

Supply Chain Design: An Overview

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Abstract

In recent years, the rapid technological advancements, the increased economic uncertainty, and the globalization of economic activities have resulted in fierce competition, and more sophisticated and demanding customers. These characteristics of the new economic environment are translated to short product life cycles, increased demand for customized products, and quick response to customers' and market's needs in terms of quality and quantity, posing significant pressure to supply chain participants. Several strategies for supply chain design have been proposed by researchers and employed in practice in order to aid enterprises to cope successfully and effectively and sustain their competitive advantage. This paper presents an overview of postponement, flexibility and new inventory control tactics that have attracted significant attention.

1. Introduction

"The ultimate core competence of an organization is supply chain design, which I define as choosing what capabilities along the value chain to invest in and develop internally and which to allocate for development by suppliers" stated Fine (2000). Both practice and theory seem to converge at this point. Firms in their effort to improve production efficiency and product quality adopt a wider perspective, beyond their boundaries, and consider the design and redesign of the entire supply chain (Baiman et al., 2001). As a result several success stories have been reported such as Benneton (Signorelli and Heskett, 1989), Sport Obermeyer (Fisher et al. 1994), Hewlett Packard (Lee et al., 1993; Lee, 1993 and Lee and Billington, 1994&1995), Toyota (Federgruen, 1993), Chrysler (Fine, 2000).

The design of supply chain incorporates a wide range of decisions. According to Graves and Willems, (2004) design decisions could be grouped in three categories: traditional design decisions, product and process design decisions and decisions that allow responsiveness to uncertainty and variability. The traditional design decisions concern the facility characteristics of each supply chain node, the number, location and sizing of facilities

and the interconnections between the supply chain nodes, that is the path products will follow along the supply chain and the mode of transportation. Product design decisions concern the effort to couple market objectives with high supply chain performance. Product design decisions concern the effort to couple market objectives with high supply chain performance. The most common tactic is that of postponement. Decisions that allow supply chain to be responsive to uncertainty and variability concern supply chain management flexibility, which includes flexible facilities, outsourcing and contracting mechanisms. Inventory control strategies fall into all three categories. For the purposes of this study we will focus on: postponement, flexibility and inventory control.

2. Design for postponement

In this age of globalization and fierce competition there is a strong movement in industry towards highly customized products, shorter lead times, better product and service quality. Mass customization although requisite and often inevitable, leads to high complexity in demand forecasting, supply, production, inventory control, and after-sales support; affecting negatively the firm level performance (Swaminathan and Lee, 2004; Venkatesh and Swaminathan, 2002; Swaminathan, 2001 and Pine 1993). In this context the notion of postponement has attracted significant attention since the 1950's when Alderson (1950) first coined the term and proposed it as an approach to reduce uncertainty and cost in managing operations. In the years that followed and as manufacturing draw away from the traditional inventory strategies postponement attracted the interest of both academics and practitioners as an attractive alternative in order to cope with mass customization. Postponement is now defined as an organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received, contrary to producing in anticipation of future orders. In the worlds of Venkatesh and Swaminathan (2002) the concept of postponement is to delay the point of commitment of WIP inventory into a particular end product and, thereby, gain leverage in terms of efficient asset utilization in a dynamic uncertain

environment. Postponement is also referred to as end of line configuration, late point differentiation, or delayed product differentiation (Lee, 1993).

2.1 Postponement Modelling

During the last two decades several modelling approaches of postponement have appeared in the literature. Eppen and Scharage (1981) presented a process standardization model where all products follow a series of common steps, after the completion of which products are differentiated, the point where the common process finishes and the differentiation starts is called differentiation point. They showed that when costs are identical at each site order-up-to is the optimal inventory policy. Lee (1996) also considered a process standardization model assuming that all products have independent demands following a normal distribution while the system follows a periodic review policy with complete backlogging. The author showed that postponement will lead to reduction of finished goods inventory. Lee and Whang (1998) investigated a similar model assuming demands follow a random walk and that demand forecast accuracy may be improved due to postponement. The authors proved that the safety stock decreases as the point of differentiation moves at a later stage. In the above models only finished products may be held as inventory. Lee and Tang (1997) analyzed a model where two products are produced following a series of common steps till a differentiation point, after that point each product follows a different path. Inventory can be held after the completion of any step before or after the differentiation point. The authors showed that as the demand correlation of the products decreases the resulting savings in inventory cost increase, while for less variable demand postponing differentiation is less attractive.

