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Editorial

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From the Editors

Supply chains within the context of business and economic systems, become conspicuous by the interconnectivity of suppliers, manufacturers, and consumers. When we introduce the concept of flexibility into this complex web, we are immersed further into the practical realities of commerce in the global, technology-driven 21st century. It is our pleasure to present some views of flexible supply chains.

Many have noted that the only constant is change. Flexibility is mandatory if one is to survive and thrive in an ever-changing competitive environment. Within the supply chain, there are so many variables – suppliers, inventory costs, inventory levels, transportation, distribution channels – and so many ways in which these variables can be affected by external forces –bankruptcy filings, dock worker strikes, natural disasters. In academia, we have used terms like agile and lean to describe organizational approaches to responses. In truth, flexibility is more proactive than reactive. Flexibility involves reactions, but flexibility is a means to achieving the reactions quickly.

We have searched for ways to define and measure flexibility. Research has examined volume flexibility, product flexibility, process flexibility, and routing flexibility, among others. Some have offered quantitative measures of these various components of flexibility. In truth, flexible supply chains are an extension of flexible business systems and flexibility allows businesses to match supply with demand in a fast responsive manner. The higher the flexibility, the faster is the response to changes. Over time, we have recognized the strategic value of the supply chain as a component of the enterprise. We have also realized the necessity of flexibility throughout the firm.

In 2000, Bowersox, Closs, and Stank offered a view of ten mega trends that they believed would revolutionize supply chain logistics. Among those trends are moves from a functional perspective to process integration, from vertical to virtual integration, and from information hoarding to information sharing. Each of these impacts the flexibility of a supply chain. In "*Supply Chain Flexibility: Building a New Model,*" the authors describe a move from a focus on functional flexibilities to an integrated view of supply chain flexibility. This shift in focus has implications for outsourcing (virtual integration) and information sharing. We believe this shift marks an important change in the examination and study of flexible supply chains.

Tiger and Simpson present results from a real-world simulation model to improve shipping from the US to the Asia - Pacific region. The simulation model allowed more flexibility in shipping options, reducing costs and improving performance. This paper reminds us that we need to use all the tools at our disposal to improve the flexibility of our supply chains.

Christiansen, Rohde, and Hald examine quick response systems within the context of varying levels of interorganizational communication. The case studies they present offer insights into ways in which interorganizational communication can affect supply chain flexibility.

Finally, Mikkola and Skjøtt-Larsen remind us of the supply chain flexibilities afforded by including suppliers early in the product development cycle. They use case studies of three European firms to highlight key considerations of early supplier involvement.

It has been a privilege to serve as co-editors for this special issue of the *Global Journal of Flexible Systems Management.* We trust that you will gain new insights from the work presented herein.

Prabir K. Bagchi
Susan White
Editors

[1]Bowersox, D. J., D. J. Closs, and T. P. Stank (2000), "Ten Mega-trends That Will Revolutionize Supply Chain Logistics," *Journal of Business Logistics*, 21(2), 1-16.

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Guidelines for Authors

Aim

The journal is intended to share concepts, researches and practical experiences to enable the organizations to become more flexible (adaptive, responsive, and agile) at the level of strategy, structure, systems, people, and culture. Flexibility relates to providing more options, quicker change mechanisms, and enhanced freedom of choice so as to respond to the changing situation with minimum time and efforts.

It is aimed to make the contributions in this direction to both the world of work and the world of knowledge so as to continuously evolve and enrich the flexible systems management paradigm at a generic level as well as specifically testing and innovating the use of SAP-LAP (Situation- Actor - Process-Learning-Action-Performance) framework in varied managerial situations to cope with the challenges of the new business models and frameworks. It is a General Management Journal with a focus on flexibility.

Scope

The Journal includes the papers relating to: conceptual frameworks, empirical studies, case experiences, insights, strategies, organizational frameworks, applications and systems, methodologies and models, tools and techniques, innovations, comparative practices, scenarios, and reviews.

The papers may be covering one or many of the following areas: Dimensions of enterprise flexibility, Connotations of flexibility, and Emerging managerial issues/approaches generating and demanding flexibility.

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The journal is organized into various sections to include following types of contributions: Research papers, Short notes/correspondence, Applications and case studies, Book reviews, Book summaries, Interviews and round tables, Information about relevant conferences and seminars, Educational and learning experiments, and any other relevant information related with the theme of the Journal.

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- **The paper is original, not submitted anywhere else.**
- **The length of the paper is commensurate with content.**
- **The title and headings are brief and catchy.**
- **The author(s) name and affiliation are given only on cover page.**
- **Abstract and keywords are provided.**
- **Focus on flexibility in management is kept.**
- **The paper incorporates innovative ideas/models in a practical framework.**
- **Mathematical models, if any, are given in Appendix.**
- **Tables/Figures are properly placed and numbered with brief titles/ captions.**
- **References are in standard style.**
- **Few highlights (8-10) of two-three lines are provided to put in boxes.**
- **Few key variables (3-5) are identified for flexibility mapping on a continuum.**
- **Some key questions (2-3) are provided to reflect the applicability in real life.**
- **Authobiographical notes and passport size photographs of all authors are provided.**

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Headings: should be short clearly defined, and numbered.

Footnotes: should be used only when absolutely necessary and must be identified in the text by consecutive numbers placed as superscript.

Text: The main text should be more readable and mathematical models, if any, should be provided in Appendix. The ideas proposed should preferably be supported by real life case examples from business situations.

Tables and Figures: All tables and figures should be kept to a minimum and numbered consecutively using arabic numerals. Each table should have a brief title written on the top of the table, and each figure should have a brief caption written on the bottom of the figure.

Photos and Illustrations: must be supplied as good quality black and white original with captions. Their position should be shown in the text by typing on a separate line the words *"take in* ***Plate n"***

References: to other publications must be in standard style. That is shown within the text as the author's name followed by a comma and year of publication, all in round brackets, e.g. (Volberda, 1997). At the end of the paper a reference list in alphabetical order must be given as follows:

For books: Surname, initials, (year) *title*, publisher, place of publication.

e.g. Mckenzie J. (1996) *Paradox: The New Strategic Dimension*, McGraw -Hill, Berkshire.

For journals: surname, initials, (year) title, *journal*, volume (number), pages.

e.g. Volberda H.W. (1997) Building Flexible Organization for Fast Moving Markets, *Long Range Planning*, 30 (2), 169-183.

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Model

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Supply Chain Flexibility : Building a New Model

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Abstract

Building on the flexibility classification schemes and flexibility typologies literature, and recent literature on supply chain management, a new model of flexibility is proposed: supply chain flexibility (SCF). The model specifies several important characteristics that are required within and between each node of the supply chain to improve supply chain flexibility. Implications for supply chain researchers and practitioners are discussed.

Keywords : flexibility, measurement, supply chain, theory-building

Introduction

Supply Chains and Flexibility

In the 1990's, firms recognized the necessity of looking beyond the borders of their own firms to their suppliers, suppliers' suppliers, and customers to improve overall customer and consumer value. This movement, titled supply chain management or demand chain management, changed the companies' focus from the internal management of business processes to managing across enterprises. The Supply Chain Council (2002) defines the concept as:

"The supply chain – a term now commonly used internationally – encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer. Supply Chain Management includes managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer."

Supply chain management has emerged as the term defining the integration of all these activities into a seamless process. Figure 1 describes a typical supply chain.

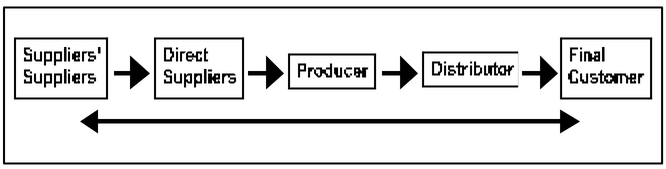

Figure 1 : Typical Supply Chain

The three main strategic imperatives that emerged in this century are low cost, high quality, and improved responsiveness (both delivery time and flexibility of product delivery). Flexibility, as described here, is often viewed as a subset of agility. The concept of an agile enterprise came about as the result of a collaborative, cross-industry workshop in 1991. Agility was loosely defined as "the ability of an organization to thrive in a continuously changing, unpredictable business environment." Agile organizations were viewed as those able to move quickly and to choose the most useful movement appropriate for the situation (Dove et al., 1991). Dove (1999) has since refined the definition as "the ability to manage and apply knowledge effectively," recognizing the importance of information in firm decision-making. Agility has become more important today as the environment is changing faster than ever before.

The concept of agility has been extended to supply chain agility (Prater et al., 2001) with its components defined as speed and flexibility. Flexibility is further broken into the capabilities of promptness and the degree to which a firm can adjust its supply chain speed, destinations and volumes. In supply chains, where material moves sequentially from one trading partner to the next, firms have recognized that to be responsive to end customer demand, all partners in the chain must be flexible in responding to change. This notion is reinforced in the supply chain measurement literature, as 'flexibility to meet particular customer needs' is viewed as an important strategic performance metric (Gunasekaran et al., 2001). While this concept of flexibility is widely viewed as important, very little work has been done to define the components of supply chain flexibility and identify the characteristics that make the supply chain flexible.

Understanding supply chain flexibility (SCF) is important for several reasons. First, recent trends, such as mass customization, require supply chains to meet individual customer requirements without adding significant cost (Gilmore and Pine, 1997, Pine 1997). Companies are allowing customers to provide specific product information needs and are producing product for that specific customer. Mass production efficiencies are required for quantities of one. Second, certain industries, particularly high-tech, require upside and downside flexibility (Hausman). This generally refers to the ability to increase or decrease production (by 20% or more) in a minimal amount of time to a new unplanned level of production and then being able to sustain the new level. Third, in many innovative product categories, such as fashion apparel and electronic devices, uncertainty of demand is a fact of life and creating a responsive supply chain is one method of avoiding uncertainty (Fisher, 1997). And last, the ever-changing environment in which companies find themselves requires rapid new product introduction, quick response to customer requirements in all parts of the world, and fast turn-around on customer orders. Chase et al. (2000) summarize the environment succinctly. “Recent trends such as outsourcing and mass customization are forcing companies to find flexible ways to meet customer demand. The focus is on optimizing core activities to maximize the speed of response to changes in customer expectations.”

Flexibility is the promptness and degree to which a firm can adjust its speed, destinations, and volumes.

The purpose of this paper is to draw from the current literature toward a model of supply chain flexibility, discuss the components that make up that model, and identify some of the characteristics across the supply chain that improve supply chain flexibility. To begin the discussion, previous literature on both flexibility and the limited literature on supply chain flexibility is provided. Next, the paper aligns the characteristics defined in the literature with a previously suggested conceptual model (see Figure 2; Duclos et al., 2003) The conceptual model is then developed into a model of supply chain flexibility and is followed by a discussion of the current literature support for the characteristics that allow the supply chain to be flexible.

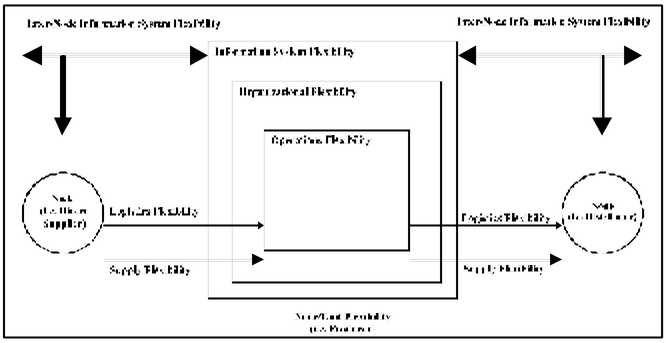

Figure 2 : Components of Supply Chain Flexibility

Supporting Literature

From Manufacturing Flexibility to Flexible Organizations

A review of the previous literature on flexibility reveals much of the focus has been on manufacturing flexibility. It is generally agreed that manufacturing flexibility does not refer to a single variable, but rather it is a multi-dimensional construct. Vokurka and O'Leary-Kelly (2000) expanded previously defined dimensions to fifteen identified dimensions of manufacturing flexibility (Table 1). Each dimension of flexibility has two elements: range and mobility. Further, they suggested a contingency relationship between manufacturing flexibility and firm performance. In their examination of past studies, they found four general forces – strategy, environmental factors, organizational attributes, and technology – comprise the dominant forces influencing manufacturing strategy.

Table 1: Definitions of Manufacturing Flexibility Dimensions

Dimension	Definition
Machine	range of operations that a piece of equipment can perform without incurring a major setup
Material handling	capabilities of a material handling process to move different parts throughout the manufacturing system
Operations	number of alternative processes or ways in which a part can be produced within the system
Automation	extent to which flexibility is housed in the automation (computerization) of manufacturing technologies
Labor	range of tasks that an operator can perform within the manufacturing system
Process	number of different parts that can be produced without incurring a major setup
Routing	number of alternative parts a part can take through the system in order to be completed
Product	time it takes to add or substitute new parts into the system
New design	speed at which products can be designed and introduced into the system
Delivery	ability of the system to respond to changes in delivery requests
Volume	range of output levels that a firm can economically produce products
Expansion	ease at which capacity may be added to the system
Program	length of time the system can operate unattended
Production	range of products the system can produce without adding new equipment
Market	ability of the manufacturing system to adapt to changes in the market environment

Source: Vokurka and O’Leary-Kelly (2000)

The hierarchy of flexibility dimensions (Figure 3) as proposed by Koste and Malhotra (1999) provides support for the argument that much of the focus on flexibility concentrates on flexibility within a single plant. The lower three tiers – Individual Resources, Shop Floor, and Plant – have a single plant, internal focus. Not until reaching the fourth level is there recognition that flexibility for the business unit is actually a combination of flexibility from many functional areas.

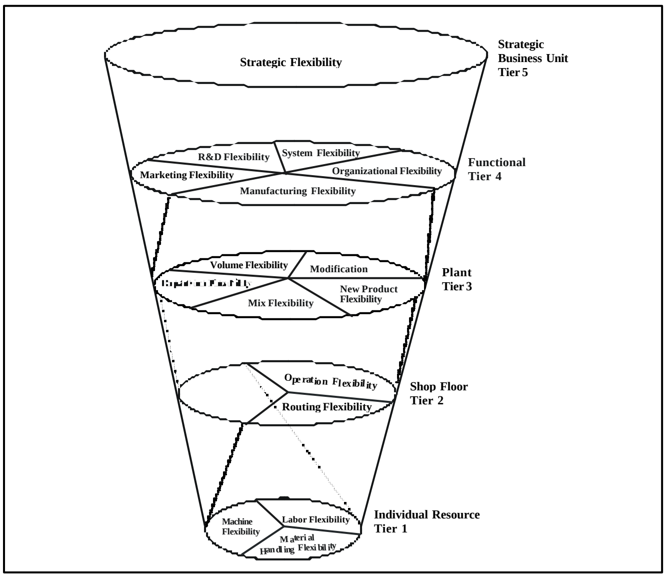

Figure 3 : Hierarchy of Flexibility Dimensions
Source : Koste and Malhotra (1999)

The manufacturing flexibility literature has recognized that manufacturing flexibility is not only a potential element of a manufacturing strategy, but it may also be a component of marketing and R&D strategies as well (Hyun and Ahn 1990, Sethi and Sethi 1990). It is also recognized as one element of a business strategy, with certain dimensions impacting growth and financial performance of the firm (Gupta and Somers, 1996). However, while the manufacturing flexibility literature provides a "bottom-up" view of flexibility in an organization, it is perhaps business strategy literature that provides the "top-down" view. Gupta and Somers (1996) make a strong argument for a linkage between business strategy, manufacturing flexibility, and the financial and growth performance of the firm.

Flexibility of entire supply chain is a results of the flexibility components at each node of the supply chain and their interrelationships.

Lau (1996) defines strategic flexibility as "a firm's ability to respond to uncertainties by adjusting its objectives with the support of its superior knowledge and capabilities"(pg. 11). He also proposes a framework for attaining strategic flexibility (Lau, 1994) that provides a broad picture of flexibility for an organization (Figure 4). It is this work that begins to recognize that flexibility is associated not only with manufacturing capabilities, but is also important for the linkages between manufacturing units and suppliers and customers – the supply chain.

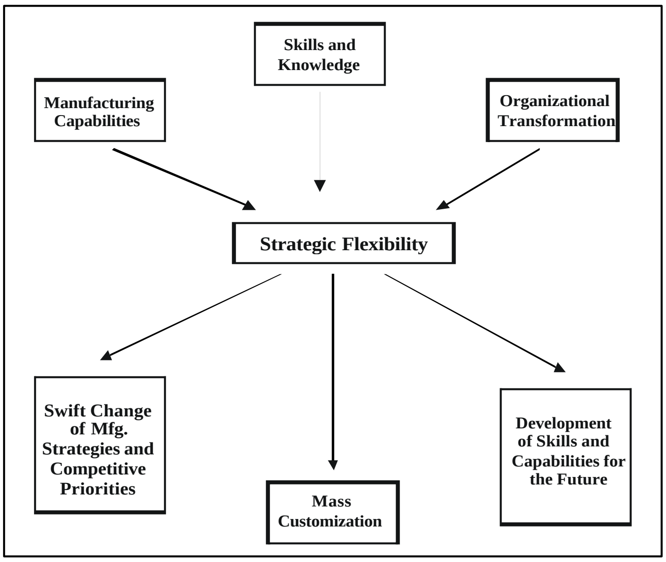

Figure 4 : A Framework for Attaining Strategic Flexibility
Source : Lau (1994)

Supply Chain Flexibility

A goal of this paper is to extend these concepts of manufacturing flexibility and flexible organizations to the supply chain. The supply chain extends beyond the enterprise which means supply chain flexibility must also extend beyond one firm's internal flexibility. This extension involves looking at those components that make an organization flexible and extends them beyond the organization's boundaries to other nodes in the supply chain. “Nodes” refer to other companies participating in the supply chain as producers, distributors, retailers or other customer outlets.

