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Supply chain management has emerged as one of the major areas for companies to gain a competitive edge. Managing supply chains effectively is a complex and challenging task, due to the current business trends of expanding product variety, short product life cycle, increasing outsourcing, globalization of businesses, and continuous advances in information technology. The Internet has contributed to both the increasing needs and opportunities for improved supply chain management. With the Internet, companies in a supply chain can be connected in real time with information and knowledge shared continuously, new products and services can be designed to fit special market segments, and new supply chain structures can be developed to serve customers in a more direct manner.

When a company faces the pressure of excessive inventory, degraded customer service, escalating costs and declining profits, or a poor return on assets, its supply chain is out of control. On the other hand, when a company moves in to new markets or new technologies, it must have its supply chain prepared for the new business challenges and opportunities. Although there are many new supply chain concepts and fads designed to exploit the advantages of the Internet, successful companies understand that the right supply chain strategy is dependent on a number of factors:

- The strategy needs to be tailored to meet specific needs of the customers.
- A product with a stable demand and a reliable source of supply should not be managed in the same way as one with a highly unpredictable demand and an unreliable source of supply.

- The Internet can be a powerful tool for supporting or enabling supply chain strategies for products with different demand and supply uncertainties.

Supply chain strategies that are based on a one-size-fits-all or a try-everything mentality will fail.

The Uncertainty Framework

A simple but powerful way to characterize a product when seeking to devise the right supply chain strategy is the “uncertainty framework.” This framework specifies the two key uncertainties faced by the product—demand and supply. Fisher introduced the matching of supply chain strategies to the right level of demand uncertainties of the product.¹ This article expands his framework to include *supply* uncertainties.

Demand uncertainty is linked to the predictability of the demand for the product. Functional products are ones that have long product life cycles and therefore stable demand, while innovative products are products that have short life cycles with high innovation and fashion contents—and which, as a result, have highly unpredictable demand.² Fashion apparel, high-end computers, the latest integrated circuits, and mass customized goods are examples of innovative products, while household consumable items, basic foods, oil and gas, and basic clothing are examples of functional products. Clearly, different supply chain strategies are required for functional versus innovative products.

Functional products tend to have less product variety than innovative products, where variety is introduced due to the fashion-oriented nature of

the product or the rapid introduction of new product options due to product technology advancements. Demand for functional products is much easier to forecast, while demand for innovative products is highly unpredictable. Due to the differences in product life cycle and the nature of the product, functional products tend to have lower product profit margins, but the cost of obsolescence is low; whereas innovative products tend to have higher product profit margins, but the cost of obsolescence is high. Figure 1 summarizes some of the differences between functional and innovative products.

FIGURE 1. Demand Characteristics

Functional	Innovative
Low demand uncertainties	High demand uncertainties
More predictable demand	Difficult to forecast
Stable demand	Variable demand
Long product life	Short selling season
Low inventory cost	high inventory cost
Low profit margins	High profit margins
Low product variety	High product variety
Higher volume per SKU	Low volumes per SKU
Low stockout cost	High stockout cost
Low obsolescence	High obsolescence

Other kinds of uncertainties revolving around the supply side of the product are equally important drivers for the right supply chain strategy. A “stable” supply process is one where the manufacturing process and the underlying technology are mature and the supply base is well established. An “evolving” supply process is where the manufacturing process and the underlying technology are still under early development and are rapidly changing, and as a result the supply base may be limited in both size and experience. In a stable supply process, manufacturing complexity tends to be low or manageable. Stable manufacturing processes tend to be highly automated, and long-term supply contracts are prevalent. In an evolving supply process, the manufacturing process requires a lot of fine-tuning and is often subject to breakdowns and uncertain yields. The supply base may not be as reliable, as the suppliers themselves are going through process innovations. Figure 2 summarizes some of the differences between stable and evolving supply processes.

While functional products tend to have more mature and stable supply process, that is not always the case. For example, the annual demand for electricity and other utility products in a locality tend to be stable and predictable, but the supply of hydroelectric power, which relies on rainfall in a region, can be erratic year by year. Some food products also have very stable demand, but the supply (both quantity and quality) of the products depends on yearly weather conditions. Similarly, there are also innovative products with a stable supply process. Fashion apparel products have short selling seasons and their demand is highly unpredictable. However, the supply process is very stable, with a reliable supply base and a mature manufacturing process technology. Figure 3 gives some examples of products that have different demand and supply uncertainties.

