The Impact of Information Sharing on Order Fulfillment in Divergent Differentiation Supply Chains

Troy J. Strader
Iowa State University, USA

Fu-Ren Lin
National Sun Yat-sen University, Taiwan, R.O.C.

Michael J. Shaw
University of Illinois at Urbana-Champaign, USA

Current information technology (IT), such as extended intranets (extranets) utilizing the components of the World Wide Web (WWW), makes information sharing between global supply chain partners feasible. Given this, an important issue is: What impact does efficient information sharing have on supply chain order fulfillment performance (specifically cycle time and inventory costs)? In this study, we focus on divergent differentiation supply chains (commonly associated with industries such as fashion apparel). We identify the impact of information sharing by simulating order fulfillment in this supply chain type and find inventory costs can be reduced while maintaining acceptable order fulfillment cycle times. This is true because information, which provides the basis for enhanced coordination and reduced uncertainty, can substitute for inventory.

In today’s business environment, organizations are finding that efficiency alone is insufficient for maintaining competitiveness. Malone (1991) states that "the revolution of the 1990s is driven not by changes in production and transportation but by changes in coordination" (p. 128), particularly global interorganizational coordination. One example of an attempt to improve coordination and competitiveness is supply chain management. Supply chain management expands the scope of the “organization” being managed beyond the enterprise level to include interorganizational relationships, and they typically involve global operations. Examples include improving coordination between suppliers and manufacturers, as well as between manufacturers and distributors. As improvements in information technology (IT) have enabled the costs of coordination to decrease (Malone, 1987), there has been a general movement toward organizing as partnerships between more specialized firms or business units.

Supply chain management is an important topic to study because it is an instance of these partnerships. Most management information systems (MIS) research related to supply chain management has concentrated on identifying the information requirements of local supply chain node decision making (Billington, 1994; Davis, 1993; Lee, 1992; Lee, 1993a; Lee, 1993b; Swaminathan, 1994). Often this involved development of models of material and information flow through the supply chain network (SCN). The purpose of our research is to analyze the impact of information sharing on one supply chain type. We study divergent differentiation supply chains (commonly seen in industries such as fashion apparel). The term divergent differentiation is applied to these supply chains because their structure diverges from a relatively small number of suppliers to a wider range of partners.
assemblers and distributors. They also involve products differentiated at the assembly stage by combining a relatively small number of components into a much larger number of final products. It is important to study these supply chains because they are seen in a number of industries, including many types of clothing firms, and involve a large range of product variations, short product life cycles, and a primary objective is responsiveness (Fisher, 1994). Additional characteristics of these supply chains are discussed in more detail later in the paper.

We investigate the characteristics of supply chain management in an environment of electronic commerce. This environment includes (1) centralized, global business and management strategies (e.g. make-to-order, assemble-to-order and make-to-stock), (2) on-line, real-time distributed information processing to the desktop, providing total supply chain information visibility, and (3) the ability to manage information not only within a company but across industries and enterprises (Kalakota, 1996). Within an overall framework for studying electronic commerce, our research is at the application level (e.g., supply chain management) enabled by the information superhighway, multimedia content and network publishing, messaging and information distribution, and common business services infrastructures (Applegate, 1996). This five-level framework was developed to succinctly capture the major elements and features of electronic commerce to enable it to be better understood. Side issues, which are outside the scope of this paper, related to this framework include public policy, legal and privacy issues, as well as technical standards for electronic documents, multimedia and network protocols.

We discuss our analysis in the following sections. We present a brief overview of supply chain management, discuss technologies that enable feasible, efficient, information sharing between supply chain partners, and analyze, based on a set of simulations, how information sharing affects overall supply chain network performance. Finally, we present our conclusions.

Supply Chain Management

We introduce supply chains by presenting (1) a general overview of supply chain management, and (2) a summary description of supply chain management.

General Overview of Supply Chain Management

A supply chain is a network of facilities that procures raw materials, transforms them into intermediate subassemblies and final products and then delivers the products to customers through a distribution system (Billington, 1994). Supply chains exist in virtually every industry, especially industries that involve product manufacturing. Management of supply chains is a difficult task because of the large amount of activities that must be coordinated across organizational and global boundaries. The most common problems involve coordinating materials inventory and production capacity availability across several organizations to produce products that can satisfy forecasted demand in a highly uncertain environment.