A limited number of authors have begun to discuss flexibility from a supply chain perspective. Fisher (1997) discussed considering the nature of a product's demand as a first step in devising an effective supply chain strategy. If a product is innovative with unpredictable demand, a market-responsive (flexible) supply chain is the more proper strategy. A more functional product with predictable demand should look at a physically efficient process.

In their paper on matching the supply chain to the marketplace, Mason-Jones et al. (2000) did not discuss supply chain flexibility per se, but discussed the importance of matching supply chain improvement initiatives to customer demand. They stressed the importance of combining the lean concepts of eliminating waste with the agility concepts of exploiting opportunities in a volatile market. Their definition of 'leagility' included creating a supply chain capable of delivering to an unpredictable marketplace that includes a decoupling point along the chain where product becomes unique. Prior to the decoupling point lean concepts are applied and product built to forecast. After the point, customer orders drive supply chain processes.

Vickery et al. (1999) defined five supply chain flexibilities based on previous operations literature. The authors stated that supply chain flexibility "should be examined from an integrative, customer-oriented perspective." Flexibilities viewed as directly impacting a firm's customers and the responsibility of two or more functions, whether internal or external to the firm, are included. The five defined flexibilities include:

- *Product flexibility* or the ability to customize product to meet specific customer demand.
- *Volume flexibility* or the ability to adjust capacity to meet changes in customer quantities
- *New product flexibility* or the ability to launch new or revised products
- *Distribution flexibility* or the ability to provide widespread access to products
- *Responsiveness flexibility* or the ability to respond to target market needs

These descriptions of flexibility are proposed in terms of types of flexibility required to meet customer demand. Not apparent is what it takes to make a supply chain flexible in meeting those customer requirements. Previous literature on flexibility fails to show the cross-functional, cross-business nature of supply chain management.

This paper draws from the current literature to develop a model of supply chain flexibility, discusses the components that make up that model, and identifies some of the characteristics across the supply chain which may improve supply chain flexibility. A flexible supply chain is one with the ability to respond to changes in customer demand. Changes might include increases or decreases in product volumes, requirements for customized products for individual customers, demand for new products, and the addition of new customer locations. Thus, supply chain flexibility requires both internal flexibility at each node and flexibility between supply chain member companies. Rather than looking at a type of flexibility (e.g., product flexibility) or a specific organization's functional flexibility (e.g., manufacturing flexibility), this paper focuses on supply chain flexibility which is defined as the supply chain's promptness and the degree to which it can adjust its supply chain speed, destinations and volumes in response to changes in customer demand (Prater, et al., 2001).

Supply chain flexibility components include operations systems, logistics processes, supply network, organizational design, and information systems.

A Model of Supply Chain Flexibility

The concepts of agility, as discussed earlier, provide a foundation for understanding flexibility. Christopher (2000) suggests that the key to creating responsive supply chains is through agility. He further defines the distinguishing characteristics of an agile supply chain as:

- *Market sensitive:* capable of reading and responding to real demand
- *Virtual capability*: information-based rather than inventory-based
- *Leveraged through process integration:* collaborative work between partners
- *Leveraged partnerships:* take advantage of partner core competencies

He goes on to note the importance of forming key supplier relationships to leverage greater agility. A key characteristic of agility, in his view, is flexibility.

Flexibility has been defined as the capabilities of promptness and the degree to which a firm can adjust its speed, destinations and volumes (Prater, 2001). Supply chain flexibility then becomes the capability of promptness and the degree to which the supply chain can adjust its speed, destinations and volume in line with changes in customer demand. A preliminary conceptual model of supply chain flexibility is shown in Figure 2 and discussed in Duclos, et al. (2003).

The suggested conceptual model included market flexibility as a required flexibility. Market flexibility was defined as 'the responsiveness to changing market conditions and customer needs and wants.' Dimensions of this component of flexibility were thought to include new product design and introduction, customization, product configurations, product postponement, and post delivery support. Little support was found in the literature for these to be considered components. However, they do appear to be outcomes that result from being flexible and, further, may be measured in terms of customer satisfaction. For example, the ability to build to demand versus build to forecast is contingent upon the ability of the information system to capture the correct data at the correct point in time such that operations can be adjusted to produce what the data has indicated the market is demanding. Therefore, a flexible supply chain has the ability to respond to the demands of the market and the result is improvements in customer satisfaction.

This model also provides a conceptual view of both internal and external elements, with respect to individual firms in the supply chain. For each node, the internal components of operations, organizational, and information system repeat. The figure only details those components within the center node. It is also noted that information system components are both within and between nodes.

Moving toward a model of SCF, a review of current literature was used to identify important characteristics of each component identified in the conceptual model. Table 2 links the characteristic to the appropriate flexibility component and identifies the research support for that linkage.

Table 2 : Supply Chain Flexibility Components and Key Characteristics

Supply Chain Flexibility Component	**Supply Chain Flexibility Characteristic Ability to ...**	**Reference**
Operations Systems	Reconfigure assets	Anderson (2000), Radjou (2000)
	Change processes	Allnoch (1997)
	Dynamically adjust capacity	Radjou, 2000
Logistics Processes	Adjust to global requirements	Bradley (1997)
	Serve customer's distinct needs	Fuller et al. (1993)
	Vary warehouse space	Richardson (1998)
	Vary transportation carriers	Huppertz (1999), Doherty (1998)
	Introduce product postponement	Swaminathan (2001), Van Hoek (2000)
Supply Network	Add and remove suppliers	Jordan (2000), Rich (1997)
	Select suppliers with fast ramp up	Burt and Soukup (1985), McGinnis and Vallopra (1999), Fisher et al. (2000)
	Vary supplier relationships	Bensaou (1999), Mason, et al. (2002), Cooper (1993)
	Have suppliers vary capacity	Choi and Hartley (1996)
Organizational Design	Change organizational structure	Miles (1989), Andrews (1994), Lau (1996)
	Change human resource practices	Zhang (2001), Power et al. (2001), Mac Duffie (1995), Wright and Snell (1998), Upton (1995)
	Change workforce capabilities	Vokurka and O'Leary-Kelly (2000), Miles (1989), Hall and Parker (1993)
	Link workforce between nodes	Kalwani and Narayandas (1995), Moller and Wilson (1995)
	Change culture	Hult et al. (2002)
Information Systems	Synchronize information systems with partners	Dabbiere (1999)
	Interface internal processes	Vokurka and O'Leary-Kelly (2000)
	Share information with partners	Magretta (1998)

Figure 5 provides a simplified, preliminary model of SCF with the propositions offered in this paper noted. The model is briefly described here and with the propositions that define the model discussed in the following sections. This model proposes that the flexibility of the entire supply chain is a result of the characteristics of the operations systems, the logistics processes, and the supply network at each location in the supply chain. It is suggested that determining whether these characteristics actually result in a flexible supply chain is affected by the organizational design and information systems of each supply chain partner. The model further details the potential customer satisfaction improvements of flexible supply chains, thus, providing a surrogate for measuring market flexibility as has been previously proposed as a characteristic of a flexible supply chain. The purpose of this model is not to present an exhaustive listing of possible characteristics or results; but rather to present a general framework for stimulating future research into this necessary but previously undocumented concept. The issues underlying supply chain management strategies is an appropriate area to research as firms today try to improve supply chain performance and revise existing industry practices.

Operations Systems Flexibility

Operations system characteristics include both manufacturing and service operations. Many of the dimensions included as characteristics of manufacturing flexibility would also be included in this category recognizing that the characteristics are associated with a specific company in the supply chain.

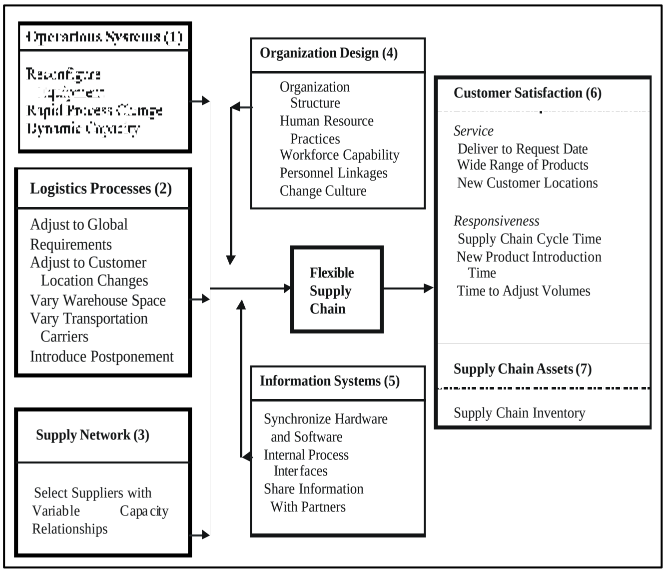

Figure 5 : A Model of Supply Chain Flexibility Characteristics

This could be a manufacturing unit, a supplier, or a customer (distribution unit). A summary of the results from a combined study between Anderson Consulting, Stanford University, Northwestern University, and INSEAD on Consumer Driven Demand Networks (Anderson and Lee, 2000) identified the components of supply chain strategy that add value to a firm. These observations suggest the following proposition:

Proposition 1: There is a positive relationship between the operations systems characteristics at each node and overall supply chain flexibility.

Operations Systems Characteristics

Three of the characteristics needed by the operating side of the business include: the ability to reconfigure assets in line with customer need, the ability to change processes as demand changes, and the ability to adjust capacity. One component identified in successful supply chain strategies is the ability to be "operationally agile." This includes the ability to configure assets and operations to react to consumer trends for both products and geographic areas. The assets and operations include equipment, workstations and processes. Building on previous discussions of supply chain flexibility (Anderson and Lee, 2000, Radjou, 2000) as well as the manufacturing flexibility literature, one operating system characteristics concentrates on the ability to reconfigure assets needed to produce a product or service.

A second system characteristic that flows from these same observations concentrates on process within the operations. As the supply chain responds to customer demand, supply chain member companies may be required to move quickly from the production of one product to another, or quickly change production levels for a given product. Either needed response may require the companies to change business or production processes. Further, a 1997 study (Allnoch, 1997) of 225 manufacturers found that average companies required much more time to respond to changes in customer demand than did the leading manufacturers. In some cases, as much as eight times longer was required. The study also found that while leading manufacturers required two weeks to meet increased production requirements per customer demand, average companies required four weeks to four months. Clearly, response speed appears to be a competitive advantage for these leading manufacturers.

Operations systems characteristics include the ability to reconfigure assets in line with customer need, the ability to change processes as demand changes, and the ability to adjust capacity.

Forrester Research, in a study of 50 global manufacturers, summarized the conditions that make global manufacturers inflexible (Radjou, 2000). Their results indicate inflexibility can be surmised by a firm's inability to transfer production from one plant to another and its inability to successfully respond when capacity is constrained. The author states that global manufacturers must be able to respond to "dynamic trade" which is defined as "the ability to satisfy current demand with customized response." Dynamic capacity includes the ability to add or reduce capacity at an existing facility, add or eliminate facilities, or source capacity.

Logistics Process Flexibility

As Anderson et al. (Anderson, 1997) noted in their discussion on logistics in the supply chain, "the logistics network probably will be more complex, involving alliances with third-party logistics providers, and will certainly have to be more flexible than the traditional network." They further observed that for many companies, tailoring distribution assets could be a source of differentiation for a manufacturer, more so than the product itself. Therefore, proposition 2 suggests:

Proposition 2: There is a positive relationship between the logistics characteristics within and between each node and supply chain flexibility.

Characteristics of Logistics Processes

The logistics characteristics identified through this research include: the ability to adjust to global requirements, the ability to serve distinct customer shipping requirements, the ability to vary warehouse space, the ability to vary transportation carriers, and the ability to introduce product postponement. Logistics flexibility is required to meet changing channels, especially as electronic commerce expands and markets open in developing countries and sourcing, manufacturing and distribution become more global (Bradley, 1997). Fuller, O'Conner and Rawlinson (1993) suggest that the logistics systems of a single firm are one of the key areas for bringing "distinct value to distinct customers." Distinct value to distinct customers implies ensuring the ability within the supply chain to serve each distinct customer's needs. Most supply chains include multiple logistics and distribution firms across the chain and require specifying delivery to specific customer locations

Part of the logistics process is warehousing product as needed. According to Mike Briggs, UPS Worldwide Logistics, there are a number of trends affecting warehouse design (Richardson, 1998). One trend is the decreasing space allocated to storage. Efficient consumer response and just-in-time (JIT) systems are just two management concepts that have placed pressure on inventory turns, increasing activity in the warehouse. Another trend is the need for warehouses to help suppliers respond appropriately to customer demand by providing such services as client-specific packaging, reverse logistics, or complex pick-and-pack operations. To manage within this customer demand-driven environment, warehouse management must focus on maintaining flexibility in all its functions, such as receiving, storage, picking and sorting, material handling, shipping, labeling and packaging.

Flexibility for moving product between nodes in the supply chain can be crucial as well. Changing customer demand may translate into changing load and delivery requirements. These changing requirements may take on many forms; shipping volume or frequency may increase or decrease; customers may need to postpone shipments, or expedite, – to name a few. As these requirements change, carrier cost and service time may also change resulting in the need to consider other carriers. Each node of the supply chain, then, must be able to balance load and delivery requirements against carrier capabilities and costs. In an effort to reduce inventory levels, many companies are expecting smaller lots, shipped more frequently to replenish their stock levels. Companies have shifted from truckload or less than truckload, toward parcel freight or other consolidation modes to meet customer requirements at a low cost (Huppertz, 1999). Other companies are looking at methods of freight consolidation and pooled delivery to achieve logistical efficiency (Doherty, 1998).

The ability of the supply chain to postpone product differentiation and pack product in-transit is another example logistics characteristic. Swaminathan (2001) noted that there is a high degree of product customization across almost all industry segments today. This in turn puts significant pressure on a firm's supply chain operations. He developed a framework of four standardization options; (1) if both the product and process are modular, process standardization works best, delaying differentiation until as late in the process as possible, (2) if the product structure is modular, but the manufacturing process is not, part standardization is the best option, (3) when the process is modular but the product is not, procurement standardization works best, and (4) if neither the product nor the process is modular, adopt product standardization and stock only a few of the many products offered in inventory. These operational strategies were tested with a number of firms in multiple industries, including IBM, Agilent Technologies, and Chrysler. Van Hoek (2000) discussed the role of third-party logistics providers in achieving mass customization. Postponement of manufacturing in the distribution channel was found to allow rapid delivery of customized products.

Logistics processes characteristics include the ability to adjust to global requirements, the ability to serve distinct customer shipping requirements, the ability to vary warehouse space, the ability to vary transportation carriers, and the ability to introduce product postponement.

Supply Network Flexibility

The ability to meet the changing needs of customers requires changing the supply of product, including mix, volume, product variations, and new products. Meeting these needs in the supply chain requires flexibility in sourcing product from raw materials to outsourced finished product. In an empirical study of purchasing managers in manufacturing firms, Narasimham and Das (2000) found that the selection, development and integration of suppliers was a key determinant of the ability of manufacturing to make rapid changes. These ideas suggest the following proposition:

Proposition 3: There is a positive relationship between the supply network characteristics at each node and supply chain flexibility.

Characteristics of Supply Flexibility

The characteristics that influence supply flexibility include: the ability to add and remove suppliers, the ability to select suppliers who can add new products quickly, the ability to vary supplier relationships, and the ability to have suppliers make volume changes. The supply chain should be designed with change in mind. As one member of the chain sees the need to add partners to complete a task, new partners with the required capabilities must be found (Jordan and Michel, 2000). As those partners complete the tasks they were brought into the chain to provide, provisions must be made to reconfigure the supply chain and dissolve the partnerships. As markets continue to change, the competitive priorities of the supplier partners must include a parallel shift in focus at each level of the supply chain down to the remotest level of supply (Rich and Hines, 1997).

Selecting suppliers who can introduce new products quickly can add responsiveness to a supply chain. Burt and Soukup (1985) suggested that the most vulnerable aspect of product development in many companies is the failure to use the creative potential of suppliers. McGinnis and Vallopra (1999) found that supplier involvement could contribute to new product success. Fisher, Raman and McClelland (2000) found that for short lifecycle products, such as fashion apparel, retailers are most successful if they can work with suppliers who can provide initial shipments of product based on forecasts, but then rapidly increase production to the right style, color, size, etc. based on actual sales. They note that fast supply chains can produce products as they sell rather than worrying about accurate forecasts. These studies suggest that supplier selection based on product development capabilities and rapid deployment capabilities positively impact the delivery time of new products.

Companies can vary the relationships they form with different supply chain partners. Companies may choose to solicit short-term bids, enter into long-term contracts and strategic supplier relationships, form joint ventures, form consortiums, create problem-solving councils or vertically integrate. Flexibility in forming these relationships along with managing the relationships is key to successfully meeting changing customer requirements. As Bensaou (1999) states, “Successful supply-chain management therefore requires the effective and efficient management of a portfolio of relationships: first, firms must match the optimal type of relationship to the various product, market, and supplier conditions; second, they must adopt the appropriate management approach for each type of relationship.” In some industries, startups and partnership changes are expensive and time consuming and long-term contracts are preferred (Mason et al., 2002). Companies must select the most appropriate relationships to match the specific set of circumstances (Cooper and Gardner, 1993).