Changing the Uncertainty Landscape

It is more challenging to operate a supply chain that is in the right column of Figure 3 than in the left column, and similarly it is more challenging to operate a supply chain that is in the lower row of Figure 3 than in the upper row. Before setting up a supply chain strategy, it is necessary to understand the sources of the underlying uncertainties and explore ways to reduce these uncertainties. If it is possible to move the uncertainty characteristics of the product

FIGURE 2. Supply Characteristics

Stable	Evolving
Less breakdowns	Vulnerable to breakdowns
Stable and higher yields	Variable and lower yields
Less quality problems	Potential quality problems
More supply sources	Limited supply sources
Reliable suppliers	Unreliable suppliers
Less process changes	More process changes
Less capacity constraint	Potential capacity constrained
Easier to changeover	Difficult to changeover
Flexible	Inflexible
Dependable lead time	Variable lead time

FIGURE 3. The Uncertainty Framework: Examples

		Demand Uncertainty	
		Low (Functional Products)	High (Innovative Products)
Supply Uncertainty	Low (Stable Process)	Grocery, basic apparel, food, oil and gas	Fashion apparel, computers, pop music
	High (Evolving Process)	Hydro-electric power, some food produce	Telecom, high-end computers, semiconductor

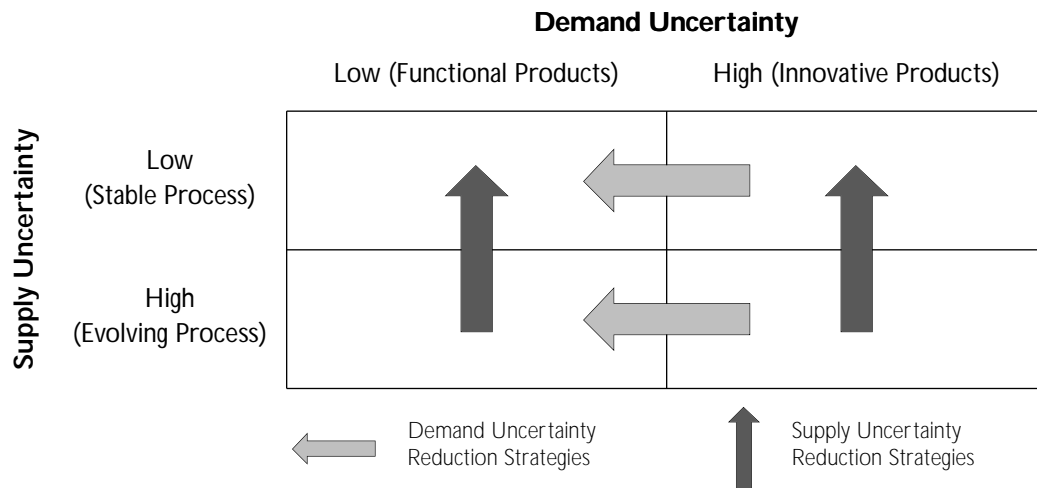
from the right hand column to the left, or from the lower row to the upper one, then the supply chain performance will improve.

Figure 4 shows the two kinds of strategies that improve supply chain performance through uncertainty reduction—demand uncertainty reduction and supply uncertainty reduction.

