologies (ICT) that allows fast, understandable and efficient transactions and information exchanges between partners.

3. Coordination: Partners can coordinate their activities using an explicit coordination framework.

This framework is used to describe cooperation and control mechanisms:

➔ Information system infrastructure: partners rely on an extensive use of new information technology to support communication and information exchange. The information system allows each partner to interact, coordinate their activities, and exchange information according to the coordination dimension described to implement the manufacturing tasks.

➔ Business models exchange: partners dynamically exchange their business models in order to better plan and coordinate their activities, anticipate actions to perform, and execute the manufacturing tasks.

➔ Efficient resources sharing: Partners may share resources. In order to do so, they keep and update a model of the shared resources. This model contains the actual resource availability as well as the agreed upon rules describing the way to collaboratively exploit the resources and solve conflicts.

➔ Explicit win-win relationship: Each partner agrees upon explicit win-win business behaviours in order to allow cooperative planning and operation management.

➔ Contingencies management: Partners identify contingencies and agree upon contingency plans that may be used in order to quickly take action when a problem occurs.

- ➔ Cooperation performance measurement: Each partner agrees upon cooperation performance criteria in order to maintain up-to-date performance measures of itself and the entire network. This performance measure process allows each partner to evaluate its own cooperation relationships contribution to the overall performance.

- ➔ In the FMNs, the partners' relationships are developed according to the objective of the networking strategy of the FMN, although some partners may be involved in different competing networks. This forces the scope of these cooperative relationships to be well defined in order to know the contribution of these partners to the FMN. Thus, the efficiency of the cooperation in FMN relies on the business relationship efficiency.

Relational aspects	▪ Partners must know each other (operational, tactic and strategic) ▪ Partners must trust each other ▪ Partners must be committed ▪ Win-win relationship ▪ Partners must be able to measures their own contribution to the collaboration ▪ They must have proactive behaviors ▪ Their strategies and goals must be alignment (avoid negative conflicts and contradictory goals) ▪ They must avoid opportunism behavior ▪ Partnership profit before individual profit ▪ They must exploit collaboration opportunities to improve the partnership
Business operation aspects	▪ Partners must have the ability to coordinate their interdependent activities ▪ Partners must have the ability to work efficiently together (explicit business methods) ▪ They must shared responsibility and self-managed partners ▪ They must or may share the profits, the resources, problems, etc. ▪ They must identify contingencies and contingency plans ▪ They may use incentive and award mechanisms ▪ They must eliminate work duplication
Communication aspects	▪ Partners must use understandable, fast and efficient communication channels ▪ (efficient information system support, same ontology, eliminate redundant communication)

Table 3-3 Generic aspects for efficient cooperation

3.4 Why should manufacturers be interested in starting a network?

SMEs, who want to improve their competitiveness, develop new products, penetrate new markets, adopt new technology, and upgrade workforce skills while keeping the unique lifestyle of a small business should be interested in the network approach. Significant progress on these objectives can be achieved more easily in a well functioning network than in isolation [37].

It is often maintained that SMEs are run by small staff that spend long hours dealing with day-to-day operational details. Lacking a large and diverse management staff, there is little time to worry about long run issues such as new market and product development, or incorporating new technology into the production process. Challenges from far away firms that have become sophisticated international competitors may arrive as disturbing surprises since such firms typically lack market scanning capabilities. SMEs lag behind larger firms in adopting advanced technology and therefore have lower productivity levels.

These competitive disadvantages of SMEs provide the most powerful rationale for the formation of FMNs. By cooperation with other firms with similar purposes; these competitive challenges can be overcome. A major advantage of the network approach is that it allows SMEs to remain small. While a great deal of job growth and prosperity can come from very dynamic firms that grow into big firms. For those SMEs that want to remain small, but successful, the network approach offers access to new markets and technology within an organizational arrangement that permits them to control the size of their individual firms.

Networks are established to pursue a wide variety of specific objectives. Some idea of the capacity of this approach to meet SMEs business needs is provided by the following examples:

- Upgrading product quality to meet customer requirements is a common problem as Original Equipment Manufacturers (OEM) demand higher quality standards and as consumers increasingly turn to higher quality products.

- Reducing per unit costs is another common goal of networks. The SMEs can establish a CAD/CAM facility to reduce design and manufacturing costs.

- Networks are often started to pursue new joint business opportunities exploiting the complementary capabilities of partners.

- Access to new markets is a frequent need of SMEs and the networks can address this opportunity.

- Sometimes a particular service is needed by a group of SMEs to improve product quality, and a network can be organized to provide that service.

CHAPTER 4

DESIGN OF FLEXIBLE MANUFACTURING NETWORKS

4.1 Manufacturing networking

Nowadays, the economic importance of SMEs is unquestionable. In addition to their high share in added value, they can contribute to the development of innovative products and services. On one hand, technological progress as well as the increased spreading of new technologies opens up numerous business opportunities especially for SMEs because they are flexible and near to the market. However, on the other hand, many SMEs face a growing competitive pressure, such as short product life cycles and growing international competition which require firms to permanently develop new products, services and techniques as well as to continuously improve their existing ones.

SMEs have to deal with permanently changing environmental influences. The special strengths of SME, such as high flexibility in decision-making, more direct ways of communication, and highly developed market-related reactivity. The pressure of daily business hardly allows the autonomous development of strategic options. Moreover, many SMEs have enormous difficulties in constructively following the new organization and corporate strategy that builds on cooperation and manufacturing networking [24]. Manufacturing networking could help in this endeavour as analyzed below.

SMEs are very important for the network based on cooperation relationships. Currently, the emergence of networks can be explained by the strategic re-orientation of firm relations. These re-orientation or new orientation causes the emergence of networking strategies. Mostly, transnational cooperation tries to implement outsourcing strategies or to sub-contract firms in order to gain market shares. SMEs only could hope to remain in the self-created good position in the market or to ensure their sustainable survival by participating in such networks.

SMEs own only limited resources in addition to their varying level of competence. Because of these restrictions they only can create limited partial sequences of process chains. Therefore, missing competencies have to be acquired or complemented by cooperation to obtain the ability to provide complex products and services in a customer-oriented manner. The favored forms of cooperation are based on hierarchical structures in and between enterprises. In other words, the technical, organizational and economic aspects of such cooperation are often extensively dominated by a single large enterprise. In many cases, specific core competencies are bought within the framework of outsourcing concepts to control segmented manufacturing tasks. A defined dependence is obligatory.

The disadvantages of these hierarchical structures are the uniform dependence and the missing direct contacts to the final customer. Present efforts aim at creating semi-hierarchical manufacturing and organization structures within large and merging enterprises. However, SMEs can participate in this development only partially because of their structure and available resources. This semi-hierarchical cooperation can be characterized by the fact that they are able to optimize the core competencies of the partner firms by cooperation. The first step to optimize the core competencies is to comprise the identification of each individual partner's core competencies. The second step, the partners can be integrated in the customer-oriented value adding process. In addition, the partners are required to be flexible, extendable (could add new machine, new production department and so on), adaptive and able to cooperate to a high degree

Networking (non-hierarchical structures) is also the present and future efforts and means to couple the necessary competencies and resources without a formal hierarchy in the structural relationships between the network's partners. The partners of the network are considered the competence cells of the network and these competence cells may be small, to a large extent economically autonomous, and technically specialized units that temporarily form networks with other competence cells to create more complex products and services. The partners draw its actual strength from the dynamic networking with the other partners.

The generation of networks, especially the establishment of strategic networks, can be interpreted as a sign of ongoing transformation of the institution "firm". Networks appear to be able to reconcile the often contradictory requirements of efficiency and flexibility better than other forms of organization. These networks are characterized by their high flexibility and only temporary existence.

The network has to be stable in time, which means that the network products, processes and management policies are the same over long periods. The main result of this stability is that the costs and complexity of network creation and modification will be low. Individual partners can join or leave the network, but this network must be considered as a persistent structure **[30]**.

4.1.1 Potentiality of the manufacturing networking

There is a lot of attention to the strategic characteristic of the new forms and relationships of enterprises. Individuals, groups, or organizations are possible partners. Depending on the objective and the acting partners, the relationships themselves can vary too. Above all, networks describe an observable pattern of interaction with a netted structure. Subsequently networks require partners with similar basic interests and cooperate in some cases being able to act and decide together. Networks can be activated spontaneously and are able to disappear just as quickly as they emerge.

Potentiality appears to be the network-generating medium and also the relationships within the networks. The first important step in developing the concept of a network is the distinction of potentiality. The coordination of providing products and services is realized by relatively lasting relationships. However, the relationships within the network can be updated by network mechanisms or the other new partners who can join the network. The products and services to be produced are variable in a temporal aspect.

Networks are present at any time, but only hidden in the sense of potential contacts. This means related to economic circumstances: in the ideal case, networks occur on the basis of networked contacts within a cooperative relationship that organized by transactions in an economic context. The network forms a potential of future collaboration. This relationship functions can be defined as a support infrastructure in the form of structures and processes, i.e. strongly influence, the function and the position of participating individuals and potential as well as present relationships between partners.

This infrastructure is called network. Networks specify clear structures and define partners' interrelationships, and ways of communication and responsibilities. The network provides flexibility. It is a medium of adaptiveness and cooperation of organizations. Networks construct the variable bridges over (rigid) organizational boundaries. The manufacturing networking promises greater productivity, reduced costs and new marketplace value. Its importance in manufacturing today warrants explicit evaluation of the performance improvements arisen from the synergy, cooperation or the manufacturing networking **[11]**.

As indicating above, the generation of networks supposes a pool of partners that can be mobilized. In an economic context, it is obvious to presume enterprises as relevant partners that bear the risk of forming networks to fulfill specified profit expectations. Furthermore, the range of possible candidates should be widely spread. The only requirement of networking lies in the legal capability and the ability to decision-making. In so far, enterprise networks consist not necessarily of enterprise organizations. They are rather constructed by business relations and related interactions and communications. Furthermore, in the networks must be a capable network management that has to coordinate the relationships that are constituted in form of a lasting network in a reflexive manner. This basic idea creates the framework for the model of networked competence cells, that can be formed not just by enterprises but likewise by enterprise units (competence cells as performance units) and cooperate on the basis of their networked relations.

4.1.2 Policy issues for networking firms

Certainly new approaches are needed for the partners within the network, but what these might be is not at all apparent. The partners within the network need an aware policy and practice that can look at the situation from a new advantage point, expecting the needs of partners and drawing the future into its current practice. The opportunity for substantial industrial development based on a revival of small firms. This is a situation where government must, in one sense, play its traditional role. It must anticipate industrial shifts and invest in the development of infrastructure systems that will enable new economic growth to take place. Government's role in the construction of railways and roads is certainly an example of the benefits for the nation of this approach. In the past, policy set on the state level provided a reasonable level of support for economic development in general. The link between policy entities and partners within the network needs to be an on-going link. Policy will need to be modified as the implication of new policies becomes apparent through practice.

For example, a system that would enable the partners within the network to act collaboratively may require an information and communication technology. These systems enable customers to interact with the network as if they are in the same building even when communicating across the country. Even though these systems are currently used primarily for voice transmission, they could easily carry other data required by partners within the network. To assess these potential approaches, manufacturing networks need to be connected to technical specialists with a deep understanding of the nature of the needs of the partners and can inform the partners with the technical solutions available now and those on the horizon **[29]**.

Firms which form networks or partnerships may transform their relationships with other firms, so that they can share information, work together to take advantage of opportunities they couldn't access by themselves, and learn in such a way that they improve their performance. Networks of firms are the key to developing effective learning systems in order to transform communities. The most successful networks of firms develop a common focus, which is often provided by a common market served by the core firms. This becomes the basis of deep, cooperative, knowledge-building activities that enable the firms to serve the needs of the market well. On the other hand, the set of partners must include sufficient diversity so that they have something to offer each other. Although firms in networks compete intensely on some projects, they tend to develop areas of specialization as well, and are able to re-invent their business by aggressively finding new markets' products or needs. But because they generally can only meet these needs by working with others in the network "combining their differences" the new product is shared and further elaborated so that even more new opportunities are opened. A market can serve to help bring a set of firms together, but as they attempt to serve the selected market, they must simultaneously change in many other ways as follows:

First, to serve emerging new markets, which usually requires ongoing development of complex products, firms must change the way they produce goods. This change needs to occur both within firms and among firms as they move to various forms of joint production of either single products or product lines.

Second, to compete and be more flexible in the development of products, firms need some way to find out about new technologies and incorporate them into their operations.

Third, both the new technologies and the joint product development require new forms of capital, which are generally not available through existing capital institutions, who do not understand the risk or benefit involved.

Fourth, the organization of work within the firms needs to be rearranged around a new focus on quality and continual improvement.

Fifth, as the firms expand and change they will need to find ways to meet their need for new resources. And finally, firms need to communicate with each other and the market, and coordinate joint production and other joint efforts. This requires ability to negotiate new kinds of agreements and access new technological systems based on computerized telecommunications that can lower costs of coordination.

Networks of firms are the ideal unit to facilitate these changes. However, even groups of firms, and especially groups of SMEs, do not often have sufficient resources to carry out strategies to meet all of these new needs for new forms of production, technology, capital, organization, training and retraining, and communication. This is the meaningful of the network

4.1.3 Partnership in the FMN

With the continuous changes in the global competitive environment and the rapid growth of information technologies, manufacturing is entering a new era, where product life is rapidly decreasing, product structure is more frequently changed and customer-oriented, and all activities related to the product life cycle are being affected by globalization.

For the manufacturing enterprise to be competitive and to thrive in a dynamic environment characterized by constantly hanging customer demands, boarder product ranges, shorter model lifetime, production to order in arbitrary lot-size, and technological innovations, it is must be capable of rapid adjustment in order to reduce the cost and the time needed to deliver to the customer a quality product. The necessity for swift recurrent changes has led to adoption of many concepts like the concurrent engineering, Just-In-Time (JIT) Total Quality Management (TQM), manufacturing partnership and production tendency into a manufacturing concept called Flexible Manufacturing Networks (FMNs). Manufacturing flexibility is the ability to thrive in a competitive environment of continuous and unanticipated change, to respond quickly to rapidly changing markets driven by customer-based valuing of products and services.

FMN is attracting increasing attention from both the academic and industrial communities. Extensive programs are being conducted worldwide on relevant issues to propagate, build and to realize FMNs. Many terms and definitions have been proposed for FMN, but so far, there is no unified definition **[40]**. For instance, "Flexible Manufacturing Network is a temporary consortium or alliance of companies formed to share costs and skills and exploit fast changing market opportunities", "The Flexible Manufacturing Network consists of a series of cooperating "nodes" of core competence which form into a network in order to address a specific opportunity in the market place", and. "Flexible Manufacturing Network is constructed by partners from different companies, who collaborate with each other to design and manufacture high quality and customized products, it is product oriented, team-collaboration styled, and featured as fast and flexible".

A set of fundamentals can be identified from the various definitions:

1. There is a leader for the network which takes charge of selecting and managing its partner firms and this leader of the network may be one of the following:
   - The network management team,
   - Any company from the network receives an order from the customer or the market can do as a leading for the network,
   - Broker Company also can do as a leading for the network.
2. The partner members and organization structure of a FMN is product oriented.
3. The product development and production are distributed among all partner factories.
4. The partnership among all the partner firms may not be permanent.

It is clear that in a FMN, the partner selection or synthesis is the basis and foundation for design and operation the FMN, and this synthesis process is strongly coupled with the product design process. This makes sense to design of FMNs which is equivalent to design for manufacturing in conventional manufacturing plants.

Within a nationwide or global manufacturing, the objective is to set up a flexible and dynamic networking among partner firms, who work jointly to capture specific business opportunities that they cannot respond to competitively in an individual manner. Flexible manufacturing networks are synthesized to respond to specific market initiatives that are conditioned by customer's whims of costs, quality and due-dates. The cooperation among qualified partners with necessary physical resources and capabilities is viewed as virtual company formation. Even though the problem of the partner selection in the FMNs have many dimensions which makes it complex problem **[31]**. These dimensions are as such as:

- Multiple criteria involving cost, quality, responsiveness and other qualitative concerns are significant to the synthesis of the manufacturing partnership,
- Relative importance between the various criteria are conditioned by the customer needs, and therefore cannot be represented in a static manner as considered in traditional partner selection,
- Customer needs corresponding to the specific business initiative need to be acquired and assimilated in a user-friendly manner and not as crisp numerical weights (or comparisons),
- Operation of FMNs and partner selection are related due to the specific requirements of resource capabilities and capacities. The existence of high quality processes of candidate partners in the FMN structure should be reflected in the final selection of processes and partners,

- ➔ When developing a new customized product, the process plans or the network operation schema are essential step and quality, lead-time information have to be available to determine the time consuming process involved in evaluating the alternative partners,
- ➔ The problem is not limited to select partner for a specific task, but a group of partners that collectively form the FMN, depending on the product features accomplished by the first partner and the subsequent partners may have less or more remaining work content,
- ➔ Transport cost and times become significant criteria when considering multiple partners that are geographically distributed, this introduces combinatorial search for determining the best sequence of partners,
- ➔ Finally, there may not be a unique solution to be the manufacturing network configuration and an opportunity for human-decision making must exist. Thus the output of the decision making system should be in terms that are best understood by network management.

In summary, several factors affect the partner selection, and it is necessary to make a trade off between conflicting tangible and intangible factors to find the best partners **[36]**.

Since the partner selection process addresses different functions within the company, it is a multi-objective decision problem, encompassing many tangible and intangible factors in a hierarchical manner as shown as an example in Fig. 4-1. The evaluation of intangible factors requires the assessment of expert judgment, and the hierarchical structure requires decomposition and synthesis of these factors.

When a partner selection decision needs to be made, the network management generally establishes a set of evaluation criteria that can be used to compare potential sources. The basic criteria typically utilized for this purpose are pricing structure, delivery (timeliness and costs), product quality, and service (personnel, facilities, research and development, capability, etc). For global markets, the set of criteria is expanded to take into account the new variables and risks associated with international business transactions. Frequently, these evaluation criteria conflict one another. In addition, the importance of each criterion varies from one project to the next. This situation can be complicated further by the fact that some of the criteria are primarily quantitative (price and delivery time) and some are qualitative (quality, flexibility, cooperation, service). Thus, a technique is needed that can adjust for the decision maker's attitude toward the importance of each criterion for each item, as well as capture both the subjective and the objective criteria.

