Supply Network Flexibility

By

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Abstract

This paper takes its starting point in a question posed by the CEO of a Swedish shirt manufacturer: *"Why cannot the fabric supplier be more flexible in dealing with our orders?"* On the basis of an analysis of the activities and resources in the supply chain of the shirt manufacturer we discuss the prerequisites for, and the consequences of, flexibility in such activity structures. In this analysis we point at the importance of including interdependencies in relation to other supply chains. The analysis of these interdependencies imply that if the suppliers of the shirt manufacturer fully adhered to the flexibility requirements of the shirt manufacturer the CEO would be faced by other problems.

Introduction

The literature on flexibility is dealing mainly with manufacturing systems while research on flexibility in distribution channels and supply chains has been very limited (e.g. Barad and Even Sapir, 2003, p. 155). When manufacturing systems are concerned flexibility issues are typically focused on the ways the systems are able to adapt to changes in the environment. For instance, Das and Abdel-Malek (2003:172) define manufacturing flexibility as: "The ability of a system or facility to adjust to changes in its internal and external environment". These definitions thus imply a more or less unpredictable market environment setting the conditions to which the manufacturing system has to adjust.

When supply chains, including several specifically related manufacturing systems, are concerned the environment necessarily needs to be pictured differently.

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These chains involve specific interdependencies among the operations of the different manufacturing systems with a consequent need to co-ordinate these operations. Therefore, flexibility must be dealt with differently in a “network of manufacturing systems” situation as compared to a single manufacturing system considered in a market environment context. Koste and Malhotra (1999) conducted an exhaustive search and analysis of literature on flexibility and concluded that only a fraction of the studies have focused on empirical observations of industrial practice. Thus, there is a general need for empirical research on flexibility and particularly on supply network flexibility.

The aim of this paper is to explore the characteristics of flexibility in supply networks. The analysis is based on a case study of a focal supply chain in the textile apparel industry. We begin the paper with a short review of the literature on flexibility in manufacturing systems and supply chains. Thereafter, the processes and flexibility requirements of the shirt manufacturer in the case study are described. We continue by presenting the operations upstream the shirt manufacturer and relate these conditions to the situation of the shirt manufacturer. The concluding discussion presents some suggestions concerning further development of the concept of supply network flexibility.

The flexibility literature

Flexibility has been defined as “the ability to change or react with little penalty in time, effort, cost or performance” (Upton, 1994, p. 73). Consequently, it is not only about coping with variety and change but also to consuming a minimum of resources in doing so. It is a multidimensional concept that is studied from various perspectives. Most research, however, takes the point of departure in manufacturing considering the operational object of change. A great number of authors have presented frameworks with such an operational perspective on manufacturing flexibility (e.g. Koste and Malhotra, 1999, Vokurka and O’Leary-Kelly, 2000, D’Souza and Williams, 2000, Giachetti et al. 2003). Several of these frameworks relate to Gerwin’s (1993) dimensions of volume, materials, mix, modification, changeover, rerouting and responsiveness flexibility. A common characteristic of these approaches is a focus on a specific manufacturing system and how its processes can match the flexibility requirements of the customers (Figure 1).

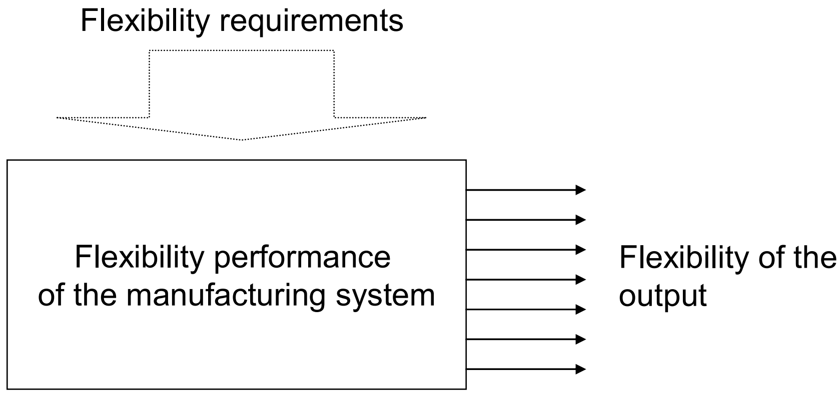

Figure 1. Flexibility focus on the individual manufacturing system

The different flexibility dimensions can be structured in various ways. Stonebraker and Leong (1994), for example, separated product-related flexibility from process-related. In their framework product related flexibility is concerned with the ability to respond quickly to changes in (i) the demand for a particular product (volume flexibility), (ii) the mix or proportion of products of a particular family that is produced (product mix flexibility), (iii) due date or delivery quantities (delivery flexibility), and finally (iv) the ability to incorporate changes in product characteristics and to develop and produce newly designed products (modification flexibility). Process related flexibility, on the other hand, deals with the ability of the processes to respond rapidly to (i) different production set-ups required for various products (changeover flexibility), (ii) variations in the sequence and production lot-sizes to accommodate required production volumes (scheduling flexibility), and (iii) defining and implementing new technologies in production processes with minimal disruption (innovation flexibility).