Demand Uncertainty Reduction Strategies

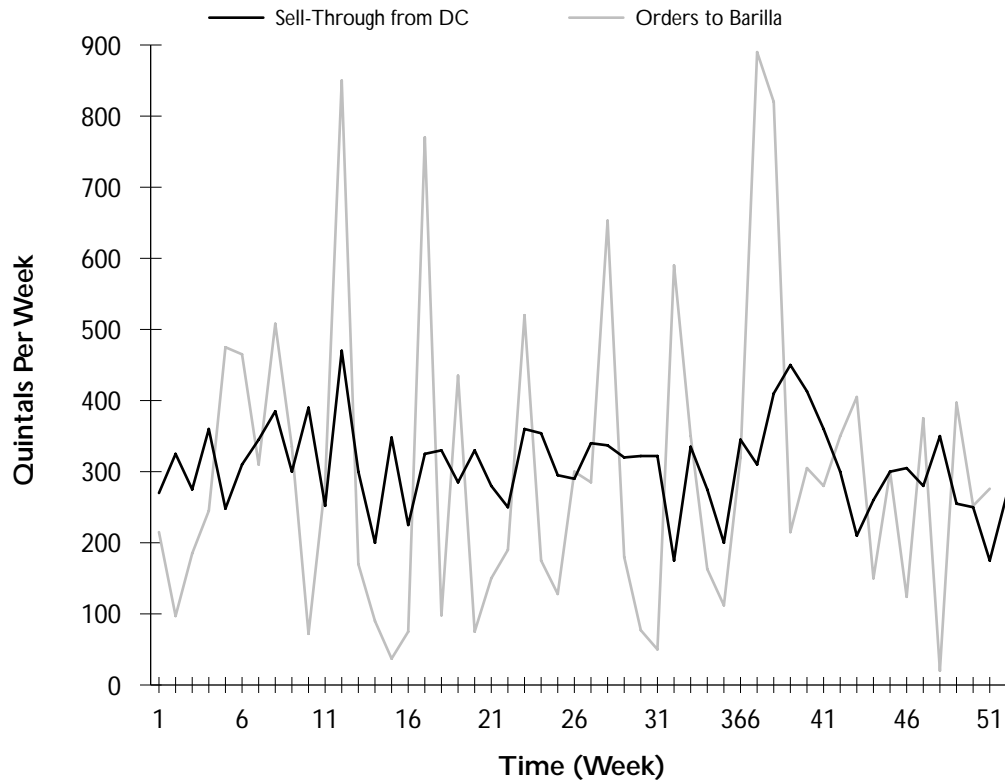
In many cases, although the demand of the product at the end consumer level is stable, distortion of demand signals can occur up the supply chain. As a result, the demand patterns at the upstream portion of the supply chain could become highly erratic. Hence, while the demand patterns at the end consumption level could be flat with small variations, the orders placed by the retailer to the wholesaler (or by the wholesaler to the manufacturer, or by the manufacturer to the supplier, and so on) exhibit increasing fluctuations. This is the well-known “bullwhip effect,” which is an amplification of order variability as one goes upstream along a supply chain.³ In this way, even though the original product demand is stable, many parts of the supply chain would still be faced with highly unpredictable demand, so that overall cost efficiency cannot be achieved across the entire supply chain. Here, the observed demand uncertainty of the product would place the product in the right column of Figure 3, although it should really belong in the left column. What is needed is a way to move the demand uncertainty back to the left column.

Only through information sharing and tight coordination can one regain control of supply chain efficiency. Sharing of demand information and synchronized planning across the supply chain are crucial for this purpose. Barilla, an Italian pasta manufacturer, is a case example. Pasta is a product that has both low demand and supply uncertainties. Yet, as a result of the retailers’ over-

FIGURE 4. The Uncertainty Reduction Strategies

reactions to demand signals, orders that are batched to make full truckloads, promotions, and order exaggerations, a high level of demand fluctuations occur, leading to significant waste and losses. Figure 5 shows the amplification of demand fluctuation of Barilla's product from the distributor to the manufacturer. Through information sharing and coordinated replenishment programs initiated by Barilla, the supply chain efficiency was greatly improved.⁴ Inventory dropped by close to 50%, and stockout rates were down to almost zero as a result of the tight coordination. In the end, the bullwhip was "tamed." Indeed, in a recent study conducted jointly by Stanford University and Accenture focused on 100 manufacturers in the food and consumer products industry, companies that reported higher than average profits were the ones who engaged in joint replenishment and planning programs with their trading partners (see Figure 6).

Information sharing and collaborative replenishments up and down the supply chain are best facilitated by the use of the Internet. The grocery industry, which consists of mostly functional products with stable supply processes, is an ideal setting to implement such strategies. Currently, the Voluntary Industry Commerce Standards Committee is working on formalizing the process models and technology framework for collaborative planning, forecasting, and replenishment for the grocery industry. It seeks to have companies utilize the Internet, with electronic bulletin boards, to pursue the collaborative efforts. Nabisco and Wegmans have successfully implemented a pilot, with very encouraging results. The total snack nut category sales went up by 11% while the corresponding sales at other retailers actually declined by 9% in the test period. Nabisco's leading brand, Planters, saw its sales rise by 40% as a result of better-planned