Several factors are making supply chain management an important issue for today's managers. These factors include (1) more instances of multisite manufacturing, where several independent entities are involved in the production and delivery process, (2) increasingly cut-throat marketing channels, (3) the maturation of the world economy, with heightened demand for "local" products, and (4) competitive pressures to provide exceptional customer service, including quick, reliable delivery (Davis, 1993). In the past, management would concentrate on making each node of the supply chain network efficient. What managers are now realizing is that efficiency at each node does not result in the supply chain as a whole operating optimally. Increasingly, the challenges related to improved product quality, customer service and operating efficiency cannot be effectively met by isolated change to specific organizational units, but instead depend critically on the relationships and interdependencies among different organizations (or organizational units) (Swaminathan, 1994).

Supply chain management is a management process that attempts to optimize the operation of the entire supply chain. Different entities in a supply chain typically operate subject to different sets of constraints and objectives. Even when belonging to the same company, supply chain entities often report to different divisions. Supply chain entities are highly interdependent when it comes to improving due date performance, increasing quality or reducing costs. As a result, the welfare of any entity in the system directly depends on the performance of the others and their willingness and ability to coordinate (Swaminathan, 1994). Specifically, supply chain management involves balancing reliable customer delivery with manufacturing and inventory management costs (Billington, 1994). Two metrics commonly used to measure overall supply chain performance include order fulfillment cycle time and inventory level and cost.

One major problem involved in supply chain management is understanding and managing the uncertainties involved in the supply chain. This is especially true in the fashion skiwear industry (where divergent differentiation supply chains are prevalent) where demand is heavily dependent on a variety of factors that are difficult to predict - weather, fashion trends, the economy - and the peak of the retail selling season is only two months long (Fisher, 1994). Different sources of uncertainty exist along a supply chain. They include demand (volume and mix), process (yield, machine downtimes, transportation reliabilities), and supply (part quality, delivery reliabilities) (Billington, 1994; Lee, 1993a; Lee, 1993b). Inventories are often used to protect the chain from these uncertainties.

Another major problem involved in supply chain management is the management of lead-time. This is discussed in more detail in a later section. The role of information technology (IT) in supply chain management is to assist managers in managing uncertainty and lead time through improved collec-
tion and sharing of information between supply chain nodes. This will result in better customer service, through better coordination, and improve asset management, by giving decisionmakers the information necessary to optimize inventory and capital asset costs. Many of these improvements occur because IT enables dynamic changes in inventory management and production planning. The difficulty arises when designing an information system that can handle the information needs of each of the supply chain nodes to allow efficient, flexible, and decentralized supply chain management. We discuss these issues throughout this paper.

Summary Description of Supply Chain Management

The information infrastructure required by supply chain management is, by nature, supported by a distributed information system. Because of this, we feel that a distributed system model is most appropriate to describe a supply chain network. Distributed problem solving is the cooperative solution of problems by a decentralized and loosely coupled collection of knowledge sources (KS’s) located in a number of distinct processor nodes (Smith, 1988). Distributed problem solving is often necessary because no one node has sufficient information to solve the entire problem. The components of a distributed, coordination intensive, problem include goals, activities, actors, and interdependencies (Malone, 1990). We feel that a supply chain can be described by identifying its actors, activities, interdependencies, goals and objective. Our supply chain description is summarized in Table 1.

The overall supply chain objective is to balance each of the goals based on their importance to supply chain managers. In some situations costs may be the priority, while in other situations customer service may be the priority.

Technologies That Enable Information Sharing Between Supply Chain Partners

In this section we discuss the issue: Does current information technology make global information sharing between supply chain partners feasible? Several technologies are currently available that potentially make information sharing between supply chain partners feasible. Each partner firm is assumed to have its own information systems that include applications for supporting sales, manufacturing, and so forth. A complete discussion of implementation issues such as the interrelationship between required supply chain business processes and information infrastructure components, as well as the impact that differences in partner’s current IT infrastructures, is outside the scope of this paper. We also do not explicitly discuss the costs of implementing the infrastructure. It is assumed that IT costs will continue to decrease to the point where the benefits of using them to share information across a supply chain exceed the costs to do so. Our goal is to show that current technology makes it feasible for supply chain partners to share information in the future. The technologies that we discuss in this section include electronic data interchange (EDI), the Internet-based World Wide Web (WWW), intranets, and expanded intranets (extranets).