The domain of flexibility, consequently, is comprised of different flexibility dimensions, but each dimension also has its own constituent elements. Koste and Malhotra (1999) used four such elements to define the level of flexibility in a dimension. The two first were developed from Gerwin (1993) and Upton (1994) and concern the range of the flexibility, i.e. the ability of a firm to operate in the broad parameters of the dimension. The range-number flexibility measures the number of available options within the dimension, while the range-heterogeneity flexibility measures the conformity of the options. The third element, also emphasized by for example Upton (1994), is mobility. It represents the ease with which the organization moves from one state to another. It could be measured through the time, cost and effort of moving within the range of a specific dimension. The fourth element, uniformity, was also emphasized by Gupta and Buzacott (1989) and Upton (1994). It captures the similarity of performance outcomes within the range, for example expressed in terms of quality, service levels and cost.

Most work on flexibility is related to manufacturing but there are some approaches of developing dimensions of supply chain flexibility and matching them with the supply chain environment. Duclos et al. (2003) developed the notion of manufacturing system flexibility for supply chains. In accordance with other authors dealing with supply chain management (e.g. Christopher, 2000, Simatupang et al 2004), they argue that the entire process must be viewed as one system. For instance, Fisher (1997) states that all members in the chain need to integrate and act as a homogenous entity in order to enhance the performance throughout the chain.

Garavelli (2003) addresses supply chain flexibility in terms of the process flexibility of each plant – the number of product types that can be manufactured in each production site, and logistics flexibility – the different logistics strategies which can be adopted either to release a product to a market or to produce a component from a supplier. Supply chain flexibility is often described in terms of agility (e.g. Christopher, 2000) and the supply chain context explained with the characteristics of three types of uncertainty: demand, manufacturing and supply. Prater et al. (2001), for example, describe the supply chain context in terms of external vulnerability, made up by the demand and forecasting uncertainty and the complexity of supply chain processes.

The supply chain flexibility approaches presented in the literature hence deal with adaptations along the supply chain in response to uncertainties in the surrounding environment (Figure 2).

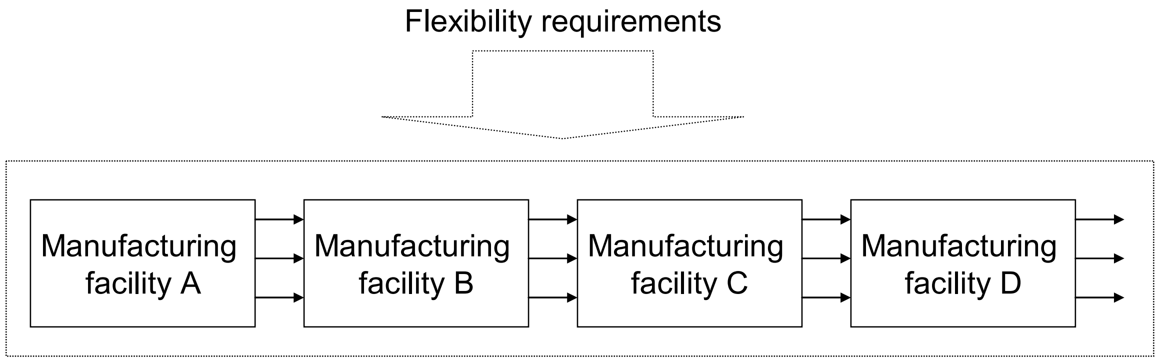

Figure 2. The supply chain as a closed system

The supply chain is thus regarded a closed system and interdependencies to other supply chains are not considered. This perspective may be appropriate for supply chains where the activities and the resources of the firms involved are more or less completely devoted to this chain. On the other hand, in situations where the activities directed to the focal chain are marginal in relation to the total operations of the firms involved this framework is not useful because it neglects the interdependencies to other supply chains in which the actors are involved.

To understand the flexibility conditions of our shirt manufacturer we need thus to describe and analyse the situation in its own manufacturing system and how this system is related to what is going in the supply network context.

The shirt manufacturer

This paper is based on a case study of a Swedish shirt manufacturing company and its supply network. Interviews and site visits have been conducted at the shirt manufacturer and its suppliers in order to explore the flexibility characteristics of the supply network. Eight interviews have been conducted at the shirt manufacturer (SM), two at the storing firm (C), four at the finishing firm (F) and three at the weaving firm (W).