In a study of supplier selection practices, Choi and Hartley (1996) found that the capability of suppliers to make product volume changes was a significant factor in supplier selection in the automotive industry. In certain industries, e.g. electronics, demand volatility poses a unique challenge to suppliers to vary output in line with demand. The increases or decreases may come at short notice and need to be sustained over some time period. The ability of firms to react quickly to customer demand is dependent on the reaction time of suppliers to make volume changes.

Organizational Design Flexibility

While operations system characteristics, logistics process characteristics and supply network capabilities provide part of the ability for supply chains to be flexible, it will not occur in the absence of organizational commitment and information systems capability. The degree to which these supply chain characteristics will actually result in increased SCF is impacted by the characteristics of each organization in the chain. In other words, supply chains may have the right operating systems characteristics, logistics processes and supply networks but still not be flexible without an encouraging organizational design at each node of the chain. Sharifi and Zhang (2001) in follow-up case studies of a survey of 1000 companies, identified several practices to achieve agility capability. Those related to the organization included: empowerment of people, concurrent team-working, and virtual organization. They defined these practices as the "practical tools" needed to respond to agility drivers. Power et al. (2001) identified a factor they called 'participative management style' as a significant variable in agile companies in their study of 3000 Australian manufacturers. Participative management included a culture that encouraged change and used change champions, defining a unity of purpose, pursuing continuous improvement, soliciting ideas from employees and effective up and down communication. These studies suggest the following proposition:

Supply network characteristics include the ability to add and remove suppliers, the ability to select suppliers who can add new products quickly, the ability to vary supplier relationships, and the ability to have suppliers make volume changes.

Proposition 4: There is a positive relationship between the organizational design at each node and supply chain flexibility.

Organization Design Characteristics

Five organization design characteristics that need to be considered with respect to supply chain flexibility are: the organizational structure, the human resource practices, the workforce capabilities, the ability to form personal links with other nodes, and the company's culture at each node of the supply chain. An organization's structure may impede relationships with another organization (Andrews and Stalick, 1994). For instance, it may be very difficult for an organization with many hierarchical levels and a top-down approach to integrate with a lean bottom-up organization. Lau (1996) adds support for the dimension of organization structure. He argues that deep organizational hierarchies impede cooperation and communication and prevent cross-functional integration, a requirement for successful supply chain management, and employee participation.

Further, human resource practices may limit the node's ability to respond to changes in its environment, as represented by changing flows in and out of the node. For example, nodes employing piece work pay systems may find a work force unwilling to respond to a supply chain requiring frequent deliveries of small batches. The ability of employees to provide operational flexibility requires that employees possess a broad set of skills (MacDuffie, 1995). The pay plans or education benefits implemented at the node may impede or encourage the development of these skills. Wright and Snell (1998) discuss how the HRM practices of the organization must support the competitive strategy of the organization and help develop the organizational capability to adapt to changes in the environment, thus tying HRM practice to organizational flexibility.

Wright and Snell (1998) applied Sanchez's (1995) model of Resource and Coordination flexibility specifically to the Human Resources Management (HRM) function targeting both business practices and workforce. They illustrate the importance of creating flexibility specifically in HRM practices and argue that the breadth of individual skills available to the firm, as well as the flexibility of employee behavior provides indicators of a firm's potential flexibility. Based on findings in his study of 61 manufacturing plants, David Upton stated, "The primary revelation of my research concerns the role of people – both managers and operators. The flexibility of the plants depended much more on people than on any technical factor" (Upton, 1995).

The relationship between a flexible workforce and operations system flexibility has been recognized in the manufacturing flexibility literature. Vokurka and O'Leary-Kelly (2000) extensively reviewed the manufacturing flexibility literature and then defined the dimension of labor within manufacturing flexibility as the range of tasks that an operator can perform within the manufacturing system. Miles (1989) argued that a new organizational form, plus a secure, mobile, and well-trained workforce, is needed to meet the challenges inherent in the global economy. Hall and Parker (1993) looked at workplace flexibility, one part of the business practices dimension, and find that this flexibility can enhance corporate performance.

Kalwani and Narayandas (1995) and Moller and Wilson (1995) suggested that suppliers seeking to build closer links between themselves and key customers will be required to create an intra-organization environment in which employees are flexible, prepared to take decisions without referring back to management, self-responsible, and can communicate effectively with their counterparts in customer organizations.

A study by Hult, Ketchen, and Nichols (2002) found that culture (measured by constructs of entrepreneurship, innovativeness, and learning) can serve as a strategic resource in supply chains. Trends such as globalization and technological innovation make environments more challenging, leading supply chains to act not as simple linked series of nodes, but rather as integrated entities. Results supported their contention that cultural competitiveness can provide a sustained competitive advantage and enhance supply chain outcomes such as cycle time.

Information Systems Flexibility

Changes in working relationships within and between companies can also result in changes to the information needs and data processing requirements of the enterprise. In order for the supply chain to respond to changes in customer requirements, all partners must be aware of the new requirements. Change within the supply chain may be inhibited if the information system cannot respond to these changing needs. Inter-firm business synchronization requires inter-firm data sharing and communication. Also, research supports the contention that capable information systems impact operations and logistics processes (Barron, 1993, Dougherty et al. 1998, Lucas and Olson 1993). These issues suggest the following proposition:

Proposition 5: There is a positive relationship between the information systems characteristics within and between each nodes and supply chain flexibility.

Information Systems Characteristics

There are three characteristics of information systems that affect supply chain flexibility. They include: the ability to synchronize information systems with supply chain partners, the ability to share information across internal business processes, and the ability to pass information along the supply chain. Supply chain partners must be willing to adapt their information systems to meet the needs of all partners, upgrading business processes as the market evolves. As Dabbiere (1999) states, "When a major player in the supply chain decides to upgrade to a new technology or adopt a new technical functionality, the rest of the industry is challenged to synchronize the change throughout the supply chain." This synchronization must incorporate the changing requirements of business partners, including items such as order information and shipping data. Information sharing is also affected by the speed with which changes can be made to hardware architecture and software to allow for synchronization between firms in the supply chain.

In addition to information sharing between supply chain partners, information systems can impact internal business process capability. Vokurka and O'Leary-Kelly (2000) found one dimension of manufacturing flexibility to be the extent to which flexibility is housed in the automation (computerization) of manufacturing technologies. For the supply chain, this automation extends beyond computerization represented by flexible manufacturing systems and computer-integrated manufacturing. Programs and interfaces that allow automation of processes, such as purchasing, transportation management and inventory management must be included as well.

Information visibility within the supply chain means sharing information to manage the flow of products and funds in real time between all supply chain members. The overall goal for the supply chain is to have perfect visibility whenever an event takes place anywhere along the chain. As customers place orders, information is shared back through the supply chain to producers, suppliers and suppliers' suppliers. One need look no further than the success of Dell Computer in its implementation of "virtual integration", gaining almost instant access to information throughout the chain, to see how visibility has lead to speed and efficiency (Magretta, 1998).

Results from Supply Chain Flexibility

The model described in Figure 5 identifies some of the potential results from attaining a flexible supply chain. The major improvements can be expected in terms of meeting customer needs and the resulting customer satisfaction. When customer needs are satisfied, even when the needs change over time, the supply chain has achieved market flexibility. By being flexible, the supply chain can meet specific customer needs and influence the long-term commitment of customers. At the same time the organizations within the supply chain should see improvements in performance as a result of supply chain flexibility. In terms of customer satisfaction, flexible supply chains should lead to improvements both in terms of service and in terms of responsiveness. Service relates to the ability to deliver to a certain request date, the specific product the customer requires to the specific location. Responsiveness factors involve anything related to time or velocity of execution. With a flexible supply chain, one would expect improvements on both dimensions. Flexible supply chains should also result in improvements for each organization. For instance, if the entire supply chain is more flexible than a competitor's, the supply chain should have fewer assets tied up in inventory.

Organizational design characteristics include the organizational structure, the human resource practices, the workforce capabilities, the ability to form personal links with other nodes, and the company's culture at each node of the supply chain.

Improved Customer Satisfaction

Customer service improvements as a result of supply chain flexibility would include the ability of the supply chain to deliver items to the customer request date, the ability to deliver a wide range of products and the ability to deliver to any customer location. For innovative products and products that are mass customized, Fisher (1997) suggests that satisfying customers will require a responsive supply chain that can produce per order or manufacture closer to the time of the order. Hausman defines service as the ability to anticipate, capture and fulfill customer demand with personalized products, on time. Also, as noted by Gunasekaran et. al. (2001) "the ever increasing trend in globalization and customer orientation requires a logistics sensitive organization."

Customer satisfaction also includes responsiveness or time related performance. Customers today are demanding more variety, better quality and service, including both reliability and faster delivery. As a result of increased global competition in the 1970s, responsiveness emerged as a strategic initiative (Stalk Jr. and Hout, 1990). Several recent empirical studies have shown a significant positive relationship between responsiveness of the supply chain and customer satisfaction (Dean and Terziovski, 2001, Goodman and Fichman 1995). Both of these studies found that overall responsiveness to customers improved their satisfaction. As a result of supply chain flexibility we propose:

Proposition 6: Supply Chain Flexibility will be positively related to increased customer satisfaction.

> ***Information systems characteristics include the ability to synchronize information systems with supply chain partners, the ability to share information across internal business processes, and the ability to pass information along the supply chain.***

Improvement in Supply Chain Assets

The last improvement we may see from increased supply chain flexibility is improvement to the overall supply chain inventory. By overall inventory, this entails summing the inventory value throughout the supply chain, including incoming stock, work-in-progress, finished goods, scrap and waste, and inventory in transit (Gunasekaran et al., 2001). Generally, it is assumed that there is a trade-off between holding additional inventory in the chain and customer service. The flexible supply chain should require lower inventories at each node as product is produced closer to customer consumption and lead times are reduced. Inventory in transit should also be reduced as supply chain partners choose modes of transportation that shorten lead times (Gunasekaran et al., 2001). This suggests a positive relationship between SCF and supply chain inventory.

Proposition 7: Increased SCF will be positively related to reductions in supply chain inventory in terms of inventory value.

Discussion

A goal of this paper is to identify the components of supply chain flexibility and potential characteristics of each component that result in a flexible supply chain. At the same time, the paper suggests results that can be expected from supply chain flexibility. The intent was not to specify every relationship or consequence associated with this concept. Rather it was to stimulate thinking on this concept of flexibility and provide new areas of research for supply chain academicians. We have done this by providing a set of propositions to initiate research on this important topic.

The concepts of a flexible organization and the benefits from having a flexible organization are not new. What has not been recognized, however, is that performance of the entire supply chain can improve if the entire chain is constructed with flexible components. With the increase in customer demand for customized products delivered with short lead times, it is not surprising that supply chains are beginning to recognize the importance of flexibility. This paper begins to identify the characteristics of flexible supply chains. What is needed now is empirical investigation of the propositions and relationships identified in this preliminary model.

The supply chain flexibility discussion presented here should also be considered in light of Fisher's (1997) contention that a more functional product with predictable demand might perform better by concentrating on process efficiencies. Each supply chain network is different and will have different requirements for flexibility. Each must understand which components would provide the best performance for their supply chain.

Implications for Researchers

The model proposed in this paper presents an interesting opportunity for researchers interested in supply chain flexibility and supply chain performance improvement. The issues underlying supply chain management strategies is an appropriate area to research as firms today try to improve supply chain performance by revising existing industry practices. Researchers may find interest in examining the following issues.

First, this article moves away from the more traditional views of flexibility that are based on flexibility dimensions (e.g. product flexibility, volume flexibility, launch flexibility, access flexibility, responsiveness flexibility). For examples, see (Vickery et al., 1999). Instead, this paper looks at the characteristics of flexible supply chains (e.g. ability to add or remove suppliers, ability to postpone product differentiation, etc.). The principle is that certain characteristics or capabilities will lead to improvements in performance. The complexity of supply chain processes makes it difficult to determine which factors improve performance. This model can serve as a testable framework for relating flexibility to performance.

A second challenge for researchers is to identify the impact of supply chain initiatives on overall supply chain performance. The proposed framework suggests that the important issue is having the entire chain flexible in order to meet changes in customer demand. Can one organization, through internal improvements in flexibility, affect overall supply chain performance or can an organization excel in one component of flexibility and influence the success of the chain? Are some characteristics more important than others in overall flexibility? How do the characteristics relate to one another? Do improvements in one characteristic affect improvements in another?

Finally, appropriate measures of supply chain flexibility, as evidenced by improved customer satisfaction, supply chain cycle times and supply chain inventory, are required to identify performance improvements. Performance measures must be identified which measure supply chain performance across supply chain nodes to determine if real change in customer value has been added. At the same time individual firm performance must be monitored to ensure increased supply chain flexibility does not lead to poorer firm financial performance. Future work is needed that examines the relationships between supply chain flexibility characteristics and supply chain performance in a variety of industries.

Implications for Supply Chain Practitioners

As the propositions in this paper posit, increased supply chain flexibility results in improved performance in customer service, time-to-market, cycle time, and supply chain inventory. Supply chain managers would do well to build on their intra-firm flexibility characteristics while improving their organizational design and information system capabilities. They must identify the right mix of equipment, systems and people to improve response times while maintaining lower inventories. Once they have improved their own capabilities, their focus must shift to finding suppliers and logistics services providers with the necessary flexibility characteristics. Managers must also look for new ways to measure supply chain performance, which identify real improvements in overall customer value and are coupled with internal firm performance measures.

The flexibility characteristics identified in this paper are not new. Rather, managers need to understand their own firm's characteristics in relationship to the entire supply chain. In the future, as supply chains further compete with other supply chains, organizations must understand that flexible supply chains will outperform those that are less agile. And, to be successful all supply chain partners must incorporate the flexibility characteristics within and between firms to maximize performance and provide value to customers.

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Flexibility Mapping : Practitioner's Perspective

1. Try to map your own organization on following continua. (Please tick mark in the appropriate box(es)).

Operations

Fixed Capacity — Flexible Capacity

Logistics Flexibility

Fixed Carrier Contracts — Flexible Transportation

Supply Flexibility

Transaction Based — Relationship Based

Organization Flexibility

Fixed Job Classifications — Cross-trained Workforce

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1. Are all your supply chain partners flexible in meeting end customer demand? What are important flexibility characteristics to look for in supply chain partners?
2. Assess your firm's capabilities on each of the key supply chain characteristics mentioned in this paper. Determine where you should focus your efforts to improve supply chain flexibility.

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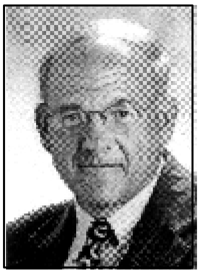

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Decision Support System

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Using Discrete-Event Simulation to Create Flexibility in APAC Supply Chain Management

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Abstract

While discrete-event simulations have been used in a number of situations to model projects and events, this paper describes how the methodology may be used in a supply chain management context to assist in decisions where time and flexibility is essential. The model was developed to assist a multi-billion dollar company in understanding the impact of material flow from the US to the Asia-Pacific region (APAC) and to allow flexibility in the supply chain. More specifically, the DSS quantified the impact of shipping directly from US sources of supply to APAC customers versus shipping through consolidation (existing and proposed) locations using cycle time, throughput, work-in-process (WIP) and shipped containers as performance measures. The DSS is organizationally structured through a partnership between academia and industry where the academician maintains the model and industry maintains and supplies the data. This unique partnership provides industry with stable, long–term modeling expertise and increased productivity. Academia benefits from the opportunity by having access to practical global supply chain management issues.

Keywords : decision support system, flexibility, simulation, supply chain management

Introduction

Supply chains encompass the flow of material, production and information from the basic raw materials through delivery to the final customer. Flexible supply chains exhibit characteristics of flexible manufacturing the ability to reduce costs while adapting rapidly to changes in consumer demand. Manufacturing system flexibility often must be designed into manufacturing equipment, thus making the equipment able to quickly change from one product to another. The similarity in supply chain management (SCM) is the ability to change the network between supplier and customer when system changes create the need. Although similar, one significant difference exists. In manufacturing, equipment design requires significant planning time. In SCM, network options are often readily available. This means that optimal network option selection and timing are the critical issues for SCM flexibility.

To address these issues, spreadsheets are often the analytical tool of choice for studying supply chains because of their affordable power and ease-of-use. Unfortunately, the time-based nature of supply chain critical performance measures (cycle time, throughput, and WIP) are not easily reproduced in static spreadsheets. A viable alternative to these problems is use of discrete event simulations (DES), a time-based modeling tool, which allows calculation of time-based statistics. Just as important, simulation code and animation provide an understandable representation usually accepted by non-modelers. The DES-based DSS's purpose is to provide useful knowledge to enable flexible supply chains to quickly adapt to changes in the system.

Several reasons likely account for the slow adoption of simulation in solving SCM process problems. Primarily, simulations are typically used for static, project solutions rather than for process ones. In a project, the output is often a point solution, a one-time, point in time answer; whereas, a process is a re-usable methodology that does not die at the end of a project. This dynamic nature of processes has likely inhibited the use of simulations as the basis of a decision support system (DSS). Other specific difficulties in using simulation for SCM processes solutions include:

1. The lack of readily available data when system changes occur.
2. The modeling tool/software language requires commitment, is expensive, and rapidly obsolete.
3. The lack of modeling expertise.
4. Poor modeling design that prevents adaptation to a changing system.
5. Complexity of many supply chains.

