Supply Chain Networks

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Introduction

> *Consider … the globe-trotting involved in manufacturing the Intel Pentium processor that powers a Dell computer. The process starts in Japan, where a single crystal is grown into a large ingot of silicon by Toshiba Ceramics. The silicon ingot is then sliced by suppliers, like Toshiba Ceramics or others, into thin wafers that are flown across the Pacific to one of Intel's semiconductor fabs in either Arizona or Oregon. At the fabs, hundreds of integrated circuits are etched and layered on each wafer, forming individual dies on the wafers. Finished wafers are packaged and then flown back across Pacific to Intel's Assembly and Test Operations in Malaysia. The wafers are treated and cut into dies, and the dies are finished into sealed ceramic "packages." The packages are then placed in substrate trays that are put into Intel's boxes and then packaged again in blank boxes (to conceal that they are Intel products) for shipment back across the Pacific to Intel warehouses in Arizona. Having traveled across the Pacific three times already, the chips are then shipped to Dell factories in Texas, Tennessee, Ireland, Brazil, Malaysia, and China, or one of its contract manufacturers in Taiwan, to be used as components in Dell computers.*
>
> Sheffi (2007, page 11)

This telling example nicely illustrates the typical challenges that modern supply chains face. The last decades have witnessed a radical movement from standalone, vertically integrated supply chains toward *networked* supply chains in which numerous suppliers belonging to several tiers in a network design, manufacture and assemble products for a few customers, who sometimes compete and sometimes cooperate. For instance, at the beginning of the twentieth century Ford revolutionized the manufacturing industry by mass-producing cars in enormous fabrication facilities. Until the middle of the century Ford generated electric power, internally procured iron ore and coal, which the company brought to Ford-owned steel mills using Ford-owned railroads and ships, and then made every part required for each automobile (Sheffi 2007, page 78). In stark contrast, now even a copper wire in a small electric power motor of a GM car starts in the copper mines of Chile, then travels to wire makers in China, then continues on to motor makers in Japan or car-door makers in Canada, then to final assembly in the U.S., before it finishes in the worldwide network of GM's 7,500 distribution dealers (Sheffi 2007, page 27).

Flows of information and money through the network are as vital as flows of products themselves. Information conveys demand all the way from customers to manufacturers, and it also helps partners in the supply chain communicate orders, invoices and payments. The complexity of supply chain networks often results in intricate flows of information and payment. For example, the “Big Three” U.S. automakers created the world’s largest virtual marketplace, Covisint, which has connected the three virtually through the Internet with thousands of suppliers. Through this business-to-business exchange, all companies have been able to communicate using a common language and make payments without investing in expensive electronic data interchange, or EDI, systems (Koudal et al. 2003). In other industries, such as apparel, a large retailer may want to help its suppliers procure raw materials because it already enjoys economies of scale and more favorable payment terms with raw material suppliers.

This radical transformation from vertically integrated local supply chains to highly decentralized global supply chain networks has been fueled by the emergence of low-cost outsourcing options in Brazil, Russia, India and China (BRIC) and other countries, and by advances in information technology, as well as by the ever-growing complexity of end products. If organized properly, these networks can enable the creation of superior products at the lowest possible cost while ensuring speedy delivery to the consumer. However, to realize these benefits, a number of new challenges need to be addressed. Among these challenges is the fact that longer supply chains complicate information sharing and demand forecasting and require more inventory; that contractual relationships with suppliers need to be intertwined with other relationships built purely on trust and long-term interactions; that concerns about supply chain disruptions call for preemptive strategies, etc. For this reason, Iansiti and Levien (2004) call such networks “business ecosystems” in which every member’s fate is tied to the health of the network as a whole. Thus, each company needs to keep an eye on the financial health of each customer, supplier and business partner in its ecosystem. The recent wave of supplier bankruptcies in the automotive industry illustrates the consequences for the manufacturer of financial instability within the supplier network, including parts shortages and production cost overruns (Swinney and Netessine 2007). Thirty-six major automotive suppliers entered bankruptcy since 1999, citing as the primary culprits production cost increases, unstable domestic volume, legacy pension plans (resulting in greater overhead expenses), and difficult access to capital. These events clearly demonstrate the problems arising from a failure to adopt a network perspective. For example, fluctuations in raw material prices affect supplier profitability if contract prices are predetermined and do not include provisions for material price increases. On the other hand, manufacturers’ unwillingness to adjust contracts to accommodate raw material price increases often leads to supplier bankruptcy which, in its turn, hurts the manufacturer that must scramble to keep parts flowing. In 2005 Lear, a key seat supplier to Chrysler, attempted to negotiate higher prices to cover recent sharp cost increases that plagued the automotive supplier base. When Lear threatened to cease shipping products to Chrysler, the automaker promptly took the supplier to court to enforce the terms of their contract, despite the fact that Lear posted a net loss of nearly $600 million in the fourth quarter of 2005 alone (Wernle 2006).