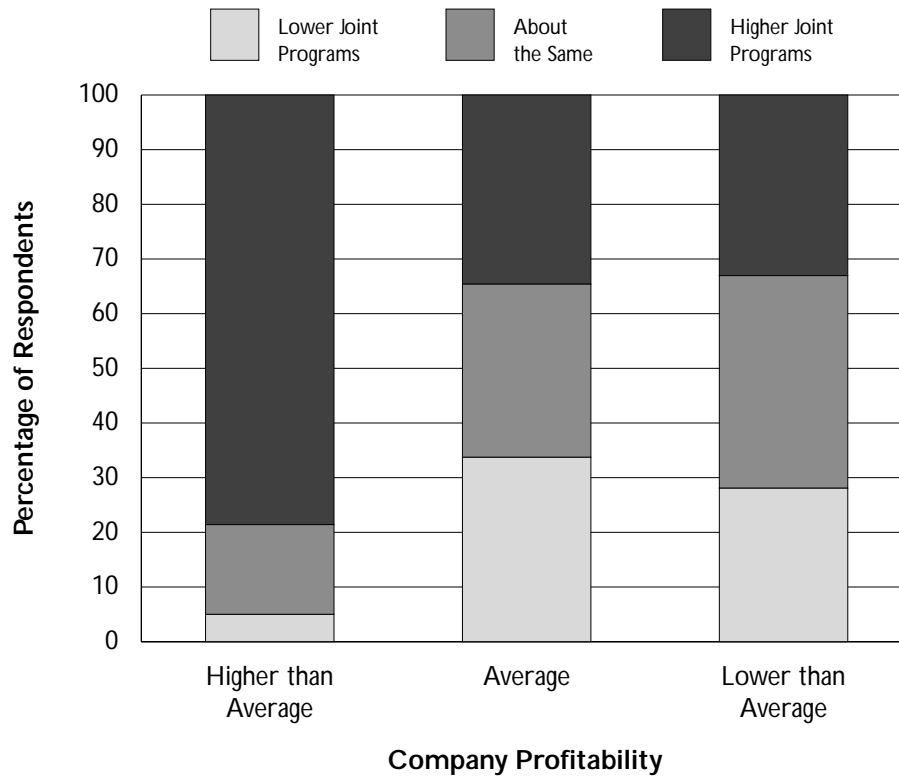
FIGURE 5. Bullwhip Effect at Barilla's Distribution Center

Based on J.H. Hammond, "Barilla SpA (A-D)," *Harvard Business School Case 6-694-046*, 1994.

promotions and discounting given to Wegmans stores, which was enabled by the collaborative efforts in replenishment. Finally, Nabisco's warehouse fill rate increased from 93% to 97%, while inventory dropped by 18%. Several other pilots are now under way at Schnuck Markets, Kmart, Circuit City, P&G, Kimberly-Clark, Sara Lee, and Wal-Mart.

