SUPPLY CHAIN ENGINEERING AND AUTOMATION

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Abstract

Integrated supply chains are networks of companies in alliance sharing the same destiny for mutual business advantage. In such networks, end-to-end material and information flows—from raw material production to retailer sales—are optimally and collaboratively managed to create value to the customers and other stakeholders. In this paper, we first introduce the configuration and physics of integrated supply chain networks (ISNs) and identify the automation and Internet technologies that are critical for their effective and efficient operation. Next, we identify the strategic, tactical, and operational decisions in ISNs and the analytical techniques used in making these decisions. We conclude the paper with a discussion on some significant problems that require attention.

1 Introduction

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

To win customers in the presence of competition, all the critical value delivery processes of the ISN such as the customer relationship management,new product development and infrastructural subprocesses such as procurement, production and distribution have to be effective and efficient. Further, coordination of the goals of these value delivery processes and the constituent companies towards the supply chain goals is important. This need calls for development of systematic analysis methodologies for evaluating the performance of value-delivery processes.

In section 2 of this paper, we introduce the configuration and physics of integrated supply chain networks (ISNs) and identify the automation and information technologies that are critical for their effective and efficient operation. We also discuss the emerging Internet technologies such as infomediaries and the factors that provide the competitive advantage. In section 4, we identify the strategic, tactical, and operational decisions in ISNs and also survey the optimization techniques used in making these decisions. We briefly outline the dynamic models and methodologies in section 4. In section 5, we discuss some outstanding problems that require attention.

2 ISN Architecture

In a traditional supply chains, all companies involved in the product delivery—suppliers, manufacturers, distributors, logistics providers, and retailers—act as islands of excellence producing goods to forecast or order. There is generally no coordination between various companies except for some contractual agreements for transport and supply of materials. Even within each company, the three fundamental functions—procurement, production, and delivery—are managed independently, buffered by large inventories. Generally, distribution centers collect customer orders and also forecast the demand. This information is used to project the replenishments needed from the manufacturing plants for several time periods into the future. This in turn will trigger the orders to the component and raw material suppliers. The continuity of material flow is maintained by holding inventories throughout the network in the form of raw materials, components, subassemblies and finished goods. The information flow is generally between adjacent companies and is paper based. Several performance and stability problems such as high inventory levels, mark downs, stockouts, and excessive swings in the inventory at various echelons (bullwhip effect) in the supply chain are reported in the literature [1].

Increasing competitive pressures, market globalization and emergence of new technologies such as wireless communications and the Internet are forcing companies towards greater integration so that higher levels of service can be offered to customers at lower cost. Figure 1 shows the schematic of an integrated manufacturing supply chain. A well-designed logistics network provides a streamlined material flow between all parties, cutting down the lead time and cost of moving the raw materials, subassemblies, and finished goods to their destinations. The extranet, a secure and reliable communications network linking all the companies of the enterprise, provides the information integration. This architecture allows broadcasting of relevant information such as inventory levels, forecasts, order status, etc. to all partners not just the adjacent ones. By providing the right information at the right time to all the stakeholders, the extranet enables efficient logistics and effective decision making. This integration will reduce the inventory levels and also the cost of delivery. Essentially information substitutes inventory [2]. In otherwords if one knows when his or her order is scheduled on the assembly plant and on the transport carrier, then the need for inventory and safety stock is reduced.

Our description of ISN as depicted in Figure 1, includes both the physical network that provides seamless material flow as well the information network. The transactions between the partners in the ISN may be through traditional supply relationships or through e-markets such as auction sites. Business to business commercial transactions such as e-procurement for indirect materials can also be a part of our ISN. The ability to move information at electronic speeds breeds the need to move goods at comparable speeds. In other words, our diagram considers both front-end (customer to business)and back-end (retailer to the other partners and among the partners) of the ISN. Since the customer is integrated into the ISN, his/her

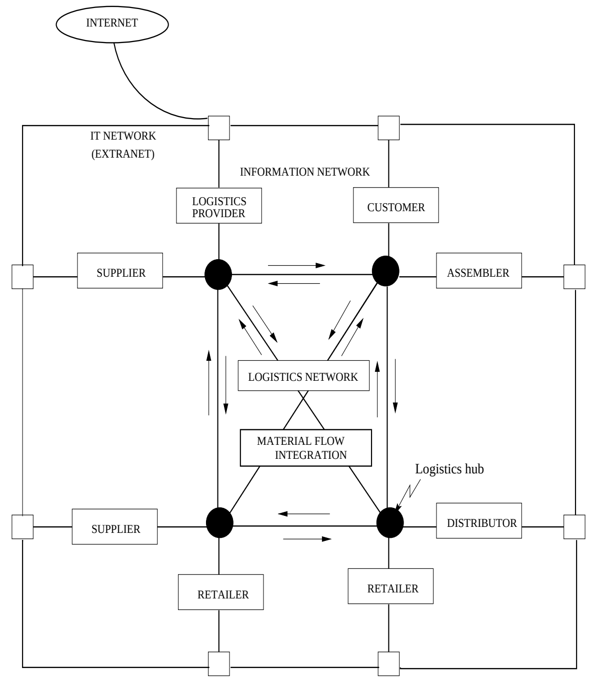

Figure 1: Integrated Supply Chain Network

orders move seamlessly from a customer facing website into the network owner's transaction-based business system. This would enable one to consider the order fulfillment and avoid the problems of the type recently reported[1].