Little is currently known about ways to achieve control and coordination in supply chain networks. Much academic literature focuses on the control and coordination of simple supply chains, with conclusions frequently based on results gathered from considering one upstream and one downstream company (see Cachon 2005). At the same time, through trial and error, best-in-class companies manage to achieve superior performance while many others stumble, falling prey to disruptions, parts shortages, and poor coordination among both customers and suppliers.

Such supply network disruptions are extremely costly: empirical evidence indicates (see Figure 1) that firms experiencing a supply chain glitch lose approximately 100% in operating income, return on sales, and return on assets relative to control firms that do not experience a disruption. Moreover, during the two-year period after the glitch is announced, operating income, sales, total costs, and inventories do not improve (Hendricks and Singhal 2005). In this study a large portion of supply chain glitches arise due to factors outside of the firm (e.g., related to suppliers or customers).

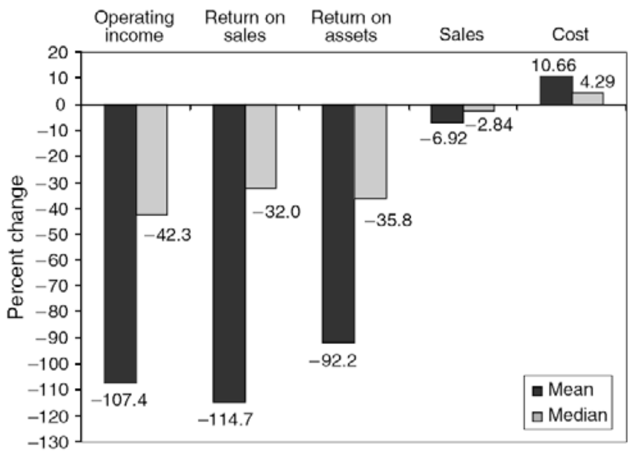

Figure 1. Change in control-adjusted operating performance of firms during the year before the announcement of a supply chain glitch (Hendricks and Singhal 2005)

To summarize, competition between companies has turned into competition between supply chain networks, resulting in a situation whereby one must carefully orchestrate every aspect of moving materials, information and payments within one's own supply chain network. In what follows, I will first provide brief case studies illustrating approaches that companies in the automotive and the aerospace and defense industries are using. I will then conclude with a review of emerging academic literature on supply chain networks.

The Automotive Industry

The automotive industry represents an interesting case of competition gone global; see Figure 2.[1] The "Big Three" U.S. automakers (GM, Ford and Chrysler) have faced rising pressure from overseas competitors in the last two decades. Japanese, South Korean and European automakers have successfully entered the U.S. market and captured a significant and increasing market share by offering more reliable, better-designed and sometimes cheaper cars. The intense competition has led to significant improvements in U.S. vehicle quality and reliability. Nevertheless, the combined market share of the Big Three manufacturers continues to slide, from 62.2% in 1997 to below 50% in 2007. Since most components of vehicle manufacturing are outsourced to suppliers (which is true for both U.S. and foreign companies), the success and failure of automakers are largely driven by their ability to orchestrate complex supplier networks, representing a case of network-to-network competition in its purest form.

[1] Much of this section is based on Koudal et al. (2003).

Automotive supplier networks are extremely complex and often cross many international borders. The product delivery cycle in the industry starts with long product development and planning cycles, then continues to complex manufacturing processes, and ends with enormous dealer networks. These complex supply chains must be able to handle millions of possible car configurations and options, to respond to sudden shifts in demand as well as supply, and to coordinate procurement and production across many countries. For example, in 2000 General Motors was challenged with handling multiple brands, 150 Web sites, 63 call centers and 23 databases. This led to difficulties in cross-selling, up-selling and maintaining consumer loyalty. Furthermore, smaller suppliers often could not afford to invest in sophisticated EDI systems and often relied on inefficient manual communication channels. These and other problems with communication led to product development cycles lasting over four years and unreliable fulfillment lead times, often up to three months.

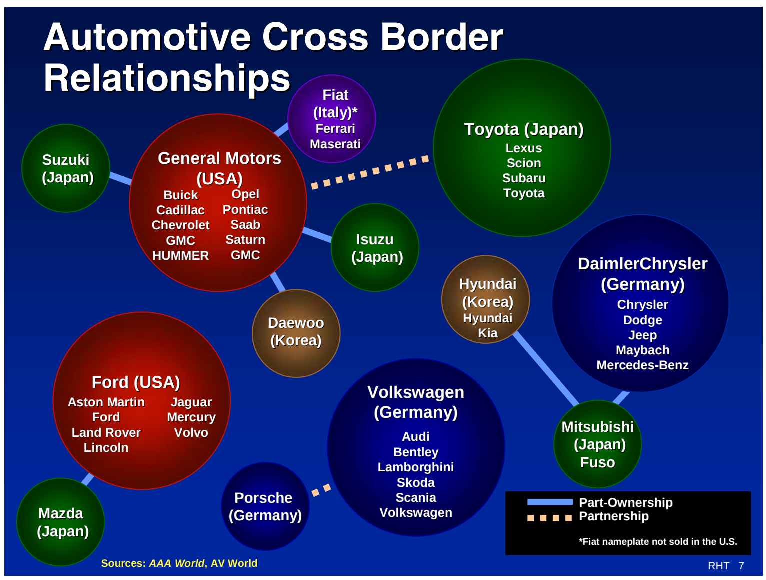

Figure 2. Global relationships in the automotive industry (from Trice 2006)