Therefore, selecting a partner is a quantitative and qualitative process. A partner should offer more than parts that meet specifications, selecting the partner that provides the best design and manufacturing expertise can make product more competitive and cost more effective **[32]**. The following criteria are an example for the criteria which may help to identify a partner who will meet the needs, and these criteria are not the all criteria:

1. **Make manufacturing easier**
   - → Reduce the time and effort to produce a product of equal or greater performance,
   - → Eliminate unnecessary complexity in the process,
   - → Remove unnecessary components from the product.
2. **Obtain higher quality**
   - → Exceeding minimum specifications and fitness for application.
3. **Increase reliability**
   - → Take into account actual operating conditions and/or operator skill.
4. **Lower cost**
   - → Reduce labor,
   - → Reduce or change material use,
   - → Use a more cost effective production approach to achieve break-even point.
5. **Improve performance**
   - → Use longer lasting components,
   - → Make components exceed specified minimum requirements,
   - → Fabricate component with greater accuracy,
   - → Integrate components for better system performance.
6. **Increase life**
   - → Revise part or component materials,
   - → Examine part or component configuration,
   - → Change component application.
7. **Lower maintenance**
   - → Increase maintenance intervals,

- ➔ Reduce required service levels,
- ➔ Match component to the application environment.

8. **Lower parts count**
   - ➔ Integrate components into a single assembly,
   - ➔ Make greater use of sub-assemblies.
9. **Reduce size and weight**
   - ➔ Examine alternative materials and technologies.
10. **More saleable product**
    - ➔ Less expensive,
    - ➔ Longer lasting,
    - ➔ Faster working,
    - ➔ More energy efficient,
    - ➔ Easier to service.
11. **Increase energy efficiency**
    - ➔ Reduce energy consumption,
    - ➔ Increase energy actually applied to work,
    - ➔ Better process control,
    - ➔ Apply more suitable materials.
12. **Add intelligence**
    - ➔ Automate as many functions to better control operating parameters,

→ Ease operator interface for more and varied functions.

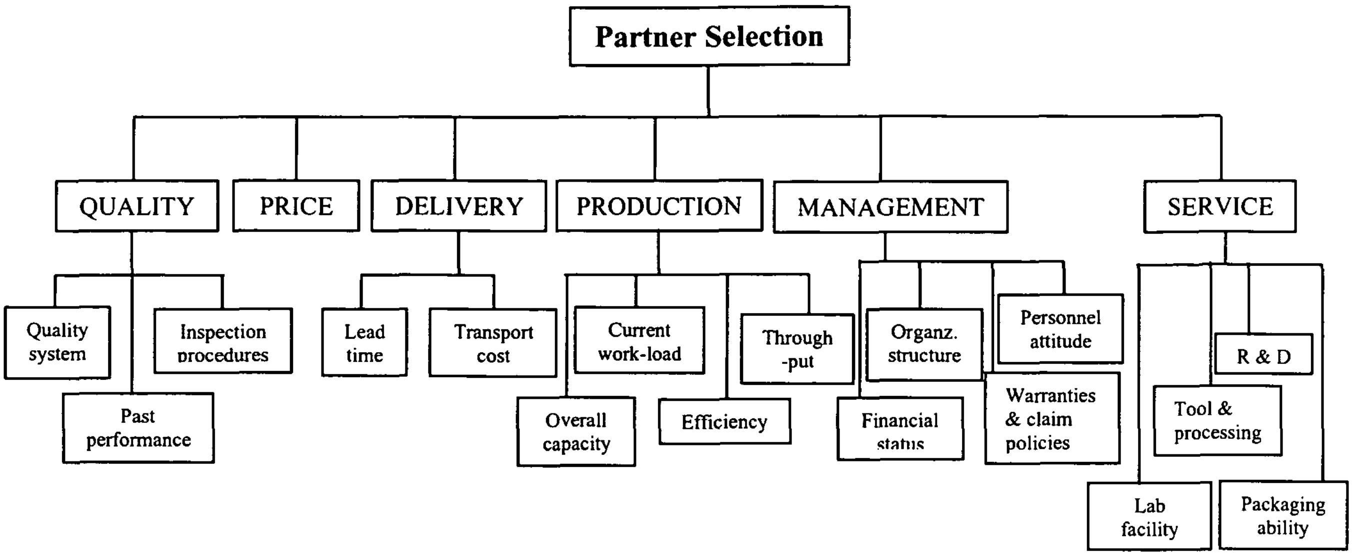


Figure 4.1 Partner selection attributes hierarchy

4.2 How do FMNs can be designed and operated?

FMN is a strategic inter-organizational network of legally independent partners, which bring competencies and resources into the network for the common development of strategic success potentials and attractive benefit potentials, to increase the value of the network.

Potential partners for FMN are firms no matter what size. These partners configure themselves dynamically in the FMN to exploit up together an identified attractive benefit potential. Positioning the network towards attractive benefit potentials makes its value to pursue a strategic cooperation **[7]**.

Essentially, the FMN value can follow one of the following two main networking strategies, Fig. 4-2:

→ ***Efficiency Strategy***: The existing FMN which has existing product follows this strategy to improve its efficiency. This strategy is primarily directed at the improvement of cost and time efficiency through inter-firm collaboration. Existing systems are inter-firm integrated in particular technological measures, with the objective to realize "economies of scale" effects.

→ By following the ***Competence Strategy***, the development of new attractive market is aimed at the multi use of existing core competencies of the partners in the FMN value. Thus the focus is on the "economies of scope", or the involved partners bring their existing core competencies into the FMN value with the objective to develop a new competitive competence.

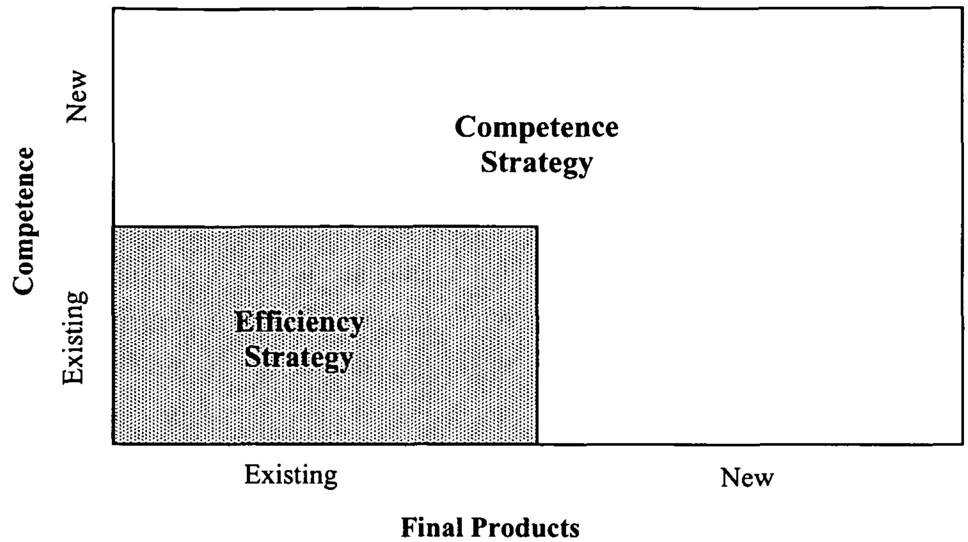


Figure 4.2 Two networking strategies

4.2.1 Procedure of the FMNs

Due to its strategic objective the relations within the FMN are stable and on a long-term basis. The procedure to establish the FMN is closely related to the procedure of the benefit potentials. Cooperation is to be understood as a project, with a defined beginning and end. The procedure to establish FMN is managed in five separate but iteratively connected phases, as shown in Fig. 4-3.

4.2.1.1 Initiation

According to the networking strategy which the FMN will follow, the initiation of the FMNs can be defined as the FMN's reason of the existence, idea, or market opportunity. A strategic analysis can be used to define the strengths, weaknesses, opportunities, and threats for this vision and also define the resources and competence requirements to achieve this vision.

The objective to set up a FMN may be one of the following:

- To be present in international growing markets and following the actual trends;
- To be able to offer high proximity to the customers through local services;
- To avoid unfavorable basic environments such as high costs;
- To overcome existing trade barriers (e.g., taxes);

- To exploit the potentials of cost and time reduction.

The value of FMN consists of suitable legally independent partners. The value of FMN represents a "symphony orchestra" of different types of partners such as design, specific suppliers, manufacturing, assembly, logistics, and sales centers. The partners in the FMN may to move itself from a semi-finished material manufacturer into the direction of a global system provider with extensive service performances. Additionally to these objectives the value of FMN may indicate the following characteristics:

- It should provide a competitive edge by accessing markets and new resources.
- It should inform rapidly about market opportunities and trends.
- It should offer proactive facilities to structure the manufacturing environment.

4.2.1.2 Partner selection phase

In the partner selection phase, the value of FMN is constituted. The partner selection phase contains:

- The partner search and selection;
- The definition of the strategic management;
- The commitment of all partners involved.

During this process, the individual objectives of the value of the partners are realized and coordinated. It is important that critical aspects like conflict regulation, sharing of gain or loss, liability and know-how protection, etc. are discussed and decided during this phase. The partner selection phase finishes with the mutual expression of commitment of all partners.

As primary long-term objective, the network management agreed to regard the FMN, as a learning field for the partners. The business relations should be optimized on the existing basic agreements with the aid of the modern information and communication technologies (ICT) and be intensified up to a determined high degree of relationships. All partners have to agree on the all the commitments to justify the temporal and financial investments. Thus objectives which can be realized within a short term of time (e.g., reduction of the lead time in the order processing) are determined. These objectives belong to the efficiency strategy.

4.2.1.3 Design phase

The quality of the activities in the initiation and partner selection phase reflects itself in the design phase. When the objectives are clearer, this leads to more commitment steps are executed and the time and cost efficiently of the design phase is passed through. Within the design phase the preconditions for a manufacturing cooperation within the FMN are managed according to the made agreements. The configuration and the coordination are the main dimensions for designing the FMN. The number of the partners, the number of the sites per one partner and the type of the partners are the two parameters for configuration the FMN. The data sharing, operation planning, financial commitments executing and structure are the four parameters for coordination the FMN. This point will be discussed in details in the following section.

4.2.1.4 Operation phase

The operation phase is the productive phase of the FMN. Continuous improvements by feedback loops to the design phase concerning changes of benefit potentials guarantee the flexibility of the FMN.

4.2.1.5 The network management team (network management)

This team consists of all persons who are responsible for the FMN. The network management determines the objectives of the FMN, coordinates and monitors the FMN activities according to the objectives.

Essential function of the network management is to supervise the FMN activities, to identify problems in time and to design and help to implement the activities according to the planning operations, and interaction level. A network management also is formed in each partner to implement the measures agreed on the higher level of the partnership. Additional expert teams can be brought in to solve special problems. These teams are formed with employees who have knowledge on the specific topic.

The other essential function for the network management is to implement and to manage processes that go beyond the FMN boundaries. The challenge consists thereby in the integration of the existing sub-processes of the individual partners.

The FMN operation is a simplified figure of the processes. It contains three productive and two supporting core processes. Those can be further refined in business processes, sub-processes, and operations. The three productive core processes are the market and customer communication process, the innovation process, and the order implementation process. The controlling process and the integration process play a supporting function. The controlling process includes the operational, strategic, and normative control of the FMN. The integration process plans, the implements, and controls measures for the further development of the cooperation. Both processes are closely interrelated and support each other mutually.

According to the defined objectives, the focus during the design of corporate processes was placed on the order implementation process. First each partner's individual relevant processes are documented. Then all partners define in several workshops the required process and start to implement it step-by-step. First objectives of the network management are decreasing stocks and an accelerated order implementation process.

In the context of the market and customer communication process, the key customers are interviewed about information and communication technology, innovation management, cooperation management and the order implementation. All the results of these interviews are taken directly into the design of the FMN.

4.2.1.6 Disbandment phase

The permanent evaluation of the activities in the FMN as well as the scanning of the business environments are the reasons for the disbandment or the reconfiguration of the FMN. In the case of disbandment the cooperation is terminated between the FMN partners. On the contrary, the reconfiguration contains the possibility of changing partners and/or accommodating new partners or adjusting the FMN with the current partners to establish new product to adjust to changed market and competitive conditions.

4.2.1.7 Evaluation and controlling of FMN procedure

The networking strategy is monitored and evaluated according to the objective of the FMN strategy. The objective of this process is to ensure continual improvement for the entire FMN procedure. The evaluation and controlling processes start from the beginning of the FMN procedure and continue to evaluate and control each step in the FMN procedure. At the beginning of the procedure of the FMN (i.e. from the initiation step), the network management defines the FMN's objective, pursues the feasibility of this objective, and also determines the requirements for this objective.

Several times during the implementation of the FMN procedure the network management examines experience and learning thus far, evaluate the strategy, and make changes in the procedure based on what has been learned. For each action the network management evaluates the changes or the improvements on two levels, how it is working for the FMN as a whole and how it is working for the individual partners within the FMN.

An additional valuable aspect of this assessment process is that learning is explicitly built into the process, and the degree to which learning occurs is itself a criterion for evaluation of the strategy. Evaluations becomes built in to a continual improvements and re-design process which results in much stronger programs based on learning and evolutionary change, rather than rigid success/failure criteria.

By bringing the networking into a cycle of strategy design, action, evaluation, and re-design based on continual improvements, partners build an additional means of evaluation which is on-going, process-based and improved by diverse perspectives. This evaluation process will result not only in better strategies, better hypotheses, and faster learning, but also in a tighter network which operates across different boundaries and diversity of perceptions.

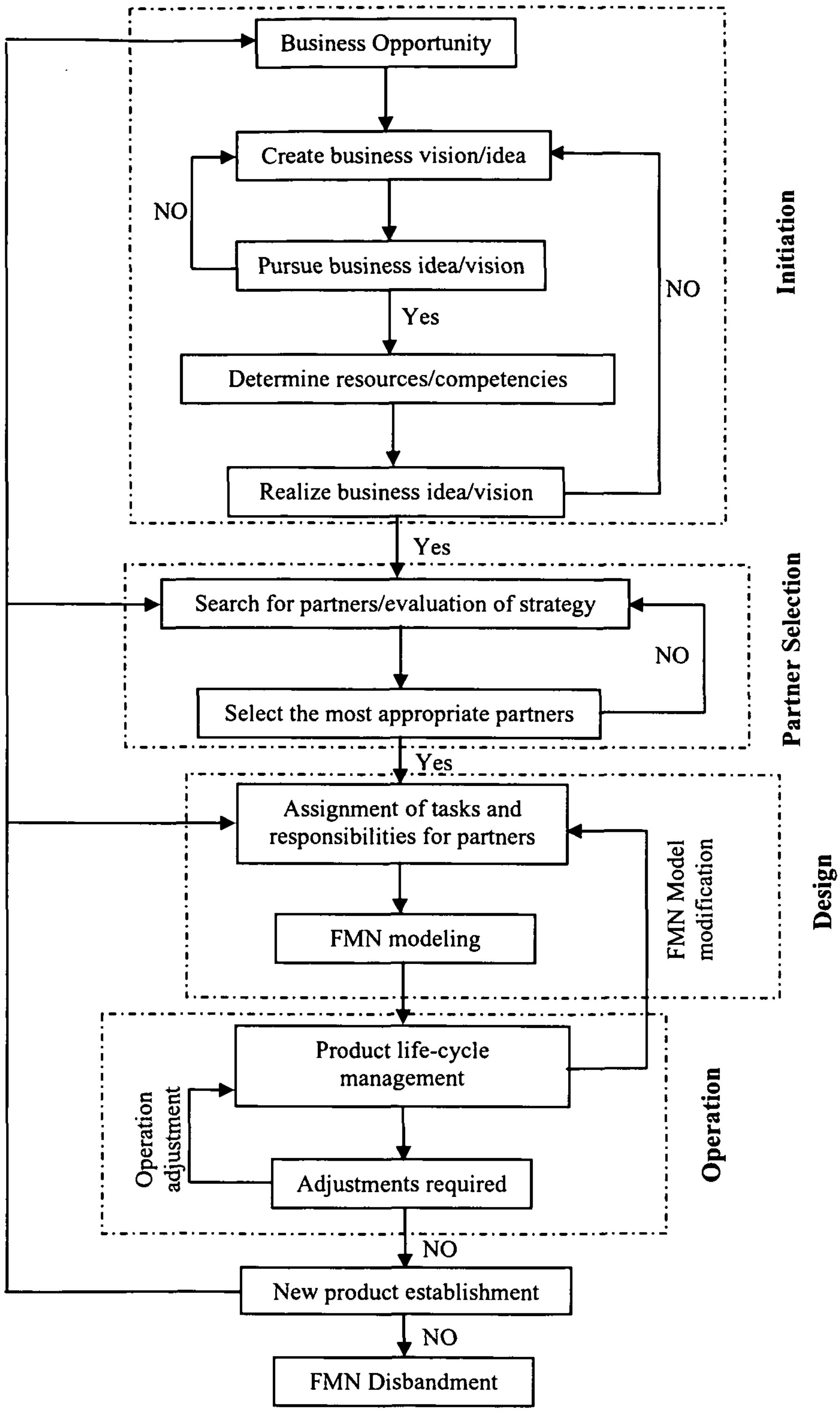


Figure 4.3 Procedure to establish FMN

4.3 Designing of FMNs

From long time, research issues associated with global manufacturing partnership have been dispersedly addressed. They have been included in the studies of plant location selection decision, diversification strategy, acquisitions, vertical integration and the configuration and coordination decisions in the global manufacturing partnership **[39]**. Most of them examine partnering issues within a broad environment context taking account of location or macro-variables. These research interests have paralleled a main concern about economic explanations for foreign direct investment. However, many of the works were concentrated on the formulation of strategy **[28]**. There is a lack of efforts dedicated to the implementation of such partnerships. Furthermore, the fundamental conditions for global manufacturing partnerships have significantly changed. Thus, this work tries to develop a full and rich understanding of the partnering process such as the partnering in the FMNs and the implemental methodology to explore what are the main dimensions of designing the FMNs.

FMNs are often analyzed using two main dimensions: the configuration and the coordination of the FMN. The following sections will discuss the configuration and coordination dimensions of designing FMNs; Fig. 4-4 presents the dimensions of designing FMNs and the parameters for each dimension.

4.3.1 Configuration of FMNs

The configuration of the FMNs describes the relationship between the different partners in the networks. The actual planning and execution of material and information flows among partners are dependent on partners' geographical dispersion. The discussion about the configuration dimension in FMNs typically examines the structure and configuration in terms of two parameters.

The first parameter is the number of organization or companies shared in the FMN and the number of sites that each organization controls (geographical dispersion), there is a need to determine the number of organizations or companies involved in the analyzed FMN. Based on the first parameter; two different types of networks are defined. The transactions among the partners differ between *inter-firm* networks and *intra-firm* networks. These typical networks are discussed in the following.