2.1 Facility Location and Design

The location, size, and organization of various supply chain partners and their facilities, such as manufacturing plants, distribution centers, warehouses, and procurement and service offices are important strategic issues. The conventional reasons to locate of manufacturing facilities in various countries, include taking advantage of cheap labor and infrastructure facilities, government subsidies, tax relief, etc., and also to gain access to local markets and technologies. In an ISN, partners are selected based on their location, competencies and loyalty. It is necessary to design the supply chain network while taking into account such tangible factors as total cost which includes transport, storage, and inventory costs, closeness to the customer, and delivery times, as well as intangible factors such as synergy between design and manufacturing, complexity in planning and scheduling, information lag, etc.

2.1.1 Infrastructure

The country or city infrastructure—ports, airports, IT networks, business communications, trade practices, etc play a significant role. These would provide the competitive advantage to the Nation and the industries located in it.

2.1.2 Staged manufacturing

Manufacturing plants provide the ISN with the ability to serve several product markets through its economies of scope. Manufacturing facilities could be organized as several small focused factories dispersed geographically or as one large flexible factory producing several products. Also, manufacturing could be done in a single stage from raw materials to components to subassemblies to assemblies. It could also be done in multiple stages by locating factories for different stages in various countries. This is because, sometimes it is cheaper to ship components and subassemblies over long distances than to ship finished products. Multi-stage manufacturing is common in PC and semiconductor manufacturing.

Decisions regarding the number of stages of the manufacturing activity and the customization stage at which the product is earmarked for the customer (at the labeling stage, packaging stage, assembly stage, subassembly stage, etc.) can profoundly influence the supply chain architecture. Such decisions can be analyzed by building cost and cycle time models [3].

2.1.3 Distribution

Distribution often implies inventories of finished or semi-finished products delivered from a factory to the distribution center and then to the customers. Some distribution centers act as final customization points where final stage of manufacturing is done including insertion of power and communication cards, packaging and labeling, thus efficiently managing the product variety. Third party logistics providers such as Fedex, UPS, MSAS, have dozens of distribution centers around the world, where customers store fast moving merchandise at the transportation hubs to serve the customers more quickly and easily and at less cost. In recent years, distribution has been a beneficiary of advances in information and automation technologies such as ASRS, WMS and also innovative practices such as cross-docking. The National semiconductor warehouse operated by Fedex in Singapore is a best practice example in warehousing.

Many warehouses are designed for storage and movement of full unit loads. With the growth of Internet commerce, there is a need for picking and packing smaller order sizes and also making home delivery. Further, when the customer orders three items at one time, he expects delivery of all three at the same time. This is complicating the warehouse function. The rise infomediaries has taken away the information (orders)consolidation function from the distribution. Coming years will see significant changes in this area.

2.1.4 Transportation

Air, rail, truck, water, and pipeline are the five modes of transport with different economic characteristics. Loading and unloading facilities; communication facilities onboard vehicles to receive telephone, fax, Internet, and EDI messages; and alliances between transport, distribution, and production partners are important issues. Delivery within the window of time specified by the customer is rated as the most important service quality. Transit time determines pipeline inventory, and its variability determines the buffer or safety stock necessary. Large transit times also reduce the ability to respond quickly to the market and thus the effectiveness of the ISN. Choice of the mode or the optimal modal mix are interesting issues and are determined taking into account the transit and warehousing costs and the premium the customers are willing to pay for freshness of products (flowers, beer).

In international supply chains, the cargo handling facilities at the Airports and Ports are vital for attaining supply chain efficiencies. The varieties of technologies in best ports such as Singapore, Hong Kong, are the state-of-the-art. Intermodal rail and road transport is also becoming competitive because of improvements in load and unload operations during transshipment. Containerization has improved the efficiencies in both shipping and intermodal transport. Important issues that need attention in aircargo, seacargo and in trucking are tracking and tracing, electronic booking, customs management and dynamic pricing.