Each of these factors that inhibit the use of simulation in processes, however, has a solution:

1. Data acquisition may be rapid. Technologies exist to generate and automatically integrate massive amounts of information into the DSS.
2. Software languages are continually being improved and competition has significantly created affordable simulation solutions. Additionally, outsourcing of the simulation modeling may reduce the commitment to rapidly obsolete software.
3. Creating a partnership between academia and industry where academia maintains the model and industry maintains the data. The academician maintains the model and the company provides the data when new situations arise that require analysis. An advantage of this partnership is model viability. One primary reason a simulation model is shelved is that the original developer vacates his position. In today's market, professionals are constantly switching career paths. Since a professor usually remains a professor, fewer opportunities exist for the model to be shelved. A benefit of this partnership is maintaining a link between academia and industry. Through these partnerships, the academician has the opportunity to be involved with practical business problems, which may provide a greater competitive advantage in recruiting quality students.
4. DSS design rules must be followed by creating scalable models and separating data from the model. Models must be planned to expect increased complexity because of larger or more detailed requirements. This is discussed in detail in the section on DSS.

The purpose of this paper is to illustrate how a discrete-event simulation may be used to provide solutions for the flexible supply chain problems of timing and selection, using a real life example. In this paper, the usefulness of the DSS is not for daily changes, but for periodic changes in the supply chain design due to fundamental shifts in the system. Examples include new product introductions, new technology in production, a changing customer base due to winning a long term contract, political changes, new laws, and so on. Consequently, the DES model is not run everyday to decide that day's (or near future) operations. Rather, it is used to modify the source of supply, change the transit mode, negotiate rates with carriers, investigate using 3PL's for consolidation of product, etc. Although not run on a daily basis, when the need does arise, an analysis is needed promptly. Without a living model, companies typically use large amounts of human effort to fight these fires. Consequently, the DSS-based analysis' value is equally as attributable to its promptness as to its quality.

The DES-based DSS's purpose is to provide useful knowledge to enable flexible supply chains to quickly adapt to changes in the system.

Literature Review

DES is a venerable and well-defined methodology of operations research and many excellent explanatory texts exist (Law and Kelton, 2000; Pritsker, 1995; Winston, 2000). The methodology is particularly useful in evaluating interdependencies among random effects that may cause a serious degradation in performance even though the average performance characteristics of the system appear to be acceptable (Shapiro, 2001). As such, DES has been used to study flexibility in manufacturing systems (Albino et al., 1999; Caprihan, 1997; Gupta et al., 1992; Garg et al., 2001; Borenstein, 2000; Pflughoeft, 1999; Nandkeolyar et al., 1992). However, simulation is primarily used to demonstrate flexibility of a design parameter, i.e. routings, polices, and equipment design. These types of simulation models are termed “throw away models” because they are seldom used after designs are finalized (Thompson, 1994). The simulation itself was not the vehicle of flexibility, which is the thesis of this paper. That is, flexibility in supply chain management is achieved through building a decision support process around a simulation model.

Simulation models are intuitive to understand, which is an important reason for their longtime and continuing application to supply chain problems (An et al., 1994; Ferguson, 1998; Chen, 1999). Similarly with manufacturing simulations, supply chain simulations are also primarily of the throw away type and only provide a point solution. In contrast, DES may also serve as a basis for a DSS process. However, a debate has arisen on whether supply chain simulation models are adequate for the basis of decision support systems. Shapiro (2000) cites two “serious deficiencies”: The first is the time and effort required. The second is a simulation model fails to provide insights into how a system can be optimized. Neither deficiency is insurmountable, however.

Companies requiring the development and use of complex supply chain simulation models may derive greater efficiencies and use of resources through outsourcing the task to experts as actualized in the example presented in this paper. As for the second deficiency, optimization techniques are inadequate for describing or solving many systems. For those cases, experimentation with simulation is a worthy alternative because the strength of simulations is in their ability to model almost any system, regardless of its complexity. Additionally, in practice, expertise of optimization problems is even more difficult to find than expertise of simulation as the mechanics of simulation models are easier than optimization models to understand because of the animation and modeling constructs that simulation provides. Companies needing analysis have more options with simulation. Finally, the application of operations research within an organization is evolutionary.

Companies at the initial stages of evolution should begin with less complex solutions, rather than jumping to the most advanced solutions. Otherwise, failure is likely, and operations research is cast aside.

A current trend of using simulation as an instrument of flexibility is real-time simulation (Wu and Wysk, 1989; Erickson et al., 1987; Harmonosky and Barrick, 1988; Harmonosky, 1990; Cho and Wysk, 1993; Smith et al. 1994; Jones et al., 1995; Peters et al., 1995). Real-time simulation is the use of simulation technology for real-time operational control within manufacturing systems. Real-time simulation emulates the control logic and mimics the behavior of the manufacturing system for short periods of time. Its objective is to provide advanced planning and scheduling capability to aid in capacity planning, sequencing, predicting leadtimes and duedate quoting. Simply put, real-time simulation is a DSS process used on a daily basis with the level of detail is at the shop floor. Users are within the walls of the plant and less emphasis is on representing the stochastic nature of the system. In contrast, the use of simulation as a process is expected to be monthly/quarterly. If daily use of the model was expected, then the academic/industry partnership would be of little value. Also, the stochastic nature of the system does play a role in the analysis, specifically in demand orders and transit times. Considering the previous use of these real-time simulations in daily operations, the potential benefits of using simulation in a SCM DSS system to facilitate order and transit time flexibility holds promise.

This dynamic nature of processes has likely inhibited the use of simulations as the basis of a decision support system (DSS).

The next section provides an example of how a DES is used to create greater flexibility in the supply chain management of a major firm. The importance of this research has several facets. First, it demonstrates the continuing use of simulation to study supply chain issues, specifically in APAC. Second, it demonstrates that simulation can be the basis of a DSS process instead of a "throw-away" model. Finally, it demonstrates that OR can be structurally organized by using an academic/industry partnership that improves the viability of the process.

The DSS for Domestic Source of Supply Material Flow to APAC

Problem Description

The company used in this example is a multi-billion dollar technology-based company with over half its sales derived from outside the United States, predominately in the Asia-Pacific (APAC) region. Known as a company of new products, the diversified product line gives the company the ability to meet its customers where they are, whether the customer is in a developing country or a state-of-the-art technological one. However, for this company sources of supply are constantly in a state of fluctuation and its APAC customers experience spiky, highly-variable demand growth patterns. Expansion, socio-economic conditions, and politics make it difficult to forecast consumer demand. Additionally, as a world-wide company, domestic and international supply chains often overlap to take advantage of scale. When redesigning one, it impacts the other. This dependency and cascading effect makes tracking difficult. Finally, the impacts of supply chain design on the performance values of cycle time, throughput, and WIP inventory are difficult to calculate for non-existing systems. Variability and interactions significantly impact these values. Consequently, effective APAC supply chain management offers immense potential savings in improved inventory management.

Not surprisingly, the company's international logistics management group is full of experienced professionals quite knowledgeable of the mechanics of establishing and maintaining operations outside the US. Measurement and incremental improvements in efficiency of existing systems is not the challenge. Rather, investigating new options due to fundamental changes both in supply and demand are the challenge. To meet the challenge, a partnership with academia was formed to create a decision support system (DSS) using discrete-event simulation (DES) that would add flexibility when operating and designing its supply chains in Asia-Pacific (APAC) operations. As a bonus, the DES-based DSS would improve productivity and free people to perform tasks where creativity is needed.

The system to be modeled is the company's current flow of material from US-based sources of supply (SOS) to APAC. From all parts of the US, more than twenty-five SOS export over 100 million tons of products annually to APAC customers in 20+ countries. The primary SCM decision at hand is whether to ship directly from a SOS to an APAC customer or to ship through a US-based consolidation point in an attempt to reduce transit costs by achieving economical load factors (Figure 1). Provided a full load is ready, shipping directly is always the preferred route both in terms of cost and transit time. However, if not enough orders have generated a full load, the company will ship the current orders to a consolidation point. Since other SOS are doing the same, an APAC customer-specific full load is generated at the US-based consolidation point.

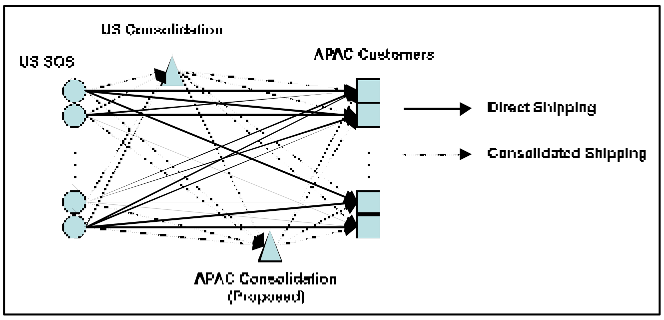

Figure 1 : US to APAC Product Flow

The decision to ship directly or through a consolidation point is complex for several reasons:

1. *The consequence of waiting for a full load:* Although shipping directly is always the cheapest and fastest, waiting for a full load before shipping increases cycle time and WIP levels.
2. *Demand variability:* For many reasons, APAC customers generate orders at different volumes and with different degrees of variability, which may substantially increase wait time.
3. *Product characteristic:* The definition of a 'full-load' is unique due to the many different products the company produces. Some loads 'cube-out' before 'weighing-out' if the product is relatively light.
4. *Delivery time components:* Delivery times are affected not only of by transit time, but also by carrier/lane availability and border-crossing times. Some APAC countries are trade friendly while others are not.
5. *Overlapping supply chains:* Although shipping direct is beneficial, shipping through the US-based consolidation point has the advantage of overlapping US/Out of US supply chains because the consolidation point is also a consolidation point for domestic and non-APAC Out of US customers. Therefore, full loads from the SOS to the consolidation point occur often.

> ***The purpose of this paper is to illustrate how a discrete-event simulation may be used to provide solutions for the flexible supply chain problems of timing and selection, using a real life example.***

Aside from these complexities, the following are questions that the DES logic system must address:

1. Using the existing network, how long should a US-based SOS wait for a full load (versus shipping through the consolidation point)?
2. Should an APAC-based consolidation point exist? If so, where? and with what impact on the domestic supply chain?
3. Can the critical components of the supply chain be determined and used to negotiate with carriers/ logistics companies to minimize shipping costs?

Each of these questions may be answered through a simulation model that allows flexibility when conditions change, despite the complex variables required in the supply chain decisions presented here. Specifics of the model developed and the software used are discussed next.

Modeling Issues

Discrete-event simulation was the technique used to model the flexible supply chain timing and load decisions. Software used to create the DES was Simul8. Simul8 is a low-priced ($1,000) DES package that offers considerable capability and ease-of-use. Its programming language, Visual Logic (VL), and global variable spreadsheets are invaluable when modeling supply chains.

Initialization Logic Using Simul8's Visual Logic and Global Variable Spreadsheets

For DES-models to become part of a process, data must be clearly separate from the model logic. Otherwise, subsequent analyses require modeling changes instead of only data changes. The more effort put in designing the separation of data and model, the more likely the model will be appropriately specified and suitable for use in subsequent analysis. In this project, all modeling parameter values were read from a MS-Excel data file. The company generated the MS-Excel file from database systems. When designing the data file, non-existing network possibilities were included to generalize the model. For example, some APAC customers had no history of ordering from some SOS. However, that possibility (and dummy values) was still modeled to (1) provide future possibilities and (2) allow the use of looping logic when initializing the model.

The software's internal programming language resembles many other application-level languages and provides complex logic and general extensibility. In this model, VL was used for initializing the system of work center parameters (Note: a work center is a Simul8 construct that performs work on an entity). For example, the definition of a full load was unique and SOS-customer specific. That is, each SOS-customer combination had uniquely defined full loads. By using clever naming conventions of the modeling work centers and using VL looping logic, work center full load values were initialized for each combination. Without this capability, a work center representing each combination would have to be modified manually, likely 200+ potential modifications.

Model parameter data inputted from MS-Excel was imported to global variable arrays defined as 'Information Store Spreadsheets' in Simul8. These spreadsheets can be readily accessed using looping logic and/or indices using VL. Within the model, each day's new orders attributes are assigned by using the spreadsheet and VL looping logic.

Time Periods and Entities

The simulation time periods were defined as days, primarily because customer orders occurred on a daily basis. The SOS operated on 5, 6, or 7 day workweeks and calendar logic represented this accordingly. A simulation entity was 2000 lbs. Several 'scaling factors' were evaluated with the tradeoff of accuracy versus CPU time. Larger scaling factors (i.e., 5,000 lbs., 10,000 lbs.) ran much quicker, but failed to adequately track the number of shipments (See section on Validation). Smaller scales (1,000 lbs.) required lengthy CPU time (over a day) to run a one-year trial. A 2000 lb.-scale trial ran in 1-2 hours on a Pentium III 1.0 GHz machine.

Simul8 has 'high-volume' capability designed to be used for Fast Moving Consumer Goods (FMCG) applications. It offers reductions in simulation time by reducing the number of entities. Unfortunately, the 'high-volume' capability was incompatible with the complex routing and collecting rules required by the system.

Modeling Waiting for a Full Load Using Simul8's Shelf Life

The primary decision logic was keeping track of how long it took for filled orders to generate a full load. If a full load occurred before some predetermined time period, direct shipping occurred. Otherwise, the filled orders were shipped to the consolidation point. Simul8's “Shelf Life” construct modeled this logic very neatly without having to use extra code. In Simul8, queues can have a shelf life, which is the maximum amount of time that an entity waits in the queue before being removed. In the model, each SOS had a queue of filled orders. Filled orders that waited until the shelf-life value was reached were immediately removed from the queue and transferred to other logic that moved the entities to the consolidation point.

Modeling Transit Times Using Simul8

Tracking filled-orders moving through the supply chain required modeling both order volume and the number of shipments. A shipment is composed of multiple orders and is a dynamic value. Visual logic was used to dynamically determine how many orders were assigned to a shipment. Once assigned, transit times were modeled using Simul8 queue's minimum wait time construct. Similar but opposite to shelf life, minimum wait time is the amount of time that entities must wait before they can leave the queue.

> ***Without a living model, companies typically use large amounts of human effort to fight these fires. Consequently, the DSS-based analysis' value is equally as attributable to its promptness as to its quality.***

Validation

Validating the model required reproducing the previous year's actual system performance measures in terms of volume (lbs) and shipments (count). Each location (SOS, consolidation point, and APAC customer) was compared by running actual shipment history through the model. Student t-tests for each location's volume and count showed the model statistically represented the actual system. Once validated, the historical shipments were fit to probability distributions. Many were classically Poisson; however, some of the low volume SOS-customer combinations were fit with empirical discrete probability distributions. A warm-up period of three months (ninety days) was used and adequately provided a stabilized time-in-system (Figure 2).

A Sample Analysis : Determining Optimal Wait Time for Direct Shipments

The initial analysis quantified the effect of waiting for a full load on cycle time and WIP. As mentioned, fully loaded, direct shipments between a US-based SOS and an APAC customer were always the fastest and cheapest. Also, full loads have the benefit of reducing the number of shipped containers through the consolidation location. However, waiting for a full-load does add WIP to the system and increases cycle time. Prior to the analysis, the assumed cost tradeoff was shipping costs versus inventory costs.

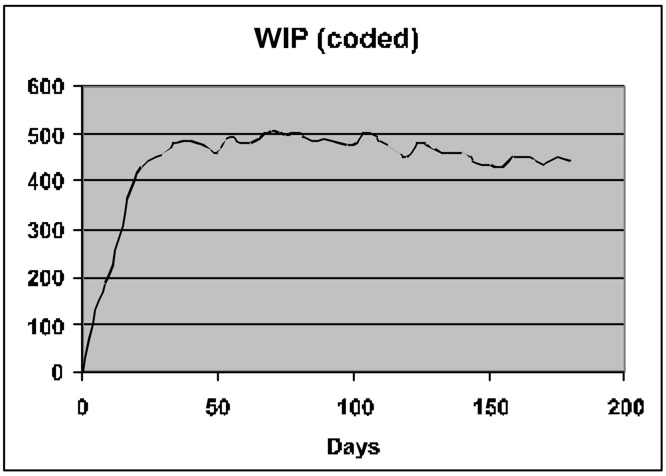

Figure 2 : Establishing the Warm-up Period

Figures 3 and 4 show the results. In all charts, the horizontal axis is the “Maximum Days Waiting for a Full Load”. For all SOS/customer combinations, an across-the-board value was chosen for the first ten runs. In the last run, an intelligent policy was used that was specific to each SOS/Customer combination. In the policy, reasonable (50% chance) time-to-generate-a-full-load estimates were calculated using a Normal approximation of the Poisson demands. Provided these demand estimates were less than a week, direct shipping was given an opportunity. If the estimates were longer, no direct shipping was used, and the SOS shipped immediately to the consolidation location.