EDI is an existing information technology that provides a method of electronic transaction transfer. It is the process of computer-to-computer, business-to-business transaction transfer. EDI involves the direct routing of information from one computer to another without interpretation or transcription by people. To achieve this, the information must be structured according to predefined formats and rules which a computer can use directly (Holland, 1992). One example of where EDI has been shown to improve part of supply chain management is in inventory management, specifically, a just-in-time (JIT) system. EDI technology was shown to facilitate accurate, frequent, and timely exchange of information to coordinate material movements between trading partners. Suppliers receiving JIT schedule information achieved better shipping performance. Similarly, suppliers with the ability to directly map incoming information to internal production control systems were found to enjoy even greater benefits. Moreover, as the supplier handles a higher proportion of customers electronically, it was found that shipment errors continued to diminish (Srinivasan, 1993).

Each year, the use of EDI increases as organizations look for methods to improve enterprise integration and interorganizational coordination. Numerous studies have been done on various aspects of EDI and they all draw the same conclusion. EDI increases the speed and the accuracy of processes compared with non-electronic transfer of information (Snapp, 1990), and it is a potential source of competitive advantage (Johnston, 1988).

When a supplier and a procurer use information technology to create joint, interpenetrating processes at the interface between value-adding stages, they are taking advantage of the electronic integration effect. This effect occurs when information technology is used not just to speed communication, but to change - and lead to tighter coupling of - the processes that create and use information. One simple benefit of this effect is the time saved and the errors avoided by the fact that data need only be entered once (Malone, 1987). This is just one of several benefits derived from supply chain partners using more highly integrated information systems.

| 1. Actors | Suppliers, manufacturers, assemblers, distributors, and customers |
| 2. Activities | Material and information processing |
| 3. Interdependencies | Material shipments and orders, Funds transfer, and Information sharing |
| 4. Goals | Minimize order fulfillment cycle time, & Minimize inventory levels and costs |
| 5. Overall Objective | Balance individual goals based on priorities to produce the best “average” performance, or the best “worst case” performance. |

Table 1: Supply Chain Management | Summary Descriptions
A practical problem that must be addressed when designing an EDI process is the lack of a globally recognized standard format for data storage and transfer (Snapp, 1990). Two examples of EDI standards are the American National Standards Institute (ANSI) X.12 and EDIFACT. The ANSI X.12 committee develops standards to facilitate EDI relating to a range of business transactions. EDIFACT is a family of standards similar to X.12 developed by the United Nations (Kalakota, 1996). Because broad-based standards are lacking in many industries, organizations must agree upon the translation software and data format on a project by project basis. Without an agreement upon a standard, the EDI process will not work. The result has been slow deployment and restricted implementation of EDI between companies (Kalakota, 1996). This is one of the reasons why there will be a general movement away from these transaction specific connections to more flexible methods of electronic information transfer. One solution that has been considered by a number of businesses is using the Internet-based WWW and Internet browsers.

The Internet is an example of a global information network composed of an existing set of information technologies that provide a method for electronic information sharing. One component of the Internet is the WWW. At first glance, it appears that messaging-based technologies such as EDI, combined with database and information management services, form the technical foundation for effective electronic commerce solutions. No single one of these technologies can deliver the full potential of electronic commerce, however. What we require is an integrated architecture the likes of which we have never seen before. This integrated architecture is emerging in the form of the WWW (Kalakota, 1996). Although the WWW was not developed specifically for sharing of information among supply chain partners, it provides a model for these types of systems. The WWW was developed to be a pool of human knowledge, which would allow collaborators in remote sites to share their ideas and all aspects of a common project (Berners-Lee, 1994). Because supply chain management is similar to the projects the WWW was designed for (remote sites, shared knowledge, common project) it can serve as a method for sharing information in a supply chain. The major problem with using the Internet for supply chain management is security. Experts say reports of Internet-related security breaches are rising. Nearly one in four respondents to an Information Week survey conducted in February 1996 say fear of Net break-ins is keeping them from using the Net (Violino, 1996). The solution seems to be a more secure version of the Internet, an intranet.