The aforementioned models were restricted to only one differentiation point. Garg and Tang (1997) proposed a system with two points of differentiation and explored two alternatives, a centralized system where only finished products may be stored and a decentralized system where products can be stored as finished goods and at any differentiation point. For the centralized system the final products demand is assumed to be independent, normal and identical. Authors showed that both late and early postponement lead reduction in total inventory while late postponement becomes more attractive when product demand across products becomes more negatively correlated. In a decentralized system inventory is assumed to be stored at both differentiation points and at the end of the

processes. Authors showed that if the lead time between the first node of the chain and the first differentiation point is greater than the lead time between the first and the second differentiation point and the lead time between the second differentiation point and the end of the chain is smaller than the lead time between the first and the second differentiation point then both early and late postponement are advantageous.

Swaminathan and Tayur (1998) introduced capacity constraints to the postponement problem. They analyzed an assembly process where inventory may be stores as components, in an intermediate form called vanilla boxes and as finished products. Therefore, the model explores assemble-to-order and make-to-stock strategies. Products may be assembled either from vanilla boxes or from components. The main advantage of vanilla boxes is that the time for customization is lower than customizing from the component level. The authors showed that vanilla boxes postponement is more attractive than assemble-to-order and make-to-stock especially under high variance and negative correlation among product demands.

The aforementioned research focuses on process standardization. Another popular postponement enabler that appears in the literature is process re-sequencing. Lee and Tang (1998) considered a two-stage system such as knitting and dyeing, where at each stage a different characteristic is added to the product. Inventory is stored at the end of each stage. The sequence of operations does not affect the end product, it only influences the inventory stored at the end of the first stage. The objective the authors set was the minimization of the total variance of the two buffers since their variance affects the required inventory. They derived a rule according to the probability a customer will choose a product with a certain characteristic that indicates what sequence is optimal. Kapuscinski and Tayur (1999) analyzed the same system but proposed the minimization of standard deviations as the objective. Often the sequence of activities in a process cannot be changed arbitrarily but need to follow certain precedence conditions. Gupta and Krishnan (1998) introduced the concept of generic sub-assembly (GSA), a feasible sub-assembly that meets all the precedence requirements. GSA is similar to vanilla box. The authors developed an algorithm that generates the GSA supports the maximum number of end products. Swaminathan and Tayur (1999) initiated the vanilla box model to the assembly sequence design problem. They presented a mathematical programming model that take into consideration design costs and sequence requirements. The authors explored two alternative

strategies: (i) vanilla boxes are determined first and then the sequence is specified in order to minimize the cost and satisfy the precedence conditions; and (ii) the most efficient sequence is determined firstly and then the appropriate vanilla boxes. Ioannou et al. (2004) modelled postponement in a single-echelon multiple-product supply chain. Inventory value is assumed an increasing function of the amount of processing performed at upstream nodes, while achieved fill-rates are dependent on the distance-time between the inventory and customer locations. They proposed an analytical approach to solve the problem for the case of normally distributed demand that is based on iterative calculations of inventory holding costs at the various potential inventory locations.

Apart from process re-sequencing and standardization the third postponement enabler is component commonality. Collier (1982) first introduced a commonality index that measure the degree of commonality in a production line. Lee and Tang (1998) incorporated into their model the cost of standardizing a component in order to facilitate process standardization and define the optimal degree of postponement. Lee and Sasser (1995) argued that when the demand and the associated costs are known the value of standardization for postponement is higher in the introduction phase of the product, low in the mature phase and high at the phase close to the end of product life.

2.2 Postponement Applications

Postponement has been successfully implemented in the industry during the last decade. The literature is swarming with success stories. One of the earliest reported applications of process re-sequencing was in Benetton (Dapiran, 1992). Traditionally, when manufacturing sweaters the yarn is first dyed into different colors and then the garment is knitted from the colored yarn. The sweaters were then stored till they were transported to retailers. Benetton realized customer's preference of color each season affected greatly demand variability. They decided to interchange the operation process and first knit the sweater, creating uncolored knit garments that will be stored till demand is revealed, then the garments will be dyed and shipped to retailers. Uncertainty was decreased leading to a significant decrease in inventory.