Supply Uncertainty Reduction Strategies

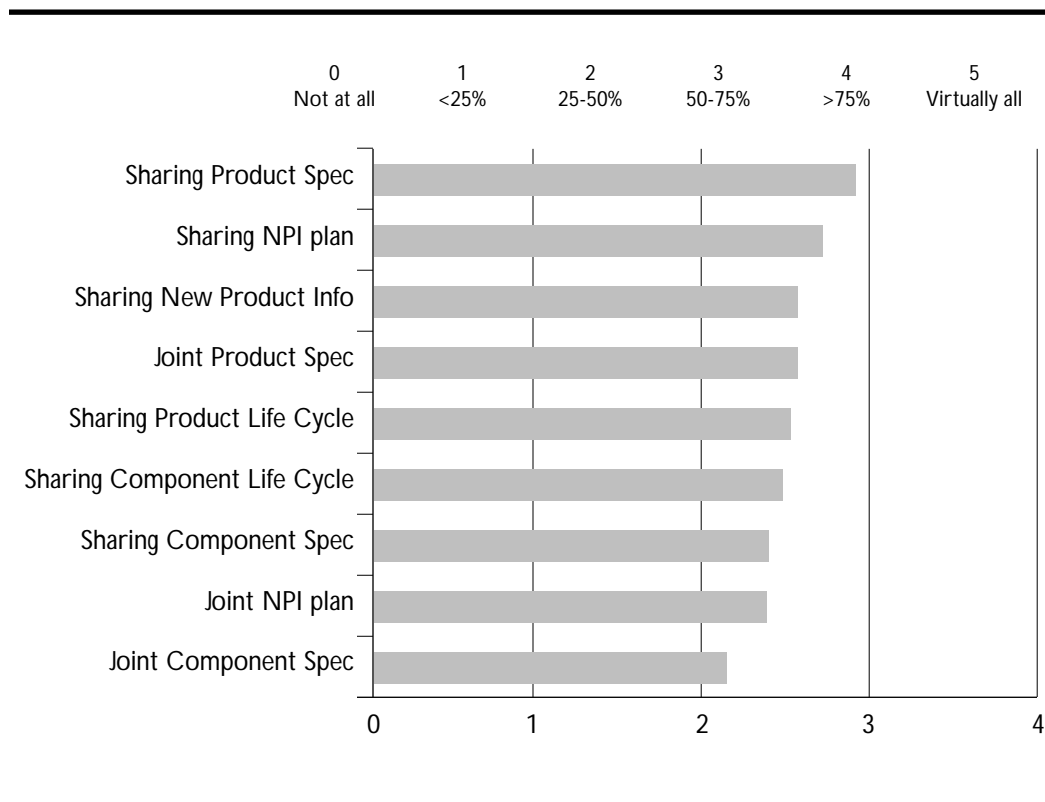
Free exchanges of information—starting with the product development stage and continuing with the mature and end-of-life phases of the product life cycle—have been found to be highly effective in reducing the risks of supplier failure. Austin and Lee have found that companies in the PC industry have engaged in extensive collaborative efforts with suppliers to help reduce the risks of suppliers not being able to ramp up fast enough in the production introduction phase as well as the risks of suppliers overproducing at the end of the product life cycle (see Figure 7).⁵

FIGURE 6. Higher Profits and Higher Level of Joint Demand and Logistics Planning

Based on study of PC industry by Stanford University and Accenture, 1998.

Billington et al. have also identified sharing product rollover plans with suppliers as a key means to manage the risks of product transitions.⁶ Indeed, the need to share and communicate important product content information to support product changes and transitions has created a software market for “product data management.” For example, Johnson and Lee described how Agile Software has been able to help manufacturers such as WebTV, Flextronics, and Pair-Gain work tightly with their suppliers so that the risks of supply failures during product transitions could be minimized.⁷

Early design collaboration is another way to reduce supply uncertainties downstream. Most of the industry consortium-based market exchanges (such as Exostar, e2Open, and Covisint) have identified design collaboration with suppliers as a key service provided by the exchanges. Bose Corporation has used the “on-site” representative concept to have a supplier representative stationed at their sites to foster communication.⁸ The Micro-Compact Car (MCC), owned by Daimler-Benz and manufacturer of the Smart Car in Europe, set up their factory

FIGURE 7. Percentage of Companies Involved in Design Collaboration in PC Industry

Based on study of PC industry by Stanford University and Accenture, 1998.

in Hambach, France, where key subsystems suppliers were given the responsibility to manage the replenishments of key modules at the factory site. Suppliers were asked to make direct investments in the Hambach factory when it was first set up in 1994 and were given space inside the factory to store their inventory. In some cases, they were also responsible for inserting their modules into the automobiles as finished products. Along with investment and increased responsibilities, suppliers are also heavily involved in the research and development of Smart Cars. This strengthened partnership relationship has paid off handsomely. Despite a difficult startup period, Smart Cars sales have recently been gaining much ground in Europe.

Supplier hubs have also been used by manufacturers to reduce the supply risks of their manufacturing lines. For example, at their former manufacturing site in Fountain, Colorado, Apple Computer created a supplier hub that was operated by a third-party logistics company, Fritz Companies. Fritz would manage the replenishment and inbound logistics of the parts and materials to a warehouse (known as the supplier hub) that was in close proximity to the Apple factory. The inventory at the hub was owned by the suppliers. The use of the

hub has allowed the suppliers to have much better information about Apple's needs and consumption patterns of their parts as well as about the inventory in transit. This had resulted in more effective management of inventory replenishment and inbound logistics by the suppliers and Fritz collectively, thereby reducing the supply uncertainties for Apple.⁹ Supplier hubs have been used by companies such as Compaq, HP, Dell, Cisco, 3Com, and Volkswagen.