An intranet is essentially any site based on Internet technology but placed on private servers and designed not to allow outsiders in (Miller, 1996). The outsiders in this case would be individuals and companies not directly involved in the management of the supply chain. Intranets use Web-based and Internet technology to inexpensively and easily share [organizational] data across a private network (Carr, 1996). We feel that the "organization" can encompass several separate firms such as in a supply chain. Intranet usage is predicted to overwhelm external Internet usage before the turn of the century. The key enablers of WWW growth are: (1) the proliferation of PCs, LANs, and modems, (2) open standards such as TCP/IP, HTTP, and HTML, (3) cross-platform support, (4) multimedia support and ease of use, and (5) support for secure transactions. (Organizational) intranets can provide information in a way that is immediate, cost-effective, easy to use, rich in format, and versatile (Netscape, 1996). What we have described is an extended intranet (or extranet). This is in line with the third wave of Internet usage identified by Netscape’s Marc Andreessen. “We are ready for a new era: the emergence of the extranet, or extended intranet, connecting companies with their suppliers and customers via Web links” (Karpinski, 1997). For example, a distributor (located in North America) in an apparel supply chain can request supply information from an assembler (located in Asia) by sending an HTTP request through their browser to a Web server. The server runs a CGI script to execute programs that access any necessary databases to process the request and return output to the HTTP server. The server translates the output into an HTTP response to the client (Lee, 1993b). To answer the initial question of this section, extranets, utilizing the WWW, its middleware, and browser software, provide a set of existing technologies that make supply chain information sharing feasible. Given that IT costs continue to decline, we also feel that the benefits of sharing information across a supply chain exceed the costs to provide the information infrastructure. The next issue then is, given this, what impact does efficient information sharing have on divergent differentiation supply chain performance?

Performance Improvements Enabled by the Information Infrastructure

We illustrate the usefulness of information sharing by presenting and discussing results from simulations of divergent differentiation supply chain performance under various information-sharing strategies that are enabled by current technology. In this section, we focus on one of the core business processes, the order fulfillment process (OFP), and use the Swarm simulation platform (The Santa Fe Institute, 1996) to simulate the OFP in supply chain networks (Lin, 1996a; Lin, 1996b).

Swarm is a multi-agent simulation platform developed for the study of complex adaptive systems. It was developed at the Santa Fe Institute and aims at providing a general-purpose simulation tool for building simulation models. A detailed description of Swarm is outside the scope of this paper, but can be found in (Lin, 1996b). Our implementation of SCNs in Swarm is described in more detail later.

An order fulfillment process begins with receiving orders from customers and ends with having the finished goods delivered (Lin, 1996a). It consists of several activities (sub-processes), such as order management, manufacturing, and distribution. The main objectives of the OFP can be generalized into two dimensions (Christopher, 1993; Goldman, 1995; Lin, 1996a): delivering qualified products to fulfill customer
orders at the right time and right place, and achieving agility to handle uncertainties from internal and external environments.

**Issues in Managing SCNs for Supporting the OFP**

Because of the complexity of a SCN, it is a challenge to coordinate the actions of entities within the network to perform in a coherent manner. When orders come into an entity in a SCN, the lead time for delivering products (called the order fulfillment cycle time) is composed of (1) order processing times, including the order transfer time from customers to manufacturers or distributors, and the due date assignment process, (2) material lead times, including material planning and purchase lead time, supplier lead time, transport lead time, receipt and inspection lead time, assembly release time, and material order picking time, (3) assembly lead times, including waiting time, processing times, and transport time to the next stage, (4) distribution lead times, including dispatch preparation time (documents, packages), and transportation time to the customer, and (5) installation lead times. These components of the order fulfillment cycle time distribute across the network, and the variation of lead times at any stage will affect the execution of the other stages and result in uncertainties for the overall order cycle time. This is called the ripple effect. For example, a product that is assembled by component parts from several different suppliers. The cycle time for assembling the product can be affected by the lead-time of material supply from different suppliers. If parts from some of the suppliers come later than the other parts for assembly, the assembly will be delayed due to the unavailability of required parts. This also increases the inventory costs for those available parts. If the product is a component for the downstream manufacturing process, the delay for shipping this product will affect the subsequent stages, and in turn, influence the entire network.