The ***intrafirm*** network, multi-site planning is viewed as the development of a set of facilities that will provide the specific capabilities required by the organization over the long term. Since there is only one organization, but with many sites this type is very similar to the theory developed in the manufacturing network area.

In the *intrafirm* network, the multiple sites that cooperate in sequence or in parallel, with a vertically or horizontally focused network, need to be optimized in order for the intrafirm network to reach its true competitive potential, i.e. to be fully productive. The problems that need to be addressed include the allocation of products and volumes to partners, and the production and distribution of products and orders within the network.

Interfirm network, which can be seen as a multiple organizations or companies with multiple sites for each organization. For this type of network the number of organizations and the total number of sites within the network determine the size of the network. The location of the sites within each respective organization can be decided by the organization's corporate headquarters, but the location of collaborative partners' sites have to be taken into consideration. The focus of the complex network is most likely a combination of vertical and horizontal focus. Depending on how the network is set up, an internal interface, external interface, or combinations of both can be present. The actual balance is determined by the "collaborative maturity" of the inter-firm network system.

The second important parameter is the type of the organizations shared in the FMNs. according to the FMN strategy; a manufacturing business dynamically organizes its operations through the configuration and activation of FMN interdependent partners (manufacturing, transportation, storage, and services). These different types of partners are fundamental components of the FMNs and responsible for making decisions and/or executing tasks.

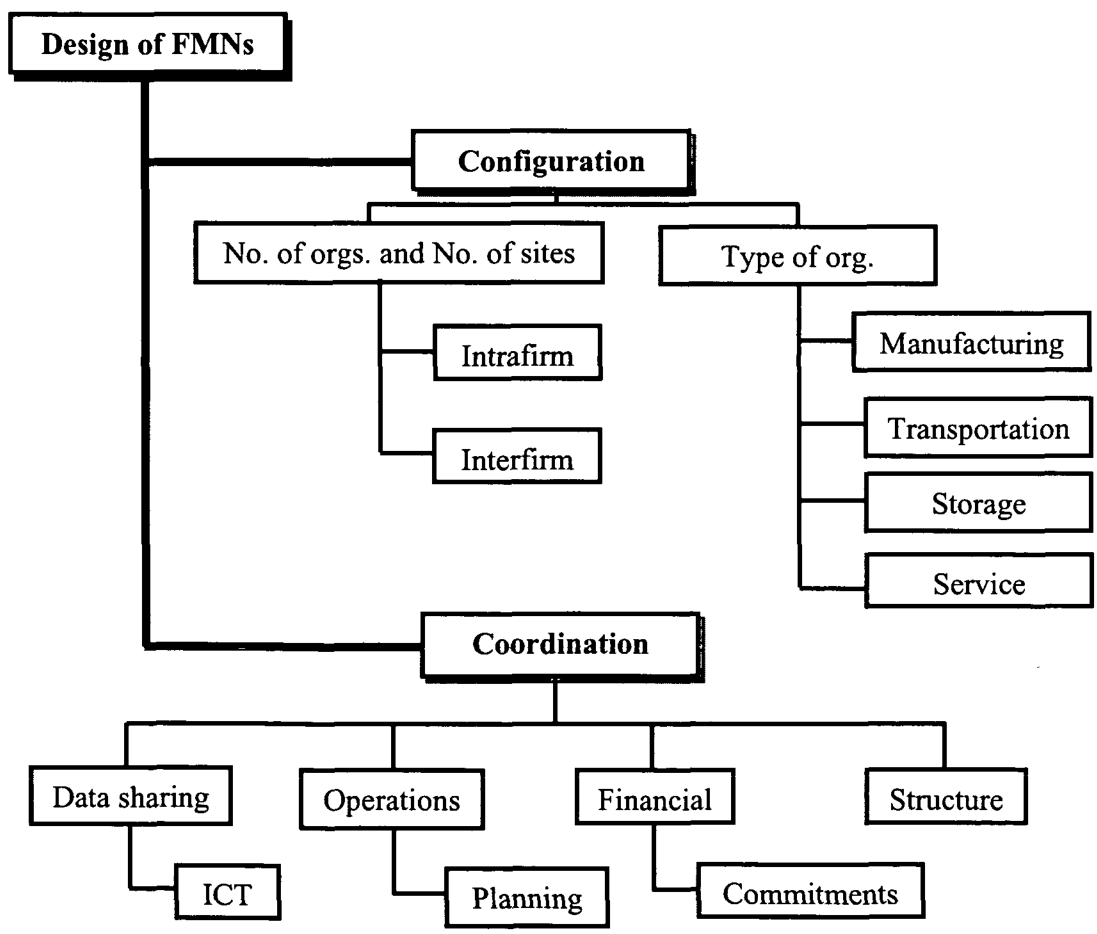


Figure 4.4 Two main dimensions of designing FMNs

The manufacturing, transportation and storage partners are the basic partners in the entire production process. The manufacturing partner is responsible for transforming the produced product from one status to another status; the transportation partner is responsible for delivery the produced product from the preceeding partners to the succeeding partners, and the storage partner is responsible for a temporary holding of the unfinished products before delivery to the succeeding partners due to timing considerations.

The type of service and support organizations, including banks and loan funds, research and development R&D institutions, training assistance providers, government entities, and technology transfer organizations, need to link with FMNs to assist them. Many of these service organizations have resources and capabilities that can be assembled to help the partners in the FMNs. Many educational institutions and government agencies may offer programs which define the legislation and/or regulation of the commitments within FMNs. However, the partners within the FMNs have to be flexible; the service organizations may create co-design custom programs with firms and to continually improve the programs as feedback on their effectiveness and limitations. The service organization must work collaboratively the other partners and the markets to develop customized services to meet emerging needs [5].

The characteristics of these different types of partners are expressed in Table 4-1 with respect to the identity, relationship, and operational perspectives.

Identity perspective	**Relationship perspective**	**Operational perspective**
• Has a focused business responsibility-based mission within the FMN; • Self managed and responsible of its decisions and commitments; • Interact with the other partners to achieve the FMN objective; • Have sufficient local resources; • To be flexible for changing and controlling.	• Using all the networking conventions in its interaction with the other partners; • Honors business agreements and commitments; • Providing information about its expected needs; • Providing up-to-date information on the realization the orders; • Maintaining up-to-date evaluation of itself.	• Maintaining up-to-date status of all its resources, its activities and the orders under its responsibility; • Providing dynamically update a model of itself to the other partners; • Planning feasible commitments by taking advantage of all provided information.

Table 4-1 Characteristics of the different types of partners

4.3.2 Coordination of the FMNs

The coordination dimension of the FMNs is about coordinating information and material flows, operations and logistics, financial commitments and structure within the FMNs. It provides flexibility and agility in responding to customer demand shifts with minimum cost overlays in resource utilization. The coordination seems to be applicable to a FMN environment. Coordination is managing the tasks of the manufacturing between the partners. Furthermore, the common tasks which need coordination within FMNs can be identified as the customer requirements, shared resources, simultaneous constraints, and flow of operations.

If coordination can generally be defined as managing tasks between partners, then what exactly are the tasks that need to be coordinated in network? There are four main coordination parameters required for coordinating across the FMN as follows:

1. Coordinating data sharing and information systems that provides information visibility across the FMNs.

2. Coordinating logistics process and operations across the FMNs.

3. Coordinating financial and system transactions, balancing financial commitments and risks among the partners in the FMNs.

4. Coordination the FMNs structure, which coordinate the form of cooperation relationships between the partners.

The data sharing, operations and structure coordination parameters can be considered more operational and tactical, whereas the financial parameter is more strategic in nature. An initial observation is that these four parameters potentially represent sequential activities across a time scale. The data indicates that information sharing is typically the first coordination efforts made by partners. This initial effort often leads to more in depth coordination of the logistics and operations.

In case of considering connected information systems, the nature of the dependency is that of the producer/customer usability, meaning that the receiver (customer of the information is dependent upon the sender (producer of the information for its usability. This suggests that important aspects of the coordination process should be standardization and participatory design.

Applying this to coordinating logistics processes and operations material flows, the nature of dependency is that of a producer/customer transfer, meaning that the receiver (customer) of material flows is dependent upon the sender (producer) of the material for the transfer of the material from one location to the next. This suggests the important aspects of this coordination process should be sequencing, tracking flows, managing storages and potential use of progressive material flows.

Applying the framework to coordinating financial flows and tradeoffs, the nature of the dependency is that of shred resources, meaning that the partners of the FMN need to coordinate sharing resource in some fashion, often budgets, managerial decision-making and decision rules serve as some of the structure to coordinate the flows. Coordination of this parameter means coordinate the network decisions that entail the tradeoffs required to improve the network performance, these decisions involve allocation and reallocations of investments, risk and risk information, allocation of costs and benefits among the partners.

The focus of the FMNs has major logistical implications, as it determines to a large extent the flow of operations in the network. Product and/or market oriented FMNs operate more as a parallel network and have other needs. In FMNs one of the logistical challenges will be to coordinate deliveries. In order to achieve logistical excellence the FMNs are dependent on a powerful ICT strategy, with ICT systems can support the management, integration and coordination of the network. FMNs are characterized by intensive communication not only between the network and customers, but also between the partners. The goal is to get every partner onto a common platform of logistics transactions and information systems for greater interrelationships. This integration can result in significantly faster system response times to volatile changes in marketplace events and patterns of demand.

The coordination of the FMNs structure depends on the type of relationships and the form of cooperation among the partners in the FMNs. The structure of the FMNs is non-hierarchal structure, which means combining the necessary partners and resources without a formal hierarchy in the structural relationships. The FMNs structure has to be stable in time, which means that the network products, processes and management policies are the same over long periods. The main result of this stability is that the costs and complexity of network creation and modification will be low. Individual partners can join or leave the network, but this must be considered as a persistent structure.

The principle behind the FMNs structure and the management of their operations is network management which orchestrates operations through the exploitation of the capabilities offered by existing manufacturing and logistic firms. Partner firms are meshed into the FMNs mainly because they extend manufacturing capacity and technological knowledge. The FMNs structure are assembled and disassembled to ensure the execution of distinctive tasks and achieve top performance.

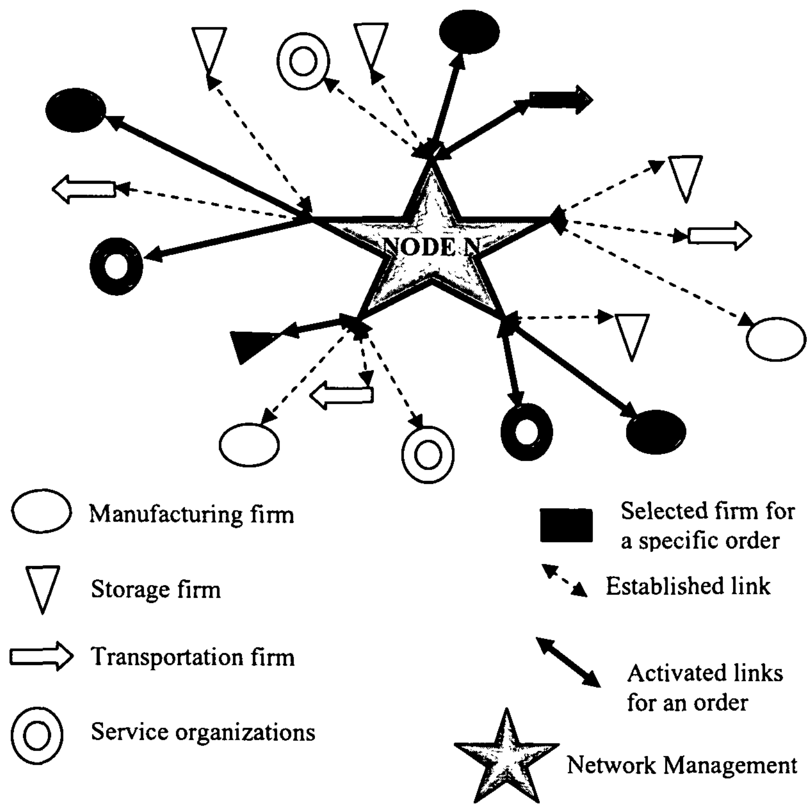


Figure 4.5 Illustration of FMN structure as perceived by node N

FMNs are comprised of intelligent self-organized competitive manufacturing, logistic firms and service institutions thriving on their tight meshing and interaction without restriction from location. A node N (network management) of the FMN having to manufacture a product and therefore it initiates a bidding process for each task to be performed. Then, manufacturing, storage and transportation sharing partners compete on a quality-time-price basis to obtain parts of the order. Fig. 4-5 illustrates the concept by showing a FMN as perceived by a network management. Links between partners are intensified when they are selected to perform specific tasks of an order, otherwise information links are constantly maintained among partners of the FMN.

4.4 Advantages of FMNs

1. Networking is a particularly urgent strategy for transforming economies because it represents a cost effective means to deal with the major barriers of the firm development. By joining, SMEs gain the economies of scale they need. As a group, they gain the capacity to leverage investment from foundations and government to set up new systems for dealing with these issues in an ongoing manner. The aggregation of firm demand also enables educational and training entities to better provide for the needs of firms, and makes it possible for them to invest in the development of new programs.

2. The lack of time on the part of SMEs is a major barrier to their capacity. A networking can generate the capacity to set up systems to streamline the amount of time firms must spend on these issues. For example, the network management can make meetings much more efficient; and the partners as a group can develop online systems for planning, design, and reflection.

3. The firms often learn best in collaboration with other firms, whether within their region or in other communities. Firms need to be leading the learning process by deciding what they need to learn, but they need to do this in the context of deep familiarity with best practices in other communities around the world. The networking, in effect, set up new high performance networks, both online and face-to-face, in order to create a larger learning system. Participation can also enhance the role of lead firms in the networks. As they try out new practices, they spread the results of that experience throughout the partnership, enabling the rapid spread of local best practice.

4. Network also leads to long term sustainability of the learning system, particularly if resources can be found to adequately invest in the restructuring that needs to take place among firms and other organizations. The partnership can enable and develop a basically self-sufficient public-private partnership system. Firms that are high performance organizations not only see the essential nature of ongoing firms' capabilities programs, but are willing to support them.

5. Partnership can provide aggregated units which can help government understand the policy support required by high performance organizations.

CHAPTER 5

Configuration and Coordination Approach of Flexible Manufacturing Networks for Specific Customer Orders

FMNs are comprised of intelligent self-organized competitive manufacturing and logistic firms thriving on their tight meshing and interaction without restriction from location or appurtenance. The firms drive their flexible operations through dynamic self-organization of multilayered virtual operations networks. When the network management of the FMN receives an order from the customer to manufacture a specific product, then the network management initiates a bidding process for each task to be performed. Then, the manufacturing, storage and transportation sharing firms compete on a quality-time-price basis to obtain parts of the order. Links between partners are intensified when they are selected to perform specific tasks of an order, otherwise information links are constantly maintained between firms of the network.

The FMNs purposes imply new tools and methodologies for planning and scheduling activities. Recently, some works in this sense have been published. Some authors have addressed the problem of structuring a global corporation as an Agile Virtual Enterprise (AVE) **[26]**. They introduced a dynamically configured AVE for manufacturing one or more products. The authors propose task decomposition for manufacturing of a product in multi-site environment. According to the initiating bidding process within the AVE and the task relationship network, the bidder, its location and the bidding price was known and also the transportation costs between the candidate partners could be estimated. An integer linear program (IP) to minimize the total manufacturing cost was presented for the partner selection problem. The solution of their program recommends transformation of IP formulation into a graph-theoretical formulation by taking the advantage of the precedence relationship between the tasks, and an efficient solution algorithm is proposed for the problem.

Another authors exposed a method to calculate satisfying routes for customers' orders within manufacturing networks of SMEs **[1]**. This method aims at designing the routing of activities, so as to meet the customers' needs in terms of cost, quality and delivery time (short-term performance constraints), and to promote learning processes and skills exchanges within the network. The authors exposed conceptual model and hypothesis to describe networks of SMEs, and then presented the modeling procedure by introducing successively the technological map, the competencies map and the product/actor attainment graph. The authors used Multi-Objective Programming (MOP) model for the short-term selection problem to obtain a set of non-dominated solutions and to coordinate the manufacturing network.

The configuration or the structuring of the FMN and coordination the operations among the partners within FMN raises the need for defining the FMN process model, new bidding processes, FMNs structuring and scheduling methods. It is the focus of this part; section 5-2 explains the FMNs process model and its requirements and describes the steps of constructing this model. Section 5-3 presents a list of parameters defining the different planning and scheduling decision processes encountered in FMN, and also discusses the different types of the manufacturing bidding mechanisms which are used to optimally configure and coordinate FMNs for the realization of a specific customer order. Finally, Section 5-4 presents the approach used to formulate the FMNs configuration and coordination process.

5.1 FMN process model

Network creation is favored by the SMEs due to its lean and flexible structure, its natural disposition toward cooperation, and gained through stable partnership links. The main obstacles to network creation are the individualistic and independent nature of SME management, the lack of contractual frameworks for these new forms of cooperation and, on the information systems side, the lack of suitable methods and tools for distributed production management.

The requirements of FMN address proposing an organization model to establish the specific customer order, where:

- ➔ The nodes are independent firms spontaneously cooperating to pursue a common objective, i.e., manufacturing and delivery together a certain product;
- ➔ Each node has basically equal rights on the manufacturing tasks originated by orders for the network final product;
- ➔ A network management (leading company) is established to plan and manage the tasks execution, ensuring proper synchronization and reactiveness;
- ➔ The decisions of the network management are driven by transparent criteria constantly updated to reflect the nodes current status and past performance.

The most critical decision-support functionalities are required for the network management for planning and processing the customer order, including:

- ➔ Order design and splitting into tasks and sub-tasks at the partner level;
- ➔ Tasks assignment based on multiple workload distribution criteria (partner selection);
- ➔ Finite capacity planning based on the partners declared capacity for each task;
- ➔ Modifications of ongoing orders in response to partner delay or other changes.

Timeliness and reliability of planning decisions are essential for acceptance of the network management role by the individual nodes. For this, a key pre-condition is to have available a consistent and updated representation of the network distributed manufacturing process as shown in Fig. 5-1.

The network operational schema is a detailed representation of the network process and consists of a product-oriented process representation given at the network level, i.e., where only sub-tasks at each node and the transportations between nodes are visible. The network operational schema is a family-based reconfigurable structure, allowing representation of alternative product features and manufacturing paths, and it is completed by information on node capacities, manufacturing, storage and transportation times. The above information produces the network flow graph, which identifies all the possible routes for delivering a product to a customer.