Zara, is also one of the most famous brands of the fashion apparel industry utilizes process standardization and vanilla boxes (Harle et al., 2001). The fashion apparel industry is characterized by extremely short product life cycles of one season

lasting less than six months. Zara changes 70% of the products every two weeks and introduces about 12,000 new products and designs every year. The company employs several strategies including standardization of the design modules, in order to create large variety and quick response to customers. At the beginning of each season the designers create a library of models. The models do not represent any physical inventory but serve as conceptual vanilla boxes. The designers after observing the latest fashion trends customize their vanilla boxes designs and create 5-8 new final designs that will be lanced in the market, every day. Without the use of vanilla designs the design process would have taken several days. Even though the physical inventory is not affected process the postponement of the design decision helps cope with short life cycles and product variety.

Hewlett Packard also utilized process standardization in order to postpone country specific operations, for the DeskJet Printer (Lee et al., 1993). The printer line was manufactured and customized in the US factory and then shipped to three distributions centers in Europe, US and Far East. Each market segment needed different power supply module with the appropriate voltage, power cord terminators and the corresponding manual. Under the existing policy the safety stock that was held in each distribution center was considerably high. Hewlett Packard re-designed to product and re-engineered the manufacturing process so that all the local characteristics of the product could be added at a later stage at the distribution centers. As a result inventory costs were decreased significantly, lower capital investment was required for in-transit inventory, freight costs were also decreased and customer service was improved. Hewlett Packard used a similar tactic for the LaserJet printer. The main part of the printer was manufactured in Japan and then a different power cord was added according to the requirements of the markets, Europe and US. The product was re-designed and the power-supply component was standardized so that it had dual capability. Although the cost of the component increased, the savings from inventory reduction lead to a 5% decrease in total manufacturing, stocking and delivering costs.

Another example of postponing product differentiation was the case of Sears/Whirlpool (Lee and Tang, 1997 and Waller et al., 2000). Whirlpool designed its dishwashers so that the color differentiating part can be divided into two modules, a metal frame common to all dishwashers and a color sheet module. Therefore, the company held as inventory generic dishwashers and inserted

the colored sheet module according to the customer preferences. A similar policy was adopted for refrigerators, where manufacturers assemble two different door types, right and left opening (Davis and Sasser, 1995 and Venkatesh and Swaminathan, 2002). Consequently, in both cases the manufacturer was able to correspond to demand more efficiently and consolidate the inventory across different product types.

Increased competition in the electronics industry resulted in an increase in customers' expectations. IBM addressed the problem of lost sales and customer dissatisfaction, for the RS/6000 server, due to long delivery times by using vanilla boxes (Swaminathan and Tayur, 1998). Each model in the product line had 50 to 75 end products differentiated by ten components. In order to assemble a final product components should first be gathered (kitting), then they should be located appropriately (assembly), tested, the software will be loaded and the final product will be packed. The demand for the end products was highly random and correlated thus, the firm was starting final assembly only when an order was received. The final assembly phase had a duration of almost one month while customers expected to receive the product in seven to ten days. In order to cope with increased demand for shorter delivery times IBM decided to stock semi-finished inventory (vanilla boxes) which could be faster configured to finished products. Although postponing the differentiation of end products came along with increased cost in processing the vanilla boxes and training the personnel it led to increased customer satisfaction. A similar system called configure-to-order has been widely used in the electronics industry.

3. Design for flexibility

In recent years the ongoing globalization of economic activity and the rapid technological advancements have resulted to fierce competition and increased economic uncertainty. Intense competition is translated to highly volatile markets, short product life cycles and more demanding and sophisticated customers (Suarez et al. 1995). In order for a supply chain to be efficient and competitive in such economic environment, it is essential to produce a large number of customized products and deliver them to the market in an acceptable speed and cost (Pujawan, 2004). Suarez et al. (1995) and Koste and Malhotra (1999) argued that a company's competitiveness is determined by its ability to meet the needs of the market in terms of quality, efficiency and flexibility. Strategic flexibility is considered to be one of the most important requirements for firms to survive and a

major determinant of their ability to respond successfully in turbulent and unpredictable environments. In this context, flexibility has attracted the attention of both researchers and managers as an important competitive advantage a supply chain should pursue in order to cope with intense competition and mass customization (Dreyer and Gronhaug, 2004; Garavelli, 2003 and Pujawan, 2004).