Demand characteristics

Textile apparels have certain common market characteristics, such as short product life cycles, high volatility, low predictability and a high level of impulsive purchase (Bruce et al., 2004). The assortment is characterized by a large number of variants of specific product types in terms of different models, fabrics of different quality, colour and pattern. Fast changing fashion trends have called for systems for immediate response to the point of sales data, also described as 'quick response' (e.g. Forza and Vinelli, 2000). The idea of quick response is to reduce the stock levels and the forecasting dependency by shortening the lead times and making the entire supply chain directly dependent on the demand changes (e.g. Richardson, 1996).

For the shirt manufacturer (SM) in our case demand follows the typical pattern of the apparel industry involving two types of orders: "stock service orders" and "fixed orders". Stock service shirts are made to stock, and stored and delivered from one of the five distribution centres of SM with delivery times of single days. Fixed orders consist of two seasonal collections of shirts. About 70 % of the orders from retailers for the fixed orders are received several months before the season commences, and allows for purchasing fabrics and making these shirts to order. The remaining 30% of the fixed order volumes and the entire volume of the stock collection is based on forecasts and consequently produced on speculation. This way of mixing different types of orders has developed into a 'common procedure' in the industry, where enhanced use of quick response strategies have increased the proportion of orders that are decided once the season has been launched (Birtwistle et al., 2003).

Consequently, complementary shirt orders of the fixed order type needs to be handled during the season. For shirt models included in both the stock service and fixed order collections, such complementary fixed orders might empty the inventories of the stock service shirts, resulting in stock-outs for these products. Such orders impose particular requirements on flexibility of the manufacturing process.

The shirt manufacturing process and its flexibility

The shirt manufacturing process consists of fabric cutting, followed by adhesive attachment of the strengthening material in cuffs and collars, ending with the sewing operations. Our shirt manufacturer (SM) operates one plant in Sweden and two production lines in Estonia. Besides these owned plants SM can access more capacity from the Estonian facility and two other plants in Estonia and Lithuania.

The overall capacity requirement in the shirt making process is almost the same irrespective of fabric and model. Thus, there is no need for changed manufacturing capacity when shirt models are varied and within this scope the product mix flexibility is high. The sequencing of different manufacturing orders, however, depends on the characteristics of the shirt models. For example, chequered or striped fabric requires an additional operation for pattern matching that is not necessary for one-coloured fabric. Such fabric, consequently, lengthens the through-put time and decreases the overall manufacturing capacity of shirts per week. Therefore, plain and patterned shirts are mixed in the weekly schedule. The set-up of sewing-thread takes long time, consequently impacting on the conditions for making small batches. Still, the possibility of frequently changing production plans and making small batches, i.e. the scheduling and changeover flexibility, is considered high and one of the strengths of the apparel manufacturing process.

The volume flexibility requirements on the apparel manufacturing process are affected by the demand seasonality and uncertainty, the sales pattern of the fixed order collection, and the fact that some models are included both in the fixed order and stock service collections. The apparel manufacturing capacity of SM consists of a mix of sub-contracting and fully-owned facilities. These conditions allow for sufficient volume flexibility in the apparel manufacturing process in order to match the capacity requirement created by the demand pattern.

The stock service collection and the complementary fixed orders placed during the season require high delivery flexibility, i.e. fast adjustment to larger quantities and shorter delivery dates than expected. The available manufacturing capacity is large enough to deal with the capacity peaks. Therefore, the Swedish plant, with the shortest delivery time to the customers, can be used as a “fast-line” capacity in order to make stock service shirts and complementary orders of fixed order shirts.

Consequently, this part of the manufacturing process is considered to have a high flexibility concerning the product mix, volume, delivery, changeover, and scheduling dimensions, which are the required flexibility dimensions of the market. This flexibility is partly secured through considerable inventories of fabric and finished shirts, in turn leading to high risk of obsolescence, and at the same time risk for frequent stock-outs of stock-service shirts. This is especially true for fashion fabric and models. The inventory turnover rate of fabric varies between once a year (or a couple of times) for fashion fabric to one or two months for standard fabric. For the stock service shirts the turnover rates vary from once a year to some months. The flexibility of the apparel manufacturing process is consequently insufficient for the shirt manufacturer. The main reasons for this situation are the requirement for high service levels, the long lead times and large batch-sizes of fabric from the suppliers, and the perceived unwillingness of the suppliers to adjust to changes in due dates and delivery quantities in order to quickly respond to demand variations. As a consequence of this the CEO of the shirt manufacturer posted the question: “Why cannot the fabric manufacturers be more flexible in dealing with our orders?” It is consequently not enough for the apparel manufacturer to have highly flexible internal processes but it is also to a great extent affected by the flexibility of its upstream supply network.