Supply Chain Strategies in the Information Age

Some uncertainty characteristics require supply chain strategies with initiatives and innovations that can provide a competitive edge to companies. These strategies can be classified into four types. Information technologies and the Internet have played an important role in shaping such strategies.

- **Efficient Supply Chains**—These are supply chains that utilize strategies aimed at creating the highest cost efficiencies in the supply chain. For such efficiencies to be achieved, non-value-added activities should be eliminated, scale economies should be pursued, optimization techniques should be deployed to get the best capacity utilization in production and distribution, and information linkages should be established to ensure the most efficient, accurate, and cost-effective transmission of information across the supply chain. The role of the Internet in this case is that it enables the supply chain to have tight and effortless information integration, as well as enabling production and distribution schedules to be optimized once the demand, inventory, and capacity information throughout the supply chain are made transparent.
- **Risk-Hedging Supply Chains**—These are supply chains that utilize strategies aimed at pooling and sharing resources in a supply chain so that the risks in supply disruption can also be shared. It is therefore a risk-hedging strategy. A single entity in a supply chain can be vulnerable to supply disruptions, but if there is more than one supply source or if alternative supply resources are available, then the risk of disruption would be reduced. A company may want to increase the safety stock of its key component to hedge against the risk of supply disruption, and by sharing the safety stock with other companies who also need this key component, the cost of maintaining this safety stock can be shared. Such inventory pooling strategies are quite common in retailing, where different retail stores or dealerships share inventory. Distributors such as Ingram-Micro have also provided similar pooling of inventory for their customers. The Internet plays a key role in providing information transparency among the members of the supply chain that are sharing inventory. Having real time information on inventory and demand allows the most cost-effective transshipment of goods from one site (with excess inventory) to another site (in need).

FIGURE 8. Matched Strategies

		Demand Uncertainty	
		Low (Functional Products)	High (Innovative Products)
Supply Uncertainty	Low (Stable Process)	Efficient supply chains	Responsive supply chains
	High (Evolving Process)	Risk-hedging supply chains	Agile supply chains

- **Responsive Supply Chains**—These are supply chains that utilize strategies aimed at being responsive and flexible to the changing and diverse needs of the customers. To be responsive, companies use build-to-order and mass customization processes as a means to meet the specific requirements of customers. The customization processes are designed to be flexible. Order accuracy (i.e., accurate specification of customer requirements) is the key to the success of mass customization. Again, the Internet has enabled very accurate and timely capturing of highly personalized requirements of customers as well as fast transfer of order information to the factory or customization centers for the final configuration of the product.
- **Agile Supply Chains**—These are supply chains that utilize strategies aimed at being responsive and flexible to customer needs, while the risks of supply shortages or disruptions are hedged by pooling inventory or other capacity resources. These supply chains essentially have strategies in place that combine the strengths of “hedged” and “responsive” supply chains. They are agile because they have the capability to be responsive to the changing, diverse, and unpredictable demands of customers on the front end, while minimizing the back-end risks of supply disruptions.

The Right Supply Chain Strategy to Match Product Uncertainty

Given the different nature of demand and supply uncertainties of different products, different supply chain strategies are needed for different products (see Figure 8).

Functional Products with Stable Supply Processes

When products have both low demand and supply uncertainties, the basis of competition is efficiency. There are two dimensions of efficiency—cost and information coordination. With predictable demand patterns and a stable supply process, companies should strive at improving supply chain efficiency so that the cost of providing the product to the customers is the lowest possible. This enables the company to gain a competitive advantage over competitors. Hence, these companies should aim at building “efficient supply chains.”

Cost efficiency can be gained by productivity improvements, which in turn are the result of basic elements of manufacturing excellence, such as just-in-time systems, automation, economies of scale, facility layout, and workflow streamlining. These are all basic tools that Japanese manufacturing companies such as Toyota have excelled in. The emphasis is on lean manufacturing to cut costs as much as possible. This is exactly how POSCO, a relatively young company in Korea, was able to become the world’s second largest steel manufacturer.¹⁰ As a functional product, the manufacturing process of steel is fairly mature and stable. POSCO focuses relentlessly on JIT techniques, total quality management, and building economies of scale at their two steel mills. The cost efficiency that POSCO was able to achieve surpasses most of the competition in the United States.