Interestingly, the success of Japanese automotive companies relative to U.S. companies is often attributed to drastically different approaches to managing supplier networks (see Liker and Choi 2004). U.S. companies often keep their relationships with suppliers at arm's-length, asking them to bid against each other every year and then selecting on the basis of lowest cost. As a result, the relationships between U.S. automotive manufacturers and their suppliers are often adversarial, built on myriad contingencies written into the contract, and rife with accusations. It is not uncommon, for example, for a manufacturer to demand significant price decreases regardless of suppliers' financial state and business realities. Ford famously demanded an across-the-board 5% price decrease from its suppliers (see Swinney and Netessine 2007). In contrast, Japanese companies operate under the concept of *keiretsu*: a network of closely related vendors that continuously improve, exchange information and learn together. For a long time the success of Japanese supplier networks was dismissed on the grounds of its being a phenomenon local to Japan and hence impossible to emulate outside of Japanese culture. However, over the last decade Japanese automotive manufacturers shifted a significant part of their production volume to the U.S., with Toyota and Honda locally manufacturing and sourcing, respectively, 60% and 80% of their vehicles sold in the U.S. Very often these two companies made highly successful partnerships with the same firms that supplied the Big Three U.S. manufacturers, and these same suppliers raved about their relationships with Japanese companies while decrying their experiences with U.S. companies. These same adversarial suppliers to GM described above are now a part of a North American *keiretsu* network, providing fast product development times, reducing costs and improving quality for Japanese companies. While it is as hard to replicate *keiretsu* as the Toyota production system itself, the following fundamental principles seem to underpin *keiretsu* relationships.

Toyota tries to learn every part of its suppliers' business and commits to their prosperity. This usually involves placing a manager in the potential supplier's working environment and investing in data collection and information sharing for a long period (e.g., a year) before committing to using that supplier. Then, a small order is placed and the supplier's quality and compliance with the schedule is observed. If necessary, the manufacturer shares its own expertise in productivity and quality. Successful handling of an order leads to more orders as well as to more serious assignments. Throughout this process, the supplier is assured of a comfortable profit margin, because the manufacturer understands the supplier's cost structure as well as the supplier does. Suppliers also understand that the Japanese company will contribute to improving all processes at the supplier's location by sharing its expertise and knowledge.

Toyota maintains joint ventures and stakes in suppliers to share their pains and gains. If an additional supplier is needed, Japanese companies will often set up a joint venture with an existing supplier, or between a U.S. and a Japanese supplier. Doing so makes the manufacturer interested in the financial health of its suppliers and encourages competition without bringing in too many outside firms.

Toyota develops suppliers' technical and innovation capabilities by exchanging best practices and conducting joint improvement activities through study groups. Toyota and Honda often do not specify exact requirements for the parts they order. The supplier should be innovative and capable enough to figure out what is needed through close collaboration with the manufacturer. Such an approach stimulates innovation on the supplier side and transforms the supplier into an active participant in the design process rather than a mere provider of "widgets." It is a tradition to have "guest engineers" visiting each other's companies for a year or two at a time. Such an approach requires sharing information through well-structured meetings. However, Japanese manufacturers are very selective with regard to which parts are designed entirely by suppliers and which parts must be designed on the manufacturer's premises. For example, parts that are quite independent of the rest of the car can be designed independently by the supplier, but parts that interface with the body of the vehicle must be designed in close collaboration with the manufacturer.

The firm supervises and benchmarks suppliers by providing constant feedback and involving top management in problem solving. Both Honda and Toyota send monthly scorecards to their suppliers that rate each on quality, delivery, performance, incidents, etc., whereas U.S. manufacturers assess their networks annually or at best biannually. While many top managers at U.S. suppliers do not like to get involved in the mundane details of production and delivery schedules, Japanese automakers always involve suppliers' top executives and make them aware of problems caused by their actions.

Finally, Japanese automotive companies tend to multi-source by working with two or three suppliers for every subsystem in order to maintain competition and enable contingency planning. Although the supplier is usually assured some part of the business for the entire life of the model, the total volume can fluctuate based on comparative performance with other suppliers. This ensures that the rivalry still exists but that it does not harm the supplier. Just two or three suppliers are sufficient to avoid excessive transaction costs. Moreover, when a supplier for a new model or new part is needed, priority is usually given to existing suppliers with a verifiable track record.