The network operational schema is a fundamental step in the configuration of the FMN, as it constitutes the basic structure for network coordination and planning.

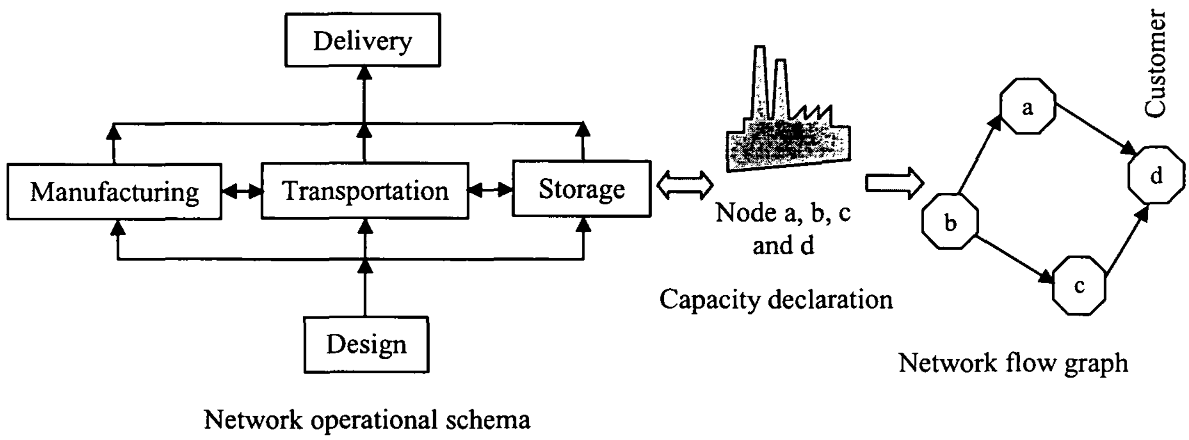


Figure 5.1 FMN configuration and coordination model

5.1.1 Process modeling requirements

The FMN planning and management functions refer to an updated representation of the network, maintained at the network management to capture appropriate knowledge elements about the nodes and their joint behavior. Primary among these elements is the description of the network distributed process, in terms of activities carried out by the different nodes to reach a common goal. This description is needed to specify the nodes capacity and responsibilities, to define the network planning policy, and to qualify the network offer with respect to external customers. More precisely, the following requirements are to be met:

1. Product-orientation: FMN supports daily network production management where a cooperative manufacturing process is produced by each customer order. Hence the process representation must be related to the final result. Furthermore,

only activities in the order are of interest, among all those performed by the network nodes.

2. Node-level details: The network process representation must include all tasks performed by the nodes to obtain a product. This does not require that every production and assembly operation is modeled. Rather, every sub-task is identified that represents all activities carried out by a node to transform the input(s) received from the supplier nodes into the output(s) transferred to the customer nodes.

3. Transfer task: To obtain the final product, each task output must be transferred to the subsequent task(s) in the network process. This usually corresponds to a physical transportation of materials between the involved nodes, but it may also represent an exchange of information or a simple precedence.

4. Family-based modeling: The FMN is a persistent and re-configurable structure, where each node is capable of offering a wide range of products. In general, a network offers different versions of the final product, that is, a family of products. For network coordination purposes, and to avoid redundancies, a unique, generalized process representation should be given for each family. In response to an individual customer order, the family process representation will be configured to obtain the required product version.

5. Scenario-independence: The network process representation must support different decision-making activities, such as planning, simulation and performance evaluation, carried out cyclically in varying network conditions and operating scenarios. This calls for a process representation which is as much as possible independent of contingent aspects, such as external demand, nodes status or calendar.

5.1.2 The network operational schema

In consideration of the above requirements, the network operational schema is defined as the sequence of all manufacturing, storage and transfer tasks required to obtain a given product, where:

- Each manufacturing task presents a basic step in the entire process,
- Each storage task presents a temporary holding of the unfinished products before delivery to the following tasks due to the timing considerations,
- Each transfer task presents the delivery output of the preceding task to the following tasks.

The network operational schema can be conveniently represented as an oriented graph, where nodes present manufacturing, storage and transfer tasks, and arcs present precedence links between subsequent tasks. The network operational schema has the following properties:

1. It is connected, in that all tasks are linked into a unique structure, representing the distributed manufacturing process for the product family which the network operational schema refers to.

2. It is a cyclical, in that no task can directly or indirectly receive input from itself. By assuming that each task introduces a component in the resulting product structure and no product can be part of itself.

3. It has a single root node, i.e., a node with no outgoing arcs. The root node is assumed to be always a transfer task, representing the finished product delivery to a customer outside the network.

4. It has a number of leaf nodes, i.e., nodes with no entering arcs. The leaf nodes are assumed to be always manufacturing tasks, representing the first operations in the network distributed process.

5. It presents alternated manufacturing, storage and transfer tasks, since:

    - ➔ A manufacturing/storage task must always be followed by a transfer task. Any two subsequent manufacturing tasks represent process steps that can be performed at different nodes, and thus a transfer is required between them. Otherwise, the two steps should be aggregated into a single task.

    - ➔ A transfer task must always be preceded by a manufacturing/storage task. The only components of interest for network coordination are those produced inside the network; thus, a transfer can only be applied to a manufacturing task output. All other materials consumed during task execution, including those feeding the leaf tasks, come from outside the network: ensuring their timely availability is up to local planning at the single node.

5.1.3 Manufacturing tasks

A manufacturing task presents a portion of the production process covered by a single node. The task represents all the activities performed at the node, from input acquisition to output delivery to the subsequent nodes, abstracting from the details of node resources operation. This does not mean that each manufacturing task is performed exclusively by a certain node. In general, being the network operational schema scenario-independent, different nodes may declare themselves available to perform the same task. These capacity declarations are taken into account by the network management to assign tasks to the available nodes, depending on the circumstances and the applied workload distribution criteria.

Formally, said $(M_i)_{i=1...M}$ and $(T_j)_{j=1...n}$ the sets of manufacturing and transfer tasks constituting the network operational schema with the set of the storage tasks $(Sx)_{x=1...y}$, the ith manufacturing task is represented by a triplet of the form: $\{ID, Output, Input\}_i$, where:

- ID is the task name. The name is required for each manufacturing task and is univocal in the network operational graph.
- Output is the indication of the task output, represented by an arc (i, j) starting from M_i and directed to a transfer task T_j. The output link is j mandatory for each manufacturing task, and the arc bears the indication of the corresponding output product P_j, representing the task final outcome.
- Input is the list of input components consumed by task M_i. Multiple input is required to represent the different components required from other network nodes in order to perform the task M_i.
    - Each item in the list is represented by an arc (k, i) entering M_i and starting from a transfer task T_k. This indicates that a quantity of the transferred k component is consumed by task M_i.
    - For each arc, the consumed quantity q_k specified in proper units, to indicate the amount of kth input component required for a unitary amount of M_i output.
    - According to the network operational schema definition, each leaf task has an empty input list. For all other tasks the list contains at least one element.

The above definition leads to the general graphical representation for manufacturing tasks, shown in Fig. 5-2.

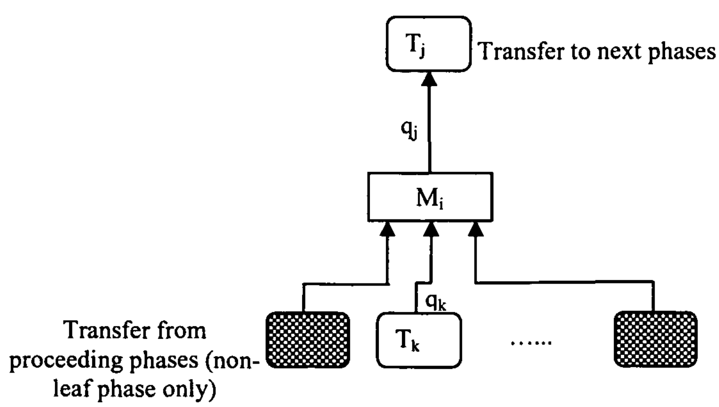


Figure 5.2 Manufacturing task

5.1.4 Task functional parameters

According to the above requirement, the network operational schema is defined as a generalized structure, representing all the different versions in a family of products. Correspondingly, a task output represents a family of components, each included into a different final product version. Given an order from the customer, the network management must configure the network operational schema to obtain the corresponding distribution of orders for the individual nodes. Each order will indicate the required component version, selected among those associated to the required task in the generalized network operational schema.

These orders shall be managed by the node local planning transparently, i.e., using the same procedures and tools as for other orders coming from outside the network. This requires a product classification mechanism which is sufficiently general to be shared by all the nodes. A general model for products classification is that a task output can be in general represented as a family of products, sharing some basic features and functionalities.

More precisely, being M_i the ith manufacturing task, the output product corresponding to the arc (i, j) is described by a triplet of the form:

$P_j = \{f, F, C\}_j$

Where: f is the name of a family of products, univocally defined at the network level; F is a set of functional parameters representing the external features and functionalities shared by all products in the family; each parameter is defined on a finite domain of values; and C is a set of specific functional conditions for each product version in the product family.

The product family technique may be used as a method for checking and comparing product designs, this enables developers to maximize reuse, accelerate the development process while reducing costs, and deliver products that are generally more reliable **[2]** and **[33]**.

5.1.5 Transfer tasks

A transfer task presents the connection between two subsequent manufacturing tasks or two subsequent manufacturing and storage tasks. Formally, said $(M_i)_{i=1...M}$ and $(t_j)_{j=1...n}$ the set of manufacturing/storage and transfer tasks constituting the network operational schema, the jth transfer task is represented by a triplet of the form:

{ID, Source, and Destination}$_j$:

Defined as follows:

- ID is the task name. The name is not required, being each manufacturing task univocally identified by the couple {Source, Destination}$_j$. The name can be useful to characterize a complex transport, whereas a simple precedence may not need to be explicitly indicated.

- Source is the indication of the manufacturing/storage task(s) whose output is being transferred. Two cases are given:

  - Source is represented by a single arc (i, j), for example, starting from the ith manufacturing task M_i to indicate that the transferred product P_j is produced by M_i, Fig. 5-3.

  - Source is represented by a set of entering arcs $\{s_h, j\}_{h=1....P}$, for example, each starting from a manufacturing task in the set $\{M_{sh}\}_{h=1....P}$ of those producing the transferred product P_j. Consequently, all the source arcs represent the same product, which is the one transferred by task T_j, Fig. 5-4. In such circumstances a manufacturing alternative is given, in that each entering arc represents a different process path to obtain the same product.

- Destination is a set of outgoing arcs $\{j, d_k\}_{k=1....q}$, where for example each arc is directed to a manufacturing task in the set $\{M_{dk}\}_{k=1....q}$ of those consuming the transferred product P_j (Figs. 5-3 and 5-4). As explained above, a consumed quantity is specified for each such arc. While the generic transfer task T_j must always have at least one Source arc, the Destination list can be empty in case the T_j represents the transfer to the final customer.

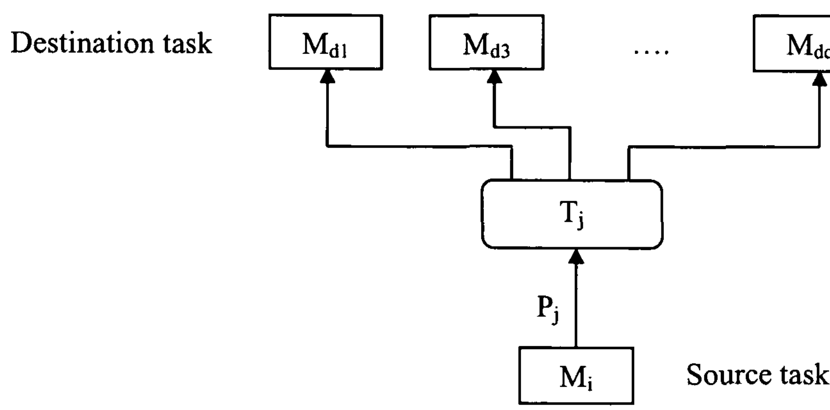


Figure 5.3 Transfer task

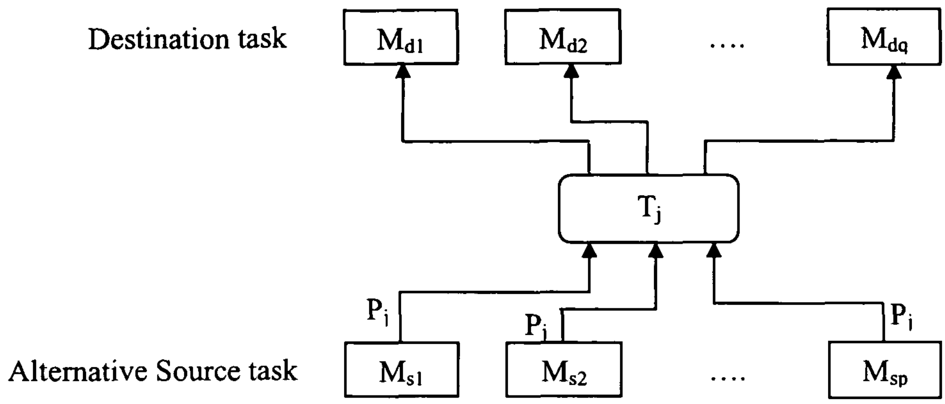


Figure 5.4 Transfer task with manufacturing alternative

5.1.6 Manufacturing alternatives

According to the previous definition for transfer tasks, a manufacturing alternative is given when a transfer task has two or more entering arcs Fig. 5-4. These represent the same output product, which can be obtained from each of the corresponding manufacturing tasks.

It has to be observed that when the choice between alternative processes is resolved by the individual node, it must not be represented at the network level. For example, a complex manufacturing task may be exploded at the node level into a process including alternative sequences of operations (e.g., FMS or traditional machining). In such cases, the node local planning is offered a range of possibilities on how to obtain the same final result. These possibilities cannot be considered at the network level, since this would require a description of manufacturing resources and activities inside each node. For this reason, a single task is used to represent the whole process, including all the possible alternatives.

Conversely, the alternative between producing and sub-contracting a component is distinguished at the network level: the former task represents the manufacturing of a component by a network node, while the latter represents acquisition of the same component from a sub-contractor outside the network. The alternative has to be considered by the network management for workload assignment, since the two tasks can be performed in different ways by two disjointed subset of nodes.

5.1.7 Composition alternatives

Another kind of alternative is given when, depending on the chosen components, different versions of the final product are obtained. In general, different product versions are characterized by different composition structures, with a shared basic structure and a number of alternative components.

Local alternatives affect the composition structure of a task output product but are visible only to the node performing that task. Since the network operational schema detail level does not extend to components managed locally by a node, these alternatives are not given an explicit representation in the network operational schema. Instead, the different versions of a task output product are represented as configurations of the above defined task functional parameters, which are mapped onto local alternatives by the node performing the task.

Network composition alternatives are given when the alternative components are visible at the network operational schema level, as output products of tasks performed by network nodes. For example, the customer may be offered product versions getting from two alternative components, each resulting from a different task performed by a different node. This kind of alternative affects the network management decisions on workload distribution and must be represented properly in the network operation schema, thus adding a further level of generalization.

Formally, said (k, i) the kth arc entering the manufacturing task M_i, a composition alternative is given when the arc joins two or more input links from different transfer tasks, rather than from a single task as in the original definition. Said $\{T_{rl}\}_{l=1....nk}$ the set of transfer tasks connected to M_i through the kth arc, Fig. 5-5, by assuming the following:

- Each task T_{rl} transfers a different product P_{rl},
- All the different product types transferred by tasks joining at the kth arc represent alternative options for the input component represented by that arc. Each of those types can be used for that component, in the indicated quantity q_{k},
- Each such alternative has associated a network functional parameter f_k with as many values as the alternative options. Formally, the parameter is defined as follows, where V_{rl} represents the value corresponding to the P_{rl} product:

f_k: $(V_{r1}, V_{r2} \ldots V_{rnk})$

By choosing one of these values a different version of the final product is obtained, which presents the corresponding component as input for the task M_i.

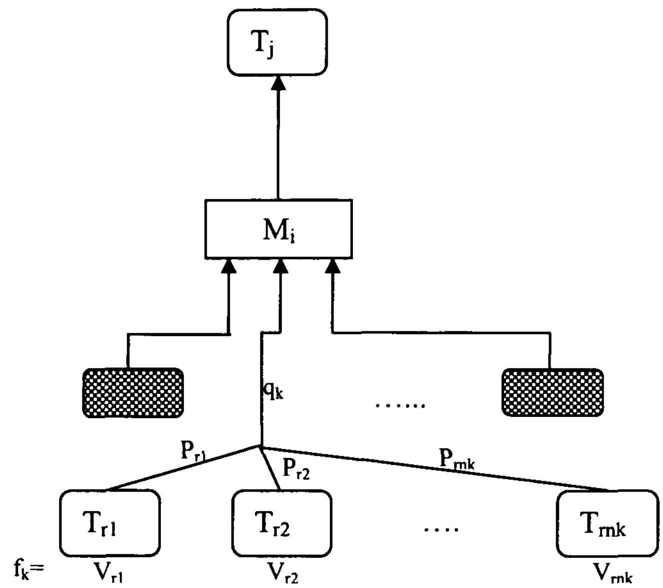


Figure 5.5 Composition alternative

5.1.8 Network operation schema configuration and instantiation

From the above analysis, three important observations can be derived about the network operational schema.

(1) The network operational schema is a generalized structure that needs to be configured against each single customer order, to obtain the specific process structure for the ordered product.

(2) The network operational schema is a representation of the distributed manufacturing process in abstract terms, describing 'how' the final product is realized without saying 'when' and 'where' (i.e. by which particular node) each different task is to be executed. To this purpose, partner nodes capacity declarations have to be introduced to complete the manufacturing task's representation. Given a task in the network operational schema, all the partner nodes declaring capacity for it are potentially enabled to perform it (bidding process).

(3) The transfer nodes represent logical precedence relationships between manufacturing/storage tasks, indicating which tasks consume a given task output, without giving any indication of the physical path followed by components in the actual network. To this purpose, FMN also includes a representation of the network configuration, describing physical links between the nodes and how transport tasks are performed across these links.

Point (1) is considered the first step in the configuration of FMN and was discussed in the previous sections. Points (2) and (3) are used to select and assign the most appropriate partner(s) to each task from the candidate partners, and consequently to determine 'when' each task is performed. Point (2) and (3) are the main objectives of network management planning. To this purpose bidding process distribution is initiated between the network management and all the partner nodes for each task.