Cost efficiency can also be gained by having a highly effective logistics system. For products with stable demand, it is often possible to ship products directly from the manufacturing source to the customer without going through distribution centers. Eliminating steps in the distribution channel reduces costs. For examples, retail giants such as Wal-Mart and Costco have direct-to-store distribution processes for their stable, high-volume products. Shipping products with erratic demand directly to stores, however, can result in less-than-truckload shipments with small batches, so that transportation is no longer cost-effective.

Longs Drug Stores, recognizing the stable nature of most of their pharmaceutical products, has utilized a state-of-the-art scientific replenishment optimization software provided by Nonstop Solutions to plan the replenishments to their warehouses and stores. The resulting inventory savings of 40% enabled Longs to relieve enough capital to purchase 20 new stores.¹¹

Functional Products with Evolving Supply Processes

When supply processes are still evolving and therefore are faced with uncertainties regarding yield, process reliability, supply source, and lead-time, companies must find ways to prevent such uncertainties from ultimately affecting demand fulfillment. These companies should aim at establishing “risk-hedging” supply chains. Here is where inventory pools can be most effective. Such inventory stocking points decouple the supply chain so that the uncertainties of supply can be shielded. When the component with the evolving supply process

is of low value, then it is clearly worthwhile to stockpile the components so that the order fulfillment process will not be disrupted due to part shortages.

With an evolving supply process, companies may also need to develop multiple supply bases so that backup supply sources are available. The costs of managing the multiple supply bases may be higher, but the risk of supply outages can be reduced. The Internet can serve as a means for companies to have supply and demand information and thereby enhance the efficiency of inventory pooling.

The Internet can also be used to support risk-hedging supply chains. First, supply conditions can be shared quickly and accurately via the Internet, so that the downstream sites can use that information to plan accordingly. Second, the Internet enables a buyer to quickly identify alternative supply sources in the face of supply uncertainties. Third, the Internet, via market exchanges, can extend the reach of a typical buyer to suppliers from a global market. SeeCommerce, a new startup company based in Palo Alto, California, was instrumental in helping DaimlerChrysler's service parts division improve its service performance drastically by providing total visibility of its service supply chain.¹² Similarly, Instill Corporation, a major market exchange in the food service industry, helps risk-hedging food operators (such as Subway) significantly improve their efficiency.¹³ Market exchanges (such as Covisint in the automobile industry) help to expand the supply base of manufacturers, as well as to identify availabilities of scarce components.

Innovative Products with Stable Supply Processes

With highly unpredictable demand, excessive inventory may result. The cost of inventory for innovative products can be significant, since the product life cycles are short. Companies with such products should pursue strategies with a "responsive" supply chain. Rather than focusing on accurate forecasting and inventory planning, companies with a very stable process and product technology can make use of the concept of postponement to pursue aggressive build-to-order strategies.¹⁴ Dell Computer is a champion in this game. As long as PC manufacturers can design their products with highly modular structures—so that the final assembly and test steps can be simply and reliably performed and suppliers of key components can provide stable supplies—then companies such as Dell, Gateway, and others can engage in build-to-order processes to be highly responsive to customer orders. These companies often utilize the concept of a supplier hub, often close to the final assembly site, to ensure a stable and reliable supply of components.

The concept of postponement for innovative products is most applicable with reliable and stable supply bases. More than seven years ago, the HP PC division switched from the conventional build-to-forecast to configure-to-order (first by HP DCs, then by some channel members). They had to work on improving the modular designs to facilitate final assembly as well as on rationalizing their supply base to ensure close coordination with their suppliers for

reliable and timely supplies. About the same time frame, IBM started their channel assembly business in which selective channel members can configure products using IBM's "vanilla boxes," matched with different subassemblies from other manufacturers. In both cases, the same two ingredients are necessary: new products are designed for ease of assembly and test, and supply integration to ensure reliable and stable supplies of components and subassemblies.