For the first ten runs, Figure 3 shows that WIP increased as SOS waited for a full loadmaterial waiting on a dock adds both time and inventory to the system. However, the expected benefit was assumed to be fewer shipments. Figure 4 shows a reduction in shipments from the

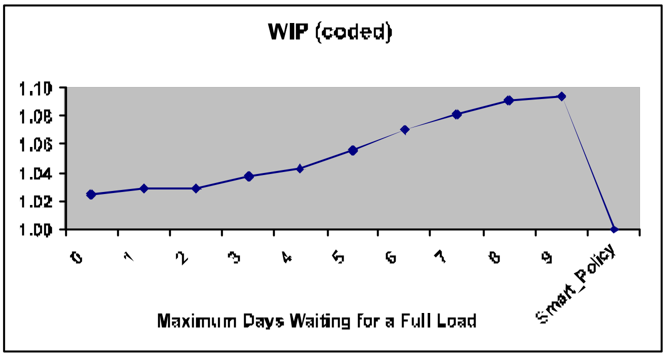

Figure 3 : The Impact of Waiting for a Full Load on CT and WIP

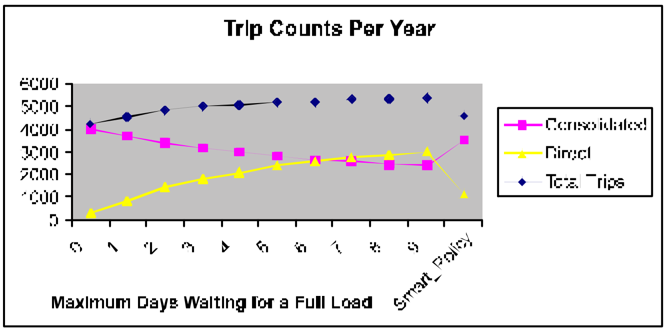

Figure 4 : The Impact of Waiting for a Full Load on Trip Count

consolidation location to APAC customers; however, direct shipments increased. From history and the model, direct shipping loading efficiencies are slightly less than through consolidation. As direct volume increases, direct container counts increase faster than consolidated container counts decrease. Consequently, total shipments gradually increase, and no advantage exists for waiting for a full load.

In the last run, the days waiting for a full load are SOS/ customer specific. It offers better WIP levels than all other runs and shows a significant decrease in total shipped containers. The final decision about the number of days to wait is an economic analysis. The exact economic analysis is proprietary; however, in an effort to provide some insight on the benefits of a single application of the model, we have prepared an analysis of the Smart policy (proposed) with the policy of waiting four days across-the-board for a full load (existing). Figures 3 and 4 show that the Smart policy reduced both WIP levels and annual total containers shipped. Specifically, Figure 3 shows that the Smart policy reduced the WIP level by 4% from the Four-Day Max Wait policy. Assuming this equates to removing one day from the supply chain cycle time the annual WIP savings formula is

Companies requiring the development and use of complex supply chain simulation models may derive greater efficiencies and use of resources through outsourcing the task to experts as actualized in the example presented in this paper.

$$\text{Annual WIP Savings} = (1/365) * \text{Annual Volume (lbs)} * \text{WIP cost (\$/lb)} \quad [1]$$

Using a WIP cost of $1/lb, for a 100 million pound volume, the annual WIP savings equals $273,973.

Figure 4 shows the Smart policy reduced the annual container shipments to 4,600 from the Four-Day Max Wait policy of 5,000, a reduction of 400 containers. Assuming the cost to ship a container is $500, and that the cost of shipping is only a function of the number of containers, irrespective of the loading efficiency, the annual shipping cost savings realized in this example would be $200,000. With both WIP levels and total shipments reduced in this example, the total annual cost savings is $473,973. Although consolidated shipments increased, the impact of double handling was more than offset by the reduction in the total containers shipped .and the reduction in waiting for a full load time.

Project/Process Management

The DSS was developed in three months. This included an initial meeting, model building, validation, and an initial analysis. During the initial meeting, the process objective was established and emphasized the development of a long-term methodology for addressing SCM questions rather than on answering a specific problem. The long-term approach minimized having to rush to provide an answer often seen in simulation projects. Secondly, a long-term outlook ensured that cost savings and beneficial results did not have to occur on the initial analysis. Simulation answers often are similar to intuition/guesses. In these instances, the simulation model has little effect on the cost savings. Short-term thinking may conclude that simulation should be abandoned. However, a situation will eventually arise where the model offers a counter-intuitive solution. A long- term outlook ensures these results can occur.

Additionally, the benefit of simulation (and operations research methodology in general) is often seen in increased productivity. Provided enough people and resources are available, most SCM problems can be reasonably solved. Unfortunately, this fire-fighting methodology requires having enough people to attack the problem on an as-needed basis. With corporate down-sizing, fire-fighting is not a reasonable approach. An operations research-based DSS replaces people effort; thus, productivity is increased. For this DSS, a second analysis was requested six weeks after the initial analysis. The initial analysis was produced in three-months, and the subsequent analysis took three days because of the establishment of the process.

Conclusions

In this paper, flexibility is defined as the distillation of massive amounts of information into useful knowledge to enable supply chains to adapt quickly to changes in the system such as consumer tastes, new technologies, or global political changes such as acts of terrorism and/or increased border security. The use of a decision support system based on discrete-event simulation for modeling material flow from US-based sources of supply to APAC-based customers was demonstrated. The simulation modeling software was Simul8, a full-featured, low-cost solution that adequately represented the supply chain of study.

Flexibility requires answers rapidly. Although supply chain design changes are not generally daily decisions, prompt answers are valuable when a design change is to be considered. To ensure this type of flexibility a partnership was established between academia and industry where the academician maintained the model, and the company maintained and provided the data. Not only does this provide flexibility, but it also reduces economic risk by removing the requirement that the company add modeling expertise resources. The partnership is providing needed analysis and improving productivity within the company while minimizing costs associated with software and expertise acquisition and retention. Future improvements to the DSS will likely include the addition of outbound supply chains (South American, Europe,) to the model and and use of the web-based capabilities of Simul8's Player.

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Flexibility Mapping : Practitioner's Perspective

Although discrete-event simulations (DES) have been used extensively in business for decades to test the outcome of specific types of events, they have not traditionally been used in supply chains to optimize material flow. This paper demonstrates how an academician--company partnership was used to develop and support a DES decision support system in this context. Specifically, the academic partner developed and maintained a simulation model for optimizing load shipment wait-time and size into the Asian-Pacific region using data provided by a company. Both the simulation modeling process and the academician--industry partnership allow firms to create and maintain flexibility while reducing required in-house resources. For example, partnered firms need only ship new datasets to their academician partner when changes arise without permanently acquiring DES-dedicated talent,

Reflecting Applicability in Real Life

This paper uses a real life situation to illustrate the way in which a discrete-event simulation was used by an academician-firm partnership to provide a flexible model designed to determine optimal shipment load/size/ time. The process described in the paper is viable across numerous situations, not just shipment size/time issues, and across most industries.

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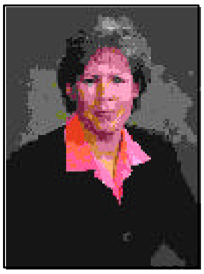

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Case Studies

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Differences in Supply Chain Performance Across Interorganizational Communication Levels: Case Studies from Denmark

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Abstract

Within the framework of Quick Response Systems (QRS), this paper examines different levels of interorganizational communication and their impact upon supply chain performance. Using case studies of three Danish firms well known for their well executed supply chains, we consider differences in supply chain performance relative to differences among levels of interorganizational communication. In each case, we demonstrate how companies can be flexible when demand forecasts are not effective as a basis for supply management. We analyze how these companies use QRS and describe the information the companies exchange with key suppliers. The type of data exchanged and the use of that data are used to classify each firm's level of interorganizational communication.

Keywords : case study, interorganizational communication, quick response

Introduction

Strategies for making supply chains lean and agile are important for companies to be competitive in a marketplace dominated with uncertainty; in this case, demand forecasts are not a sufficient basis for improving supply chain performance (Christopher & Towill, 2000). Over the last ten to fifteen years, the US and European grocers have developed and refined Quick Response Systems (QRS) to improve supply chain performance in a market with highly variable demand. These systems integrate supply activities across companies downstream in the supply chain focusing on retailer-wholesaler relationships (Kotzab, 1999, pp. 365). The goal is to achieve an agile and lean supply chain by sharing actual information regarding demand and inventory position (at the SKU-level) instead of having supply chain partners rely on forecasts. Sharing this data helps firms reduce the Forrester-effect (Forrester, 1961). An important tool for achieving quick response is interorganizational integration of systems based on the extranet defined as Interorganizational Systems (Premkumar, 2000). In recent years some of the ideas, principles and systems have been implemented in leading Danish manufacturing companies. This paper focuses on one facet of interorganizational systems: the level of communication.

We will focus on dyadic relationships between a manufacturer and its upstream suppliers in the supply chain. In this context, the buyer/supplier relationships are based on a single sourcing strategy, i.e. the supplier is given all the buying volume from the manufacturer, and thus the relation is one of close and longstanding cooperation based on mutual trust between the parties. Furthermore, this type of buyer/supplier relationship presents ideal conditions for applying Premkumar's interorganizational systems framework (Premkumar, 2000). We discuss theory of supply chain performance, quick response and interorganizational systems as a basis for developing a model for describing and analyzing the three case studies.

Supply Chain Performance

In this paper, supply chain management: Encompasses all activities associated with the flow and transformation of goods from the raw materials stage, through to the end user, as well as associated information flows. Material and information flow both up and down the supply chain. Supply chain management is the integration of these activities through improved supply chain relationships to achieve a sustainable competitive advantage (Handfield & Nichols, 1999).

This definition focuses explicitly on materials and information flows. Hence, effective flow of information across the supply chain can improve the flow of materials. Therefore, electronic flows of information across supply chains can be important drivers for improving supply chain performance.

The definition also focuses on the integration of business processes across companies in the supply chain. Business processes include processes such as product development, order fulfillment, production planning, and procurement. In this paper, we define Quick Response Systems (QRS) as a tool for integrating the material and information flow among the companies in the supply chain.

The goal of a supply chain is to deliver superior end customer value at minimal cost to the supply chain as a whole (Christopher, 1998). More specifically the first goal of supply chain management (SCM) can be seen as to maximize the effectiveness of the chain's outcome, thereby providing superior service to the common end customer of the chain. This first goal demands that the company be agile. In this paper, we consider agile to be synonymous with flexible, despite differences in the definitions of these concepts. Agile elements could include lead time, reliability, change in volume and product mix, and delivery information – many of these are also considered in definitions of flexibility. The second goal of SCM is to maximize the efficiency in the supply chain processes thereby minimizing total supply chain costs. This second goal demands that the company to be lean. Lean elements can include price, productivity, inventory, utility of assets and transaction costs. Seen from a system perspective (Arbnor & Bjerke, 1997), optimal supply chain performance can be achieved through synergy by a combination of the effectiveness of the chain outcome (being agile) and the efficiency attained in the supply chain processes (being lean).

An important tool for achieving quick response is interorganizational integration of systems based on the extranet defined as Interorganizational Systems (Premkumar, 2000). In recent years some of the ideas, principles and systems have been implemented in leading Danish manufacturing companies. This paper focuses on one facet of interorganizational systems: the level of communication.

Beamon (1999) investigates which measures normally are used to measure supply chain performance and concludes that supply chain models predominantly utilize two different groups of performance measures: cost and a combination of cost and customer responsiveness. Beamon also suggests three types of measures to monitor the performance of the supply chain:

- Efficiency oriented measures that are related to the usage of resources
- Effectiveness oriented measures that are related to outputs
- Response oriented measures that are related to the flexibility of the supply chain.

According to Beamon, flexibility of the supply chain in this definition includes both lean and agile elements: for example, holding inventory is a way of maintaining flexibility to ensure the right delivery performance. In this paper, we will use this definition of flexibility to analyze supply chain performance.

Quick Response Systems

In the early 1990s, Efficient Consumer Response (ECR) was introduced as a powerful tool for optimizing the supply chain performance within the US grocery industry. This system has also been presented as Vendor Managed Inventory (VMI) or Continuous Replenishment Programs (CRP) and further developed into a broader concept like Collaborative Planning, Forecasting and Replenishment (CPFR). These systems and concepts can be categorized under the umbrella called Quick Response Systems (Christopher, 1998). Quick Response Systems can be seen as "IT-driven just-in-time-oriented logistics systems combining EDI, barcode and scanning technology for their uses. The basic structure lies in the realization of the just-in time principle by meeting actual demands with supply synchronized delivery systems" (Kotzab, 1999, pp. 365). Hence the supply chain is considered both agile (flexible) and lean (productive) if it can react quickly to demand changes and at the same time be cost efficient (Naylor, 1999). The key issue in Quick Response Systems (QRS) is how far real demand is made visible upstream and how feedback can have a beneficial impact on reducing upstream amplification and distortion of demand. The main information in QRSs which is shared between the partners for use in decision support includes:

- Forecasts
- Production plans
- Maximum-minimum inventory levels
- Actual inventory levels
- Reorder points
- Order quantities

Based on this information, the supplier assumes the responsibility for the replenishment of goods to the manufacturer. QRSs pursue both agile and lean objectives including improved responsiveness, reduced delivery times, reduced distortion of demand, reduced double buffering, reduced administrative costs, and improved capacity planning

Interorganizational Systems

Interorganizational Systems, also called extranets, "are application systems that link various partners in the supply chain using a public or private telecommunications infrastructure" (Premkumar, 2000, p 59).

New standard applications for Interorganizational Systems have been a driver for implementing QRSs in supply chains. Premkumar (2000) divides Interorganizational Systems into three levels of sophistication: communication, coordination, and cooperation.

Communication

Communication means electronic communication of messages between partners in the supply chain, which may or may not be integrated with the rest of the information systems in the organization. At this lowest level, firms substitute paper, phone or fax modes of communication for computer-to computer communication.

Coordination

At the second level, there is active coordination in terms of production planning, procurement, and distribution between the partners, in which the communication is integrated with the internal information systems. Premkumar mentions Dell as a good example of how a company shares orders and customer information with suppliers and logistics providers to reduce lead-time, costs, and improve responsiveness.

Cooperation

At the third level, "two business partners cooperate by sharing common goals and use similar performance measures to evaluate the performance of their interorganizational activities" (Premkumar, 2000, pp. 59). At this level, companies not only exchange and share information but also plan their supply activities in cooperation. (In this paper, we assume that information is freely shared among the partners because all members in the supply chain benefit from the implementation.)

The key issue in Quick Response Systems (QRS) is how far real demand is made visible upstream and how feedback can have a beneficial impact on reducing upstream amplification and distortion of demand.

Table 1 : Summary of the Correlations between QRSs and Modes of Interorganizational Communication

Quick Response Systems	Mode of Interorganizational Communication		
Information exchanged	Communication	Coordination	Cooperation
Actual inventory levels	Data flow	Data flow	Data flow
Reorder point	Data flow	Data flow	Data flow
Forecast	Data flow	Coordinated with partner	Developed cooperatively
Max/min inventory levels	Data flow	Coordinated with partner	Developed cooperatively
Order quantity	Data flow	Coordinated with partner	Developed cooperatively
Production plan	<not necessarily shared>	Coordinated with partner	Developed cooperatively

Research Questions and Methodology

The objective of this study is to examine buyer/supplier relationships in supply chains in three Danish manufacturing companies and analyze how and to what extent they have integrated ideas from Quick Response Systems in their business processes by effectively using varying levels of interorganizational communication. In the paper, we address the following questions:

– What information is communicated between the companies?

– At which level are the firms communicating across organizations?

– What are the effects on supply chain performance?

To answer the questions we use the relationships summarized in Table 1.

The first objective of our study is to consider information exchanged between the partners, such as forecast, production plan, maximum-minimum inventory, actual inventory, reorder point and order quantity. The second object of our study is to consider the level of interorganizational communication and its impact upon supply chain performance.

The companies we have chosen are well known for their supply chain capabilities. That is, they represent best practices and unique cases in Danish industry. At each firm, we interviewed purchasing and logistics managers and project leaders at these firms who were responsible for the implementation of Quick Response Systems.

Case Studies

In the following we describe three Danish cases of an implementation of Vendor Managed Inventory Systems (VMI). As stated earlier, VMI is a management tool categorized under the umbrella named Quick Response Systems. We choose to use the name VMI in our case descriptions, because this is the name used by the companies. However, we will evaluate the three case stories in relation to all the information described in the Quick Response Systems theory. This way we may examine how long the three cases have progressed compared to the three modes of interorganizational communication shown in Table 1.

Novo Nordisk Ltd.: Case A

Novo Nordisk Ltd. is a holding company with worldwide markets in pharmaceuticals and industrial enzymes. Novo Nordisk has a turnover of 25 billion DKK, of which 70 % is from diabetics, and the rest is from haemostasis management and hormone replacement therapy. Novo Nordisk employs 16,000 people. The headquarters is located in Bagsværd, Denmark and it also has manufacturing facilities in France and the US. Subsidiaries are located worldwide. In this paper, we focus only on the diabetes supply chain. In 2000, Novo Nordisk started up a vendor managed inventory pilot project with two suppliers and the system has been functioning for one year. The top management is considering rolling out the system to all 25 suppliers. Before this project, Novo Nordisk had already experienced good results from establishing a direct link between subsidiaries and production facilities. The responsibility for inventory management was transferred to the production department. The ordering process no longer had to pass through the customer service department. This reduced the order cycle time from six to two months on average. Figure 1 describes the information flow of the supplier- manufacturer relationship.

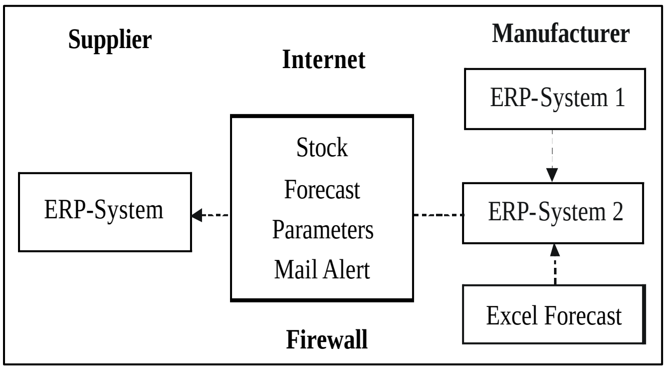

Figure 1: Novo Nordisk : Interorganizational Communication Mode

Novo Nordisk uses two Enterprise Resource Planning - systems (ERP) and a tailored Excel system for forecasting. ERP 1 is an old system, which runs the logistics modules. ERP 2 is SAP R3-based and primarily runs finance data. Information on stocks, order quantity, parameters and lead-time are transferred asynchronously but direct without no human intervention from ERP 1 to ERP 2. Forecast from the Excel system is transferred to ERP 2. Via the Internet, the information is then communicated from ERP 2 to the supplier's ERP-system once a week, which is Axapta from Microsoft. Hence three different systems are involved. According to strict definitions of ERP, Novo Nordisk does not have an integrated information system, but has legacy systems.