For what attains in point (1), the resulting configured network operational schema will be the basis for assigning manufacturing tasks to the network nodes.

5.2 FMN planning and scheduling

Bringing the optimization a step further, the problem is raised once the network management wants to satisfy an order from a customer by exploiting the potential of its manufacturing network (make-to-order). The network management has to configure and coordinate the needed tasks through a Flexible Manufacturing Network (FMN) composed of manufacturing, storage and transportation firms. The objective is to deliver the order at minimal cost within the delivery time window allowed by the customer.

The problem of planning and scheduling FMN raises the need for efficient information exchanges between the partner nodes, and consequently, for new bidding processes ensuring optimal decisions. FMN is without doubt built on a strategic understanding of the network, on its process and on its identity. Relations are established through formal and informal information exchanges between the different partner nodes in the network.

Although information exchange seems to be promising and has shown positive improvement on the supply-chain performance, an important aspect of it needs to be considered: information distortion. Some authors have studied this supply-chain management problem called the bullwhip effect **[12]**. The bullwhip effect is referred to as the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer and the distortion amplifies upstream in the supply chain. The authors demonstrate how the information transferred in the forms of "orders" tends to be distorted and can misguide members of the supply chain. This is due to multiple levels of information processing. They explain that combinations of activities are needed to counter the bullwhip effect. These strategies are mostly based on rich and efficient information sharing. As an example, the authors discuss a typical way of transferring demand to the supplier, reducing its possible margins of adjustment as delivery date gets closer.

There are many parameters, which affect the planning and scheduling processes in the FMN **[37]**. The network management of FMN may face many decision processes for exploiting the FMN. The decisions may be defined by seven parameters, which are:

1. The production type

2. The number of products involved

3. The dependence between orders
4. The process structure
5. The processes flow strategy
6. The demand knowledge
7. The partner reliability

The complexity of addressing planning and scheduling processes depends on a variety of these seven main issues. At first, a decision is defined by a specific type of production: order production is done punctually in time, compared to series production, which is continuously performed to respect demands periodically. A second distinction is made between productions of a single product versus multiple products. On the next level, independent orders are distinguished from coordinated orders. The characterization follows with the process structure. The process structure can be defined by operation sequences represented as a line, a tree or generic network of operations. Then the characterization distinguishes monolithic orders from fragmented orders. Monolithic orders refer to order that must be processed as a block, while fragmented orders refer to orders that can be processed in parallel in various factories through its multiple steps. Finally, the last two decision parameters having some potential impacts on the scheduling decisions; they are the demand knowledge and the partner reliability.

5.2.1 Description of decision process of planning and scheduling

Flexible manufacturing networks are characterized by an important number of nodes, defined by the network's firms, interacting together by exchanging flows of products, information, knowledge, money and resources of all kind on the network's arcs. This kind of organization provides a wide range of alternatives for processing an order, where planning and scheduling operations translate in a time-based activation of appropriate nodes and arcs of the network. The goal is to minimize the price of activating a meshed group of nodes for realizing an order.

The planning and scheduling situation can then be started as follows. Suppose that the FMN includes a set of manufacturing, transportation and storage nodes. The network management of the FMN needs to orchestrate the production of an order containing a batch of specific product, and deliver it to customer. To manufacture and deliver this product, a series of linearly sequenced manufacturing and logistic operations needs to be performed.

The network management of the FMN seeks to minimize price associated with the execution of the order. After studying each product, it decides to transform the production of the product into the network operation schema. Request for bids on each task is sent to every partner node capable of performing the required tasks. To ensure fluidity, transportation nodes need to be activated when different firms execute successive tasks. Request for bid on potential transportation moves are thus sent to transportation nodes. Finally, timing considerations may force unfinished goods for storing before delivery. In such case bids are needed from storing nodes capable of performing.

To take advantage of the dynamic potential of the FMN, the network management of the FMN looks for bids expressing the flexibility of the invited nodes. The partner nodes detail their flexibility with its discrete pricing function. In term of launching period, sojourn duration and quantity. The form in which the partner nodes present their bids depends on the type of order to be processed, the type of relationship meshing the firms, as well as on their knowledge and experience.

Once the bids are received, the network firm of the FMN needs to select manufacturing nodes (m_i) for each task. The network management of the FMN has to identify the activation period (launching date and sojourn duration) for each firm as well as the quantity it needs to manufacture. Then the network management of the FMN needs to select transportation nodes (tr_i) to be used between successive tasks performed by different manufacturing or storage nodes. The transportation firms are specified with their activation period, the quantity of units to transport and the departure and the destination nodes. The network management of the FMN also needs to choose storage firms (s_i) and identify their activation period, as well as the quantity of units they have to store.

Ultimately, the network management of the FMN faces a final decision consisting in putting a price for manufacturing the product under different timing alternatives. All of these decisions are influenced by technological precedence constraints, time phasing constraints and capacity constraints. The technological precedence constraints are imposed by the sequence in which operations are to be performed. The time phasing constraints are imposed by the need to synchronize launching periods, sojourn durations, transportation delay and required delivery windows. Partner nodes have capacity constraints due to limitation of their resources and to their already scheduled activities.

5.2.2 The bidding process

Considering the context of FMN, the problem of interest is when the network management wants to plan and schedule its network to realize a make-to-order production program under the best price-time trade-off possible. After studying the product design and its specifications, the network management invites the partner nodes for bidding for realizing parts of the production program. Then, the network management orchestrates its internal and external networks optimizing a price-time trade-off. The network management provides the planned time and duration of the intervention as well as the quantity of products needed for each partner node in the network.

The network management sends requests for bidding on specific manufacturing, transportation and storage tasks, respectively, to manufacturing firms (m_i), transportation firms (tr_i) and storage firms (s_i) known to have the needed processing capability. Partner nodes (m_i), (tr_i) or (s_i) may provide as many distinct bids as they want on successive sets of tasks. Each task can be performed in parallel by different partner nodes. The bids are required for one production order and are treated without reference to future businesses. Fig. 5-6 shows an example of network flow graph of a potential FMN composed of manufacturing, transportation and storage firms considered as potential partner nodes in the realization of an order divided in four stages of operations linearly sequenced.

Manufacturing bids are for specific tasks under precise specifications and quality requirements. Transportation bids are for specific moves which refer to a source-destination combination, coupled with the status of the product after the completion of a set of production tasks. Finally, storage bids are for specific storage of the product at a given status.

To satisfy the needs of flexibility for the manufacturing network, the bidding firms express their tenders as a series of discrete pricing functions in terms of launching period, sojourn duration and quantity. They also express, through their bids, capacity constraints which are essential to limit over-allocation of manufacturing, transportation and storage processing to small firms. Capacity constraints do not only express resource, technology and equipment time-conflicting constraints, they also express strategic resource utilization based on their expectation about their future potential commitments.

This section discusses different manufacturing bidding processes in relation with the level of information transferred between the partner nodes and the network management. There are three different generic types of bidding mechanism. These bidding processes are used to optimally configure and plan a manufacturing network for the realization of an order characterized by a linear set of operations.

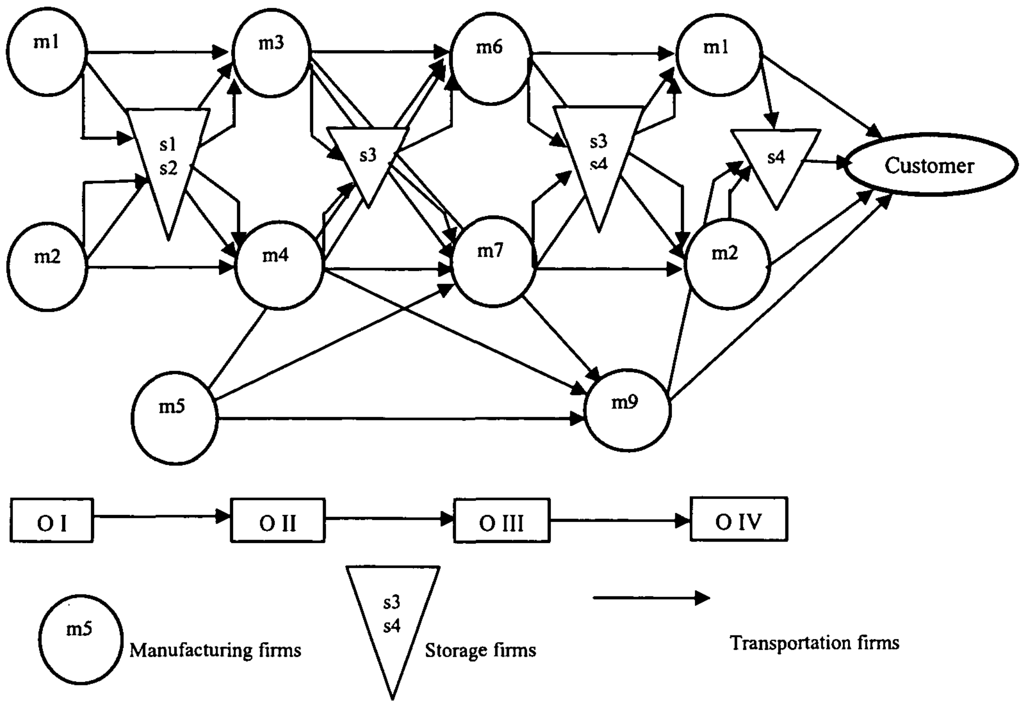


Figure 5.6 Potential manufacturing network flow graph

Bidding processes can take several forms starting with limited information exchanges up to integrated information exchanges. On one hand, the type and quantity of information exchanged will be determined by the network management accordingly to its ability to integrate it in its decision support system. This implies that the information structures, as well as the availability of information technology, are critical factors in the pursuing of efficiency. In fact, a network management will seek for rich information from its partner nodes when it controls the technology to support the information flow (e.g. data, easily transfer them to the network management and see benefits resulting from this). The level of information a partner firm will be willing to provide depends on many aspects, but essentially on the potential benefits of the deal.

The three generic bidding mechanisms based on the format which may be used in the context of manufacturing network in order to perform the optimization of the networking decisions. The simplest bidding process is the supplying-type bid, where activities are priced to process the complete order. The second bidding process is the customizing-type bid, where the partner firms try to accommodate the different potential processing needs of the network management, with minimum internal operational disturbances. Finally, the third bidding process can be used in the case of integrated-partnership; in such setting webbing-type bids contain generic day-to-day operating and pricing information offering higher flexibility to the network management.

5.2.2.1 Supplying-type bids

A supplying-type bid can be associated with very weak form of business relationship. It is like buying from a catalogue, where products are offered at pre-determined prices. If the buyer is not satisfied, its only choice is to look elsewhere as the partner has no flexibility. In fact, the partner nodes and the network firm are investing no efforts into the relation.

In the make-to-order context, this type of bid limits the transferred information to publicly known price-time packages. The bids express priced alternatives (launching and sojourn duration) for processing the net requirements of an order. The bids are of two forms. In Style A, the partner prices all timing alternatives equally. On the contrary, in Style B, alternatives are priced differently taking into account the impact of timing. In fact, type A represents the most current form of bid encountered today, while Style B represents an extension of this most current form.

5.2.2.2 Customizing-type bids

A customizing-type bid can be associated with weak form of business relationship but richer form than the supplying-type. The network management may establish its needs (time, capacity) and seek for a maximum set of alternatives from the partner nodes. The partner nodes provide more than just a price. They try to understand the needs of the network management and to offer a customized solution. The partner nodes and the network management invest more energy into the relationship.

In the make-to-order context, this type of bid describes a set of timing alternatives (launching date and sojourn duration) which are distinctively priced. Capacity constraints are imposed on different time-conflicting sets of alternatives in a bid to protect from overload.

5.2.2.3 Webbing-type bids

A webbing-type bid can be associated with strong form of relationship and the most integrated network partnership relation. The network management may establish its needs and ask for the day-to-day operating characteristics of the partner firm. With full knowledge of their production abilities, capacities and pricing functions, the network management obtains a maximum level of flexibility. The partner nodes and the network management invest a lot of energy into the relationship.

In the make-to-order context, a webbing-type bid defines a new form of contract, moving toward an open- type of relationships. The partner nodes present explicit pricing functions in terms of launching dates and sojourn durations. They also specify the availability of all needed resources. The network management generates itself the best opportunities from the webbing-type bid.

Table 5-1 summarizes these different types of bid when used in FMNs, for producing an order composed of linearly sequenced operations.

	Supplying		Customizing	Webbing
	Style A	Style B		
Price	Unique price specified for all alternatives (specific launching date, sojourn duration) and full satisfaction of capacity needs.	Price specified for an alternative with specific launching date, sojourn duration and full satisfaction of capacity needs.	Price specified for an alternative with specific launching date, sojourn duration and capacity limit	Specified as a pricing function in terms of launching date, sojourn duration and a capacity limit.
Resource	No capacity limits.		Capacity limit on time-conflicting alternatives.	Resources availability as a function of time.
Relationship	Very weak		Weak	Strong

Table 5-1 Three different types of bidding mechanisms used in FMNs

5.3 Configuration and coordination approach for FMNs

This section presents the methodology used to model the networking decision process. Assume that the network management receives an order from the customer to produce (Q) units of a specific product. Therefore, the network management has to configure and coordinate its FMN to produce (Q) units of this product and deliver it to the customer within allowable delivery time.

The network management seeks to minimize the total price of the execution of the order. After studying the product and designing this product, it decides to divide the order in a linear sequence of production tasks, constructs the network operation schema, and decides to select the most appropriate manufacturing, storage and transportation partners. Requests for bidding on manufacturing tasks are sent to each manufacturing firm capable of processing the task or a set of continuous tasks. To ensure a fluid processing of the order, the network management also sends requests for bidding on storage and transportation tasks needed to complete the order.

The network management receives the bids from the manufacturing firms for each task along with their respective launching period and sojourn window, as well as the quantity to be produced by each of them. Second, it must decide where, how long and how many units are to be stored between operations. Third, the transportation firms to be used after each set of tasks, to move the products from the actual manufacturing/storage firm to the next manufacturing/storage firm and ultimately to the customer, specifying for each move the departure date, transportation time window and quantity to be moved. Finally, the network management has to decide on the price to be charged to the customer, where the delivery to customer is bounded by a delivery time window.

This decision process can be modeled as an operational network constructed as the union of operational sub-networks associated to each received manufacturing, storage and transportation bid.

5.3.1 Modeling manufacturing and storage tenders

A sub-network is constructed for each tender on a manufacturing or storage task. Each tender is composed of a set of alternatives expressed in terms of different sojourn durations (w), launching periods (t_i) and finishing periods (t_j). A node (x) is created for each distinctive launching period of a tender. Fig. 5-7 explains the tender identification. The nodes are labeled with:

➔ The tender firm identifier,

➔ The occurrence time (corresponding to the launching period in this case) and

➔ The product status at this point.

A final set of nodes (y) is created for each possible distinctive finishing period. Nodes (x) and (y) of the sub-network represent time-space events which occur at a specific location and a specific time. They are drawn to explicitly define these location and occurrence time. An arc (x, y) is created for each possible distinctive sojourn duration (w) of a tender. It is characterized by a specific operation of the order, a manufacturing or storage firm identifier, a maximum quantity ($q_{xy}max$) and a unit price (p_{xy}) in order to use this specific tender alternative. A flow variable (Q_{xy}) is associated with the utilization of the arc. Fig. 5-8 illustrates an example of the transposition of the tenders as operational sub-networks.

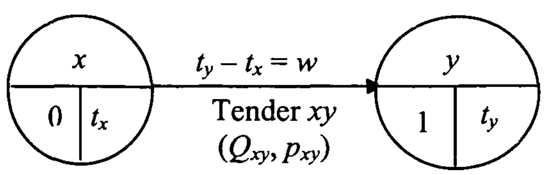


Figure 5.7 The tender identification

5.3.2 Modeling transportation tenders

Each transportation tender focuses on a specific move, from a manufacturing firm to either another manufacturing firm or a storage firm, or from a storage firm to a manufacturing firm. Each such tender by a carrier specifies a set of traveling time windows (w) departing at time (t_x) and arriving at time (t_y) The sub-network for a transportation tender links the sub-networks associated with different manufacturing and storage quotations given to realize successive tasks. For each move and for each traveling time window, an arc (x, y) must be created, starting at node (x) (corresponding to a departure node identified by a firm, an occurrence time and a product status) and finishing at node (y) (corresponding to a departure node identified by a firm, an occurrence time and a product status). It should be noted that node (x) and node (y) must refer to the same product status as the transportation operation to be performed on arc (x, y) is not supposed to alter the status of the product. Arc (x, y) is characterized by a specific transportation operation, a transportation firm identifier, a maximum quantity ($q_{xy}max$) and a unit price (p_{xy}) for using this specific quoted alternative. A flow variable (Q_{xy}) is associated with the utilization of the arc. At last, a series of node (C_x) are created to represent the possible delivery periods of the order to the customer. Transportation arcs (x, C_x) are added to the network to ensure delivery.