It has been widely recognized that it is particularly difficult to define flexibility satisfactorily (Dreyer and Gronhaug, 2004). Zhang et al. (2003) define flexibility as the ability of an organization to meet an increasing variety of customer expectations without excessive costs, time, organizational disruptions, or performance losses. Upton (1995) defines flexibility as increasing the product variety, improving firms responsiveness to internal and external changes and achieving high performance over the wide range of products. Flexibility is a complex and multi-dimensional concept of either reactive (responds to market uncertainties) or proactive (redefines market uncertainties) nature and a relative attribute since it is always examined with respect to an alternative in order to assess its magnitude (Gerwin, 1993 and Koste and Malhotra, 1999). Sethi and Sethi (1990) identified more than 50 different terms covering various aspects of flexibility. In addition, there is a significant variation in perspectives when analyzing flexibility dimensions and measures (Pujawan, 2004).

3.1 Manufacturing Flexibility

The majority of current research has focused on a single firm's strive for flexibility and competitiveness and especially on manufacturing companies. Zhang et al. (2003), D'Souza and Williams (2000) and Kathuria and Partovi (1999) define manufacturing flexibility as the ability of the firm to manage production resources and uncertainty to meet customer requests. Manufacturing flexibility has appeared in the literature in the mid 40's when Leaver and Brown (1946) proposed a series of functionally oriented machines that when altering their sequence different products may be produced. Diebold (1952) acknowledged manufacturing flexibility as a key factor for production efficiency. Abernathy (1978) viewed manufacturing flexibility as a trade-off between production efficiency and dependability in the marketplace. During the 80's manufacturing flexibility has been recognized as a strategic business element, along with cost, quality and reliability that can be achieved by reducing set-up time and cost, shifting to product-oriented layouts, increasing equipment reliability, and

enhancing quality (Zhang et al. 2003; Hayes and Wheelwright, 1984). During the 90's a more broader view was adopted. Parthasarthy and Sethi (1993) investigated the influence of flexibility on firm performance taking into consideration the technological environment and the strategic and structural choices of the firm. Sethi and Sethi (1990) considered manufacturing flexibility as a group of elements that are designed in order to facilitate the adaptation of processes and equipment to multiple tasks. Upton (1995) identified attributes of flexibility and illustrated the distinction between internal and external flexibility. Upton described internal flexibility as the competences of the firm, that is what the firm can do and external flexibility as the capabilities of the firm, that is what the customers see.

A vast literature exists on manufacturing flexibility. Narasimhan et al. (2004) classified literature on manufacturing flexibility into four related themes: studies where the main reason for manufacturing flexibility is environmental uncertainties of volume and variety (Pagell and Krause, 2004; Pagell and Krause, 1999; Gerwin, 1993; Swamidass and Newell, 1987); studies that identify key structural and infrastructural influences (Zhang et al. 2003; Narasimhan and Das, 1999; Suarez et al. 1996; Slack, 1990); studies that examine the relationships between manufacturing flexibility and performance (Narasimhan and Das, 1999; Suarez et al., 1996; Parthasarthy and Sethi, 1993) and taxonomies and classifications of literature (Sethi and Sethi, 1990; Koste and Malhotra, 1999; Vokurka and O'Leary-Kelly, 2000; D'Souza and Williams, 2000; Koste et al. 2004). Several research methodologies have been used to investigate and model manufacturing flexibility: empirical studies (Jaikumar, 1986; Dixon, 1992; Suarez et al., 1995 & 1996; Narasimhan and Das, 1999), mathematical models (Benjaafar, 1994; Laengle et al. 1994; Byrne and Chutima, 1997; Wainwright and Bateman, 1998), simulation models (Gertosio et al. 2000), theoretical frameworks (Koste and Malhotra, 1999; Koste et al. 2004) and literature reviews and taxonomies (Sethi and Sethi, 1990; Vokurka and O'Leary-Kelly, 2000; D'Souza and Williams, 2000).