Therefore, the first issue in managing a SCN is how to control the ripple effect of lead-time so that the variability of a SCN can be mitigated. How to coordinate the policies of up and downstream entities in facilitating such variability reduction is the main concern. Demand forecasting is used to estimate demand for each stage, and the inventory between stages of the network is used for protecting against fluctuations in supply and demand across the network such as machine breakdown, extra large demand, etc. Due to the shortening of product life cycles, such protection seems unwise and actually reduces flexibility.

Because of the decentralized control properties of the SCN, control of the ripple effect requires coordination between entities in performing their tasks. The management of interdependencies is the key to smooth material flow within the SCN. The interdependencies between entities of the SCN can be described in the following situations:

1. **Producer/consumer dependence** can be used to describe the supplier/manufacturer relationship in the SCN. This requires cooperation between suppliers and manufacturers in an efficient and effective way. Efficiency means to reduce material lead times, and effectiveness means to supply only the needed materials. This dependence also implies a constraint satisfaction problem; through the network, it is a constraint propagation issue too.

2. **Material flows within the SCN** implies a synchronization problem, where related materials for a product are delivered to the manufacturer at a coherent speed which incurs minimal inventory and delay.

Inventory is an unwise approach to dealing with highly changing market demand and short life cycle products. What would be the substitution for inventory? Information can substitute for inventory. The material lead-time information from different suppliers can be used for planning the material arrival, instead of building up inventory. The demand information can be transmitted to the manufacturers on a timely basis, so that orders can be fulfilled with less inventory costs. The second main issue is how to manage the information flow within a SCN so that decisions made by business entities can take more global factors into consideration. In this way, we can increase SCN visibility. These issues are addressed because of the essential concern: how to make the network respond effectively and efficiently to satisfy customer demand, which leads to the motivation for managing SCNs to support the OFP.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Type I SCN</th>
<th>Type II SCN</th>
<th>Type III SCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing process</td>
<td>Convergent Assembly</td>
<td>Divergent Assembly</td>
<td>Divergent Differentiation</td>
</tr>
<tr>
<td>Primary business objectives</td>
<td>Lean production</td>
<td>Customization</td>
<td>Responsiveness</td>
</tr>
<tr>
<td>Product differentiation</td>
<td>Early</td>
<td>Late</td>
<td>Late</td>
</tr>
<tr>
<td>Range of product variations</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Assembly process</td>
<td>Concentrating at the manufacturing stage</td>
<td>Distributed to the distribution stage</td>
<td>Concentrating at the manufacturing stage</td>
</tr>
<tr>
<td>Product life cycle</td>
<td>Years</td>
<td>Months to years</td>
<td>Weeks to months</td>
</tr>
<tr>
<td>Main inventory type</td>
<td>End products</td>
<td>Semi-products</td>
<td>Raw materials</td>
</tr>
<tr>
<td>Example industries</td>
<td>Automobile and aerospace</td>
<td>Appliance, electronics and computers</td>
<td>Apparel/fashion</td>
</tr>
</tbody>
</table>

**Table 2: The Properties of Type I, II, and III SCNs**
Lin identified three main types of SCNs, Type I, II and III, based on such attributes as manufacturing process, primary business objective, product differentiation, range of product variation, assembly stages, product life cycle, and main inventory type as shown in Table 2 (Lin, 1996a).

The apparel/fashion industry involves Type III SCNs, where acquiring market information to respond to demand, and deferring product differentiation to maintain flexibility to handle constantly changing markets, are two main issues and challenges. In these SCNs, the number of end items is larger than the number of raw materials. There are a small number of suppliers and manufacturers, but a larger number of distributors and retailers.

The Implementation of Swarm for Simulating Order Fulfillment in SCNs

Figure 1 describes the SCN implementation on the Swarm platform. The uppermost swarm, the OFP Batch Swarm, is designed to control the whole simulation. It creates two swarms, the OFP Model Swarm and the Statistics Swarm, creates actions, and then activates the simulation process. The OFP Model Swarm is composed of an array of SCN Entities created while building objects. The SCN configuration with each entity’s properties and product information are fed in during the entities creation. The OFP model actions are composed of each SCN entity’s actions, and are activated when the OFP Model Swarm is activated. A SCN entity is composed of several agents, such as an order management agent, an inventory management agent, and a SCN management agent. An entity with manufacturing capability includes a production planning agent, a capacity planning agent, a materials planning agent, a shop floor control agent, and manufacturing systems agent. A SCN Entity Swarm holds entity level information such as suppliers, customers, order transfer delay time, and product delivery time, which are accessible by internal agents and other entities. The encapsulated agents perform certain functions in enabling the movement of information and material within the entity and between entities. The Statistics Swarm is used to compute the statistics data gathered through the simulation for analysis purposes.