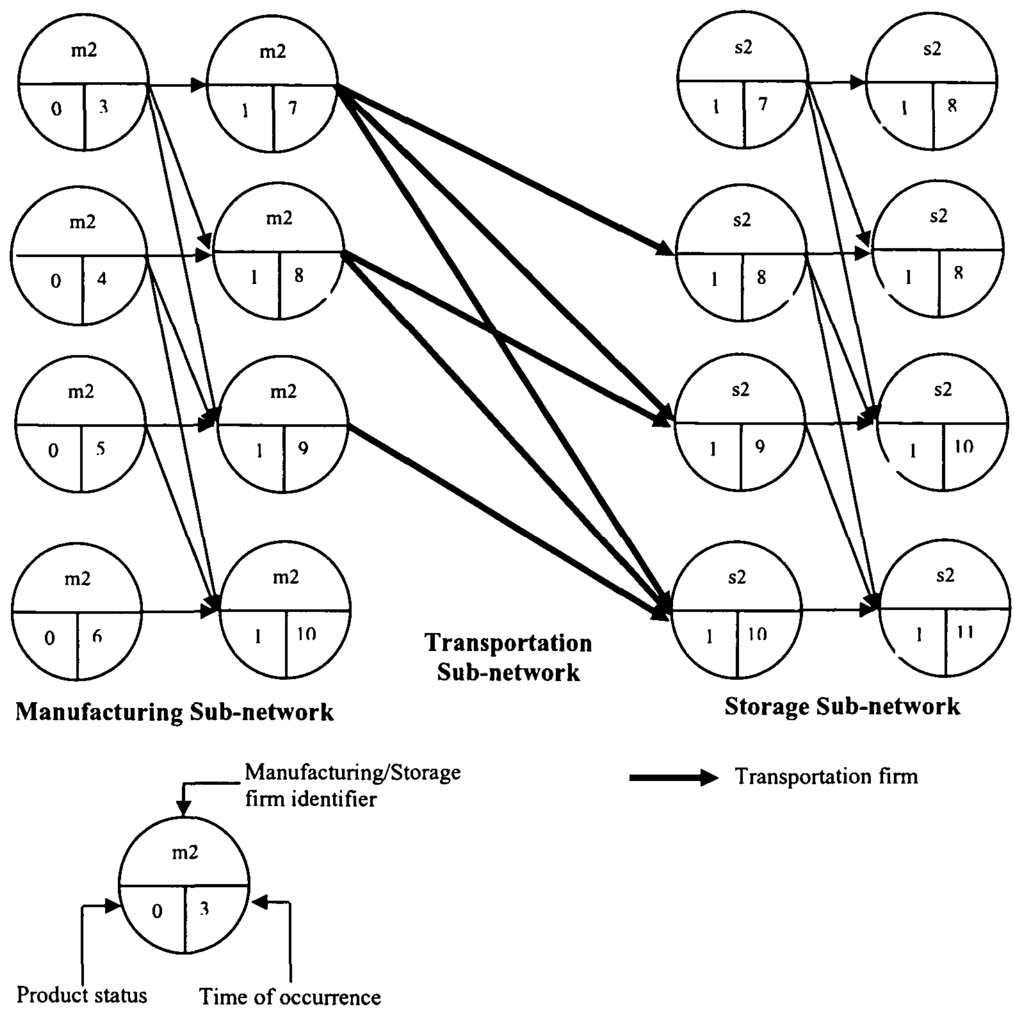


Figure 5.8 Part of an operational network

5.3.3 Building the operational network

Once the operation sub-networks for all manufacturing, storage and transportation tenders have been created, they are simply overlaid to form the network flow graph. Source and terminal nodes, respectively (*source*) and (*term*), are created and are associated with a demand (*d*). Arcs are created to link node (*source*) to all starting nodes (x) of all sub-networks modeling the tenders received for performing the first operation of the order. Finally arcs (C_x, *term*) are created from all nodes (C_x) to the terminal node. These two final sets of arcs are characterized by unbounded flows and unit prices of zero.

5.3.4 The approach

The integrated configuration and coordination approach is derived from the network flow graph created by overlapping all operational manufacturing, storage and transportation sub-networks. The approach can be used to solve a single-product order. An order is characterized by its linear structure and by the possibility to have more than one partner node executing a task. The approach is presented in a generic form where nodes are identified by (x) and (y), and where arcs (x, y) link nodes (x) and (y) together. Fig. 5-9 and Table 5-2 present the variable, parameters, indices, and sets identifications. Assuming that the operational network flow graph is generically feasible; i.e. that the operational network capacity is sufficient to meet the total demands for each manufacturing and logistic task of the order. If it is not the case, then unfeasibility is to be proven at solution time, indicating the need for new bids with modified capacity constraints and/or modified delivery windows.

A linear programming (LP) formulation used for the configuration and coordination of the FMN for producing single product orders is as follows:

Minimize total cost of processing the order:

Minimize $\sum p_{xy} Q_{xy} \qquad \forall\, xy \in A$ .... (1)

Subject to:

Flow conservation constraints

$$\sum Q_{xy} - \sum Q_{zx} = 0 \qquad where \quad y \in S(x),\ z \in P(x),\ x = 1,2,\ldots z \qquad (2)$$

$$\sum Q_{xy} - \sum Q_{zx} = -d \qquad where \quad y \in S(x),\ z \in P(x),\ x = term \qquad (3)$$

Capacity constraints

$$q_{xy}^{min} \leq Q_{xy} \leq q_{xy}^{max} \qquad \forall\, xy \in A \qquad (4)$$

$$c_{r,\tau}^{min} \leq \sum u_{r,xy} * Q_{xy} \leq c_{r,\tau}^{max} \qquad \forall r, \forall \tau,\ and\ xy \in U_{r,\tau} \qquad (5)$$

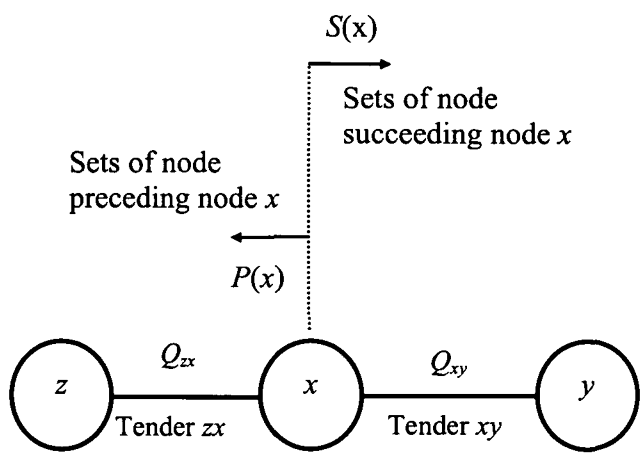
Integrality constraints

$$Q_{xy} \geq 0 \quad and \quad Q_{xy} = \text{integer} \qquad \forall\, xy \in A \qquad (6)$$

The objective function (1) of the integrated configuration and coordination approach is to minimize the cost of processing the order, given a specific delivery time window to the customer. The constraints (2) and (3) are related to flow conservation, and the constraints (4) and (5) are respectively related to the capacity limits on distinct alternative as well as on the sets of conflicting alternatives. The last constraints (6), imposing an integer value on (Q_{xy}) are activated only when the order is of low volume.

The approach output gives the actual manufacturing, transportation and storage partner nodes to be selected in the FMN to achieve the specific customer order. The variables identify all timing alternatives (launching date and sojourn duration) and processing quantities to be allowed. The simplicity of the model comes from the modeling of the tenders which takes care of the timing constraints into its structure. Table 5-2 presents the model's variables, parameters, indices, and sets identifications.

P_{xy}: unit price for tender xy
$U_{r,xy}$: quantity of resource r on tender xy



A: sets of tender
N: sets of node
$U_{r,\tau}$: sets of tender using resource r during time period τ

Figure 5.9 The approach variables

Depending upon the content of the tenders, the model can be solved using different optimization tools. When all tenders take the form of a supplying-type bid, the model may be solved using the network shortest path algorithm. In this case, constraints 4 and 5 are dropped from the model since the arcs are unbounded. When tenders take the form of a customizing-type bid, where capacity constraints are imposed only on the arc (constraints 4), a minimum cost-flow algorithm can be used to solve the model. Finally, when tenders take the generic form of a customized-type bid or a webbing-type bid, the model may be solved by using linear programming techniques.

Variable	**Identification**	**Sets**	**Identification**
Q_{xy}	Quantity processed by tender *xy*	A	Sets of tender
Parameters	**Identification**	N	Sets of node
$c_{r,\tau}^{min}$, $c_{r,\tau}^{max}$	Minimum and maximum available capacity of resource r during time τ	$P(x)$	Sets of node immediately preceding node x
d	Quantity to be processed in the order	$S(x)$	Sets of node immediately succeeding node x
p_{xy}	Unit price for tender *xy*	$U_{r,\tau}$	Sets of tender using resources r during time period τ
q_{xy}^{min}, q_{xy}^{max}	Minimum and maximum allowed quantity for tender *xy*		
$u_{r,xy}$	Quantity of resource r used in tender *xy*		
Indices	**Identification**		
x, y	Node identifier		
source	Source node		
term	End node (customer)		
xy	Tender identifier		
r	Resource identifier		
τ	Time period identifier		

Table 5-2 Variable, parameters, indices, and sets identifications

5.4 An illustrative example

In this section an illustrative example is presented to configure and coordinate FMN for processing a specific order for a single product. For example, the network management received an order from a specific customer and this order can be established on the FMN basis. The network management needs to orchestrate the production of this order through its FMN and deliver it within a given allowable time period. Assume that the customer permits delivery at 12 to 14 periods. After a design contest, the product can be produced in batches through the FMN which has manufacturing and logistic firms coordinated by a specialized network management. According to that context, the network management is responsible for the realization of a batch of a unique product *P* requiring the execution of two linearly sequenced manufacturing operations. To start planning the FMN, the network management constructs the network operational schema as illustrated in Fig. 5-10.

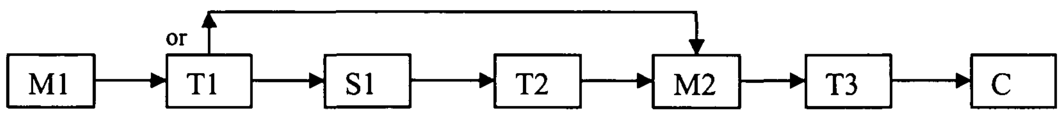


Figure 5.10 Network operational schema for the illustrated example

After constructing the network operational schema, the network management answered to the first question, how to produce this product. In order to answer about the other two questions of where and when can execute each task, the network management initiates a bidding process for each task among the partners in the FMN.

To ensure the feasibility to manufacture a product in the FMN, a preliminary selection of partners should be carried out by using the information from the bids in considering the time compatibility. This process can be performed by human decision maker. In this stage, some partners may be taken away and the selection will be from the remaining partners to minimize the manufacturing cost. Fig 5-11 presents the manufacturing network flow graph.

This illustrative example is developed to gain understanding the performance versus business relationships, which are defined on the basis of the level of inter-relationships and information sharing and ca be realized through different types of bidding process. To do so, the first section of this part will develop the webbing-type bids and progressively develop the two other types of bids.

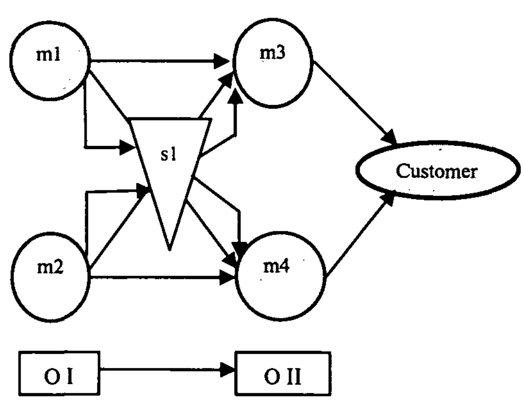


Figure 5.11 Potential manufacturing network flow graph

5.4.1 Applying the proposed approach on the supplying-type bids

A supplying-type bid can be associated to the weakest form of the business relationship. It is like buying from catalogue, where products are offered at pre-determined prices. Table 5-3 presented the list of the partner's price for each task. Table 5-10 lists the traveling distances between the partners in kilometers. The transportation's price is 0.005 €/unit*Km.

To solve this problem with the linear programming techniques a program was done by using "A Modeling Language for Mathematical Programming (AMPL[4])" and CPLEX solver **[35]**.The program was executed 3 times for three different customer demands (500, 1000, and 1500 units of the product). Fig. 5-12 presents the solution for the customer demand.

Partner	Task	cost/unit product (€) for any period
m1	M1	7.0
m2	M1	7.5
m3	M2	14.0
m4	M2	13.0
s1	S1	0.4

Table 5-3 List of the partner's price (€) for each task

[4] AMPL is a language for large-scale optimization and mathematical programming problems in production, scheduling and many other applications. AMPL makes it easy to create models used a wide variety of solvers and examines solutions. It also offers the speed and generality needed for repeated large-scale production runs.

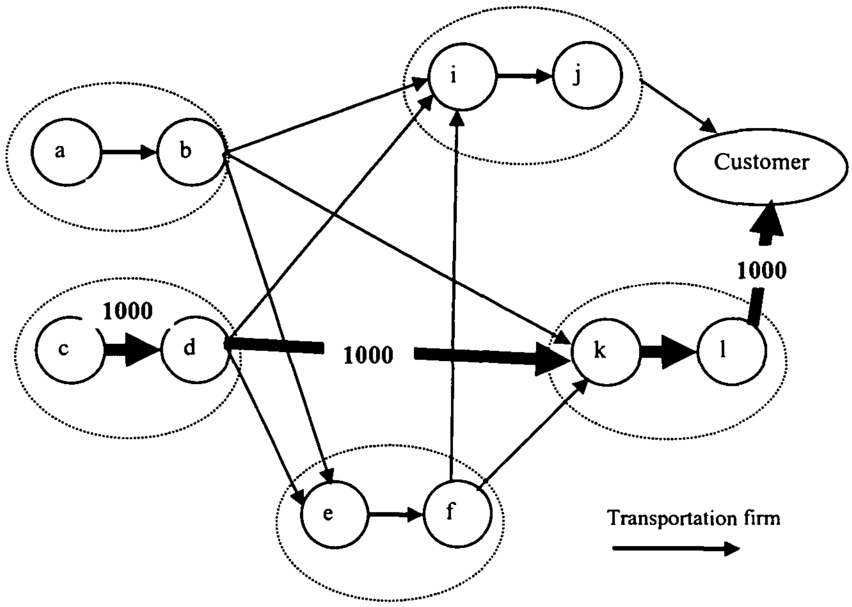


Figure 5.12 The solution for the customer demand 1000 unit (supplying tenders)

The total cost for customer demands 1500, 1000, and 500 units are respectively € 34638, 23092, and 11546.

5.4.2 Applying the proposed approach on the customizing-type bids

In this version of the bid, the alternatives are priced individually and capacity constraints are much more conventional than in the webbing-type bid because of their simplified description and the need for the partner to protect himself from overflow. Table 5-4 shows the tasks and the partners who can execute these manufacturing tasks and their capacity limits. Tables 5-5 to Table 5-9 lists the prices associated to each manufacturing and storage bids, the rows are launching period, the columns are finishing period and cell entities are unit price (€). Table 5-10 lists the traveling distances between the partners in kilometers. Table 5-11 and Fig. 5-13 present the bids alternatives for each partner to execute each task.

The program was executed 3 times for three different customer demands (500, 1000, and 1500 units of the product). Fig. 5-14, Fig. 5-15 and Fig. 5-16 present the solutions for each customer demand.

Partners	Partner type	Tasks	Capacity limit for any period
m1	Manufacturing	M1	1500
m2	Manufacturing	M1	1000
m3	Manufacturing	M2	800
m4	Manufacturing	M2	750
s1	Storage	S1	1000

Table 5-4 Capacity constraints for the partners

	3	5
0	6	4
2		6

Table 5-5 List of prices (€) of manufacturing bids for task M1, partner m1

	7	8
3	7	6
4		7

Table 5-6 List of prices (€) of manufacturing bids for task M1, partner m2

	12	14
6	12	14
8		12

Table 5-7 List of prices (€) of manufacturing bids for task M2, partner m3

	12	13
8	11	12
9		11

Table 5-8 List of prices (€) of manufacturing bids for task M2, partner m4

	7	8
6	0.20	0.40
7		0.20

Table 5-9 List of prices (€) of storage bids for task S1, partner s1

	m1	**m2**	**m3**	**m4**	**s1**	**customer**
m1		240	210	435	210	240
m2			174	216	192	10
m3				273	300	174
m4					405	216
s1						192

Table 5-10 Traveling distances between the partners and customer in kilometers

Transportation partner (tr1) ⇨ traveling duration = 1 time period; price 0.005 €/unit*Km

Transportation partner (tr2) ⇨ traveling duration = 2 time period; price 0.004 €/unit*Km

Transportation partner (tr3) ⇨ traveling duration = 3 time period; price 0.005 €/unit*Km

Note: all transportation partners offer services for any launching period

No.	Task		Partner	Cost/unit product (€)	Capacity limit (units)
	Start	Finish			
1	0	3	m1	6	1500
2	0	5	m1	4	1500
3	2	5	m1	6	1500
4	3	7	m2	7	1000
5	3	8	m2	6	1000
6	4	8	m2	7	1000
7	3	6	tr3	0.005*210=1.05	no limit
8	3	6	tr3	0.005*210=1.05	no limit
9	5	6	tr1	0.005*210=1.05	no limit
10	5	8	tr3	0.005*210=1.05	no limit
11	5	8	tr3	0.005*435=2.175	no limit
12	5	6	tr1	0.005*210=1.05	no limit
13	5	7	tr2	0.004*210= 0.84	no limit
14	7	8	tr1	0.005*174=0.87	no limit
15	7	8	tr1	0.005*216=1.08	no limit
16	7	9	tr2	0.004*216=0.864	no limit
17	8	9	tr1	0.005*216=1.08	no limit
18	7	8	tr1	0.005*300=1.5	no limit
19	7	8	tr1	0.005*405=2.025	no limit
20	7	9	tr2	0.004*405=1.62	no limit
21	6	7	s1	0.2	1000
22	6	8	s1	0.4	1000
23	7	8	s1	0.2	1000
24	8	9	tr1	0.005*405=2.025	no limit
25	6	12	m3	12	800
26	6	14	m3	14	800
27	8	14	m3	12	800
28	12	customer	tr1	0.005*174=0.87	no limit
29	14	customer	tr1	0.005*174=0.87	no limit
30	8	12	m4	11	750
31	8	13	m4	12	750
32	9	13	m4	11	750
33	12	customer	tr1	0.005*216=1.08	no limit
34	13	customer	tr1	0.005*216=1.08	no limit