2.2 B to B Communications

In ISNs, information is actually the vital commodity for exchange between partners, and it also represents a large percentage of the cost structure. There is a tremendous amount of information flow between the stakeholders of the supply chain. If one can reduce the information asymmetry between manufacturers and suppliers then substantial cost reductions are possible. This will enable the partners to make decisions based on global information that benefits the entire ISN. A variety of information-sharing patterns are practiced in the industry. These vary between the two extremes of sharing no information and sharing all relevant information. These patterns are marketed as best practices in the industry circles and include vendor-managed inventories, quick response manufacturing, supplier scheduling, JIT purchasing, JIT II, efficient consumer response [4] and collaborative planning, forecasting and replenishment (CPFR). Basically, these are information-sharing patterns among two or more partners in an ISN. An ISN derives its competitive advantage because of sharing of information with its partners on demand forecasts, point of sale data, production schedules, logistics plans, market trends, etc. Thus the only uncertainty is the market uncertainty, which is mostly beyond the control of the ISN but could be partially influenced through CPFR and differential pricing strategies.

Electronic point of sale (EPOS) systems have made possible automation of stock-taking and replenishment i.e. sales-based ordering. Sharing of EPOS information among partners, makes possible scheduling of production and logistics activities in relation to the demand. One of the recent trends is to warehouse and mine the EPOS data to determine *which products are sold to whom and in what markets.* This information can be used for forecasting and analyzing the logistics usage patterns and a host of others. Electronic Data Interchange (EDI) is a common tool to exchange business data between organizations in a machine-processable format. Recent developments in the Internet, intranets, extranets, and the World-Wide-Web have immense possibilities for sharing information reliably and securely among partners.

The Automotive Network exchange (ANX), the most visible of the new wave of business-to-business virtual private networks (VPNs) running over the Internet, promises to provide the network infrastructure to cut costs by billions of dollars and change the way the automotive supply chain does business. Similarly, grocery companies are trying to form food exchanges, and textile manufacturers have formed AMTEX, the American textile partnership. Instill corporation is a leading provider of e-business services to the food service industry. Oracle has recently announced an open standards exchange for B2B communications.

Whenever information is shared between two parties, the party supplying information is running a risk. When a retailer provides point of sale data to the supplier, then the retailer is running a risk of a shift in bargaining power. In addition, the supplier gains strategically from better forecasts. The retailer has to evaluate the gains of the suppliers and get price advantages through appropriate contracts. Studies are needed to evaluate risk coverage policies in B2B communications.

2.3 Value Delivery Processes in an ISN

For the purpose of analysis we decompose the ISN into value delivery processes which run horizontally through the constituents of the ISN. The important value-delivery processes include– new product development, customer relationship management, logistics, procurement and delivery between ISN partners, supply chain network management, and collaborative forecasting.

3 Decision Making In ISNs

Decision making in the SCN is very complex because a large number of organizations are involved and several alternative routes are possible to fulfill an order. A supply chain has several facilities in different geographic locations, producing different products and serving different customers by supplying them with the required variety and lot sizes at the time and place they specify. Thus modern-day supply chains need to solve a five-dimensional decision problem: *When, Where, What and How Much to produce, and for Whom.* This problem is in contrast to the one dimensional decision problem of mass production systems: how to keep the production of a single product for a single market going. The supply chain problem is further complicated because all the stakeholders are autonomous and may not share the information, whereas most mass production enterprises are vertically integrated and information is centralized. In section 2.2, we discussed several possible information-sharing patterns among the supply chain partners.

Here, we now identify the strategic, tactical, and operational decisions in integrated supply chain networks.

3.1 Strategic Decisions

The strategic decisions are long-term and are often one-time decisions. They determine the competitiveness of the supply chain. These include partner selection, strategic alliances, location of facilities, technology choices and outsourcing decisions, business models and decisions regarding which products to produce and for what markets.

3.2 Tactical Decisions

At the tactical level, the time horizon is weeks or months. Demand forecasting, resource allocation, routing of the orders along the supply chain, subcontracting, scheduling production onto the supply chain facilities, load leveling, and bottleneck scheduling are all issues at this level.

3.3 Operational Decisions

The operational-level decisions include order processing, production matters, fleet scheduling, inspection, and delivery, to mention a few. These are basically day-to-day decisions. The questions that are addressed at this level include which customer order is to be filled, how to react to breakdown of a truck carrying items to a customer, the disruption of the supply of subassemblies from a supplier due to labor problems, etc.

Effective supply chain management involves addressing issues at all the three levels simultaneously. Basically, all decisions made in the supply chain world have to counter some kind of uncertainty. The traditional answer to customer service problems has been to increase inventories. Unfortunately, inventory bears a high cost in terms of capital consumption and expense. To understand the opportunities for dramatically reducing inventories, it is worthwhile to examine the drivers of inventory. The use of collaborative planning, forecasting and replenishment has the promise to minimize inventories.