The most celebrated example of a postponement strategy in the apparel industry is Benetton, in which the company redesigned their sweater manufacturing process from dye first, knit second, to knit first, then dye; thereby postponing the color destination of the product. Similarly, HP postponed their localization step for their Deskjet Printer (localizing the printer for different country needs) from the factory to distribution. The new processes may actually be more costly, but when product demand is unpredictable, pursuing a "responsive" supply chain strategy is more appropriate than a "cost-efficient" strategy.

The Internet has enabled companies to tap into a bigger supply base to ensure reliable supply of the products so as to be responsive. Solectron, the unprecedented two-time winner of the National Malcolm Baldrige Award, makes use of Agile Buyer (an Internet-based procurement software provided by Agile Software) to reach multiple suppliers and obtain price and availability quotes within a day or two. This drastically reduced their cycle time to support their customers' new product introduction process.¹⁵

Innovative Products with Evolving Supply Processes

Companies with innovative products and evolving and unstable supply processes have to utilize the combination of risk-hedging and responsive strategies. The appropriate strategy here is to establish "agile" supply chains.

Xilinx Inc., a fab-less semiconductor company specializing in high-end integrated circuits known as field-programmable logic, relies on such a strategy to compete successfully in the market place.¹⁶ High-end semiconductor chips are highly innovative products, often representing the first generation of the most powerful integrated circuits. Since they are pushing the frontier, the process technology used and process control methods required for the wafer fabrication process are very demanding and challenging. A highly sophisticated fabrication facility is needed. Xilinx has formed very tight partnerships with two such foundries, United Microelectronics Corporation in Taiwan and Seiko in Japan. Fabricated wafers are then stocked, forming a decoupling point known as die banks. As demand for specific chips is known through orders from customers such as Cisco, Dell, Motorola, HP, and Lucent Technologies, the final assembly and testing of the chips are carried out by other supply chain partners in Korea and the Philippines. Such a decoupling point strategy enables Xilinx to be responsive to the diverse and changing needs of their customers, who themselves are faced with highly unpredictable demand for their end products.

The latest innovation by Xilinx has been to create Internet-Reconfigurable-Logic (IRL). Xilinx products are field-programmable, i.e., some of the functionalities of their chips can be specified by software in the field, even after they have been delivered to the customer. In this age of rapid technological developments, some of the products in which Xilinx chips reside are going through constant product generation changes that would require the updating of the functionalities of the Xilinx chips. With IRL, the field-programming logic can be modified or updated after the installation at the end user's premises over networks and the Internet. These online field upgradable systems can range from multi-use set-top boxes and wireless telephone cellular base stations to communications satellites and network management systems. Since 1999, Xilinx has surpassed its competitors and is now the market leader for field-programmable logic.

Adaptec, another fab-less semiconductor company faced with both evolving supply processes and innovative products, also relied on advanced Internet-based solutions to exchange information and coordinate their production plans with their supply chain partners. Using software called Alliance developed by Extricity, the company communicates in real time with their foundry (Taiwan Semiconductor Manufacturing Company) and their assembly partners (Amkor, ASAT, and Seiko) with information such as detailed and complex design drawings, prototype plans, test results, and production and shipment schedules. This greatly facilitates their ability to be aware of demand and supply levels, and they can respond quickly to potential mismatch problems. It also helps to shorten their new product development times. With the use of Alliance, Adaptec's cycle time was cut by more than 50%.¹⁷

Realizing the tremendous uncertainties that it faces in both supply and demand, Cisco has embarked on a very ambitious project to create an e-Hub.¹⁸ The e-Hub will link multiple tiers of suppliers via the Internet, and it will coordinate supply and demand planning across the supply chain, using intelligent planning software provided by Manugistics. The e-Hub will also enable the identification of potential supply and demand problems early, with proper warning given to the appropriate parties and resolution actions taken promptly via the Internet.

Market exchanges in the high-tech sector, such as Converge and e2open, have to deal with the market uncertainties in both supply and demand. These exchanges have aimed at creating agile supply chains for their member companies.

Conclusion

Demand and supply uncertainties can be used as a framework to devise the right supply chain strategy. Innovative products with unpredictable demand and an evolving supply process face a major challenge. Because of shorter and shorter product life cycles, the pressure for dynamically adjusting and adapting

a company's supply chain strategy is mounting. Using the Internet to develop agile supply chains with information sharing, coordination, and postponement has enabled companies such as Xilinx and Adaptec to compete successfully in their market places. The challenges are great, but so are the opportunities.

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