Manufacturing flexibility is a complex, multidimensional construct. There is a significant variation in literature when manufacturing flexibility is analyzed in dimensions and measures. Gerwin (1993) proposed seven primary dimensions of manufacturing flexibility: volume flexibility, the ability to change the volume of output; materials flexibility, the ability to accommodate uncontrollable variations in the materials processed; mix flexibility, the ability to produce many

different products during one planning period; modification flexibility, the ability to incorporate design changes to a specific product; changeover flexibility, the ability to adapt to changes in the production process; rerouting flexibility, the ability to change the sequence of steps in the production process; and flexibility responsiveness, the ability to adjust emphasis on the above flexibility dimensions given changes in the internal or external environment. D'Souza and Williams (2000) limited the primary dimensions of manufacturing flexibility to externally driven dimensions, that is volume and variety flexibility and to internally driven dimensions, that is process and materials handling flexibility. In addition, the authors identified two measures for each type of flexibility: range and mobility. Table 2.1 presents the definitions of the four dimensions and the measurement items D'Souza and Williams used in their study. Vokurka and O'Leary-Kelly (2000) identified fifteen manufacturing flexibility dimensions: machine, material handling, operations, automation, labor, process, routing, product, new design, delivery, volume, expansion, program, production and market.

Koste and Malhotra, (1999) named five types of strategic flexibility: system, organizational, manufacturing, marketing, and R&D flexibility. They also presented a detailed and comprehensive review on manufacturing flexibility and suggested that four elements should be used to define the different types of manufacturing flexibility: the range of flexibility options considering both the number of options and the heterogeneity of options, the mobility, that is the ability of the firm to move from one option to the other, and the uniformity of performance outcomes within the range. Moreover, the authors identified ten dimensions of flexibility: machine, labor, material handling, routing, operation, expansion, volume, mix, new product and modification flexibility. In a more recent research Koste et al. (2004) focused on six dimensions of manufacturing flexibility (machine, labor, material handling, mix, new product and modification) each one consisted of four elements (range-number, range-heterogeneity, mobility and uniformity), in order to create general and non-industry specific measures of flexibility. They showed that the four elements can be grouped into two conceptually separate factors representing scope and achievability of flexible reactions. Therefore, a set of firms can be compared according to the score on scope and achievability their flexibility choices represent.

In their recent work Zhang et al. (2003) highlighted the dichotomy of flexible manufacturing

capabilities and competences. They argued that customers value more the capabilities that are visible and increase directly their satisfaction (volume and mix flexibility) while they are not willing to pay more for the internally oriented competences (machine, labor, material handling and routing flexibility). However, volume and mix flexibility are attained and successfully implemented only through the effective adoption of the flexible manufacturing competences. The authors propose that managers should plan and manage manufacturing flexibility in terms of value-adding capabilities and supporting competences in order to achieve mass customization and enhance customer satisfaction.

3.2 Supply chain flexibility

In the context of the supply chain a single firm's ability to be flexible is no longer adequate while all participants of a supply chain should be considered (Lambert et al., 1998 and Lummus and Vokurka, 1999). Despite the fact that supply chain management and flexibility are very active research areas and among the leading concerns of operations managers during the last decade (Garavelli, 2003) there is a limited number of studies on supply chain flexibility. Garavelli (2003) proposes a useful categorization of certain supply chain flexibility aspects based on taxonomies presented in the literature: (i) functional aspects: flexibility in operations, marketing, logistics (ii) hierarchical aspects: flexibility at shop, plant or company (iii) measurement aspects: global flexibility measures vs. context specific ones (iv) strategic aspects (v) time horizon aspects: long-term vs. short-term (vi) object of change aspect: flexibility of product, mix, volume etc. Still most studies focus only on specific aspects and do not adopt a holistic view of supply chain and supply chain flexibility.

Supply chain flexibility has several dimensions or types that incorporate the dimensions of manufacturing flexibility. Pujawan (2004) argued that supply chain flexibility dimensions should be related to supply chain functions and proposed four dimensions: sourcing flexibility, the ability to reconfigure the supply chain, altering the supply of product according to customer demand; product development flexibility, the ability of the company to produce various new designs in a timely and cost effective manner and to flexibly deploy resources related to product development; production flexibility, the ability of the manufacturing system to produce products of different types and different volume at an acceptable cost and time; and delivery flexibility the ability of the supply chain to alter delivery dates of different types of products to the

customers with a wide range of volume at an acceptable cost and time.