4 Modeling of ISNs

Performance measures are useful to monitor, evaluate, benchmark and improve the value delivery processes. In traditional supply chains performance measures are generally defined for an organization and are typically financial in nature. In an ISN several organizations are involved in product manufacture and delivery to the customers, individual financial statements do not give a complete picture of the performance of the product or the ISN. Also, all the companies involved in the supply chain share the same goals, such as cycle time reduction, six-sigma on-time delivery, or quality or customer-perceived service levels, etc., and exchange information and expertise for the benefit of the entire chain.

The nonfinancial measures that would indicate the health of the entire ISN and its constituents include lead time, quality, cost, capacity, reliability, asset utilization, and flexibility. These seven measures are very generic and from them the customer satisfaction levels and the operational effectiveness and efficiency of the value delivery process can be computed. Measuring the quality along an order-to-delivery process will directly measure customer satisfaction levels. It will also present information on defects in products, missed deliveries, wrong deliveries, incomplete deliveries, delayed installation, etc. Monitoring these measures will help correct the defects and conduct continuous improvement. Similarly, cycle time monitoring in the supply chain networks will help reduce the inventories, establish good supplier relationships, reduce setup times, etc.

4.1 Dynamic Models of ISNs

For the ISN to be competitive, its critical value delivery processes have to be effective, efficient, and optimal in cost, lead time, and quality. Mathematical modeling provides a systematic foundation for decision making at strategic, tactical and operational levels.

The models useful at the strategic level—for example, for supply chain facility location—are nonlinear integer programming models [5]. Similarly, capacity planning models are also nonlinear integer programming models and are solvable using Lagrangian relaxation [6]. Several other optimization problems can be posed and solved. Operational-level decision making and optimization are conducted using discrete event models.

ISNs are discrete event dynamical systems (DEDS) in which the evolution of the system depends on the complex interaction of the timing of various discrete events such as the arrival of components at the supplier, the departure of the truck from the supplier, the start of an assembly at the manufacturer, the arrival of the finished goods at the customer, payment approval by the seller, etc. The state of the system changes only at discrete events in time. Over the last two decades, there has been a tremendous amount of research interest in this area. There are several classes of models that are useful in this context. These models can be used for either qualitative or quantitative analysis. Qualitative analysis yields results on stability and deadlock analysis [7]. Quantitative methods, on the other hand, highlight the determination of system performance measures such as throughput and lead time. Markov chains, Petri nets and queuing networks are fundamental models for DEDS[6]. Discrete event simulation is a very general method and is widely followed.

5 Future Directions

Supply chain management(SCM) is very hot research topic. Many researchers around the world are involved in advancing the frontiers of SCM. There are lots of white papers, concept papers, and vision papers written by management consultants, ERP vendors, IT companies such as HP, IBM, i2, and Netscape, scheduling software vendors, and market researchers. ISN is an important back-end of the Internet order fulfillment process, and got lot of attention with the booming of I-commerce. Internet based category killer companies such as amazon.com and e-toys are highly successful business ventures with new business models and value propositions. Overall, there is lots of excitement all round. There is no doubt that ISNs and their management will occupy the minds of researchers for few more years. I will point our some directions that need attention.

1. Design of supply chains is not a well studied subject. There have been studies on reengineering existing supply chains using new technologies, new modular product designs, etc. A clean slate design of an ISN starts with the identification of the product structure and the markets and ends with the delivery of the final product to the customer.The steps involed include design products and decide markets, engineer the ISN structure, engineer the product manufacture and delivery, operate ISN, and deliver products. These six steps can be further expanded to develop a design manual for ISNs.

2. Now SCM is offered as a universal methodology— independent of the markets, products and the network architecture. Individual industry segments and regional chains may offer sharper solutions.

3. Most studies on supply chains concentrate on PCs, deskjet printers, apparels, grocery and automobiles. Recently, there are initiatives on aircraft supply chains. Attention to the old industries such as iron, steel, paper, chemical, electrical, petrochemical, and pharmaceutical industries will yield large payoffs. Studies on E-business system redesign ie reengineering of the value delivery processes by taking advantage of Internet technologies are needed here.

4. Among infrastructure and service supply chains IT supply chains, health care, and banking dominate. Construction supply chains are well developed particularly in UK.

5. Most of the developments in the area of supply chains are taking place in the U.S. and to some extent in Europe. In all other countries particularly those in Asia and Africa , the IT and logistics infrastructure are minimal. It is important to have ISNs in place in these countries, for the success of rapidly expanding e-business ventures around the world. To this end studies on infrastructure chains is very important.

6. There have been tremendous developments in B to B and B to C commerce. It is estimated that Trillions of dollars worth of business is going to take place around the world. Development of mathematical models for performance analysis, design and optimization is an urgent need to place the existing software solutions on firm footing.

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