The operations upstream the shirt manufacturer

The supply of fabrics

SM’s direct counterpart in the upstream business transactions is a Swiss firm that takes no part in the manufacturing processes in the supply chain. This company (C) is identified as a ‘converter’ meaning that it is involved in the design of fabrics and links buyers of fabric with the upstream operations in the supply chain. These coordinative operations involve 10-12 suppliers and 80-100 customers. Most customers are located in England, Scandinavia, the US, and Canada. SM is one of the most important customers of C both in terms of the volumes purchased and the quality of fabric demanded. SM accounts for about 20 percent of the total business of C within 'shirt & blouse fabrics', one of its five business areas.

When a customer orders fabric, C estimates the weaving capacity needed, contacts a weaving firm and assigns the order to a specific loom at this supplier. Some weaving firms are involved also in 'finishing' which is the final step in the manufacturing of fabrics involving a number of sub-processes. Increasingly, however, firms have specialized in either weaving or finishing. The requirements in terms of finishing operations are estimated and allocated by C in the same way as for weaving. After the final finishing operations the fabric is delivered to C which holds inventory for SM and other customers. C receives SM's detailed forecasts and plans in order to establish the delivery schedules in terms of total meters of fabric at specific due dates. Therefore, the two companies have a daily communication regarding call offs of fabric.

The upstream operations coordinated by C thus involve weaving and finishing. Our case deals with these operations in one of the two supply chains providing SM with fabrics. The weaving company involved is called W, while the finishing operations are undertaken by F. Both firms are located in Switzerland and belong to the most important suppliers of C. Over time, these three companies have come to work quite closely together and they have, for example, developed a recipe that is important for the quality of wrinkle-free shirts. But C is, to some extent, involved also in the supply process further upstream. The quality of the fabric is strongly dependent on the features of the yarn supplied by spinning mills, which, in turn, are determined by the features of the cotton. Therefore, our analysis of the operations upstream SM also needs to involve the characteristics of these processes which serve as input to weaving and finishing (see figure 3).

Figure 3. The processes upstream the shirt manufacturer

The yarn input

Spun yarn is the input to the weaving operations. The weaver in this supply chain uses around 100 different types of yarn. For cotton yarn W has relationships with 10 main suppliers while non-cotton yarn is supplied by about 60 vendors. The features of the yarn are determined primarily by the length of the cotton staples and the spinning technique applied. The longer the staples are, the better the quality of the yarn, and hence, the quality of the fabric. Moreover, the cotton characteristics set the conditions for the spinning techniques. High quality yarn relies on compact spun yarn with a double twisting technique. This means that the features of the cotton fibers are crucial for the flexibility in the supply chain. For shirts manufactured by SM specific fibers (grown in special soils) must be used and the characteristics of these fibers determine what type of spinning mills that can be used.

Weaving

W is involved in design of fabric as well as in the actual weaving of the fabric. It is important for W to plan its production so that orders from different customers can be combined to fully utilize its production capacity. The number of customers exceeds 200 of which 10 customers account for more than two thirds of total sales. SM is an 'indirect' customer of W because C is handling all the business transactions. C accounts for about 10 percent of W's output, half of which is supplied to SM. W produces some standard collections that are offered to many customers but also unique designs that are customer specific.

Reliability in yarn supply is crucial for a weaving firm. Lack of yarn would force a weaver to stop its operations. Therefore, W normally orders yarn six months in advance of its actual need. In addition they have chosen to use some closely located suppliers in order to reduce delivery times when yarn has to be purchased with short notice. Moreover, W holds about 200 tons of yarn in stock which corresponds to about one month's demand. The delivery times are about 1 week from Italian suppliers and 1 day from suppliers in Switzerland.

The weaving process consists of five steps from warp preparation to quality control where the fabrics pass through a machine with five cameras searching for irregularities that need adjustment. After approximately four weeks the yarn has become fabric and is ready for the finishing process to provide the fabric with its final features. More than 50 % of the fabric produced by W is transported to F for finishing operations.

Finishing

F is the finisher used by C for fabrics woven by W for SM. The finisher works on commission and does not take title to the fabric which is owned by C. F provides 60-65 customers with a mix of various finishing services to give the fabric its special visual appeal and required properties, for example, non-iron, impregnated, flame-retardant, anti-microbial etc, for various types of fabrics (shirts, linen, industrial clothing and so on). Some fabric goes directly to the finishing operations, while other fabric might need coloring before finishing. F provides so called piece dyeing implying that whole lots of fabrics are colored before finishing. Sometimes weaving companies are involved in piece dyeing and supply W with fabrics for finishing. The fabrics used for SM's shirts are not colored in this way, but are weaved from colored yarn (i.e. so called yarn dyeing).