While the steps outlined above are intuitively appealing and easy to understand, U.S. automotive manufacturers have struggled to emulate similar approaches. Chrysler has made great progress in this direction, but the process stalled after the merger with Daimler. Meanwhile, both Honda and Toyota continue to develop their supplier networks, which grow and improve as the manufacturers themselves advance. Their example seems to indicate that extensive supplier networks can be managed by the manufacturer on a global basis, although new challenges arising in such networks are unique and require novel approaches.

The Aerospace and Defense Industry

Ever-increasing product complexity and constant innovation are best reflected in the aerospace and defense industry, where companies are faced with the uncertainties inherent in multiyear, multibillion-dollar new product development projects. Because a typical product is so expensive to develop, the average lifecycle of a product is relatively long (an airplane, for example, might be in active use for 25 years or longer) and therefore supply chain costs associated with delivering and maintaining these products are extremely important. Major players in the industry have a truly global presence and provide support to their equipment in most countries throughout the world, either directly or through a network of subcontractors. For example, Airbus Industries[2] has 57,000 employees in 160 offices and 16 production sites worldwide. Its supply chain operates through three customer support centers (in France, the U.S. and China), four training centers (in France, Germany, the U.S., and China), five spare-parts centers (in France, Germany, the U.S., Singapore and China), and 1,500 suppliers in 30 countries.

Technology is paramount to managing such a complex global supply chain. For example, Airbus manages its network of suppliers through several Internet portals. Airbussupply.com provides suppliers with the latest news, projects and tools, and helps them to manage their performance and to exchange product information. AirbusSupply.com covers procurement, the supply chain, product development, engineering, aircraft programs and customer support. Esourcing.airbus.com allows buyers and suppliers to exchange online requirements and proposals during calls for tender and reverse auctions. This paperless process, which covers everything from identifying a potential supplier to developing the final contract, ensures secure information exchanges and fairness among suppliers. Suppliers have the opportunity to inform

[2] This material is based on information from Airbus.com.

Airbus buyers about their capabilities through a self-registration process. Airbussupply.com facilitates ordering any goods and services from existing suppliers through a harmonized and automated ordering process across all Airbus entities from the initial request to payment approval, and it covers the whole supply chain cycle, from initial requests to suppliers all the way to invoicing, including dispatch, transport, receiving and storage of goods through an integrated, collaborative workplace. Finally, for personnel who work with the end product, there is Airbusworld.com, a portal for Airbus aircraft operators, flight crews, maintenance personnel, and service providers, as well as for airline industry professionals.

Another example of leveraging technology to manage complex products at Airbus is the implementation of RFID (radio-frequency identification) tags. While it is often hard to justify using RFID in retail and other industries due to the high cost of tags relative to the product's value, the great value of the products in the aerospace and defense industry makes implementation feasible. Airbus pioneered the use of RFID technology in aircraft tool management in 1999, enabling identification of each tool with a microchip for radio frequency identification, offering electronic support when tools are lent or used in repairs. The microchips are installed in the tools as well as in the toolboxes and contain data about the history of the tool, as well as shipping, routing and customs information. In case of product failure, the availability of this ground-breaking technology on aircraft spare parts helps to simplify inventory and repair management of the spare parts. One of the major benefits of this new technology for the airlines is simpler management of component repairs whereby the repair and flight history of the component becomes available electronically, and the company within the supply chain that is in possession of the needed expertise can be identified immediately. The microchip ensures the availability and accuracy of vital information and documentation and also feeds information into a comprehensive tracking system.

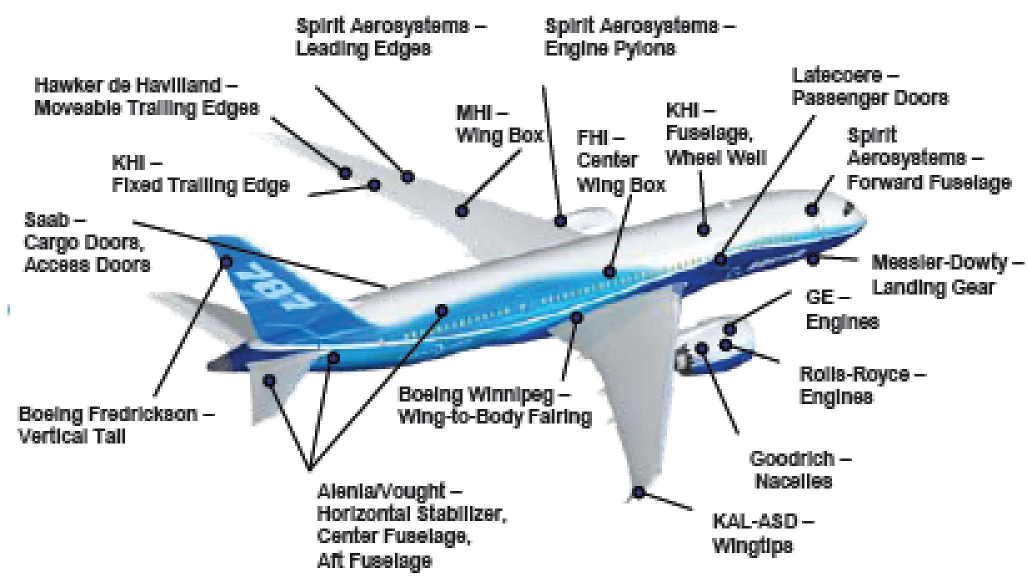

Figure 3. Major suppliers for the Boeing 787 (from Georgevitch 2007)