The following scenario describes the interactions among these agents, and Figure 2 summarizes them. For example, an entity ScnESwarm A receives an order from its customer ScnESwarm C. The order flows to the order management agent (OrdM). According to the customer lead times, the inventory availability information (from InvM), the production plan (from PrdP), and the manufacturing capacity (CapP), the order management agent assigns a due date to the order. If the products are in stock, the order is filled by shipping the products from inventory. If the products are in receiving, the due date is set according to the delivery date of the products.

For an entity with manufacturing capability, the order is forwarded to the production planning agent (PrdP) where the schedule for making the products is planned. The capacity planning agent (CapP) and the material planning agent (MatP) are partner agents in generating achievable build plans. The material planning agent obtains build plans from the production planning agent to allocate materials for manufacturing. It also contributes information about material availability to production planning for scheduling. The capacity planning agent (CapP) plans capacity by taking the build plan from PrdP and sends capacity usage information to PrdP for scheduling the build plan. The SCN management agent (ScnM) takes the order information to choose suppliers in allocating material sources. The outgoing orders are transferred through its SCN Entity (ScnESwarm A) to be transferred to other entities (i.e., ScnESwarm B). This describes the information within an entity.

If the entity is a distribution center or a retailer without manufacturing capability, the ordered products are delivered from suppliers as end products to ship to its customers. For an
entity with manufacturing capability, the ordered end products are supplied from the shop floor (ManuS) to its customers. The input materials are components for the end products. This represents the material flow with an entity. The interaction of these agents enables the flow of materials and information within an entity, and through the SCN Entity Swarm (ScnESwarm), the information and materials flow across the supply chain network.

In this section, we described the components of our SCN simulation model. The specific business environments that we simulate are described in the next section.

Simulation Environment

We implemented a supply chain designed to simulate a Type III SCN. “Scn-III” in Figure 3 represents a Type III SCN. It consists of 16 entities aligned into five tiers. The entity at tier 1 is a distribution center without manufacturing capability, entities in tiers 2 and 3 make the products, and entities in tiers 4 and 5 distribute products. The divergent assembly, late product differentiation, many resulting end-items, and manufacturing concentrating at manufacturing stages are common to Type III SCNs.

Two sets of parameters provide the input to the Swarm system used for these simulations. The parameters and their values are summarized in Table 3.

The global parameters are held constant for each simulation to isolate the cycle time and inventory cost impact of different information sharing and demand management strategies. The interactions between agents are described above in the supply chain structure. Finally, each entity in the structure is characterized by the attributes shown in the entity parameter list. Production costs, such as setup costs, are not included in this study given that they do not directly impact the cycle time and inventory cost performance parameters studied. The values were chosen as reasonably representative of operating supply chains. System documentation and source code is available through the WWW (Lin, 1998).

We conducted experiments to evaluate OFP performance using various information-sharing strategies. Information sharing between business entities considers three issues: (1) the information contents, (2) the depth of information penetration (the number of tiers for which information is accessible), and (3) the information acquisition direction (upward or downward sharing). Agent decision-making processes are held constant to isolate the impact of information sharing.

In the design of the simulation platform, the information acquired by downstream entities is mainly material and capacity availability information from their suppliers. The information acquired by an upstream entity is information about customer demand and orders. The depth of information penetration can be specified in various degrees, e.g., isolated, upward one tier, upward two tiers, downward one tier, down-