F handles around 15 million meters of fabric annually, divided into 11 000 different 'lots'. A lot may consist of fabric to be used for different customers that can be sewn together since these fabrics demand the same finishing processes. The finishing process consists of 10-15 different sub-processes. In average it takes 15-17 working days for one lot to undergo all the required sub-processes in finishing. Fabric that is used for non-iron apparel requires further treatment which adds five days to the throughput time.

Implications from the case

The description of the upstream operations revealed a number of aspects of significance for the flexibility of the input to SM's sewing facilities. First, the specific features of the fabric needed for wrinkle-free shirts are created mainly in the finishing operations. However, these features are dependent on the treatment of the fabric in the weaving facilities and require cotton fibers with specific characteristics which in turn demand specialized spinning techniques. This means that even if W is able to work on a broad range in terms of product mix flexibility the possibilities to adapt quickly to changes imposed by SM are limited. For example, responding to SM's demand for increasing volumes with a short notice will call for either buffering of yarn or using yarn planned for another customer with the same quality requirements. Owing to the huge range of yarn qualities and colors this would be an expensive way of assuring volume and delivery flexibility. Moreover, once the weaving operations at W have started, these fabrics are exclusively made for SM and other customers demanding specially patterned fabric. This means that from this point in the supply chain neither W nor F can adjust the ongoing processes to keep up with changing requirements from SM. The process then needs to start from the beginning implying quite low changeover flexibility. What might be done is to change the sequencing of the fabrics produced for different customers. However, this scheduling flexibility cannot affect the minimum lead time of the whole process.

Second, SM is perceived to be an important customer by all the involved suppliers – C, W and F. In spite of that, the volumes of fabric used by SM represent a quite small share of the capacity of the facilities for weaving and finishing (see Figure 4). If the capacity of the weaving facility in terms of meters of fabric produced annually is 100, half of this demand is supplied to F where SM's demand amounts at 5. This means that the volume of fabric purchased by SM represents around 5 percent of the total capacity for both W and F. Therefore, gains in flexibility owing to adjustments to changing requirements of SM would affect the economies of scale in these facilities considerably and in turn increase costs for all buyers of fabric, including SM.

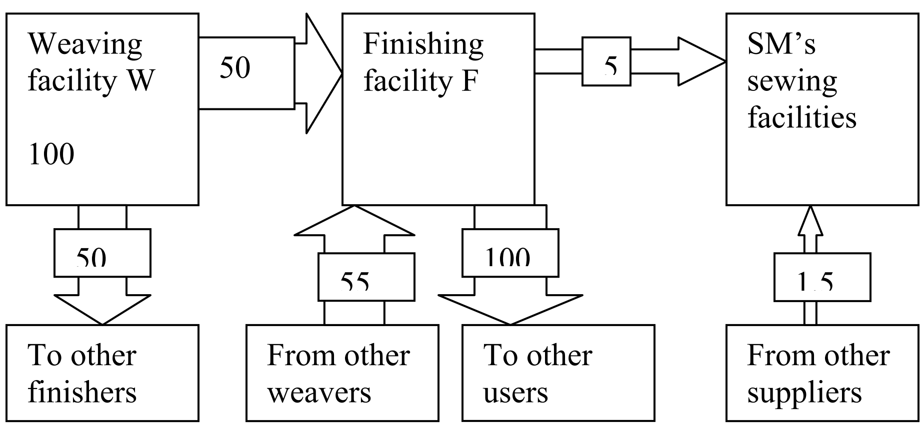

Figure 4. The flow of materials in the supply network.

Analysis

From the buying company's point of view, flexibility features in terms of volume and delivery in relation to the supply chain as a whole appear to be of obvious interest. When scrutinising the chain of activities and resources involved in the supply chain, these features can be identified and analysed in different ways. The following analysis is structured according to two levels. First, we analyse flexibility aspects of the specific chain of activities related to the shirts. Second, by adding interdependencies to other supply chains on the basis of their joint use of specific production facilities in the chain, we explore some supply network flexibility aspects.

Flexibility features of the supply chain

In the analysis of the flexibility of the supply chain upstream in relation to SM's shirts, there are two different but interrelated dimensions that need consideration: (1) the features of the production facilities involved and (2) how these features are activated in specific relation to SM's shirts in the sequence of production activities. Both these aspects are related to the design of the particular supply chain. The ways in which this organised structure is activated is a matter of continuous co-ordination among the parties involved. The conditions for this co-ordination may take different forms and may change over time owing to the complex and changing context in which it takes place.