Another interesting example of managing a comprehensive network of suppliers comes from Boeing, Airbus's key U.S.-based competitor. The Boeing 787, or Dreamliner, is a family of new, fuel-efficient airplanes that have used advanced carbon-fiber composite materials to achieve an unprecedented 20% improvement in fuel efficiency as well as point-to-point service nearly everywhere in the world. The first aircraft off the production line was promised to All Nippon Airways as early as in 2008, but at this point the actual date is likely to be 2009. For previous Boeing models, the company designed all major components but outsourced production to suppliers and performed only the final assembly of all parts and pieces. However, such an approach often resulted in schedule disruptions due to missed deadlines by suppliers, capacity shortages, and conflicts among suppliers. Additionally, the new 787 jet has presented unique challenges due to the radical transformation of materials used and Boeing's ambitious goals with respect to efficiency and passenger comfort. Thus, Boeing took a decidedly different approach to manage the extensive network of suppliers involved in the making of the 787 (see Figure 3).

First, the company's suppliers now have unprecedented responsibility for designing and delivering major portions of the aircraft. Instead of working out design details, Boeing delegated this task to suppliers who would now design, manufacture and validate parts, then communicate with other suppliers, assemble parts into subassemblies and deliver them to Boeing's final assembly facility in Everett, Washington. This approach permitted the concurrent rather than serial development of various components of the aircraft, which shortened the development cycle and therefore allowed for the latest technologies to be delivered to the market sooner. Forty-three top-tier suppliers helped Boeing to finalize the airplane's configuration in September 2005. Moreover, if previously Boeing had to handle the enormous task of assembling and testing even minor pieces of the airplane while obtaining information from scores of suppliers regarding the best way to do so, now suppliers performed these tasks while directly communicating with each other. This monumental shift also implied that suppliers, who often never communicated with each other before, now had to coordinate delivery schedules and purchase order requirements directly with one another. Such communication and coordination required real-time visibility throughout the entire global supply chain, which was achieved through Exostar's Supply Chain Management Solution powered by E2open software. Currently, the software virtually links 135 sites across 12 countries located on five continents.[3] However, only 11 major subassemblies will be delivered to Everett, Washington, for final assembly.

Second, Boeing implemented advanced sourcing for key raw materials. In the past, the entire manufacturing process could be halted because of shortages in some materials necessary to manufacture parts. Due to extensive usage of new composite materials (50% of the 787's structure is composite, 20% is aluminum and 15% is titanium, whereas 80% of the 777's structure is aluminum and 10% is composite materials), this problem could become even more destructive. In fact, only a single supplier, Toray, was qualified to supply the key composite material. To avoid raw material shortages, Boeing coordinated capacity development with Toray. This involved tracking closely the aggregate demand across all suppliers but still allowed individual suppliers to negotiate directly with Toray, because composite materials are usually specific to certain uses or to a single producer (Stundza 2007).

[3] Source: http://www.boeing.com.

Third, to minimize disruptions in the production process and work-in-process inventory, Boeing streamlined the manufacturing process by reducing variability in parts content. For example, all options and features were standardized, and variations were postponed as late in the production process as possible (i.e., to the final assembly stage).

Fourth, the company created a framework for managing the supply network over the product lifecycle. For example, early in the production process, when the Dreamliner faces the highest uncertainties in demand and supply, supply chain management processes have been focused on achieving flexibility to serve fluctuating demand. Later in the product lifecycle, when demand matures and achieves high volumes, the supply chain will focus on cost efficiencies. Finally, during the phase-out stage, which is again rife with uncertainties regarding demand, supply chain management will aim to avoid excessive inventories through asset flexibility (Georgevitch 2007).

Although Boeing achieved certain successes with its new approach to managing supply chain networks, numerous problems surfaced in the late stages of the project. In late 2007, the company was struggling to overcome a six months' delay in production due to the "global outsourcing" of development and production to suppliers (see Lunsford 2007), which led to tens of thousands of parts missing at the time of assembly. The reason was that Boeing seems to have overestimated the ability of its suppliers to handle many tasks that Boeing used to handle internally. Furthermore, the company did not commit sufficient resources to overseeing suppliers and hence was often ill-informed about progress. This example illustrates nicely why Toyota pays so much attention to the inside workings of its suppliers. To overcome this issue Boeing deployed hundreds of its own employees to plants in Italy, Japan and the U.S. and set aside about $2 billion in additional money for increasing costs due to delays. While there is little doubt among Boeing's leaders that the global sourcing approach is viable (and Airbus has said that it plans to use the same approach to build a competing plane), these costs probably could have been avoided had Boeing begun with a more network-based perspective on the entire process.