<table>
<thead>
<tr>
<th>Parameter Type</th>
<th>Simulation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global parameters</td>
<td>Time step</td>
<td>One day</td>
</tr>
<tr>
<td></td>
<td>Time period</td>
<td>240 days</td>
</tr>
<tr>
<td></td>
<td>Production planning horizon</td>
<td>24 days</td>
</tr>
<tr>
<td></td>
<td>Forecasting horizon</td>
<td>48 days</td>
</tr>
<tr>
<td></td>
<td>EOQ period</td>
<td>240 days</td>
</tr>
<tr>
<td></td>
<td>Reorder point check</td>
<td>48 days</td>
</tr>
<tr>
<td></td>
<td>Order distribution</td>
<td>U(2,10) units</td>
</tr>
<tr>
<td>Entity parameters</td>
<td>Manufacturing capability</td>
<td>Yes/No</td>
</tr>
<tr>
<td></td>
<td>List of supplier entities</td>
<td>Varies based on SCN structure</td>
</tr>
<tr>
<td></td>
<td>List of customer entities</td>
<td>Varies based on SCN structure</td>
</tr>
<tr>
<td></td>
<td>Order cost</td>
<td>2.0 dollars</td>
</tr>
<tr>
<td></td>
<td>Inventory holding cost</td>
<td>0.1 dollars</td>
</tr>
<tr>
<td></td>
<td>Production processing time</td>
<td>0.2 days</td>
</tr>
<tr>
<td></td>
<td>Time to forward order</td>
<td>0.5 days</td>
</tr>
<tr>
<td></td>
<td>Time to deliver product</td>
<td>1.0 days</td>
</tr>
</tbody>
</table>

Table 3: Simulation Parameter Summary
ward two tiers, and so forth.

The obtained capacity and material information from suppliers is used to estimate the due dates of incoming orders, which are the basis for generating build plans or reordering schedules. The obtained customer demand information is used to estimate the demand for the next period, so that the production or reordering schedules can adapt to external demand.

Demand management policies, such as make-to-order (MTO), make-to-stock (MTS), and assemble-to-order (ATO) have their characteristics and application situations described in Table 4 (Lin, 1996a; McCutcheon, 1994).

If the amount of customization is low, the firm can usually employ a MTS approach and then use inventories of finished goods to provide short lead times. For products with high customization, the MTS strategy cannot efficiently and effectively match customer preferences. If customers are willing to wait for customized products after submitting orders, the make-to-order strategy can be applied to high-customization firms. When the product design allows the product differentiation stage to occur late enough in the production process, the firm can employ an assemble-to-order approach.

**Table 4: Some Demand Management Policies for the Order Fulfillment Process**

<table>
<thead>
<tr>
<th>Policies</th>
<th>Characteristics</th>
<th>Application Situations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-To-Order (MTO)</td>
<td>Production is triggered by customer orders</td>
<td>High customization pressure but low responsiveness.</td>
</tr>
<tr>
<td>Assemble-To-Order (ATO)</td>
<td>Final assembly is order-driven, but the component parts are forecast-driven and built to stock.</td>
<td>High customization pressure, high responsiveness, and products with late differentiation.</td>
</tr>
<tr>
<td>Make-to-Stock (MTS)</td>
<td>Production is triggered by inventory replenishment points.</td>
<td>Low customization pressure.</td>
</tr>
</tbody>
</table>

Impact of Information Sharing on Divergent Differentiation Supply Chains

The results from evaluating various information-sharing strategies in divergent differentiation supply chains are shown in Figures 4 through 5. The three information sharing strategies are (1) no information sharing, (2) supply information sharing, and (3) supply and demand information sharing. The three demand management policies were described earlier. Figures 4 and 5 illustrate order cycle time and inventory cost respectively in a Type III SCN using the three information sharing strategies with the three demand management policies. In Figure 4 we see that the highest cycle time is for the MTO strategy, while the lowest cycle time is for the MTS strategy. This is the expected result given that the MTO strategy waits for orders to arrive before processing them and

![Figure 4: OFP Improvement in Order Cycle Time Reduction Using Various Information Sharing Strategies in a Type III SCN](image1)

![Figure 5: OFP Improvement in Inventory Cost Reduction Using Various Information Sharing Strategies in a Type III SCN](image2)
the MTS strategy produces products for inventory in anticipation of orders. The most improved cycle time performance (-73 hours or -17%) results from sharing supply information when using an ATO strategy. One interesting result is that the SDI strategy results in an increase (+83 hours or +71%) in the order cycle time when applying the MTS demand management strategy. The demand information provided from downstream is made available to the upstream entities to factor into their component or product reordering decision making instead of just reordering exclusively according to the reorder point calculated by stock level. Therefore, it reduces a significant amount of inventory as shown in Figure 5. However, due to the ripple effect, the demand information fails to penetrate to upper tiers with sufficient lead time, thus the aggregated cycle time increases. Therefore, the information penetration span and lead-time are crucial in implementing the information sharing strategy.