The specific features of SM's shirts are created in more or less all stages of the activity structure in the supply chain, which thus can be described as end product specific all the way from the selection of cotton fibres. Hence, the activities from the choice of cotton qualities and onwards are closely complementary and they thus require *ex ante* matching of plans among the firms that are involved (Richardson 1972). This implies that although some of the activities in the facilities are based on speculation to cope with the production facilities' features in terms of optimal batch sizes, this speculation is not made in relation to an expected general market demand, but specifically directed towards SM and its shirt production. Moreover, since the parties involved all strive to utilise their production capacities as much as possible, the volume of fabric produced on speculation directed towards SM will vary depending on what is produced for other customers. This means that whether or not material is available for use when an unforeseen order is placed at one of the facilities in the chain is a matter of how the individual firm deals with its production planning towards its whole set of customers. These conditions may explain the perceived irregularity in the delivery time for short-term orders.

The planning operations required within the chain involves two time frames since the volumes and product mixes are forecasted by SM on a long term basis and then subject to weekly, or less frequent, call offs based on retail orders and SM's own stock replenishment orders and production plans. How the individual firms deal with the long term forecasts may differ owing to (1) their total production mix, (2) the features of their production facilities with regard to the different flexibility dimensions (e.g. volume, product mix and changeover), and (3) the flexibility of their suppliers. Moreover, the variety characterising SM's product mix impacts on the planning of the activities in the production facilities since SM’s particular mix is combined with production activities directed towards other customers of W and F (see Figure 4).

The sequence of the activities also affects the delivery flexibility of the whole supply chain. Based on simulations of supply chains, including facilities with different degrees of flexibility, Garavelli (2003, p. 151) argues that efforts aiming at implementing similar flexibility in the plants in a supply chain “can often yield better company performance than implementing more flexibility only in one stage of the supply chain”. Hence, investments in increasing flexibility in one stage of a supply chain may not result in total flexibility gains unless the other stages are adjusted as well. In this case, SM has invested in flexibility in its sewing facility and may not have considered the way in which the activities up-stream need to be adjusted in order to realise the flexibility potential, or how the design of its own facilities could have been adjusted to the flexibility features of the other facilities. Consequently, large inventories may be needed in order to fully utilise the flexibility in SM's own plant as long as the rest of the fabric supply chain remains unchanged or SM adjust its production plans to the fabric supply.

The long lead-time in the whole supply chain is explained by the features of the individual facilities and by the adjustments necessary to create efficient combinations of various customers’ orders and plans in each stage of the chain. The connections among the individual activities thus have their own features when flexibility is concerned as these connections depend on how SM’s orders are combined with other orders to capture economies of scale. Economies of scale in the operations are captured through similarity among activities, since activities are similar when they make use of the same resource (Richardson 1972). Similarity among activities may be captured in various ways in the different facilities, for example by combining yarn qualities with the same requirements on spinning operations or fabrics in need of the same colouring treatment in the finishing facilities. In addition, certain dissimilarities, e.g. with regard to due dates and planning horizon among orders, are decisive of the terms for the total lead-time in a particular supply chain. These aspects all relate to other supply chains that are connected to SM's chain through their joint use of the production facilities. These chains constitute the network context of the particular supply chain.

The links to other chains are crucial for the efficiency of SM's supply chain since the production volume directed towards SM is but a small share of what is produced in total by the different production facilities involved. Therefore, the supply chain flexibility approach suggested by Duclos et al (2003) would not be particularly useful in the case presented in this paper since the supply chain behind SM's shirts cannot be viewed or dealt with as one (closed) system. Rather, the case describes a situation where the activity structure is open to its character implying that the output of each production facility is directed towards several customers at the same time as these customers use input from several sources.

Supply network flexibility

Interdependencies among supply chains imply conditions that are very different from what traditional conceptions of a supply chain suggest (Dubois et al 2004). One of the main differences is that the individual production facilities are involved in several closely complementary supply chains that require *ex ante* matching of plans among the firms involved. Hence, the individual firm, or plant manager, is not dealing with an uncertain general environment but needs to interact with several customers and suppliers individually to have an idea of what should be produced and when.

Based on the discussion above we may argue that the efficiency of a specific supply chain may not be improved even if a customer, such as SM, succeeded in making all the actors involved in the supply chain to adjust to its requirements. The reason for this is the variety among different customers' demands in terms of lead times, volumes, and their end products' various features that are created in different parts of their supply chains. Through joint utilisation of the production facilities that give the shirts their features, production activities can be efficiently undertaken, although this comes at the 'cost' of a certain degree of inflexibility as perceived by a particular end customer.