Table 5-11 The partner alternative tenders to execute the requirement tasks

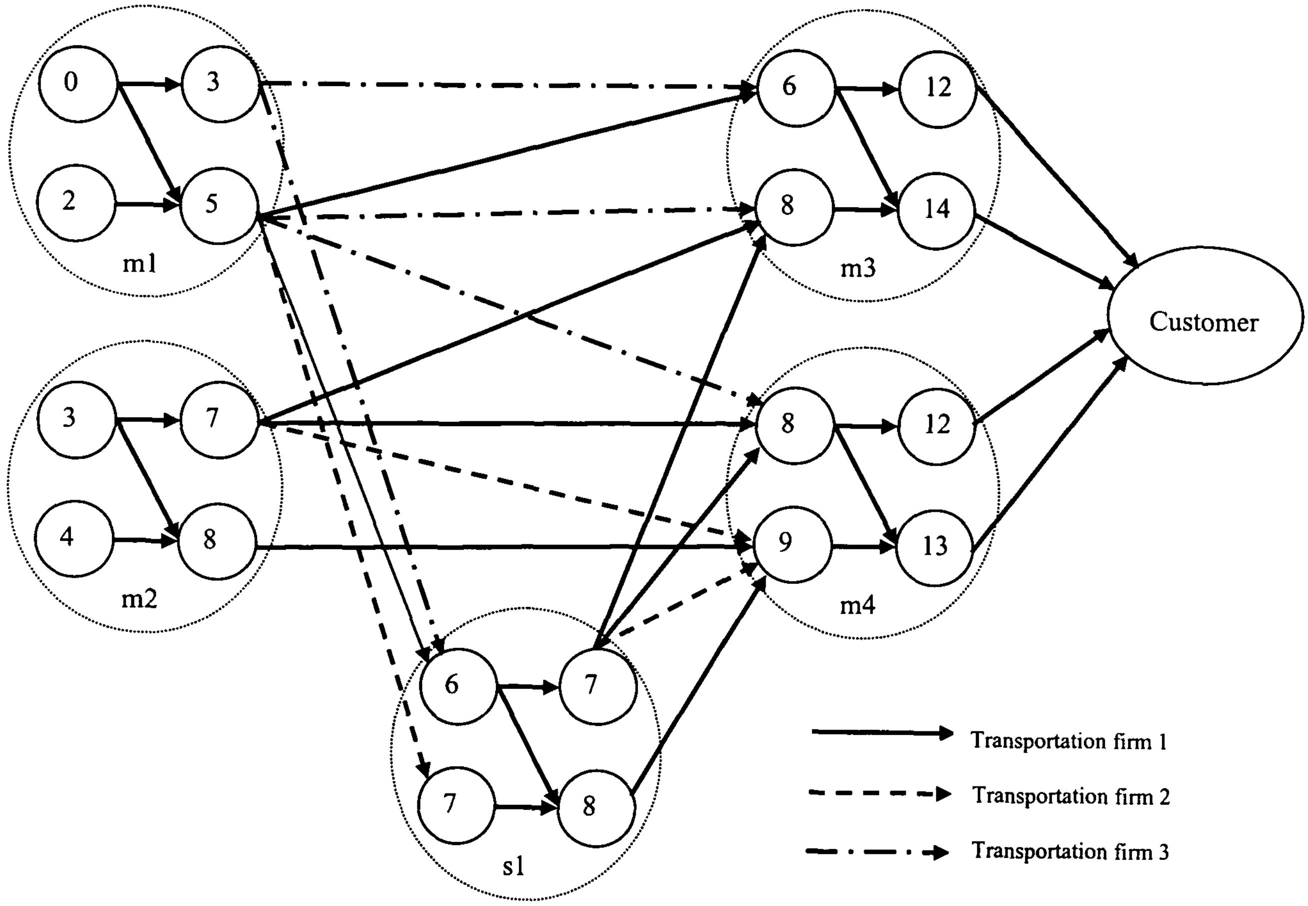


Figure 5.13 Network flow graph for customizing tenders

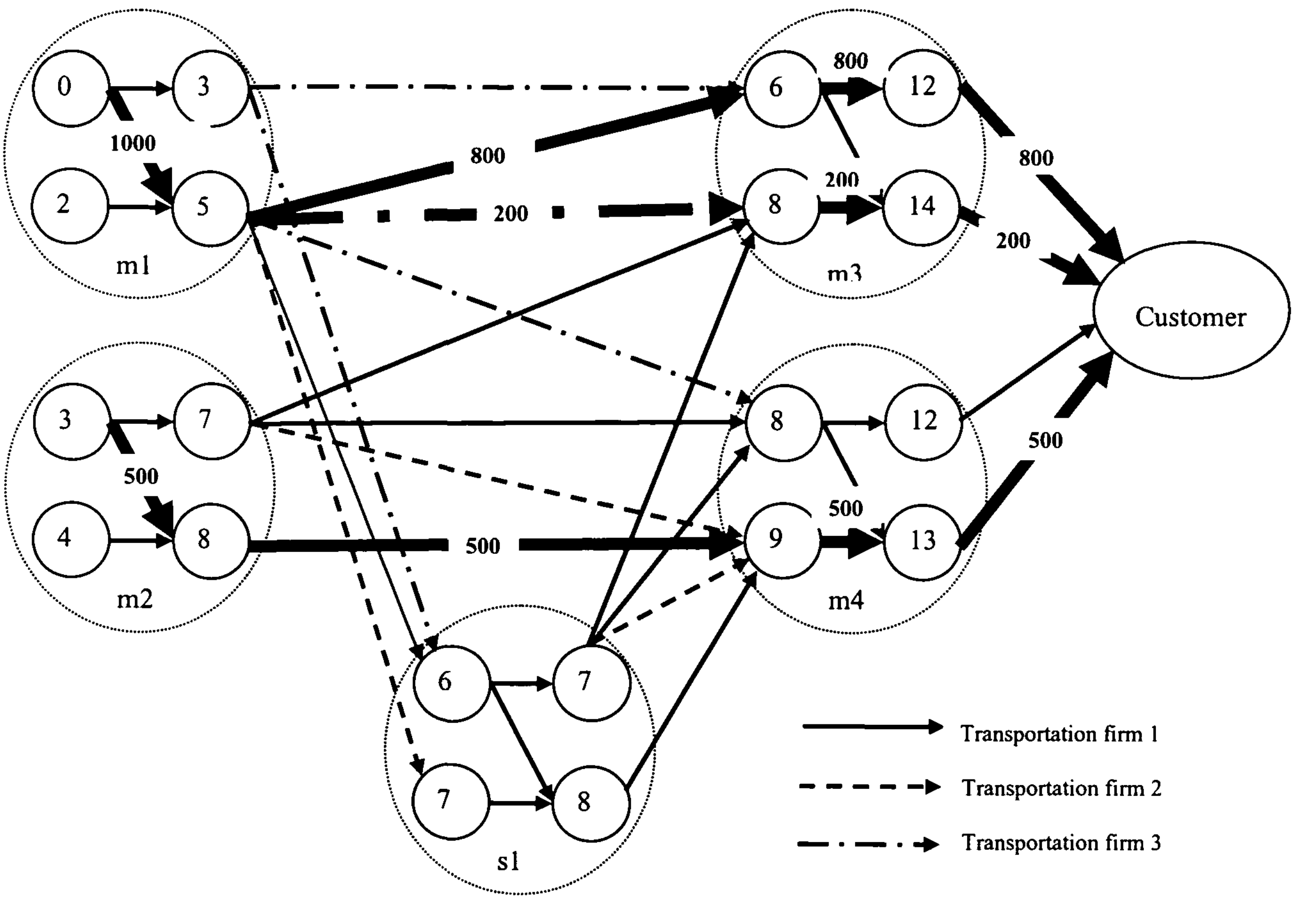


Figure 5.14 The solution for the customer demand 1500 units (Customizing tenders)

The total cost is: € 27500

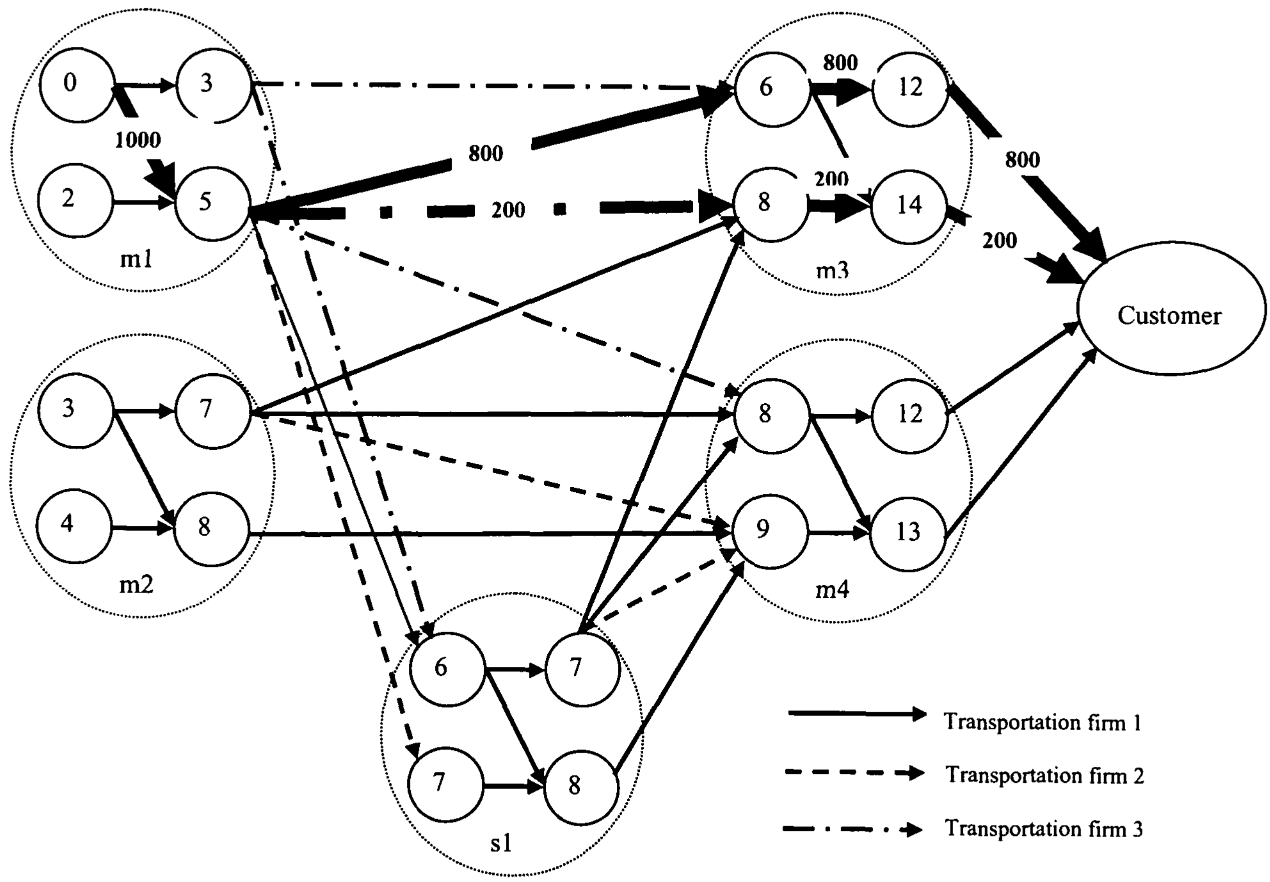


Figure 5.15 The solution for the customer demand 1000 units (Customizing tenders)

The total cost is: € 17920

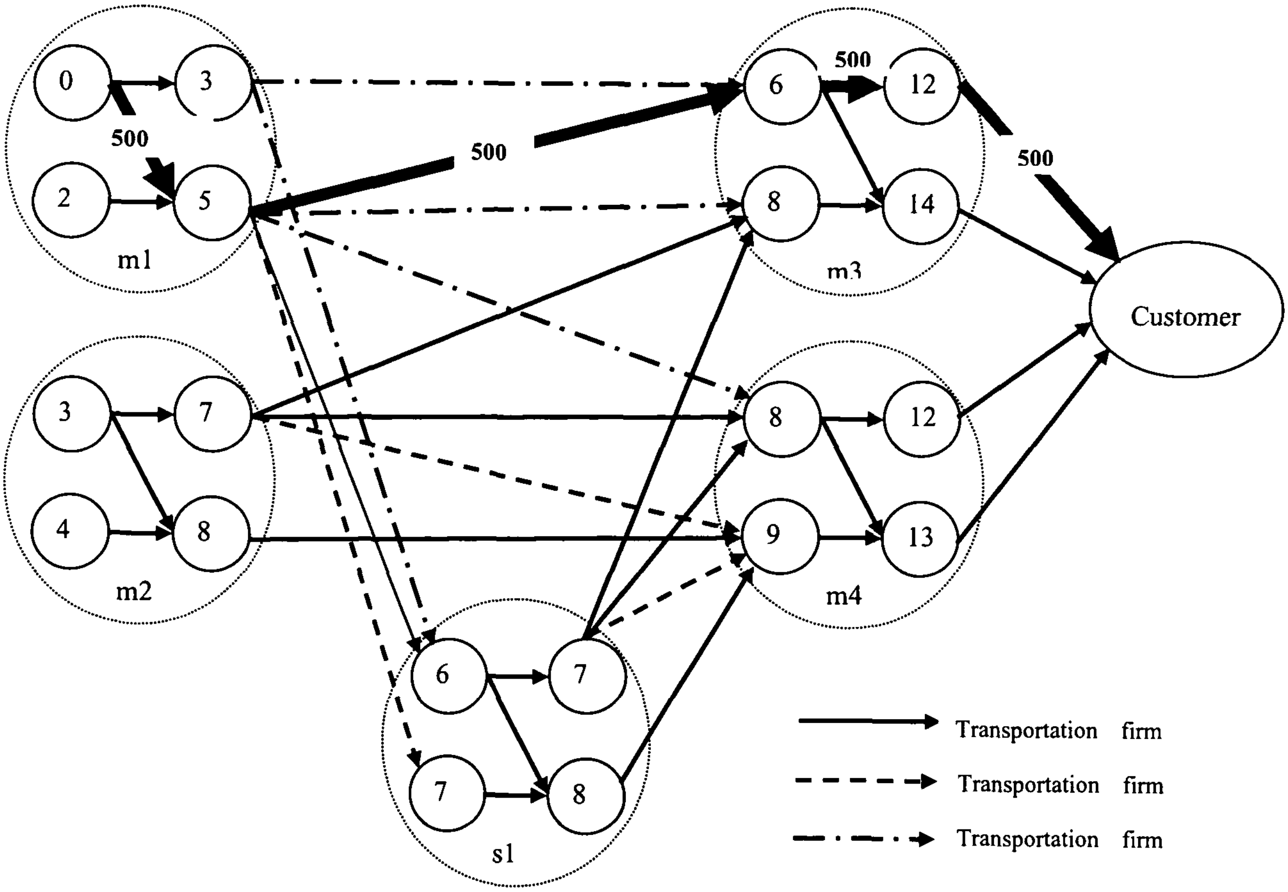


Figure 5.16 The solution for the customer demand 500 units (Customizing tenders)

The total cost is: € 8960

5.4.3 Applying the proposed approach on the webbing-type bids

Assuming strong relationships, the network management seeks for webbing-type bids from partners, where extensive pricing and capacity functions are given. In this example the pricing functions are expressed for complete range of alternatives in term of launching periods and sojourn durations. The capacity functions are expressed differently depending on the partners. Some partners provide, for each significant resource needed to realize the task. Table 5-12 explains the primary selected partners for each manufacturing and storage task. Table 5-13 explains the resource needs and availability for each manufacturing partner. Tables 5-14 to 5-18 present the price-time functions for the manufacturing and storage partners, the rows are launching period, the columns are finishing period and cell entities are unit price (€). Table 5-19 presents the traveling distances between the partners in Kilometers. Table 5-20 and Fig. 5-17 present all the alternative tenders for realizing the tasks.

The program was executed 3 times for three different customer demands (500, 1000, and 1500 units of the product). Fig. 5-18, Fig. 5-19 and Fig. 5-20 present the solutions for each customer demand.

Partners	Partner Type	Tasks
m1	Manufacturing	M1
m2	Manufacturing	M1
m3	Manufacturing	M2
m4	Manufacturing	M2
s1	Storage	S1

Table 5-12 The primary selected partners for each manufacturing and storage task

Partner	Resources needs and its maximum availability (units)	
m1	R1	R2
	1000	1200
m2	R3	R4
	900	1100
m3	R5	R6
	1300	1300
m4	R7	R8
	1400	1100

Table 5-13 The resource needs and availability for each manufacturing partner

	3	5
0	5	3.5
2		5

Table 5-14 List of prices (€) of manufacturing bids for task M1, partner m1

	7	8
3	4	3
4		4

Table 5-15 List of prices (€) of manufacturing bids for task M1, partner m2

	12	14
6	10	11
8		10

Table 5-16 List of prices (€) of manufacturing bids for task M2, partner m3

	12	13
8	9	7
9		9

Table 5-17 List of prices (€) of manufacturing bids for task M2, partner m4

	7	8
6	0.20	0.40
7		0.20

Table 5-18 List of prices of storage bids/unit product for task S1, partner s1

	m1	m2	m3	m4	s1	customer
m1		240	210	435	210	240
m2			174	216	192	10
m3				273	300	174
m4					405	216
s1						192

Table 5-19 Traveling distances between the partners and customer in kilometers

Transportation partner (tr1) ⇨ traveling duration = 1 time period; price 0.005 €/unit*Km

Transportation partner (tr2) ⇨ traveling duration = 2 time period; price 0.004 €/unit*Km

Transportation partner (tr3) ⇨ traveling duration = 3 time period; price 0.005 €/unit*Km

Note: all transportation partners offer services for any launching period

No.	Task		Partner	Cost/unit product (€)
	Start	Finish		
1	0	3	m1	5
2	0	5	m1	3.5
3	2	5	m1	5
4	3	7	m2	4
5	3	8	m2	3
6	4	8	m2	4
7	3	6	tr3	0.005*210=1.05
8	3	6	tr3	0.005*210=1.05
9	5	6	tr1	0.005*210=1.05
10	5	8	tr3	0.005*210=1.05
11	5	8	tr3	0.005*435=2.175
12	5	6	tr1	0.005*210=1.05
13	5	7	tr2	0.004*210= 0.84
14	7	8	tr1	0.005*174=0.87
15	7	8	tr1	0.005*216=1.08
16	7	9	tr2	0.004*216=0.864
17	8	9	tr1	0.005*216=1.08
18	7	8	tr1	0.005*300=1.5
19	7	8	tr1	0.005*405=2.025
20	7	9	tr2	0.004*405=1.62
21	6	7	s1	0.2
22	6	8	s1	0.4
23	7	8	s1	0.2
24	8	9	tr1	0.005*405=2.025
25	6	12	m3	10
26	6	14	m3	11
27	8	14	m3	10
28	12	customer	tr1	0.005*174=0.87
29	14	customer	tr1	0.005*174=0.87
30	8	12	m4	9
31	8	13	m4	7
32	9	13	m4	9
33	12	customer	tr1	0.005*216=1.08
34	13	customer	tr1	0.005*216=1.08