Research on Managing Supplier Networks

The above case studies clearly demonstrate that global supply chain networks are emerging as the preferred form of fulfilling customer needs in the age of globalization. However, the academic literature on supply chain management has been slow to react to these advances. The main difficulty lies in the methodological challenges of modeling the multifaceted relationships that exist in contemporary supply chains. Although current literature recognizes the need to study contractual relations between buyers and suppliers (see Cachon 2003) and competition/cooperation in supply chains (see Cachon and Netessine 2004), most of the voluminous supply chain literature still focuses on monopolistic situations. For example, extensive supplier networks are key to maintaining and repairing complex equipment such as airplanes or weapons systems, but much of the literature on this topic has focused on a centrally managed supply chain (see Muckstadt 2005), and more developed models that take into consideration contracting aspects in such supply chains are only beginning to emerge (Kim et al. 2007). But even papers that do study decentralized decision making tend to focus on competition rather than cooperation while limiting analysis to bilateral rather than to multilateral relationships. For example, there is an impressive body of literature on competitive bidding in auctions (see, e.g., Klemperer 2004) but little is known about when a more cooperative supplier selection process might be preferable. The major exception is the empirical work of Bajari et al. (2006), which shows that there are important limitations to competitive bidding and that contract negotiations might work better when projects are complex, contractual design is incomplete, and there are few potential bidders. Moreover, auctions tend to stifle communication between buyers and sellers, which more or less nullifies the contractor's expertise during the project design stage. This finding is consistent with the examples above, clearly indicating that successful management of supply chain networks involves significant collaboration and information sharing among network members, with technology playing an important role as mediator.

Since the above discussion indicates that some of the best supplier networks are managed through cooperation rather than competition, it appears that the preferred methodology for studying supply chain networks should incorporate elements of cooperative game theory. Brandenburger and Nalebuff (1997) provide a number of fascinating examples indicating that companies often both compete and cooperate to achieve sustainable advantages. Nagarajan and Sosic (2007) provide a comprehensive overview of the recent literature, subdividing this literature into models for negotiation (e.g., bargaining models, cooperative bargaining and negotiation power) and coalition formation/coalition structures (profit allocation rules, structure of the core of the game). Research in this area is very scant, and the focus of this work is on studying ways to share gains from cooperative supply chain management (e.g., Anupindi et al. 1999, Granot and Sosic 2005, Nagarajan and Sosic 2006) and how the supply chain can be made secure through joint investment by several parties (Bakshi and Kleindorfer 2007).

There is very limited literature on how the entry and exit of firms into various echelons of the supply chain affect the entire network. Corbett and Karmarkar (2001) examine the impact of fixed and variable costs on the structure and competitiveness of supply chains with a serial structure and price-sensitive linear deterministic demand and then characterize the viability and stability of supply-chain structures. Majumder and Srinivasan (2006) study multistage serial supply chains with price-dependent deterministic demand and increasing marginal costs. They analyze cooperation and the implications of leader location in uncoordinated chains. Their results demonstrate the importance of considering the entire sequence of successive contracts when assessing the performance of a supply chain, and they also find that in some cases an inefficient supply chain may tend naturally to reduce inefficiency through cooperation among non-leader members. Majumder and Srinivasan (2005) develop a framework to analyze large supply chain networks involving long sequences of contracts and show that contract leadership and leader position affect the performance of the entire supply chain. They model competition between supply chain networks and show the effect of changes in leader position as well as changes in the cost structure on the equilibrium of the network.

Examples in this article illustrate the important role that the latest technology plays in managing global supply chain networks. For example, the Retail Link system introduced by Wal-Mart to deliver real-time sales information to its suppliers has played a critical role in the company's ability to orchestrate a complex supply chain network and has led to the company's dramatic success. A special issue of *Information Systems Research* on The Digitally Enabled Extended Enterprise in a Global Economy (Krishnan et al. 2007) sheds light on some issues surrounding the use of information technology. For example, Malhotra, Gosain and El Sawy (2007) investigate the relationship between the use of standard electronic business interfaces (SEBIs) and the adaptive capability of supply chain partnerships, and find empirical support for conceptualizing SEBIs as the mechanism to enable adaptive capability. Bala and Venkatesh (2007) investigate how a firm's role in its supply chain explains differences in the extent to which firms participating in RosettaNet (which allows trading partners of all sizes to connect electronically to process transactions and move information within their extended supply chains) adopted consortium-developed inter-organizational business process standards. Wu and Kleindorfer (2005) survey literature on B2B exchanges, while specifically focusing on supply chain contracting in competitive environments arising in capital-intensive industries such as chemicals, electric power, metals, natural gas, plastics and semiconductors. Steffenson-McElheran (2008) further demonstrates empirically that manufacturing plants that exhibit leading productivity indicators are more likely to adopt e-buying technologies but not necessarily e-selling technologies.