The author also presented seven flexibility drivers that could enable the assessment of the degree of flexibility requirements: the length of product life cycles, it affects the need for sourcing, development and production flexibility; product variety, it affects the for development, production and delivery flexibility; customer requirement disparity, refers to the different speed and service levels required by different customer segments and it affects the degree of flexibility requirements in delivery functions; order stability, refers to the stability of orders in terms of due date, order quantity and the types of items required and affects the need for in delivery, production and sourcing flexibility; component commonality, is negatively related to the degree of flexibility in sourcing, development and production functions; process similarity, it affects the need for production flexibility; and supply uncertainty, that is the ability to obtain materials from alternative sources and the nature of materials availability affects the need for supply flexibility and indirectly the requirements for development and sourcing flexibility.

When exploring an emerging concept it is of great importance the development of an analytical framework. Other aspects of supply chain flexibility that have been explored in the literature concern performance, configuration and contracting. Graves and Tomlin (2003) focused on process flexibility in supply chains. The authors developed a framework for analyzing the benefits from flexibility in multistage supply chains and determined a cost-effective flexibility configuration in order to meet demand. They proposed certain guidelines for designing flexibility in supply chains with moderate number of stages and products (less than 10 stages and less than 20 products): encompass as many plants and products as possible in one single chain; equalize the number of plants, in capacity units, to which each product in the chain is directly connected; equalize the number of products, in units of expected demand, to which each plant in the chain is directly connected. Garavelli (2003) also proposed a supply chain flexibility framework. He used a simulation model to evaluate the effects of different degrees of flexibility on the performance of the supply chain. He showed that supply chain configurations with limited flexibility provide good performance due to the trade-off between the capability of reacting to uncertainty and the limited increase of the material flow congestion.

The effect of supply chain flexibility on performance has also been examined in literature. Dreyer and Gronhaug (2004) tested empirically the impact of flexibility on performance. Their findings showed that flexibility is a valuable skill which has a major impact on competitive position among the firms studied and that it is possible to achieve sustained competitive advantage in highly uncertainty environments. Pujawan (2004) presented a framework for assessing supply chain flexibility. In a case study the framework was tested and proved to be helpful in aiding managers to which elements of flexibility should be enhanced and emphasized in order to increase supply chain flexibility.

In the literature there has been a significant attempt to model the supply chain design problem in view of flexibility by Bertrand (2004). The author suggested that “the supply chain design problem consists of answering two questions:

1. What should be the supply levels, including flexibility options, for each of the items in the product structure.
2. What technology and what capacity should be installed to produce each of the items in the product structure.”

The author formulated the supply chain design problem as an iterative decision process consisting of selecting technologies for production processes and balancing the maximum supply rates for all products, taking into account investment and production costs, demand uncertainty and product prices; and developed a model that can be used to analyze decision options for volume, mix and new product flexibility.

Supply chain flexibility especially in two-tiers supply chains consisting of suppliers and a manufacturer has been investigated through supply contracts or quantity contracts. Contracting in supply chain management is a very popular concept. Tsay et al. (2004) presented a very thorough review of supply chain contract modeling. Bernard (2004) reviewed research on contracts that take into consideration flexibility issues. Eppen and Iyer (1997) focused on backup agreements between a catalog company and manufacturers that provide upstream sourcing flexibility for fashion products. Tsay and Lovejoy (1999) examined quantity flexibility contracts as a method to coordinate materials and information in supply chains and investigated their implications on the performance and design of supply chains. Li and Kouvelis (1999) studied supply contracts with time, quantity and supplier flexibility under purchase price uncertainties. They developed a methodology for evaluating sourcing contracts and illustrated that

contractual flexibility in sourcing agreements can lead to sourcing cost reduction in environments that are characterized by deterministic demand and price uncertainty. Cachon and Lariviere (2001) examine supply contracts under forced compliance, where the capacity flexibility of the supplier is limited and supply contracts under voluntary compliance, where the supplier enjoys increased flexibility. Kamrad and Siddique (2004) analyzed and evaluated supply contracts characterized by supply and quantity flexibility, exchange rate uncertainty, profit sharing and supplier reaction options. Skintzi et al. (2005a) focused on warehousing flexibility in a single echelon supply chain. They investigated three different warehousing policies and ownership structures of the warehousing facilities.

Although manufacturing flexibility has been a very active research area during the last two decades and attracted the attention of both the academic and the business world, supply chain flexibility has not been extensively and exhaustively examined and analyzed. Since supply chain flexibility encompasses the flexibility of the manufacturing systems that consist the supply chain we may presume that the existing literature will provide a solid and fertile ground for further research.