Inventory costs are calculated by accumulating all finished and work-in-process products within the supply chain. In Figure 5, we see that the highest inventory cost is for the MTS strategy, while the lowest inventory cost is for the MTO strategy. This is the expected result given the characteristics of these strategies described earlier. The most improved inventory cost performance (-$188,191 or -76%) results from sharing supply and demand information when using the ATO strategy. Therefore, we feel that the best overall strategy for divergent differentitation supply chains is to apply an ATO strategy while sharing supply and demand information between supply chain partners. Cycle time is held at a reasonable level, but inventory costs are much lower when supply and demand information is shared. Since a Type III SCN faces constantly changing markets, the accessible demand information may allow suppliers to deliver the right products at the right time with less inventory. Our findings support this. The critical component of the information infrastructure is the link between distributors and the market.

Supply information (coupled with a MTS demand management policy) is crucial for OFP improvement when the constituent materials for products are unique and delivered by different suppliers. But as the range of product variations and changes in market demand increases (as commonly seen in fashion/apparel supply chains), the importance of demand information increases. This information, coupled with an ATO demand management policy, results in improved performance in these SCNs.

Conclusions

Two sets of conclusions can be drawn from our study. The first set relates to findings specific to divergent differentitation supply chains, while the second set relates to overall findings concerning the relationship between information infrastructure and supply chain management. Management of Type III (divergent differentitation) supply chains is most effective when using an ATO policy coupled with sharing of demand information. Supply information is useful, but less critical. Inventory costs are reduced while cycle times remain relatively stable. These results, related to divergent differentiation supply chains, produce some interesting overall conclusions.

First, supply chain management relies heavily on its information infrastructure. Supply chain performance can be improved through the information sharing and coordination enabled by current technology. Also, an extranet, with its associated components, provides a current technology for the functional requirements required for efficient, electronic, information sharing that is more flexible than EDI, while increasing data and message security relative to the Internet.

Finally, supply chain management involves a fundamental tradeoff between cycle time, inventory and information. In many cases, information can replace inventory while maintaining acceptable cycle times. In the past, when information costs were high, inventory was held to manage uncertainty. Today, when information technology continues to reduce information costs, uncertainty can be reduced resulting in lower inventory requirements. Our results illustrate some of the potential impacts of the electronic integration effect (Malone, 1987). The benefits that we illustrate related to this effect are that supply chain managers may reduce inventory costs because of reduced uncertainty in decision making. This is possible because IT (incorporated into electronic hierarchies) reduces coordination costs. The development of an analytical model to describe this tradeoff is an issue that should be addressed by future research.

Overall, we feel that extranets provide an interorganizational information system that can support the processes and decision making required for effective supply chain management resulting in improved coordination and lower inventory costs. Additional research should involve implementation of current technology for information sharing across supply chains to empirically test our simulation findings.

References


Troy J. Strader is an Assistant Professor of Management Information Systems in the Department of Logistics, Operations and MIS, Iowa State University. He received the Ph.D. degree in Business Administration (Information Systems) from the University of Illinois at Urbana-Champaign in 1997. His research interests include electronic commerce, strategic impacts of information systems, and information economics. He is a member of ACM, AIS, and INFORMS.

Fu-Ren Lin is an Associate Professor of Management Information Systems, Department of Information Management, at the National Sun Yat-sen University in Taiwan. He received the Ph.D. degree in Business Administration (Information Systems) from the University of Illinois at Urbana-Champaign in 1996. His research interests include decision support systems, artificial intelligence applications for business, supply chain management, and electronic commerce.

Michael J. Shaw is a Professor of Information Systems and Technology at the Department of Business Administration, the University of Illinois at Urbana-Champaign, where he has been a faculty member since 1984. He is also a Senior Research Scientist of the National Center for Supercomputing Applications (NCSA) and a Professor at the Beckman Institute for Advanced Science and Technology. His research is focused on the Management of Information Technology, Electronic Commerce, IT for Business Process Reengineering, Data Mining, and Decision Support Systems.
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