It appears difficult, if not impossible, to reflect in a model many issues that challenge contemporary supply chain networks. For example, Sheffi (2007) illustrates many challenges posed by managing complex supply chain networks due to the possibility of disruptions and security breaches anywhere in the network and emphasizes that public-private collaborations provide one possible solution for securing the network. Such solutions are hard to model properly, so it might be more instrumental to apply other approaches including empirical and field studies to their analysis. Vereecke et al. (2006) represent one such study in which the authors use network analysis to understand the position of plants in international manufacturing networks. See Vereecke et al. (2006) for a literature survey on the network approaches to facility location. This analysis demonstrates that different types of plants play different strategic roles in a company, each having a different focus and differing in age, autonomy, and level of resources and investments. However, as Nohria (1992, p. 8) indicates, "if we are to take a network perspective seriously, it means adopting a different intellectual lens and discipline, gathering different kinds of data, learning new analytical and methodological techniques, and seeking explanations that are quite different from conventional ones." This observation is likely to hold true as we learn more about supply chain networks. One other potentially attractive approach might be the empirical game theoretic analysis which is aimed at designing simulations of strategic interactions among multiple agents. See Wellman et al. (2005) and Argoneto et al. (2007). Such an approach helps to overcome the issue of analytical tractability which otherwise makes analyzing such networks all but impossible. At the same time, it might allow us to obtain insights into supply chain networks with numerous self-interested agents that compete or cooperate.

Conclusion

At this point we know very little about what works and what does not in supply network management. Knowledge advances slowly for at least two reasons. First, traditional analytical approaches to modeling supply chains seem to falter when representing complex supply chain networks. Second, data analysis is handicapped by the necessity to collect independent information from multiple companies. Clearly, the challenges are likely to differ greatly between managing a hub-and-spoke network with a central orchestrator such as Toyota, Airbus or Boeing and managing a much more decentralized network like that of Li & Fung (Wind et al. 2008). The hub-and-spoke network has a relatively stable configuration, whereas the decentralized network has the advantage of being reconfigurable and adaptable to an ever-changing environment. But in either case technologies such as ERP systems, EDI and Web-based B2B management tools are likely to play an ever-increasing role in our ability to manage and develop supply chain networks. Furthermore, growing pressure on businesses to focus on environmental issues has led to the emergence of sustainable operations management (Kleindorfer et al. 2005) as a new paradigm. Thus, we can expect to see integration between *forward* networks, or supply chain networks designed to deliver products to customers, and *reverse* networks that maximize product recovery potential over the lifecycle.

It is safe to say that right now the world of supply chain management is changing and we are at the earliest stages of this change. Powerful global forces continue to drive the creation of supply chain networks to enable division of labor through outsourcing, to explore cross-country cost differentials, or simply for historical/political reasons. No matter what drives the creation of a network, we can say with great certainty that supply chain management is entering the era of competition among networks rather than at the chain level. The danger is that the creation of many supply networks is driven by forces outside of the company, so it becomes possible that old tools inherited from the time when supply chains were much simpler will be applied to new business realities. While successful supply chain network orchestration is still much more of an art than a science, it is obvious that thinking incorrectly about supply chain management can be very costly (Hendricks and Singhal 2005). Amaral et al. (2006) describe numerous hazards that can arise in the outsourcing relationship, and they subdivide these hazards into planning, executing and managing physical, informational and financial activities. Finally, it is important to remember that supply chain networks employed by different companies often exhibit a high degree of interdependence, and they compete with each other. For example, Sheffi (2007) describes how different responses by Nokia and Ericsson to a supply chain disruption at their common supplier Philips led to a 3% market-share shift from Ericsson to Nokia. In summary, there is ample evidence that supply chain network management involves more than just showing up with a checkbook. The reality is that adopting vigilant network-based approaches is crucial.

References

Amaral, J., C. A. Billington and A.A. Tsay. 2006. Safeguarding the promise of production outsourcing. *Interfaces* 36, 220-233.

Anupindi, R., Y. Bassok and E. Zemel. 1999. A general framework for the study of decentralized distribution systems. *Manufacturing and Service Operations Management* 3, 349-368.

Argoneto, P., M. Bruccoleri, G. L. Nigro, G. Perrone and P. Renna. 2007. Production planning, negotiation and coalition: The advanced keys for B2B success. Working paper, University of Palermo, Italy.

Bajari, P., R. McMillan and S. Tadelis. 2006. Auction versus negotiations in procurement: An empirical analysis. Working paper, University of Minnesota.

Bakshi, N. and P. Kleindorfer. 2007. Co-Opetition and investment for resilience in global supply chains. Working paper, University of Pennsylvania.