4. Design for inventory control

During the last two decades inventory theory and specifically inventory control found a fertile ground to develop in the context of supply chain management. Traditionally inventory has been employed to cope with demand uncertainty and fluctuations. Cachon (2002) reviews supply chain inventory management models. The author classifies models into six categories according to the aspects they highlight: multiple retailers with stochastic demand (Axsater, 1993; Hausman and Erkip, 1994; Cachon and Fisher, 1997), multiple retailers with deterministic demand (Roundy, 1985), capacity allocation (Lee et al., 1997), information and production timing (Eppen and Iyer, 1997; Tsay and Lovejoy, 1999; Tsay et al. 2004), internal markets (Porteus and Whang, 1991), and vendor managed inventories. Recently, companies in their attempt to cope with increased competition and more sophisticated customers in highly volatile markets have explored new inventory control tactics. Empirical results indicate that in certain industries there has been a significant alteration in the perspective and the way inventory is managed. In contrast with “traditional” supply chains where the downstream node makes stock level decisions and controls inventory there has been a tendency in supply chain management to shift inventory decisions and control to the upstream.

4.1 Empirical Research on Upstream Inventory Control

Although shifting inventories to the upstream is a rather new concept several authors have studied the applications and the effects of the new approaches in supply chain management, design and performance. Upstream inventory control has been adopted by a significant number of organizations as an effective and efficient method to establish successful relations with supply chain partners that could lead to win-win situations for all supply chain participants. The grocery sector is one of the premier areas of VMI (vendor managed inventory) successful implementation. Clark and Hammond (1997) studied retailers that implemented VMI with the Campbell Soup Company. They concluded that retailers who adopted VMI performed significantly better than retailers who used electronic services only to submit orders. On the other hand Cachon and Fisher (1997), analyzing the same case, found that the same benefits would have been achieved even if the retailers kept control of inventory. Tyan and Wee (2005) investigated VMI as a form of strategic alliance in a supply chain and through a survey of the Taiwanese grocery industry illustrated that VMI, if implemented successfully, may result to cost reduction, service level improvement and create business opportunity for all the supply chain partners.

It has been suggested that the success of VMI in the grocery sector could be extended to other sectors too (De Toni and Zamolo, 2005). Holmstrom (1998) presented a case study of implementing VMI. He found that delivery and administration costs were reduced significantly, as well as the inventory level and the delivery time. Achabal et al. (2000) presented a decision support system (DSS) for VMI that combined inventory optimization models with promotional models from marketing. The DSS was implemented by a major apparel manufacturer and over 30 of its retail partners. As a result, customer service levels improved dramatically and there was also a significant improvement in inventory turnover. Kuk (2004) studied the effects of organizational size, employee involvement, and logistics integration on VMI in the electronics industry. The findings suggest that small organizations expect and enjoy higher returns from VMI. In addition, high employee involvement and more integrated logistics partnerships ensure success and add value to VMI. De Toni and Zamolo (2005) analyzed a real application of VMI in the household electrical appliances sector and specifically in Electrolux Italia. The results indicate that the inventory reduced significantly from 1998,

when the VMI was introduced until 2000 (the year in which the process can be considered routine) while the Order Fill Rate, that is the percentage of orders that are satisfied considering both on time delivery of the appropriate quantity, increased considerably.

4.2 Modelling of Upstream Inventory Control

The increasing number of applications in the field of upstream inventory control indicated the significance of the approach and the need for theoretical background. Not until recently inventory theory has expanded to examine and analyze the new trends in upstream managed inventory, as they arise in practice. Cachon and Fisher (1997) investigated supply chains with a single supplier and multiple retailers. The supplier selected the operating policies of all supply chain members so that he optimizes his preferences without leaving the retailers worse-off than the competitive case. Results indicated that the supplier did not always selected the optimal policies but frequently led retailers to more preferable policies than the competitive solution. Therefore, shifting control often mitigates competition leading to more beneficial solutions for all players. The author in a more recent work (Cachon, 2001) considered a supply chain consisting of one supplier and multiple retailers that operates under VMI but both the upstream and downstream nodes carry inventory while only the upstream node may re-order for all supply chain members. He resulted that the supplier will choose optimal policies that maximize profits for the entire supply chain provided that the supply chain members will share the benefits of VMI. Mishra and Raghunathan (2004) considered a retailer that sells multiple brands from different manufacturers. The authors resulted that VMI policy will lead to increased competition between manufactures, who will be forced to keep more inventory and therefore, benefit the retailer that sells the competing brands.