Analysing the full consequences of being involved in a supply network like this requires a lot more detail than an overall description of the specific supply chain can provide. Each individual shirt is subject to a more or less unique resource combination if the various activities and resources involved along the supply chain are taken into account. Hence, when flexibility is concerned the specific interdependence among production facilities with regard to a particular end product adds to the complexity, because the flexibility dimensions relevant for the individual production facility in relation to a specific customer must consider also other customers and the suppliers.

In addition to the differences in terms of product features customers may display a variety concerning their flexibility requirements implying various consequences for the production facilities involved. Hence, the flexibility demands on a particular production facility can be very different. When combining the production activities towards these customers the flexibility dimensions can thus neither be dealt with as inherent in the production facility, nor as resulting only from the specific product features required by the customers, but are also related to their various requirements on flexibility. For a discussion of these issues we turn to Figure 5 illustrating a production facility used by three customers A, B and C with different requirements on the output of the facility in one specific dimension.

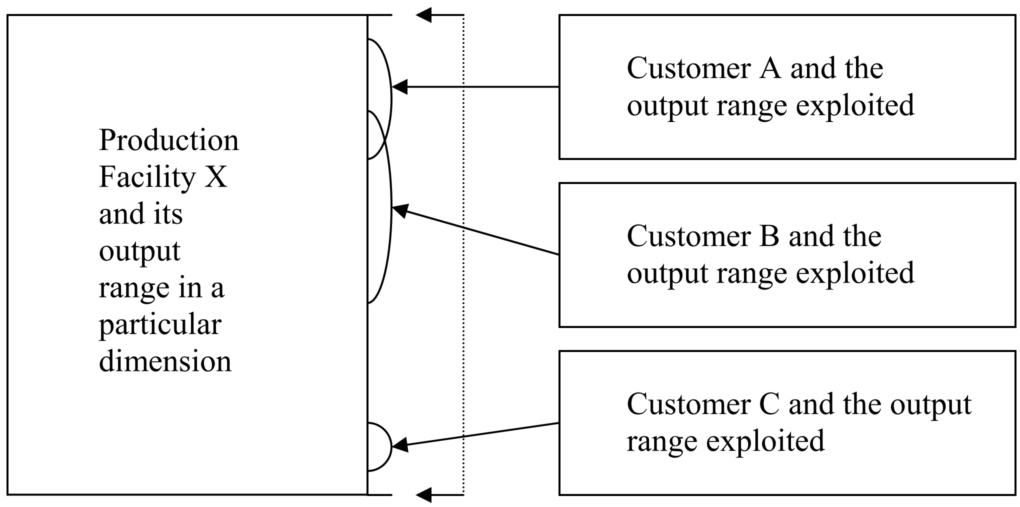

Figure 5. Customer requirements and facility range exploitation

First, the requirements of the customers can be described in terms of the extent to which they exploit the total range of what can be produced by the facility. In this case customer B makes use of a large range in comparison with customer C. Second, the requirements of the customers may be more or less similar with regard to which part of the total range they exploit, both in terms of range-number and range-heterogeneity. For example, the requirements of A and B are partly overlapping. Hence, whereas range exploitation refers to the extent to which customers utilise a flexibility feature of the production facility, similarity refers to the extent to which different customers' requirements coincide. These factors together determine the conditions for flexibility of the facility's operations and therefore also for the extent to which economies of scale may be captured. Within the range of the potential output they utilise, the flexibility requirements of the customers may be different.

From the perspective of the users of the facility it is interesting to develop products that are unique in terms of their features. In doing this they might be interested in utilising a spectrum of the facility’s range that is unexploited by others, resulting in increased flexibility requirements. However, another issue with consequences for the users is the impact on the facility’s potential for capturing economies of scale by pooling the requirements from different users. It is most likely also that the possibility for the firm running facility X to be flexible in relation to a particular customer is affected by the way in which this customer's exploitation of the range is related to other users. In a supply network context, therefore, the performance of the single facility is improved, both in terms of economies of scale and flexibility, from limited range exploitation and/or a high degree of similarity across the customer requirements. On the other hand, these conditions may entail similarity in the output of the facility thus hampering the possibilities for an individual user to develop a unique end product.

A supplier operating a facility may thus enhance both economies of scale and flexibility (in terms of mobility and uniformity) by affecting the users' requirements in a way that reduces the output range that is exploited. Such changes, however, will require changes of the activities and resources of the suppliers of the facility. In Figure 6 we have complemented the picture in Figure 5 with the suppliers of PFx running the production facilities a, b and c.