A mail alert is communicated to the supplier and the supplier receives a list containing per item information on forecast, reorder point, and parameters such as maximum-minimum inventory for each item. The supplier does not decide the order quantity, but can decide upon replenishment with a 10% variation. No automatic coordination occurs between the information systems. The benefit for the supplier is to plan capacity and delivery based on data provided directly from Novo Nordisk. The Interorganizational Systems can be classified at the lowest communication level. It has not been possible yet to interview the supplier, but Novo Nordisk claims that inventory is reduced by at least 12%. By rolling out to all suppliers, Novo Nordisk sees significant savings, especially when consignment inventory is also considered. Seen from a supplier perspective the system is not very flexible since the supplier is controlled by the inventory control system of Novo Nordisk. Still they have some benefit of better capacity planning based on forecast from Novo Nordisk and reduced safety stock since they can react to actual demand.

There are more potential benefits for both parties in future developments of the system. We will characterize the VMI system in Novo Nordisk as a communication mode of interorganizational communication. This means there still is great potential for developing a more flexible and responsive system.

Interorganizational Systems, also called extranets, "are application systems that link various partners in the supply chain using a public or private telecommunications infrastructure" (Premkumar, 2000).

Oticon Ltd.: Case B

Oticon Inc. is one of the world's leading producers of advanced hearing aides. It is a well-known Danish company and part of William Demant Holding Group. Oticon employs 2,000 people with its largest manufacturing operations in Thisted, Denmark, while smaller plants are located in Scotland and Australia. Oticon has a significant number of end items with stable demand and common components. These items comprise about 75% of Oticon's production, while the other 25% are variants handled by individual, computer generated work orders. The special orders are usually placed by Oticon's own subsidiaries and are produced and shipped within 24 hours (Christiansen & Maltz, 2002). Since 1997 the operation in Thisted has relied on a VMI system called "Supplier Monitored Delivery System" (SMDS). Recently this system was updated to a second-generation SMDS using Videlity software,[1] allowing quicker implementation and adaptation by the suppliers. Oticon expects to implement the new system with an increased number of suppliers. Today Oticon already has VMI-cooperation with 12 suppliers, corresponding to 70% of the total purchasing volume of the factory in Thisted. The new SMDS solution is expected to follow the footsteps of the old version, adding value to the operations by increasing inventory turnover and reducing the manual handling of orders. Figure 2 describes the information flow of the supplier- manufacturer relationship in Supplier Monitored Delivery System.

[1]Videlity Software A/S is a Danish owned software company founded by former employees of IBM. \Videlity Software develops and implements IT-solutions aimed at connecting supply chain partners.

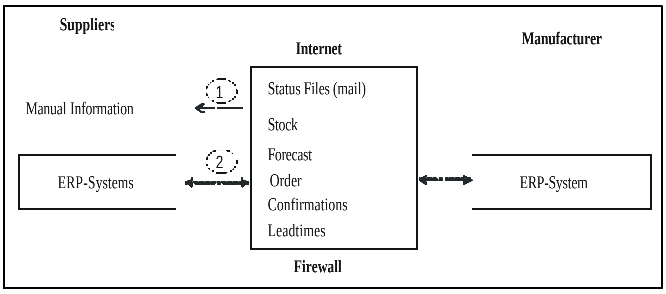

Figure 2 : Oticon : Interorganizational Coordination Mode

Oticon uses Videlity software to extract and control data from their ERP system. Oticon divides their suppliers of their new SMDS system into two categories: (1) a simplified manual model providing only push information via e-mails; and (2) a highly integrated advanced model designed to exchange information between the Oticon's ERP-system and the supplier's ERP system. In the highly integrated model, information is transferred, on supplier request, directly and without no human intervention from the Oticon ERP-system into supplier's ERP-system. Dividing the new SMDS system into two categories gives Oticon the opportunity to reach technologically immature but still very important suppliers.

The objective of this study is to examine buyer/supplier relationships in supply chains in three Danish manufacturing companies and analyze how and to what extent they have integrated ideas from Quick Response Systems in their business processes by effectively using varying levels of interorganizational communication.

In the highly integrated setup, Oticon exchanges stock levels and forecasts on request from suppliers logging on via the Internet. These suppliers respond by providing order confirmations and updated lead-times, which is transferred back into the Oticon ERP-system. Minimum and maximum inventory levels are decided and controlled by Oticon. Actually the minimum and maximum inventory levels are adjusted on a daily basis through a function of the forecast and supplier lead-times and expressed by "days of inventory." In principle, the supplier has full flexibility to decide order quantity between minimum and maximum stock levels, but Oticon requests information on what and when the supplier is going to deliver in advance via order confirmations.

In this relationship, there are several flexible and coordinating elements according to the two dimensions in our design model. Based on direct two-way computer-to-computer communication, the supplier coordinates internal capacity planning based on forecast production plan from Oticon. The supplier has some flexibility in ordering up to a certain limit controlled by Oticon. Oticon has benefited from an improved delivery service compared to their competitors since they have installed this system. As forecasts, min/max inventory levels, order quantities and production plans are co-ordinated with suppliers due to the model presented in Table 1, we will characterize the VMI system in Oticon as a coordination mode of interorganizational communication

Bang & Olufsen Inc.: Case C

The Bang & Olufsen group is a world famous manufacturer of technologically sophisticated, high-quality and high-end design consumer audio, video and telecom products. The 2001/2002 net turnovers were approximately 4.2 billion DKK and 81% of the sales came from foreign markets. Bang & Olufsen employs 2,900 people. The headquarters is located in Struer, Denmark. All production is made at the factories in and around Struer. All purchasing, production and logistics for the Bang & Olufsen group is handled by Bang & Olufsen Operations Inc.

Bang & Olufsen Operations Inc. was organized as a separate company in June 2001 to strengthen the focus on internal profitability in the production and the logistical operations in the Bang & Olufsen group. The case, presented in this paper focuses on Bang & Olufsen Operations Inc. The top priorities in Bang & Olufsen Operations Inc. are to reduce stock levels across the supply chain and to improve supply reliability and precision towards retailers in the market. Current primary focus is on integrating with first tier system suppliers (Hines, 2000).

One of the tools is called "the vendor on-line system." The first version of "the vendor on-line system" dates back to the early 1990s, when a dedicated Value Added Network Services interface to the suppliers was used to communicate data. Today the system is more sophisticated in its functionality and uses the Internet as an integration platform. Bang & Olufsen Operations Inc. has three ways of communicating production needs to the suppliers in the chain: paper orders, EDI-messages, and "the vendor on-line system." The number of transactions in "the vendor on-line system" corresponds to around 35% of the total transaction volume and the system is primarily used to connect Bang & Olufsen and the system suppliers delivering system. Systems suppliers supplies complete strategic product-subsystems, to the final assembly lines in Struer, Denmark. Figure 3 describes the information flow of the supplier-manufacturer relationship in "the vendor on-line system."

The production requirements and current stock levels resulting from the daily MRP-run is transferred to a data warehouse from the SAS Institute[2] (SAS-system). On top of this, information about current quality and logistical performance per supplier/material number and information about delivery address per material number is transferred from SAP R3 to the SAS-system at least once a day. In

[2]SAS Institute is a global company that develops, markets and supports data warehouses and decision support software for businesses and government agencies.

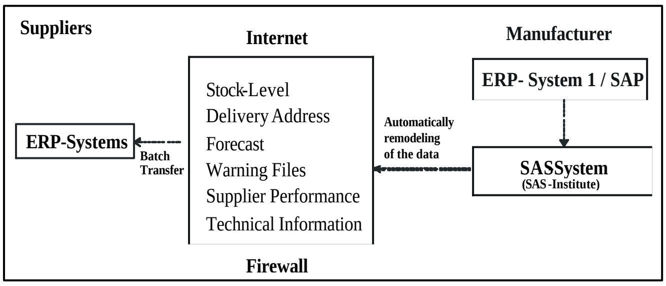

Figure 3 : Bang & Olufsen: Interorganizational Coordination and Limited Cooperation Mode

connection with the data transfers to the SAS-system, the data are automatically remodeled to fit a predetermined layout and data format. The SAS-system further provides a flexible engine for statistical analyses and different data aggregations requested by the suppliers via the Internet.

At least once a day, typically just after the batch runs, the system supplier connects via the Internet to the "vendor on-line system." Here the supplier pulls the data needed in a flexible way with multiple options. In this process, the data is actually remodeled in the SAS-system at Bang & Olufsen Operations and transferred directly to the supplier's ERP-system. Degree of flexibility inside minimum and maximum inventory levels are agreed upon in regular coordination meetings between representatives from Bang & Olufsen Operations and the supplier. Within the minimum and maximum inventory, the supplier has full flexibility to decide the order quantity.

There are more potential benefits for both parties in future developments of the system. We will characterize the VMI system in Novo Nordisk as a communication mode of interorganizational communication. This means there still is great potential for developing a more flexible and responsive system.

In this relationship the two partners are not only using systems to coordinate plans and ordering, they also coordinate their plans systematically at meetings. So the supplier has more influence on supplies to Bang & Olufson. Hence we characterize the VMI system in Bang & Olufson as a coordination mode and a limited cooperation mode of interorganizational communication. They can still benefit of a more direct and responsive Interorganizational System.

Analyses and Implications of the Case Studies

The findings in the three cases are summarized in Table 2. The left hand column shows the information exchanged between the supplier and manufacturer. The right hand column shows the mode of interorganizational communication used.

Novo Nordisk, (Case A), communicates information on forecast, inventory level, and maximum-minimum inventory with its suppliers. The supplier only uses information for capacity planning. No coordination or cooperation is conducted between the partners. The alert does not give the supplier much freedom to reduce safety stocks. Hence it is most beneficial to Novo Nordisk and to some extent also to the supplier.

Table 2 : Evaluating Three Cases (A, B & C) to Quick Response Systems and Modes of Interorganizational Communication

Information Exchanged	Communication	Coordination	Cooperation
Quick Response Systems	**Mode of Interorganizational Communication**		
Actual Inventory	A,B,C		
Reorder Point	A,B,C	B,C	
Forecast	A	B,C	
Max-min Inventory	A	B,C	
Order Quantity		B	C
Production Plan		B,C	

We have evaluated the effects on supply chain performance, and we conclude that the Interorganizational Systems implemented between Novo Nordisk and their suppliers increased the supply chain efficiency moderately (lean) but have no pronounced effect on the supply chain effectiveness (agile). The small efficiency increase is attained through a productivity increase in the Novo Nordisk purchasing department, no pronounced productivity decrease in the purchasing department of the suppliers and the effects on transaction cost between the partners through the conversion of some tasks from the physical supply chain to the virtual value chain (mail etc.).

Oticon, (Case B), coordinates information across interorganizational boundaries. After the internal aggregate planning is performed at Oticon, the combined forecast and production plan is coordinated with the suppliers. The min/max inventory level is adjusted as a function of supplier lead-time. Finally, the relationship with respect to the order quantity is coordinated. The supplier decides the order quantity as long as the resulting inventory levels stays inside the max inventory level on delivery. But the order quantity must be communicated to Oticon in advance of delivery.

We have evaluated the effects on supply chain performance, and conclude that the Interorganizational Systems implemented between Oticon and their suppliers both increased the supply chain efficiency and makes the supply chain more agile, that is increases the effectiveness of the chain as a hole. The efficiency increase obtained at Oticon is contrary to the Novo Nordisk case attained through a combination of several factors. Besides the effects on productivity and transaction cost which is similar to the Novo Nordisk case, we have observed that the flexibility given to the suppliers in this case results in lover inventory levels in the supply chain as a whole. The increase in the effectiveness of the chain as a whole is attained through a combination of more reliable deliveries and decreased lead-times from the suppliers to Oticon and this effect can be traced further down the supply chain through to the final customer of the chain.

Bang & Olufsen, (Case C), combines coordination and cooperation. The combined forecast and production plan coordinated with the suppliers is exactly the same way as in the Oticon case. The minimum-maximum inventory levels are coordinated in regular meetings between the purchaser at Bang & Olufsen and the sales representative at supplier. This coordination ensures flexibility for the suppliers. The flexibility level is often agreed as a function of the module value and volume. Finally, the relationship with respect to the order quantity can be described as cooperation. There is complete flexibility for the suppliers to decide when and how much to deliver, as long as the resulting inventory levels stay inside the maximum inventory level on delivery. Bang & Olufsen Operations is not interested in order confirmations, which means that the delivery can be changed up to minutes before delivery.

As forecasts, min/max inventory levels, order quantities and production plans are co-ordinated with suppliers due to the model presented in Table 1, we will characterize the VMI system in Oticon as a coordination mode of interorganizational communication.

We have evaluated the effects on supply chain performance and conclude that the Interorganizational Systems implemented between Bang & Olufsen and their suppliers both increased the supply chain efficiency and makes the supply chain more agile, that is increases the effectiveness of the chain as a hole. The effects and the conclusion are the same as in the Oticon case, that is we conclude that they only differ on one single point. As mentioned earlier in this paper, Bang & Olufsen Operations is not interested in order confirmations, that is, the delivery can be changed up to minutes before delivery. We observed that this feature in the system of Bang & Olufsen affected the efficiency and the effectiveness of the supply chain as a whole compared to the mode of interorganizational communication in Oticon.

The three cases are different with regards to the type of information exchanged and to the level of Interorganizational Systems in use. Bang & Olufsen is the most developed system; it gives the suppliers the opportunity to reduce inventory, smooth demand, increase internal operational flexibility, and to integrate with an important customer. While some of the system suppliers have been successful in achieving this, others still have a long way to go.

Conclusion

In this paper we have discussed the two main goals of the supply chain, which are to maximize the effectiveness of the chain outcome and to maximize the efficiency of the supply chain processes. We have shown how these goals relate to the ability of the supply chain to be both lean and agile and how this can be accomplished through different modes of communication in dyadic supplier-buyer relationships.

A model has been proposed for analyzing case studies of three successful Danish companies that have implemented Quick Response Systems with their key suppliers. The paper describes which information these companies communicate to their key suppliers and which modes of interorganizational communication they have implemented and thereby improved supply chain performance in order to be more agile and leaner. The cases show differences in the degree of integration and benefit for the partners in the supply chain. It seems that the manufacturer in all three cases are becoming leaner by reducing inventory and in one case the suppliers have gained more flexibility related to delivery quantity and production planning. However, none of the cases are integrated at the same level as Quick Response Systems in the grocery industry. So there is great potential for Danish industry to improve supply chain performance by implementing interorganizational communication as a flexible tool.

The three cases included in this article describe relations at the same level upstream in the supply chain. In these cases, we are able to ascertain the use of various modes of interorganizational communication. It would be interesting to examine whether it is possible in industrial supply chains to use cooperation modes of interorganizational communication downstream in the supply chain the way it is done in the grocery industry (Seidmann & Sundararajan, 1997). It would also be interesting to investigate which types of goods are suitable compared to where businesses are placed in the supply chain and compared to the three modes of interorganizational communication. Finally, it would be interesting to examine the relation between integration level (Lambert & Cooper, 2000) and the corresponding cooperation strategy (Helper, 1993) which matches the three modes of interorganizational communication.

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Flexibility Mapping : Practitioner's Perspective

1. Try to map your own organization on following continua regarding to the level of interorganizational Communication (Please tick mark in the appropriate box(es)).

Inventory levels

Communication (| | | | |) Cooperation

Reorder Point

Communication (| | | | |) Cooperation

Forecast

Communication (| | | | |) Cooperation

Order Quantity

Communication (| | | | |) Cooperation

Production Plan

Communication (| | | | |) Cooperation

2. To what extent do you find the supply chain in your organization lean and agile (flexible)?

Reflecting Applicability in Real Life

1. How could you enhance your Quick Response System? Which of the ideas presented in the three cases could be relevant for your own organizational context regarding to achieve a leaner and more flexible supply chain?
2. Identify and describe the types of Interorganizational Systems that could support your enhanced Quick Response System? Are these ideas from the system configurations presented in the three cases that could support your Quick Response System?

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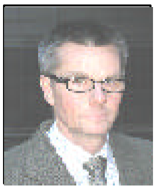

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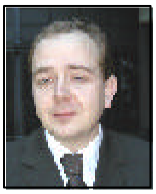

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Case Studies

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Early Supplier Involvement: Implications for New Product Development Outsourcing and Supplier-Buyer Interdependence

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Abstract

Rapid technological development, shorter product life cycle, clockspeed competition, and increased outsourcing have prompted many firms to involve their suppliers early in their new product development activities. This paper examines early supplier involvement in new product development and how it is influenced by outsourcing and degree of supplier-buyer interdependence. One of the objectives behind early supplier involvement is to increase product development efficiency and effectiveness as well as to tap into supplier's technological capabilities. However, suppliers can introduce serious problems as well, aggravating the complexity of managing new product development projects furthermore. The aim of the paper is to show that the degree of supplier involvement is dependent on various tradeoffs between sourcing strategies and the degree of supplier-buyer interdependence. The three case studies indicate that, although these firms are aware of the potential benefits of early supplier involvement in NPD, only one firm is embracing the idea, in spite of high degree of outsourcing. Depending on the technological complexity of the product architecture and how it is decomposed, the suppliers can be involved during the planning, design, or production stages of new product development process. Based on the findings of the case studies, some implications for theory and practice are then discussed.