Dong and Xu (2002) investigated the effects of VMI on a supply channel. They resulted that VMI can reduce effectively the inventory costs and in the long term the channel profits will be increased. This increase in profit although it is very evident for the buyer, it is not so clear as far as the supplier is concerned. Pohlen and Goldby (2003) distinguish between supplier managed inventory (SMI) and VMI. According to the authors "...VMI involves the coordinated management of finished goods inventories outbound from a manufacturer, distributor or reseller to a retailer or other merchandiser while SMI involves the flow of raw materials and component parts inbound to a

manufacturing process". They compared the two approaches with respect to the concept of economic value added, and investigated their effect on shareholder value and performance. Choi et al. (2004) studied the supplier-manufacturer relations in a supply chain and specifically the problem of supplier's service level in a VMI contract so as to allow the manufacturer to achieve the desired customer service level. They showed that setting a minimum service level to be maintained by the supplier does not always guarantee that the desired service level will be achieved in terms of fill rate and stock-out. The authors proposed a flexible supply contract that provides the supplier with a set of different combinations of stock-out rates and the expected backorders he could choose from. Therefore, although local service levels cannot guarantee high supply chain performance, coordination mechanisms can lead to the desired outcome. Lee and Chu (2005) examined a two-member supply chain operating in a newsboy environment and examined the expected pay-offs in case the upstream or the downstream node is responsible for the inventory decisions. The authors suggest that the upstream node will in general have no incentive to desire inventory control, while in the case he does then keeping inventories upstream will be beneficial for both the upstream and the downstream node. Skintzi et al. (2005b) considered a serial capacitated supply chain consisting of one manufacturer and one retailer. Downstream and upstream inventory control policies were analyzed in such a way the members of the supply chain do not passively determine their optimal policies but with respect to each other's strategies in a game theoretical setting. Moreover conditions to decide what policy should be applied depending on both the demand and the investment in warehousing were provided.

Researchers have also investigated the effects on upstream inventory control on the Bullwhip effect. Disney and Towill (2003a) presented through simulation the effect of vendor managed dynamics on the Bullwhip effect. They concluded that independently of the bullwhip measure utilized, the employment of VMI strategy led to a more effective response to volatile changes in demand that resulted to a reduction in bullwhip. The same authors in another study (Disney and Towill, 2003b) compared a VMI supply chain with a traditional supply chain with respect to the bullwhip effect. They resulted that two sources of the bullwhip effect can be completely eliminated (rationing and gaming, and the order batching effect) while the impact of other sources can be reduced significantly. In addition, VMI can respond effectively to demand changes due to the promotion

effect and to the price induced variations. Disney and Towill (2002) proposed a decision support system to determine the optimum design parameters of a VMI system that incorporates a production or distribution-scheduling algorithm termed Automatic Pipeline, Inventory and Order Based Production Control System (APIOBPCS).

Several authors have also investigated the implications of VMI on transportation operations. Cheung and Lee (2002) explored the case of one supplier serving multiple retailers located closely. The authors examined the impact of information sharing tactics often adopted when VMI process are implemented on shipment coordination and stock rebalancing. Cetinkaya and Lee (2000) presented an analytical model for coordinating inventory and transportation decisions in a VMI system. The considered a vendor realizing random demands from a group of retailers and computed the optimum replenishment quantity and dispatch frequency simultaneously. Disney et al. (2003) evaluated how VMI affects transportation operations in a supply chain. The authors concluded that VMI enables a reduction in manufacturing and transportation costs. Rusdiansyah and Tsao (2005), proposed a model for delivery of products in the vending machine supply-chains operated under VMI. Their results indicate that substantial savings in costs can be achieved by incorporating inventory and vehicle routing decisions into a single model.

5. Conclusions

The major conclusion drawn from this review is that supply chain design and re-design is a powerful competence in improving production efficiency, product quality and customer satisfaction. This study has focused on design decisions that allow responsiveness to uncertainty and variability. Evidence from empirical studies and literature indicate that postponement, inventory control and flexibility are key issues in supply chain design in order for a company to survive successfully in the new economic environment.

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