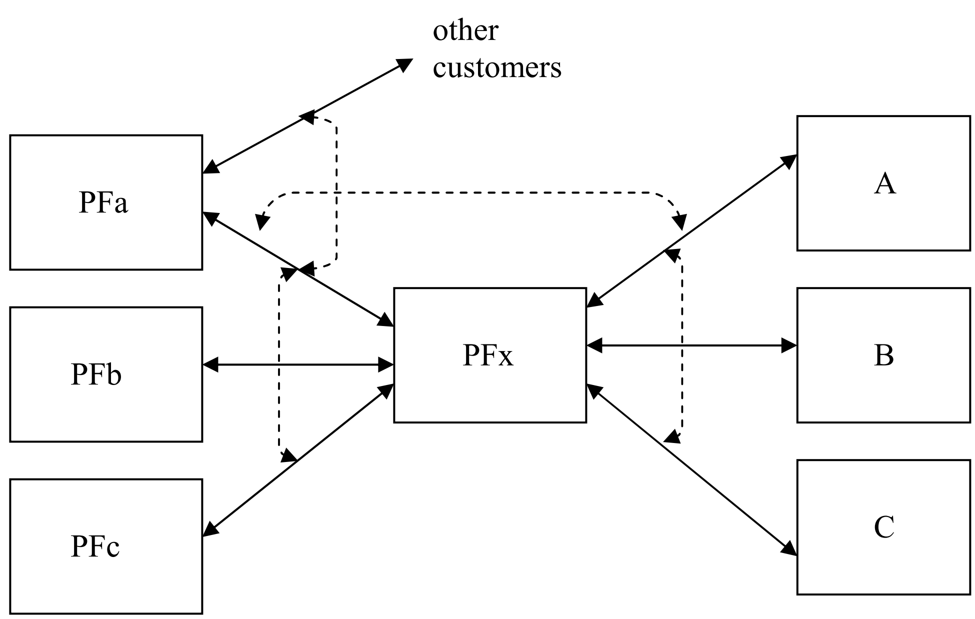

Figure 6. Interdependence within and among customer and supplier interfaces

The supply chains of A, B and C cross in PFx, where the operations directed towards them depend on input from suppliers a, b, and c, respectively. We argued above that the product features required, for example, by customer B may have different impact on the flexibility potential of the supplying facilities – PFx and PFa. Because these production facilities are sequentially interdependent PFx cannot, when its output is concerned, be more flexible than within the restrictions imposed by PFa. Moreover, any attempt to increase the similarity in the output ranges exploited by A, B and C, is contingent on corresponding changes in PFa, PFb and PFc. Consequently, potential benefits in terms of economies of scale and flexibility in terms of mobility are not possible to realise unless the suppliers of PFx can deal with the subsequent requirements on their facilities.

Concluding discussion

The aim of this paper has been to explore flexibility characteristics in a supply network context. The main implication from changing the perspective from focusing on the flexibility of individual production facilities towards networks of connected facilities is that supply chain flexibility must be viewed in new light. Any consideration of the flexibility of a particular supply chain has to take into account both the interdependencies within the chain and the interdependence to other supply chains. For a customer this complex picture of supply network flexibility points to the need to interact with actors operating the production facilities involved in order to put 'the right' kinds of requirements on them. There may be huge potential for a customer in adapting its requirements, in terms of product features and flexibility in various dimensions, to better coincide with those of other customers. Such adjustments impact on the exploitation of the output range of the facilities and thus on the similarity among activities.

For an individual customer, decisions regarding to what extent the range is exploited is related to purchasing strategic dimensions such as the number and content of supplier relationships. Hence, if the customer only utilises a narrow range of each supplier it may need to be involved in too many relationships which may entail co-ordination problems, high indirect purchasing costs and a weak position in relation to each supplier. For suppliers, these conditions imply that they may be able to increase the perceived flexibility of their suppliers by encouraging them to change their requirements in ways that positively impacts on the range exploitation of the facilities. Suppliers sometimes may provide too much flexibility – in terms of flexibility that is not valued by customers but nevertheless impose costs. Perry et al (1999:127) describe an example of 'obstacle removal' where a shoe production manager explained the necessity in making over two hundred shoe samples for the coming season because he thought he had to show all possible styles and colours to buyers. His two suppliers also talked about having to supply large numbers of samples of their products to the manufacturer. The buyers then surprised them by saying that: "We don't need so many colours, we are more interested in the styles".

Our final remark relates to the fact that flexibility is multidimensional. Our analysis of network flexibility thus needs to be further deepened to include the consequences of the 'balancing problem' (Dreyer and Grönhaug 2004). This balancing problem arises because different dimensions of flexibility may be conflicting. According to Dreyer and Grönhaug these conditions constitute major problems both in the study and in the management of flexibility.

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