Keywords : early supplier involvement, new product development, outsourcing, supplier-buyer interdependence

Introduction

Globalization, deregulation, more demanding customers, the advances in information and transportation technology contribute to the complexity of designing and managing supply chains (van Hoek et al., 1999) as well as innovation management of a firm. In addition, shorter product life cycles and competitive pressures (not only in technology but also in services) have forced firms to find new ways to manage the supply chain of their products. Value added services are becoming increasingly important to consumers, and advancement of production technology is enabling products to be more easily imitated. This comprehensive information regarding consumer purchase behavior has shifted the power structure of distribution channels from manufacturers to retailers, making the product-service bundles dominant differentiating platforms (Bowersox and Cantalone, 1998). This also has reflected the way supply chains are evolving.

It is generally known that approximately 80 per cent of the manufacturing cost of a product is determined by the design of the product (Clark and Fujimoto, 1991; Jaikumar, 1986; Ernst and Kamrad, 2000), and the opportunities for further savings lie in the integration of product design and the supply chain. The integrated supply chain brings suppliers and customers closer to the manufacturer so increased value can be created. It also increases the proliferation of product offerings in the market making supplier networks more complex than the traditional supply chain. The increasing trend towards supply chain integration is in concert with discussion of consolidation of the supply base and the subsequent benefits of early supplier involvement in new product development (NPD) as a means of shortening lead times. Intensified competitive pressures during the early 1980s have forced Western assemblers to look for further savings from their components. Many automakers tried to exploit economies of scale in parts production, which meant rationalizing their supplier structure and reducing the number of suppliers (Womack et al., 1990; Lamming, 1993). It has been shown that every mass producer of automobiles during the 1980s, reduced their number of suppliers from a range of 2,000 to 2,500 at the beginning of the decade to between 1,000 and 1,500 at the end (Womack et al., 1990:157). Early supplier involvement in NPD has gained importance, both within practitioner and academic communities. Rapid technological development, shorter product life cycle, clockspeed competition (Fine, 1998), and increased outsourcing are some of the main drivers. One of the motivations behind early supplier involvement is to increase product development efficiency and effectiveness as well as to tap into suppliers' technological capabilities. However, suppliers can introduce serious problems as well, aggravating the complexity of managing new product development projects furthermore. Given the current trend of increasing supply chain integration, how does supplier involvement in NPD impact outsourcing decisions of firms? How should relationship shared between the supplier and buyer be managed?

In order to answer these questions, we focus our discussion on the processes of supplier involvement and collaboration in product development with respect to outsourcing and degree of supplier-buyer interdependence. Outsourcing decisions of technological systems are dependent on product architecture strategies. The extent to which a system can be decomposed with well-specified and standardized interfaces determines whether component outsourcing is a viable strategy (Mikkola, 2003; Mikkola and Gassmann, 2003). Modular product architectures, for instance, require that interfaces shared among the components of a system to be 'loosely coupled' (Orton and Weick, 1990), hence promoting competition among suppliers, as they possess specialized expertise to innovate independently and deliver the best technological solutions to enhance performance of the system. The division of tasks through outsourcing creates a certain degree of supplier-buyer interdependence, which can vary according to the technological complexity and strategic importance of the component. The integration of supply chain has a tremendous influence in how manufacturers of complex products manage the stream of innovative products through platform and architectural design strategy vis-a-vis suppliers' roles in new product development and manufacturing activities of the firm. This trend also forces firms to make strategic planning of its resources as well as the regime appropriability of the innovation with respect to the market and competitors.

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The paper is organized as follows. Firstly, a literature review on early supplier involvement in NPD is reviewed including its advantages and disadvantages. This is complemented with a discussion of outsourcing and degree of supplier-buyer interdependence. Next, we present three case studies of Danish firms. Based on the findings of our case studies, we discuss some implications for theory and practice. Finally, the paper ends with a summary and future research.

Early Supplier Involvement

Early supplier involvement is generally defined as a form of vertical cooperation in which manufacturers involve suppliers at an early stage in the product development and/or innovation process (Bidault et al., 1998). Involving suppliers in NPD is one way of gaining strategic flexibility through reduced cost, reduced concept-to-customer development time, improved quality, and access to innovative technologies that can help firms gain capture market share (Handfield et al., 1999). A generic NPD process and activities can be analyzed in three stages: planning, design, and production. The planning phase activities refers to the functional specification of the new product such as general product definition, lead time requirements, definition of interface specifications, platform/architecture design specifications, and outsourcing decisions. The design and production stages are often referred to as the *detailed engineering*[1] phase where bill of materials (BOM) and blue prints are generated, prototypes are built and tested, manufacturing processes and equipment are selected and qualified, and so on. Supplier involvement in the NPD process can take place at all three stages, as illustrated in Figure 1.

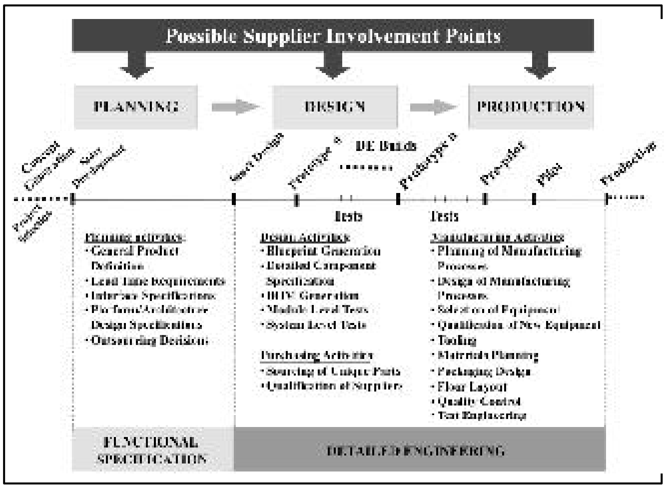

Figure 1 : Possible Supplier Involvement Points

There is a large body of literature focusing on supplier-buyer collaboration, mostly in terms of supplier-buyer relationships (Dyer, 1997; Mudambi and Helper, 1998; Veloso and Fixon, 2001), trust in supplier relations (Sako and Helper, 1998), contractual aspects (Cox, 1996), and organizational learning (Kogut and Zander, 1992). However, very little academic research examines the extent of collaboration between manufacturers and their suppliers in the development of new parts or end products (Bonaccorsi

1. Functional specification and detailed engineering are terminologies primarily used in the automotive industry (Clark and Fujimoto, 1991; Clark, 1989; Lamming, 1993; Womack et al., 1990).

and Lipparini, 1994). There is also little evidence as to how or when suppliers and customers should be involved in the development process (Brown and Eisenhardt, 1995). Over the last decade, there is an increasing interest on the notion of 'early supplier involvement in NPD,' both within the practitioners and academic communities. For instance, Handfield et al. (1999) propose a process model for reaching consensus on suppliers integrate into new product development project. They also provide a framework to facilitate insourcing and outsourcing decisions. Ragatz et al. (2002) have developed a conceptual model to test the effect of elements of the supplier integration process on cost, quality, and NPD time, under conditions of technology uncertainty.

The literature mentions many advantages of early supplier involvement. One of the main drivers behind involving suppliers early in the NPD process is to gain better leverage of suppliers' technical capabilities and expertise to improve product development efficiency and effectiveness (Wynstra et al., 2001). Using suppliers' knowledge and expertise to complement internal capabilities reduce concept-to-customer cycle time, costs, quality problems, and improve the overall design effort (Ragatz et al., 2002). On the other hand, suppliers can also introduce many problems. One of the main criteria for supplier involvement is the in-house technical capability of the supplier (Wasti and Liker, 1997). If the supplier does not have the technical capabilities, then the firm has to either help the supplier to improve its capabilities, or substitute the supplier for a better one. The manufacturer, too, can introduce problems, such as resistance from purchasing and engineering departments when the supplier does not have a finished product to base their decision on (Wynstra et al., 2001). Some of the major risks of collaborative product development include leakage of information, loss of control or ownership, longer development lead time, conflicts due to different aims and objectives, and collaborators becoming competitors (Littler et al., 1995). Some advantages and disadvantages of early supplier involvement in NPD are summarized in Table 1. The degree of supplier involvement in NPD activities is dependent upon the division of labor of functional specification and detail engineering tasks between the firm and its suppliers. Product architecture and platform specifications are generally determined at the functional specification stage of NPD process. Depending on product modularity strategies pursued by the firms, it is during this stage that component outsourcing decisions take place. In the automotive industry, for instance, outsourced components are typically classified as: supplier proprietary parts, detail-controlled parts, and black-box parts (Lamming, 1993; Clark, 1989; Womack et al., 1990). With supplier proprietary parts, suppliers are responsible for functional specification and detailed engineering activities. With detail-controlled parts, on the other, buyers are typically responsible for functional specification and detailed engineering activities. With black-box parts, buyers determine the functional specification activities while suppliers typically carry out detailed engineering activities. These components, to a great extent, dictate the degree of supplier involvement in NPD and how they cooperate to solve technical problems (Mikkola, 2003).

How a firm decides to decompose its system is dependent on the technological complexity of the system and its NPD capabilities as well as on the suppliers capabilities in developing the component at lower cost and faster lead times than by the firm itself.

Table 1: Advantages and Disadvantages of Early Supplier Involvement in NPD

Early Supplier Involvement in NPD	
Advantages	• Shorter project development lead times • Improved perceived product quality • Savings in project costs • Better manufacturability • Shared knowledge and learning • Improved NPD efficiency and effectiveness • Accessibility to supplier's technical capabilities
Disadvantages	• Risk of losing proprietary knowledge • Hollowing out internal competencies • Eased accessibility for competitors to copy or acquire key technologies • Increased dependence on strategic suppliers • Increased standardization of components through specified interfaces

Outsourcing

One of the main purposes of outsourcing is to have the supplier assume certain classes of investments and risks, such as demand variability. Due to greater complexity, higher specialization, and new technological capabilities, outside suppliers can perform many activities at lower cost and with higher value added than a fully integrated company can. New production technologies have also moved manufacturing economies of scale toward the supplier (Quinn and Hilmer, 1994). On the other hand, outsourcing is also an important cause for the continuing loss of international competitiveness by Western firms (Bettis et al., 1992).

Firms formulate strategies to leverage the supply chain with product variety and customization. The suppliers are gaining more bargaining power with the increasing state-of-the-art technology and process complexities embedded in the products. Standardization of interfaces of components in product architectures creates the option for firms to engage in component outsourcing, as it enables division of labor hence increased specialization of tasks (Langlois, 1992), encouraging the firm to pursue specialized learning curves and increase its differentiation from competitors (Schilling, 2000). Component outsourcing enables the firm to purchase components from multiple sources, hence decreasing switching costs (Sanchez, 1995). It also implies that the firm has to share its technological knowledge with its suppliers, and competitors can gain access to such knowledge, which has been a source of incentive for many entrepreneurial firms. For the assembler, this can be extremely risky as it may lose the technological control of its product architectures, especially if it takes its suppliers capabilities and management practices for granted.

Involving suppliers early during the development process is one way to cope with the risks of outsourcing (Trent and Monczka, 1998; Bidault et al., 1998; Wasti and Liker, 1997; Dowlatshahi, 1998). Advantages of supplier participation in NPD include shorter project development lead times (Gupta and Souder, 1998; Clark 1989) and project costs (Kessler, 2000; Clark, 1989), improved perceived product quality (McGinnis and Vallopra, 1999; Ragatz et al., 1997), and better manufacturability (Wasti and Liker, 1997; Swink, 1999). It also brings the supplier and the firm closer in sharing not only knowledge and learning, but technological risks as well. Outsourcing and the subsequent supplier involvement is only possible when a system can be decomposed in such a way that interfaces of the components are well specified and standardized. How a firm decides to decompose its system is dependent on the technological complexity of the system and its NPD capabilities as well as on the suppliers capabilities in developing the component at lower cost and faster lead times than by the firm itself.

The development teams are responsible for the entire process from development of sub-components, tools, and production set-ups to serial production. Thereby, B&K has been able to reduce time-to-market from 5-7 years to 1-2 years for some products.

From transaction cost economics (TCE) perspective (Williamson, 1975, 1985, 1996), component outsourcing decisions change the boundary decisions as well. With outsourcing a firm enters into a contractual agreement with a supplier, hence shifting the ownership and decision rights of the outsourced function to the supplier (Momme et al., 2000). Both greater product complexity and technological uncertainty favor making a component in-house because they are likely to increase the cost of writing fully-specified contracts which would result in higher transaction costs compared with the option of doing the design and production work in-house at a lower coordination cost (Masten, 1984). From a TCE perspective, outsourcing decisions should be governed by specificity of the assets required to engage in development and production of the product. Asset specificity (Williamson, 1996:377) refers to "a specialized investment that cannot be redeployed to alternative users or by alternative users except at a loss of productive value." Manufacturers incur high transaction costs during component development, which can be indicated by specific assets, engage in greater collaboration with their specialized suppliers (Bello et al., 1999). On the other hand, outsourcing may also give access to heterogeneous resources and capabilities, which are controlled by the suppliers (Hskansson and Snehota, 1995). This is especially important in industries competing on rapid technological development (e.g., biotech and electronics) or on economies of scale (e.g., semiconductors or electronic manufacturing services).

Degree of Supplier-Buyer Interdependence

Supplier-buyer interdependence denotes the degree of supplier involvement in product development leading to capabilities benchmarking, trust development, and creation of inter-firm knowledge (Hsuan, 1999). In developing an innovation, such as a modular innovation, the degree of interdependence depends on the proprietary sensitivity of the innovation as well as supplier management practices, that in turn determines how responsibilities for functional specification and detailed engineering are split between the supplier and the buyer.

The nature of partnerships can broadly be assumed to vary from one extreme, an arm's-length relationship, to the other extreme, a strategic partnership. The key question is to decide, which type of relationship the firm should develop with each supplier. Dyer et al. (1998) suggest a segmentation of suppliers into three categories: short-term arm's length relationships, durable arm's length relationships, and strategic partnerships. The arm's-length model fits best for low value, non-strategic inputs that are not related to the buying firm's core competence, but may still play a significant role in differentiating the buying firm's products. It has been stated that in order to increase supplier-buyer interdependence, the buyer should increase its purchases from a single supplier (Dyer et al., 1998). They call it "durable" arm's length relationship. There are several advantages of developing this kind of supplier-buyer relationship. First, the transaction costs, such as searching costs and contract costs can be reduced by having long-term relationships with fewer suppliers. Second, it is possible to achieve economies of scale. Third, it is still possible to maintain a competitive situation among two or three suppliers. This is in accordance with the 'multiple-supplier' policy in Japan where a car manufacturer purchases several parts at the same time from several firms but only one supplier is selected during the development period of a new model. The major difference is that once the firm is selected, it remains the supplier throughout the life cycle of the model (Asanuma, 1985).

In order to cope with the continuous pressure to reduce supply chain costs and assets, many firms have entered into partnerships with channel participants as a means to broaden their customer base, reduce costs, and to deepen customer relationships (Evans and Danks, 1998). One outcome of such partnerships is evidenced by manufacturers' tendency to reduce their supplier base. It has been estimated that industrial customers such as Allied-Signal, Ford, GM, Motorola, Texas Instruments, and Xerox have cut the number of suppliers they use by some 20 per cent to 90 per cent during the last decade and have demanded new supply chain arrangements from those they continue to do business with (Emshwiller, 1991). An A.T. Kearney/University of Michigan study estimated that in 2005 as much as 80 per cent of the value added of the car being bought from the suppliers rather than generated by the assembler (Veloso and Fixson, 2001).

Case Studies

In order to gain better understanding about the phenomena of early supplier involvement in NPD, we have chosen exploratory case studies as our research methodology. According to Yin (1994:13) a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. Case study is also a research strategy, which seeks to understand the dynamics present within single settings (Eisenhardt, 1989). In this paper, we present our findings of the following Danish firms: Coloplast, Bruel & Kjaer, and Bang & Olufsen. For all three case studies, semi-structured personal interviews with follow-ups were conducted with Logistics Managers from the firms. Secondary data such as trade journals, newspapers, company newsletters, and books (such as Schary and Skjoett-Larsen, 2001) were also used. The frequency of interviews varied between the three companies. We divided our research topics for the firms into two parts: (1) sourcing strategies and supplier-buyer interdependence, and (2) early supplier involvement in NPD. The first portion of our research is part of an on-going research process that we have with the firms; hence the information is updated regularly. We included the early supplier involvement in NPD to our study in 2003. Some of the main questions we asked include: How does the firm describe its relationship with its key suppliers? How long has the firm work with the key suppliers? How does the firm evaluate and monitor its suppliers? How closely do purchasing work with NPD and vendors for procurement of new components? If the firm involves its suppliers and/or customers in NPD, how does the firm organize its sourcing strategies?

Because of the high asset specificity and the high technological complexity of the components, the relationship B&O shares with most of its system suppliers are based on single sourcing, and they are involved already at the planning and design stages of the NPD process.

Coloplast

Coloplast is a Danish company that develops, manufactures, and markets medical disposables, such as highly sophisticated adhesive intended for medical applications. Based on skin-friendly adhesives, the medical devices have been developed within six business areas: (1) ostomy products; (2) continence care products; (3) wound dressing; (4) skin care products; (5) breast forms; and (6) special dressings. Coloplast operates mainly in niche markets with few big suppliers. In 2002/03, Coloplast had a turnover of 5.7 billion DKK (approximately 0.7 billion EURO) and 6,100 employees. More than 98 per cent of the turnover is generated in countries outside Denmark, including about 79 per cent in Europe and 15 per cent in the U.S.A. Influenced by the globalization, which had affected deeply the health care industry, currently Coloplast has three major competitors.