Table 5-20 The partner alternative bids to execute the requirement tasks

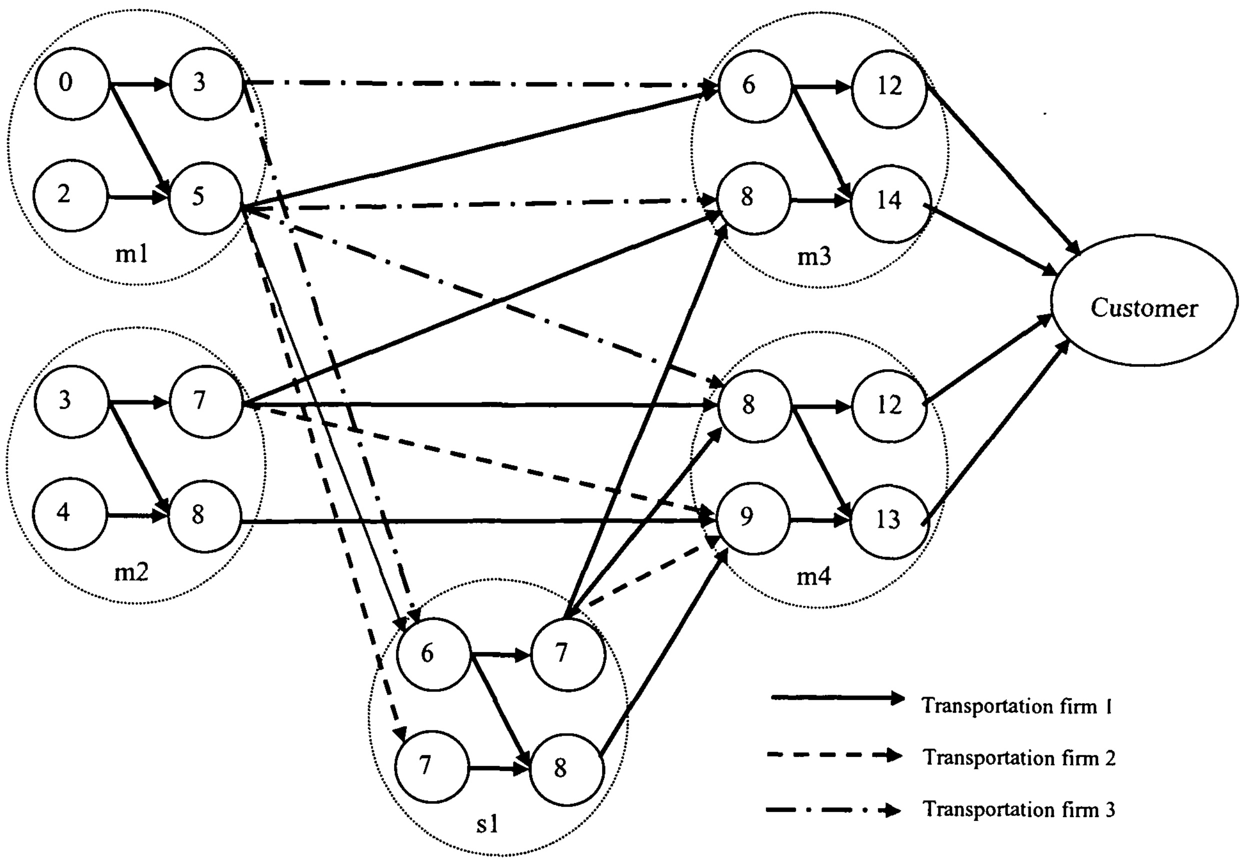


Figure 5.17 Network flow graph for the webbing-type tenders

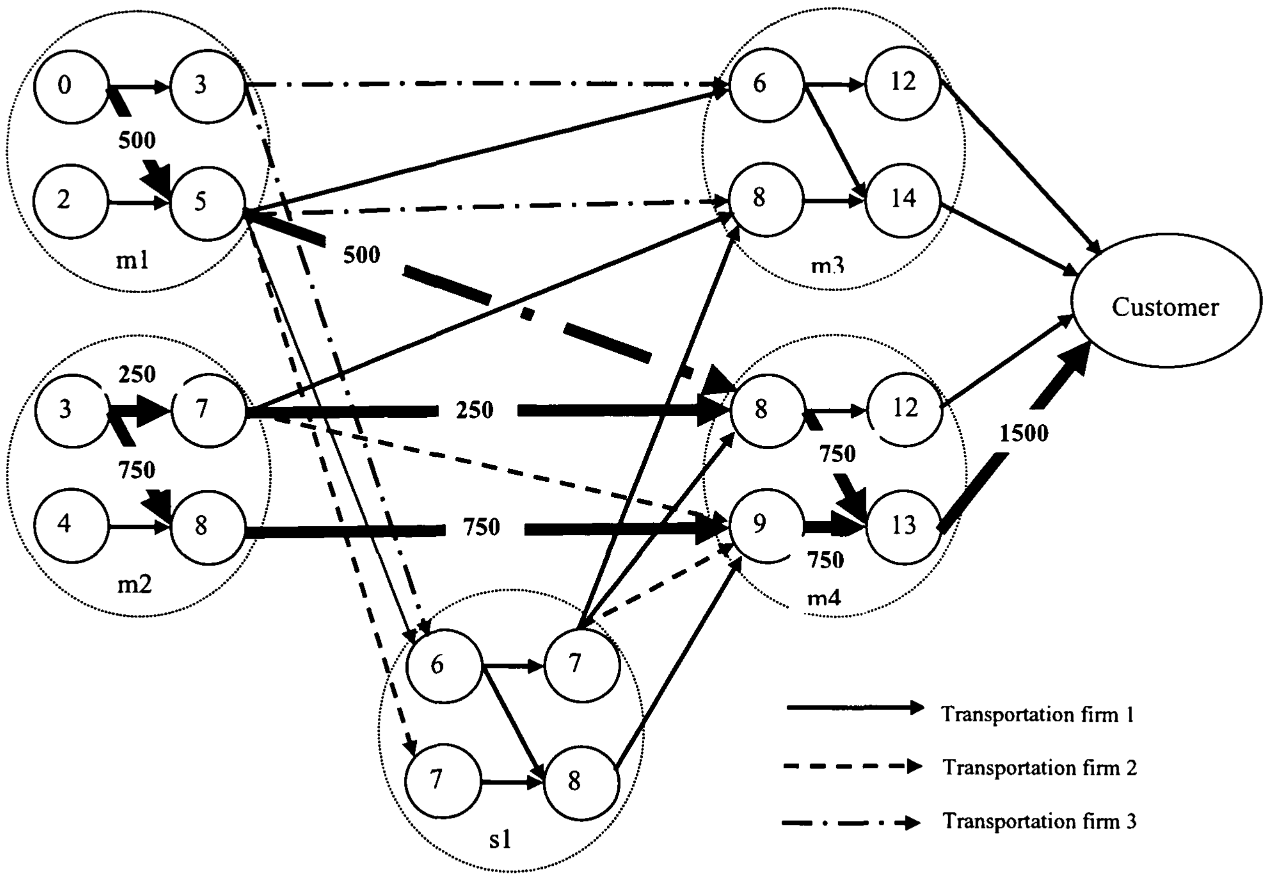


Figure 5.18 The solution for the customer demand 1500 units (Webbing tenders)

The total cost is: € 20787.5

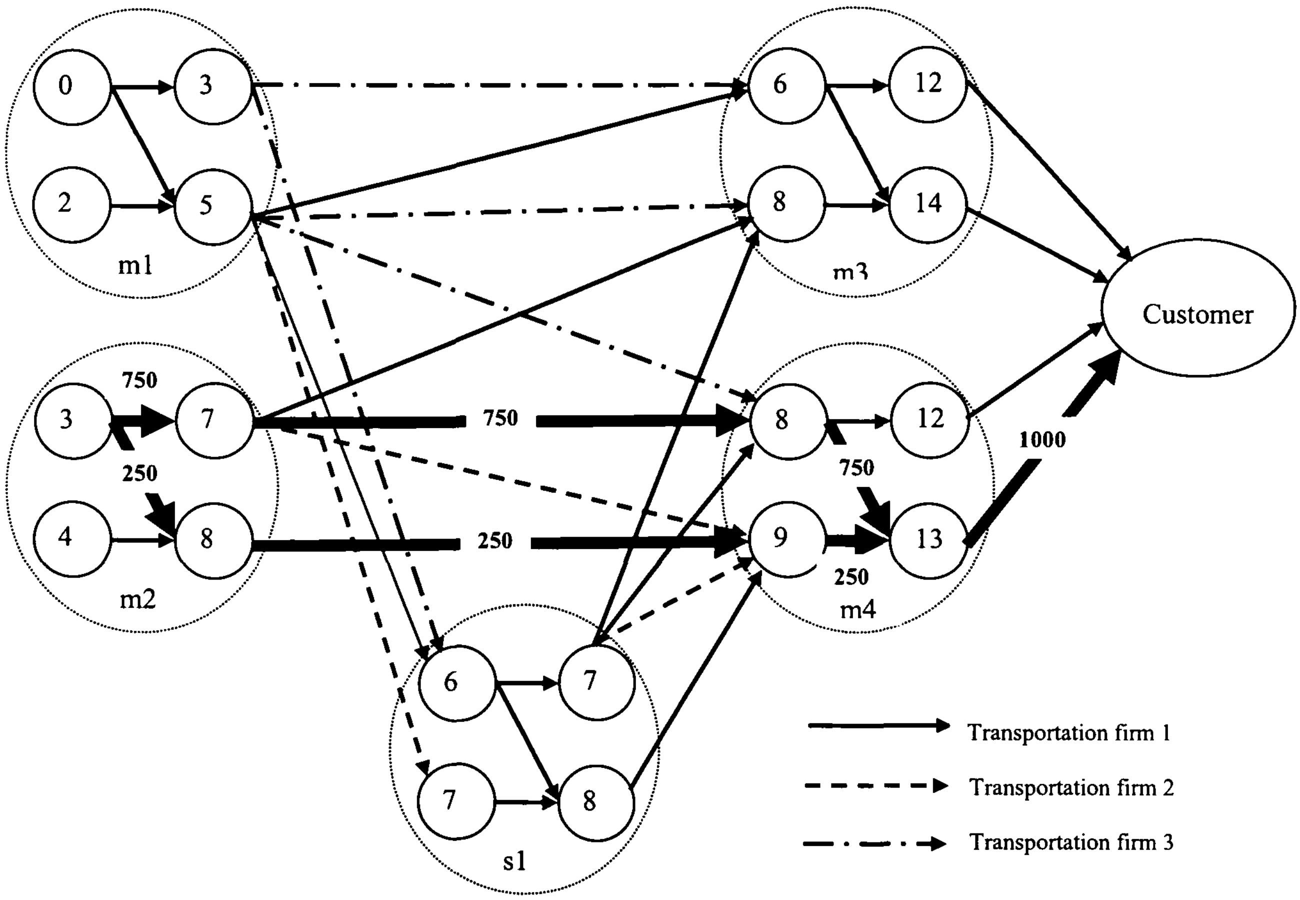


Figure 5.19 The solution for the customer demand 1000 units (Webbing tenders)

The total cost is: € 13410

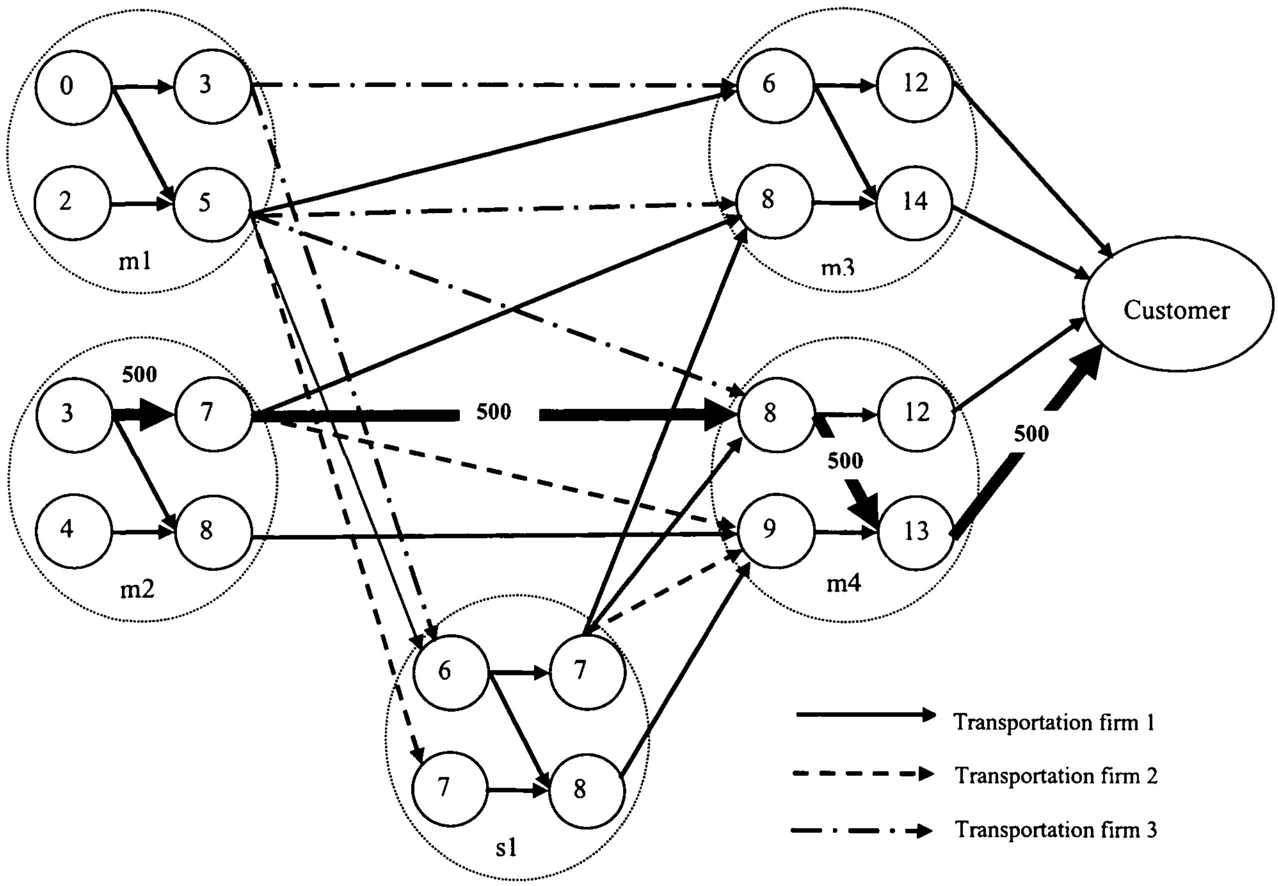


Figure 5.20 The solution for the customer demand 500 units (Webbing tenders)

The total cost is: € 6580

5.4.4 Results

Each case corresponds to solving a distinct operational network constructed through the modeling of different types of bid (supplying, customizing, and webbing). This example is a simple example just for explanation and presentation the modeling differences between the three different types of bids. This example models 12 manufacturing tenders for 2 manufacturing tasks, 3 storage tenders for 1 storage task, and 3 transportation tenders for each transportation task.

Using the proposed approach described in Section 5-3, 9 optimal solutions were obtained for each bidding type and for each customer demand. The optimal solution suggests the most appropriate selection of the partner and its alternative.

In fact, the different optimal solutions depend upon the type of bid required by the network management. The fact that different FMN configurations are obtained from the different types of bids implies that level of the inter-relationships and the level of the shared information influences the selection of partners to be activated in the FMN as well as their time windows of activation. The obtained FMN when using supplying-type is always simple, since a unique firm is selected for each task. On the other hand, using customizing and webbing-type bids for designing and operating FMN may imply managing an increased number of manufacturing and logistic tenders. This is due to the capacity constraints. The FMN, although is more complex to manage, but can produce a specific order at a lower price. Table 5-21 presents the optimal costs for completing the different customer demands within the delivery time-window specified by the customer.

As predicted, the webbing-type bids perform the other types of bids. The different pricing functions show that costs become lower as the level of inter-relationship and information sharing is intensified.

Customer Demand (Units)	Total Cost associated with the bidding type (€)		
	Supplying	Customizing	Webbing
500	11546	8960	6580
1000	23092	17920	13410
1500	34638	27500	20787.5

Table 5-21 The minimum costs for processing the order in terms of different types of bids

CHAPTER 6

CONCLUSION

Flexible manufacturing is the strategy of the 21st century and should be realized by Flexible Manufacturing Networks (FMNs). FMN is considered as a set of operational partners with equal rights, coordinated by a network management that interacts with the customers, assigns tasks to partners on the basis of bidding process and up-to-date information on the partner state and reliability, and informs each partner on its position in the network with respect to the manufacturing process. The partners are responsible of executing the assigned tasks within given time intervals and, to this purpose; they maintain direct relations with the respective partners and customers and try to solve possible network conflicts. This new approach is very promising to SMEs, because it offers the advantages of the manufacturing paradigm parallel giving the possibility of keeping the traditional individualism of SMEs. The FMNs prove that it is possible to develop network-based coordination for SMEs that is general enough to be applied in completely different production fields.

The evolution of the Flexible manufacturing networks raises the needs for adapted configuration and coordination tools. The FMN is configured to manufacture a specific customer product and each partner in the FMN performs one or more tasks for the manufacturing. The cost of manufacturing the product in the FMN includes the manufacturing cost and the transportation cost. Besides, in the FMN environment, the configuration and coordination are challenges for the FMNs. Therefore, the activities and the tasks of the different partners in the different sits must be coordinated and the time taken by the transportation should be taken into consideration as well.

This thesis advances the theoretical ground for coordinating tasks in the FMNs. In order to help planning and scheduling tasks for a specific customer order, the network operational schema is constructed to define the sequence of all manufacturing, storage and transfer tasks required to obtain a given family of products. Manufacturing tasks, storage tasks, transfer tasks and also the links between the tasks present the network operational schema. The network operational schema has to be constructed before planning the tasks among the partners. The network operational schema will be the basis for assigning tasks to the network partners. Since a partner has been added in the FMN, it can declare its capacities for a number of tasks (bidding process). Bidding process can be independent of the output product version.

According to the bidding process, the decision process is modeled as linear programming model to configure and coordinate a FMN. This model can be solved rapidly by the most known networking algorithms. The proposed approach permits to solve optimally complex large-scale problems in the context of FMN. This result is impressive if compared with the state of the art in optimization of the production scheduling using a given set of resources. The decision process discussed in this thesis is one of the many interesting contexts to be studied in the FMNs. Therefore, one of the significant challenges for implementing FMN is how to design and operate the FMN.

An illustrative example, considering the bidding process, is used to show how the level of the inter-relationships and information sharing can affect on the network decisions. The results show that better price–time scheduling performance is achieved as high levels of inter-relationships and information on price and capacity are shared by the partners with the network management. It also shows that this gain is achieved through the management of a more complex FMN. The complexity of the FMN is defined here in terms of the number of manufacturing and logistic units selected to perform the order, and the level of inter-relationships and information sharing.

Finally, a model is developed to represent the trade-off in networking decisions in terms of numbers of partners firms and their level of integration. Further research should analyze the impact of information sharing on different crucial issues of manufacturing partner such as quality, reliability, flexibility and transaction costs.

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