Bala H. and V. Venkatesh. 2007. Assimilation of interorganizational business process standards. *Information Systems Research* 18, 340–362.
Brandenburger A. M. and B. J. Nalebuff, 1997. Co-Opetition: A revolutionary mindset that combines competition and cooperation. New York: Doubleday.
Cachon, G. P. 2003. Supply chain coordination with contracts. In *Handbooks in operations research and management science: supply chain management*. Edited by S. Graves and T. de Kok. New York: North Holland.
Cachon, G. and S. Netessine. 2004. Game theory in supply chain analysis. In *Handbook of Quantitative Supply Chain Analysis: Modeling in the eBusiness Era*. Edited by D. Simchi-Levi, S. D. Wu and Z.-J. Shen. Kluwer.
Corbett, C. and U. Karmarkar. 2001. Competition and structure in serial supply chains with deterministic demand. *Management Science* 47, 966–978.
Georgevitch, S. 2007. 787 Dreamliner: Business model & supply chain overview. Presentation on March 15, 2007 at the Air Force Logistics Transformation Forum. http://www.dla.mil/j-6/AIT/Conferences/AirForce_Log_Trans_Forum/default.aspx .
Granot, D. and G. Sosic. 2005. Formation of alliances in Internet-based supply exchanges. *Management Science* 51, 92-105.
Hendricks, K. and V. Singhal. 2005. Association between supply chain glitches and operating performance. *Management Science* 51, 695-711.
Iansiti, M. and R. Levien. 2004. *The keystone advantage*. Harvard Business School Press.
Kim, S.-H., M. Cohen and S. Netessine. 2007. Performance contracting in after-sales service supply chains. *Management Science* 53, 1843-1858.
Kleindorfer, P. R., K. Singhal and L. N. Van Wassenhove. 2005. Sustainable operations management. *Production and Operations Management* 14, 482-492.
Klemperer, P. 2004. *Auctions: Theory and practice*. Princeton University Press.
Koudal, P., H. Lee, B. Peleg, P. Rajwat and R. Tully. 2003. General Motors: Building a digital loyalty network through demand and supply integration. Stanford Graduate School of Business Case GS-29.
Krishnan, M. S., A. Rai and R. Zmud. 2007. Editorial overview: the digitally enabled extended enterprise in a global economy. *Information Systems Research*, 18, 233-236.
Liker, J. K., and T.Y. Choi. 2004. Building deep supplier relationships. *Harvard Business Review*, 82, 104-113.
Lunsford, J. L. 2007. Boeing scrambles to repair problems with new plane. *The Wall Street Journal*, December 7, A1.
Majumder, P. and A. Srinivasan. 2005. Asset-specific supply tree competition and leadership. Working paper, Duke University.
Majumder, P. and A. Srinivasan. 2006. Leader location, cooperation and coordination in serial supply chains. Forthcoming in *Production and Operations Management*.
Malhotra, A., S. Gosain and O. A. El Sawy. 2007. Leveraging standard electronic business interfaces to enable adaptive supply chain partnerships. *Information Systems Research* 18, 260–279.
Muckstadt, J. A. 2005. *Analysis and Algorithms for Service Parts Supply Chains*. Springer.
Nagarajan, M. and G. Sosic. 2006. Coalition stability in assembly models. Working paper, University of Southern California.

Nagarajan, M. and G. Sosic. 2007. Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. Forthcoming in *European Journal of Operational Research*.
Nohria, N. 1992. Is a network perspective a useful way of studying organizations? In N. Nohria, R. G. Eccles, editors, *Networks and Organizations*. Harvard Business School Press, Boston, MA, 1-22.
Sheffi, Y. 2007. *The resilient enterprise: Overcoming vulnerability for competitive advantage*. The MIT Press.
Steffenson-McElheran, K. 2008. Productivity leadership and strategic investments in innovation: The adoption of e-business capabilities. Working paper, Northwestern University.
Stundza, T. 2007. Composites bring Boeing's buyers, engineers and parts suppliers closer. *Purchasing Magazine Online*, March 1.
Swinney R. and S. Netessine. 2007. Long-term contracts under the threat of supplier default. Forthcoming in *Manufacturing and Services Operations Management.*
Trice, R. H. 2006. Trade and the defense industrial base. Presentation, Israel Aerospace Conference.
Vereecke, A., R. Van Dierdonck and A. De Meyer. 2006. A typology of plants in global manufacturing networks. *Management Science* 52, 1737-1750.
Wellman, M.P., J. J. Estelle, S. Singh, Y. Vorobeychik, C. Kiekintveld and V. Soni. 2005. Strategic interactions in a supply chain game. *Computational Intelligence* 21, 1-26.
Wernle, B. 2006. Suppliers in "shambles," so why's Ross buying? *Automotive News* 80.6199, 28.
Wind. J., V. Fung and W. Fung. 2008. Network orchestration: Core competency for a borderless world. Chapter 17 in P. Kleindorfer and J. Wind, *Network-Based Strategies and Competencies*.
Wu, D.J. and P. Kleindorfer. 2005. Competitive options, supply contracting, and electronic markets. *Management Science* 51, 452-466.