Coloplast has decentralized purchasing, but with some key suppliers, demand is combined into total frame orders, which are negotiated to cover a 15-month period but revised every quarter. While most external suppliers provide only raw materials, some suppliers also provide their unique R&D capabilities. There are approximately 110 significant suppliers, and the choice of suppliers is determined by Coloplast's materials requirements. Risk profile of the suppliers is also conducted, which are based on: (1) the ability to deliver; (2) the willingness to deliver; and (3) the existence of other alternatives. Although geographic proximity is not a critical criterion for supplier selection, for some services such as product sterilization, it is important that the supplier be closely located. The same applies to the purchase of large-volume products such as corrugated boxes and other forms of packaging.

Coloplast cooperates with suppliers by allowing some suppliers direct access to a web site where some information can be accessed quickly such as historical usage patterns, product codes, location, and replenishment points. There are few situations in which suppliers are involved early in new product development. An example of co-development of a new product together with a supplier is a sterilized catheter for use in hospitals and clinics. Here, Coloplast is responsible for the development of the lubricant in which the catheter is kept sterilized, and a supplier in England is responsible for the development of the catheter. The lubricants and the catheters are sent to another factory, where the catheters are sealed in plastic containers together with the sterilizing lubricant. Although Coloplast pursues an integrated product architecture strategy (in the sense that the product architectures can not be easily decomposed), but because the technological complexity of outsourced components is low, Coloplast is not very dependent on its suppliers for knowledge. Hence, it is possible to involve the suppliers at the production part of NPD process.

Bruel & Kjaer

Bruel & Kjaer (B&K) is a Danish company competing in the sound and vibration measurement market, which is a specialized industry niche requiring in-depth understanding of the nature of the sound and vibration, combined with a good understanding of customers' needs and applications. B&K was established at the beginning of 1940s, and until the beginning of the 1990s the firm was family-owned. Currently a British company owns B&K. When the ownership changed hands, B&K reduced its staff from 2,600 to about 500. Today, B&K employs 1,200 people and has a turnover of one billion DKK (0.13 billion EURO). B&K has a wide product range in excess of 1,500 products including transducers, hand-held sound level meters, analyzers, systems, service products, and customized solutions. These products are sold to a wide range of industries including automotive sub-suppliers, aerospace, consumer goods, rotary machinery, telecommunication, and national government agencies.

B&K believes that the range and quality of products can be improved by forming key alliances with other businesses. This is a win-win situation for B&K because a better solution creates additional sales for everyone involved and benefits the customer by decreasing the amount of time, money, and worry invested in the solution. For example, the recent alliance with Endevco has further strengthened B&K's market position, in which Endevco has taken over production of B&K's products within vibration measurement, while B&K takes care of the sales and distribution of Endevco's products worldwide except in U.S.A. Another example of partnership is B&K's cooperation with the German firms Stapelfeldt and DGMR, who are experts in the field of environmental noise prediction software. With this alliance, B&K can better meet the increasing demands for noise mapping and calculation of environmental noise levels and thereby supplement their own core competences.

The three case studies suggest that the degree of early supplier involvement in NPD, degree of supplier-interdependence, and the extent of asset specific investment vary. All three companies differ in the way suppliers are chosen and how much responsibility in NPD should be allocated to the suppliers, which is reflected in the extent of capital the firms are willing to put in asset-specific investments.

For B&K outsourcing was a matter of survival. Since then, B&K has changed from in-house production and design to maximum outsourcing. About 95 per cent of B&K's input is outsourced such as PCBs, metal works, machined items, painting shop, to name a few. B&K has a supplier base of about 200 active suppliers. However, 80 per cent of the purchased materials are coming from 50 suppliers. In few instances B&K practices single sourcing, and it expects to have access to the suppliers' cost calculations (i.e. open book policy). Sometimes, B&K makes frame orders with the supplier's supplier in order to get better terms. B&K has a good reputation in the world market, therefore some component suppliers consider being inside B&K's products as a quality stamp. For B&K, outsourcing reduces costs, enables better utilization of resources, allows firms to focus on key competences, and to gain flexibility from fixed to variable costs. With outsourcing B&K has achieved strategic focus, simpler supply chain, zero investment, lower costs, and free capital (such as from buildings). B&K considers product development, design, and assembly of microphones as their core competences; hence it keeps these activities in-house. Outsourcing of other activities is based on B&K's component specifications, hence the suppliers are not responsible for simply developing black boxes, and do not become involved in the NPD process until the production stage.

B&K has also changed its organization of product development. Integrated product development is implemented with representatives from suppliers, customers, sales/marketing, production, and services. The development teams are responsible for the entire process from development of sub-components, tools, and production set-ups to serial production. Thereby, B&K has been able to reduce time-to-market from 5-7 years to 1-2 years for some products. B&K informs the suppliers six months ahead, when new products are launched. If necessary, B&K provides the suppliers with knowledge about the newest technologies. In some cases, B&K co-invests in new IC equipment at the supplier's plant. In other cases, B&K buys the IC equipment, and then installs it at the supplier's plant. Because the technological complexity of its components is high, but very little specific assets are invested in the suppliers, B&K is somewhat dependent on its suppliers for knowledge development, but does not want to share a close relationship with them.

Bang & Olufsen

Bang & Olufsen (B&O) is an internationally famous producer of audio-visual equipment, known for its high quality, advanced design, and perfect functionality. In 2003, B&O had a turnover of approximately DKK 4.0 billion (0.5 billion EURO), of which 15 per cent were from Denmark. B&O have approximately 2,600 employees. Sales take place through 12 national sales companies that are 100 per cent owned by B&O, as well as through a number of independent agents. There are some 2,100 dealers spread out across 40 countries. Approximately 85 per cent of B&O's sales take place in Europe.

At the beginning of the 1990s, B&O implemented a new procurement strategy. The supplier base was reduced from about 1,000 to 300 and most of the standard components and processes were outsourced to subcontractors. B&O kept its core competencies in-house such as chemical and mechanical surface treatment of aluminum, product design and development, advanced plastic molding, and final assembly of products. Since 2000 B&O has developed a new sourcing strategy. One element in this strategy was a segmentation of suppliers into four categories: standard suppliers, capacity suppliers, key suppliers, and system suppliers.

Standard suppliers supply B&O with commodity components. The market is very competitive and price, quality and logistics service are important criteria for the choice of suppliers. Typically, the relationships are of arm's length type. Electronic market places are used to compare and select the suppliers.

Capacity suppliers perform simple production and assembly processes according to specifications set by B&O. These suppliers are mainly used in periods of peak loads on B&O's own production capacity. "Open and honest" relations characterize the supplier relationships. The market is regularly tested for new potential suppliers, and it is expected that the current suppliers are able to demonstrate productivity improvements over time.

Key suppliers are suppliers with proprietary key technologies that are important for B&O's final products. B&O often undertakes specific investments related to interface compatibility issues between the key components and the other components in the product. This increases the dependency of the suppliers. Besides, B&O often relies on single sourcing. There is also a collaboration agreement between the parties, where the technology, project and operations relations are established and clearly defined. B&O has access to the supplier's roadmap for technological development. A relations committee with top managers from both parties meets at least once per year.

System suppliers or strategic suppliers are suppliers with whom B&O has a very close collaboration, where co-development of unique components takes place. The system supplier is critical for the production process and often constitutes an essential value of the products. The system supplier is responsible for managing and coordinating its own supply chain and for the assembly process of sub-components from various suppliers. The system suppliers are involved both in the design and development stages. They have on-line access to sales forecasts, production plans, and materials requirements. They are often part of a Vendor Management Inventory (VMI) agreement. Open-book calculations are used and yearly productivity improvements are agreed upon. The investments in specific assets are high and in several cases, B&O develops unique technology in collaboration with the system supplier. Because of the high asset specificity and the high technological complexity of the components, the relationship B&O shares with most of its system suppliers are based on single sourcing, and they are involved already at the planning and design stages of the NPD process. This type of supplier-buyer relationships is very resource demanding for both parties and therefore limited to relatively few suppliers. Currently B&O has about 12 system suppliers.

Comparing the Three Cases

B&O's strategy of segmenting its suppliers into four categories reflects its procurement policies and higher degree of supplier involvement in NPD. Coloplast, in comparison, has decentralized purchasing, of which the supplier selection is based on materials requirements. Hence, very little supplier involvement in NPD is needed. A comparison of the three cases is summarized in Table 2.

Table 2: A Comparison of the Case Studies

Variables	Coloplast	B&K	B&O
Degree of Early Supplier Involvement in NPD	Low	Low	High
Degree of Outsourcing	High	High	High
Degree of Supplier-Buyer Interdependence	Medium	Low	High
Asset-specific Investment	Medium	Low	Medium
Supplier Involvement Points	Production	Production	Planning and Design
Product Architecture	Integrated	Integrated	Modular
Technological Complexity	Low	High	High

The three case studies suggest that the degree of early supplier involvement in NPD, degree of supplier-interdependence, and the extent of asset specific investment vary. All three companies differ in the way suppliers are chosen and how much responsibility in NPD should be allocated to the suppliers, which is reflected in the extent of capital the firms are willing to put in asset-specific investments. B&O, for instance, practices co-development with its key suppliers, but B&K and Coloplast mostly give its suppliers the full responsibility for component development, and sometimes they are involved only in the production stage of the NPD. However, both B&K and Coloplast have started to increase their key suppliers' involvement in NPD.

From the network perspective, the efficiency of activity structure is contingent on the way the resources in the network are utilized. Available resources can be combined in new ways, introducing dynamics and innovation. Resources used by a firm are not only those residing inside the boundary of the firm.

The findings from B&K case are in accordance with other findings in the literature on outsourcing. B&O's case, however, seems to contradict the literature. Although the degree of outsourcing is high, B&O also provides asset specific investments, which explains the high degree of supplier-buyer interdependence. TCE explains that outsourcing decision should be governed by specificity of the assets required to engage in development and production of the good. Uniqueness of the assets involved in the relation or uncertainty on the outcomes increases the likelihood of opportunist behavior from the supplier, hence increasing the transaction costs of using market to secure production. As asset specificity decreases, switching becomes easier, and opportunistic behavior is less likely to happen. Consequently, market price relationships become better to assume efficiency because they avoid transaction costs of in-house bureaucratic control (Veloso and Fixon, 2001). Both greater product complexity and technological uncertainty favor making a component in-house because they are likely to increase the cost of writing fully-specified contracts which would result in higher transaction costs compared with the option of doing the design and production work in-house at a lower coordination cost (Masten, 1984). As the case studies indicate, in spite of the fairly high degree of outsourcing for all three firms, the degree of supplier involvement in NPD is actually low, with the exception of B&O. Although the technology embedded in both B&O and B&K products can be considered complex, B&O incurs higher asset specific investment than B&K. This explains B&O's willingness to involve its strategic suppliers early in the NPD process as one way to reduce the coordination and transaction costs in the long run.

Summary and Future Research

A firm should manage its business activities (i.e. in-house and outsourcing decisions) in relation to its capabilities and those of its potential partners (Barney, 1999), and such decisions are dependent upon how tasks are decomposed and specified. Outsourcing of product design and/or manufacturing tasks of a component, for instance, is made possible when its interfaces become standardized and specified (that is, modularized), hence creating a set of loosely-coupled components, modules or sub-systems. Although modular product architectures facilitate component outsourcing, in the sense that suppliers can perform NPD and manufacturing tasks independently of the buyer, the degree of supplier involvement in NPD can still influence the success of the project. Hsuan (1999), for instance, has shown that higher degree of modularization is possible when more collaborative forms of partnership are shared between the partners during NPD. Our case studies also support this argument. While the product architecture strategy pursued by B&O is more modular than Coloplast's or B&K's, B&O seeks to maximize its mutual learning with its strategic suppliers in order to shorter NPD lead times and to improve on manufacturability.

From the network perspective, the efficiency of activity structure is contingent on the way the resources in the network are utilized. Available resources can be combined in new ways, introducing dynamics and innovation. Resources used by a firm are not only those residing inside the boundary of the firm. In other words, outsourcing and supplier involvement have made access to the resources of other firms as important as the resources acquired and deployed inside the firm (Gadde and Hskansson, 2001). Internal resources are part of a large resource constellation within the firm (Hskansson and Snehota, 1995) while external resources are spread over a number of suppliers and customers.

In this paper, we have examined early supplier involvement in NPD and how it is influenced by outsourcing and degree of supplier-buyer interdependence. Three case studies of Danish firms are presented: Coloplast, Bruel & Kjaer, and Bang & Olufsen. Although the case studies are explorative, we still gain better understanding of how these firms manage their outsourcing activities vis-a-vis degree of supplier involvement in NPD. With the exception of B&K, the case studies seem to suggest that outsourcing, although related to the companies' core competences, also takes into consideration the types of relationships firms are engaging with their suppliers. The sole sourcing strategy of these firms as well as the increasing involvement of suppliers in their NPD activities evidences this. These firms are also delegating more NPD responsibilities to their suppliers, not only on design and development but also through co-development.

Our study suggests that product architecture design strategies (which, typically takes place during the functional specification of the NPD process) influence outsourcing decisions; hence the amount tasks to be given to the suppliers. Depending on the technological complexity of the product architecture and how it is decomposed, the suppliers can be involved during the planning, design, or production stages of NPD. Outsourcing is not only about protecting core competences of firms, but also sharing strategic resources and risks with suppliers. This is evident from the increasing responsibilities of suppliers in NPD activities of the buyer. Our findings are consistent with the literature, which suggests that the increasing trend on early supplier involvement in the NPD process (Wasti and Liker, 1997; Bozdogan et al., 1998; Dowlatshahi, 1998; Clark and Fujimoto, 1991; Clark, 1989) has led to changes in the management of supplier-buyer relationships, with a tendency towards the partnership form (Twigg, 1998). According to Lamming (1993), this poses greater responsibilities to the suppliers, in the form of black boxes, as operating uncertainties are resulted through joint discussions, reciprocal dialogue of information, and long-term cost knowledge. Bidault et al. (1998) also highlight the importance of black box part in industrial transactions, as it lies at the heart of the early supplier involvement concept since the supplier assumes some level of design responsibility and therefore need to be involved in project discussion early in the development process.

For future research, we have plans to conduct more interviews with Danish firms so that we can create a database with enough samples in order to improve the robustness of our study. We also have plans to investigate performance measurement issues related to early supplier involvement in NPD. There are several approaches to estimate the degree of supplier involvement. For instance, Cox (1996) provides a typology of internal and external contractual relationships. Under high asset specificity and core competences the form of contract is clear. For low asset specificity, the contracts will be external and can be adversarial and based on competitive market criteria. Medium asset specificity requires special treatment because the nearer they are to the core competences of the firm, the more the firm will have to consider vertical integration through merger and acquisition. Based on this insight, Cox suggests a range of hypothetically possible contractual relationships: adversarial leverage, preferred suppliers, single sourcing, network sourcing and partnerships, and strategic supplier alliances. The types of partnering relationships are determined by the degree to which firms can operate at relative arm's-length in their external contractual relationships, as against their desire to vertically integrate the production of goods or services internally. The degree of supplier involvement can also be developed with respect to inter-firm interdependence in terms of investments in relation-specific assets vis-a-vis transaction costs. as proposed by Dyer (1997). In a study of automotive industry, Dyer found that the level of relation specific investments made by the suppliers is strongly influenced by the automaker's strategy with regard to supplier management and governance. He proposes a model of inter-firm collaboration that maximizes transaction value, which suggests that the credibility of a firm's promise to behave cooperatively increases as transactors: (1) demonstrate through behavior a commitment to future interaction, (2) increase the amount of information sharing, and (3) employ self-enforcing safeguards to govern the relationship. Dyer further argues that an increase in trustworthiness within the trading relationship reduces transaction costs and increases the likelihood that transactors will invest in relation-specific assets, hence maximizes the transaction value or the joint performance of the transactors. Although the approaches and models suggested by Cox (1996) and Dyer (1997) are not on NPD, they can nevertheless provide a solid foundation as well as serve as good lenses for investigating early supplier involvement in NPD, especially with respect to asset specificity and degree of supplier-buyer interdependence.

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Flexibility Mapping : Practitioner's Perspective

1. What types of flexibilities you see in the practical situation of "Early Supplier Involvement" on the following points:
   - Flexibility in terms of **"options"**
   - Flexibility in terms of **"change mechanisms"**
   - Flexibility in terms of **"freedom of choice"** to participating actors.
2. Identify and describe the types of flexibilities that are relevant for your own organizational context? On which dimensions, flexibility should be enhanced?
3. Try to map your own organization on following continua
   (Please tick mark in the appropriate box(es))

   Early Supplier Involvement in NPD

   Low ☐☐☐☐☐ High

   Degree of Outsourcing

   Low ☐☐☐☐☐ High

   Supplier-buyer Interdependence

   Low ☐☐☐☐☐ High

   Asset-specific Investment

   Low ☐☐☐☐☐ High

   Technological Complexity

   Low ☐☐☐☐☐ High
4. Develop a SAP-LAP (Situation Actor Process-Learning Action Performance) model of "Early Supplier Involvement in New Product Development " relevant to your organization.

Reflecting Applicability in Real Life

1. What is the level of Early Supplier Involvement in your industry and why?
2. How integrated is your organization upstream and downstream in the supply chain?

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