October 2006

Supply Chain Design for Flexibility: A Review

by Dr Georgia Skintzi, Research Fellow MSL

According to Fine (2000), 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. 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 (Bairman 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 and Billington, 1995), 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, which 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. Decisions allowing 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, but in this article our focus is on flexibility.

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 companys 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 (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).

Supply Chain Flexibility

The majority of current research has focused on a single firms strive for flexibility and competitiveness and especially on manufacturing companies (manufacturing flexibility). Zhang et al. (2003) define manufacturing flexibility as the ability of the firm to manage production resources and uncertainty to meet customer requests. In the context of the supply chain a single firms ability to be flexible is no longer adequate while all participants of a supply chain should be considered. 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:

- What should be the supply levels, including flexibility options, for each of the items in the product structure.
- 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-tier 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 Lyer (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.

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.

The research from which this paper is drawn is supported by a grant from the Greek Ministry of Education and the European Union.

References

Baiman, S.; Fischer, P.E. and Rajan M.V. (2001). Performance measurement and design in supply chains. *Management Science*. 47(1), 173-188.

Bertrand, W. (2004). Supply chain design: Flexibility Considerations. *Handbook in Operations Research and Management Science Vol. 11, Supply Chain Management: Design, Coordination and Operation.*. de Kok, A.G. and Graves, S.C. (Eds.). North-Holland Publishing Company, Amsterdam.

Cachon, G.P. and Lariviere, M.A. (2001). Contracting to assure supply: How to share demand forecasts in a supply chain. *Management Science*. 47(5), 629-646.

Dreyer, B. and Gronhaug, K. (2004). Uncertainty, flexibility and sustained competitive advantage. *Journal of Business Research*. 37, 484-494.

Eppen, G. and Iyer, A.V. (1997). Backup agreements in fashion buying The value of upstream flexibility. *Management Science*. 43(11), 1469-1484.

Fine C.H. (2000). Clockspeed-based strategies for supply chain design. *Production and Operations Management*. 9(3), 213-221.

Fisher, M.L.; Obermeyer, W.R.; Hammond, J. and Raman, A. (1994). Making supply meet demand in an uncertain world. *Harvard Business Review*. May-June, 83-93.

Garavelli, A.C. (2003). Flexibility configurations for the supply chain management. *International Journal of Production Economics*. 85, 141-153.

Gerwin, D. (1993). Manufacturing flexibility: A strategic perspective. *Management Science*. 39(4), 395-410.

Graves S.C. and Tomlin B. (2003). Process flexibility in supply chains. *Management Science*. 49(7),907-919.

Graves, S.C. and Willems, S.P. (2004). Supply chain design: safety stock placement and supply chain configuration. *Handbook in Operations Research and Management Science Vol. 11, Supply Chain Management: Design, Coordination and Operation.*. de Kok, A.G. and Graves, S.C. (Eds.). North-Holland Publishing Company, Amsterdam.

Kamrad, B. and Siddique, A. (2004). Supply contracts, profit sharing, switching, and reaction options. *Management Science*. 50(1), 64-82.

Koste, L.L. and Malhotra, M.K. (1999). A theoretical framework for analyzing the dimensions of manufacturing flexibility. *Journal of Operations Management*. 18(1), 75-93.

Koste, L.L.; Malhotra, M.K. and Sharma S. (2004). Measuring dimensions of manufacturing flexibility. *Journal of Operations Management*. 22, 171-196.

Kuk, G. (2004). Effectiveness of vendor-managed inventory in the electronics industry: determinants and outcomes. *Information & Management*. 41, 645-654.

Lee, H.L. and Billington, C. (1995). The evolution of supply chain management models and practice at Hewlett-Packard. *Interfaces*. 25, 42-63.

Li, C.L. and Kouvelis, P. (1999). Flexible and risk-sharing supply contracts under price uncertainty. *Management Science*. 45(10), 1378-1398.

Parthasarthy, R. and Sethi, A.K. (1993). Relating strategy and structure to flexible automation: a test of fit and performance implications. *Strategic Management Journal*. 14(7), 529-549.

Pujawan, I.N. (2004). Assessing supply chain flexibility: a conceptual framework and case study. *International Journal of Integrated Supply Management*. 1(1), 79-97.

Sethi, A.K. and Sethi, S.P. (1990). Flexibility in manufacturing: a survey. *The International Journal of Flexible Manufacturing Systems*. 2, 289-328.

Signorelli, S. and Heskett, J.L. (1989) Benetton (A). Harvard Business School.

Suarez, F.F.; Cusumano, M.A. and Fine, C.H. (1995). An empirical study of flexibility in manufacturing. *Sloan Management Review*. Fall, 25-32.

Suarez, F.F.; Cusumano, M.A. and Fine, C.H. (1996). An empirical study of manufacturing flexibility in printed circuit board assembly. *Operations Research*. 44(1), 223-240.

Tsay, A.A. and Lovejoy, W.S. (1999). Quantity flexibility contracts and supply chain performance. Manufacturing & Service Operations Management. 1(2), 89-111.

Tsay, A.A.; Nahmias, S. and Agrawal N. (2004). Modeling supply chain contracts: A review. *Handbook in Operations Research and Management Science Vol. 11, Supply Chain Management: Design, Coordination and Operation.* de Kok, A.G. and Graves, S.C. (Eds.), North-Holland Publishing Company, Amsterdam.

Upton, D.M. (1995). What really makes factories flexible? *Harvard Business Review*. 73(4), 74-84.

Zhang, Q.; Vonderembse, M.A. and Lim, J.S. (2003). Manufacturing flexibility: Defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal of Operations Management*. 21, 173-191.