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Managing uncertainty through supply chain flexibility: reactive vs. proactive approaches

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The purpose of this paper is to obtain insights into the typology of uncertainty and relevant strategies adopted by manufacturing companies to achieve better supply chain flexibility. Strategies are classified into reactive (buffering) and proactive (redesigning). We develop a framework that links supply chain uncertainty, the two types of strategies for achieving supply chain flexibility and the relevant objectives to be achieved. Four case studies are compared in terms of uncertainty typology and strategies being adopted to improve supply chain flexibility. We present three propositions as a result of the study. First, to achieve better flexibility, companies have been focusing more on buffering than on proactive or redesign strategies. Second, companies tend to focus on internal operations rather than collaborating with external parties, and third, the power structure in a supply chain governs the type and configuration of supply chain flexibility.

Keywords: supply chain flexibility; uncertainty; strategy; proactive; reactive

1. Introduction

To remain competitive in business, manufacturers are required to produce products of a quality acceptable to customers and to deliver those products at competitive cost with highly reliable delivery times. Achieving high quality levels, timeliness of deliveries, and efficient processes along the supply chain cannot be reliant on a single organization, but should be ensured through collaboration and coordination with trading partners.

Increasing uncertainty has made the task of satisfying customers more challenging. Efficiency along the supply chain is important to maintain acceptable product prices, but flexibility to deal with time-varying or dynamic demand could be even more important nowadays. With the high probability that customers will suddenly increase, reduce, cancel, or move forward or backward their orders, supply chain players need to be more flexible in many respects. This may include the need to change capacity levels, to use different transportation modes, to switch supplier, to deal with small lot sizes and to have short or even negligible changeover times. Researchers have considered that flexibility, along with quality, cost, and speed of delivery, is critical for competitiveness (Avittathur & Swamidass, 2007; Bernardo & Mohamed, 1992; Gong, 2008; Shin, Collier, & Wilson, 2000) and should be viewed from the supply chain perspective in a collaborative way (Fantazy, Kumar, & Kumar, 2009; Kumar, Fantazy, Kumar, & Boyle, 2006; Pujawan, 2004; Zhang, Vonderembse, & Lim, 2006). As pointed out by Vickery,

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Calantone, and Dröge (1999), supply chain flexibility has a positive impact on the bottom line of the companies. Their empirical study also reveals that volume flexibility is highly related to market share and market share growth.

Researchers have paid a great deal of interest to flexibility. Slack (1988) and Gupta (Gupta & Goyal, 1989; Gupta & Somers, 1992) are among the early authors that have brought up the issue of flexibility in the context of internal operations systems. Following their works, many authors have published papers on flexibility. Currently, flexibility is viewed not only from the perspective of internal operations systems; more and more authors are trying to link it to a supply chain context. Vickery et al. (1999), Duclos, Vokurka, and Lummus (2003), and Pujawan (2004) are among the authors that have extended flexibility from internal operations to the supply chain context. Seebacher and Winkler (2013) provide a comprehensive review and citation analysis of works on manufacturing as well as supply chain flexibility. Although there has been continuing interest in the flexibility issue within the context of the supply chain, further debate and discussion are required.

Although it is important to remain competitive in the market, supply chain flexibility is costly (Gupta & Goyal, 1989; Koste & Malhotra, 1999; Merschmann & Thonemann, 2011; Pujawan, 2004) and flexibility dimensions are not equally important for every supply chain (Sánchez & Pérez, 2005; Stevenson & Spring, 2007). Therefore, a supply chain should carefully assess how much flexibility is really needed (Pujawan, 2004) because increased flexibility does not always result in greater economic income (Bernardo & Mohamed, 1992; Gong, 2008). Hence, it is necessary to decide the right degree of supply chain flexibility and the appropriate strategy that should be adopted to respond to the need for flexibility. In this respect, companies may just reactively build up safety stock or add safety buffers to the lead time, or pursue more proactive paths such as redesigning products or supply chain networks. In spite of its importance, there have been very few works that attempt to classify flexibility strategies and to relate the typology of uncertainties to those strategies. The objective of this paper is to present a conceptual model and case studies that address uncertainty typology, strategies to improve supply chain flexibility, and the relevant objectives that the companies in a supply chain aim to achieve. In particular, this paper aims to address the following questions in an explorative manner:

- (1) What strategies have companies pursued to improve flexibility in the supply chain?
- (2) In dealing with uncertainty, do companies tend to reactively buffer themselves or use more proactive strategies?

2. Literature review

The subject of flexibility has been present in the literature for more than two decades. This topic is highly related to uncertainty, both internal and external to a company or a supply chain. Supply chain flexibility is defined as the ability of a system or a chain to respond to unexpected and unpredictable changes due to uncertain environments to meet a variety of customer needs or requirements, while still maintaining customer satisfaction without adding significant cost. The type of strategies used to increase flexibility should be in line with the typology of uncertainty.

There have been changes in the direction of flexibility research. In the early stages, at the end of the eighties, flexibility was often discussed in the context of internal

manufacturing systems. Cox (1989) stated that flexibility was a new concept with no acceptable measurement. Consequently, this triggered several researchers to develop an instrument to measure or assess flexibility (Bernardo & Mohamed, 1992; Gupta & Goyal, 1989; Gupta & Somers, 1992; Slack, 1988). Sethi and Sethi (1990) mentioned that flexibility is a complex, multi-dimensional, and hard-to-capture concept leading to several studies seeking to establish dimensions of flexibility during the 90s (Koste & Malhotra, 1999; Vokurka & O’Leary-Kelly, 2000). In the last few decades, intensifying market competition forced companies to change their orientation from internal operation systems to a supply chain context. Likewise, people extended the viewpoint of flexibility from the manufacturing to the supply chain context. Since then, a number of researchers have contributed to the literature on supply chain flexibility.

The major stream of work on flexibility has been related to the development of flexibility measures, as well as the conceptual framework that defines the relationships between various flexibility dimensions. Duclos et al. (2003) and Lummus, Duclos, and Vokurka (2003) developed a conceptual model and extended flexibility dimensions to the supply chain context. A framework for assessing supply chain flexibility has been developed by Pujawan (2004). The aim was to capture the relationship between supply chain flexibility drivers and flexibility dimensions, and ultimately to identify which dimensions have to be prioritized for improvement. Sánchez and Pérez (2005) built a hierarchy of supply chain flexibility dimensions based on bottom-up classification and tried to find a relationship between supply chain flexibility and firm performance. Kumar et al. (2006) developed a framework which recommended steps for implementing supply chain flexibility. It gives an overview of the relationship between each flexibility dimension in a supply chain.

As mentioned, a number of authors have tried to develop a framework to assess the importance of flexibility dimensions or relationships between flexibility dimensions and firm performance. However, little has been done to address and classify strategies to achieve the appropriate level of supply chain flexibility. In particular, no attention has been paid to relationships between the typology of uncertainty and the type of strategies chosen for better supply chain performance. Among the few authors to have addressed flexibility, Tachizawa (2007) and Tachizawa and Thomsen (2007) and Tachizawa and Gimenez (2010) developed models that relate between supply flexibility drivers and strategies to improve supply chain flexibility. However, the focus of their study is the purchasing or supply side, not the supply chain.

3. The conceptual model

In this paper, a conceptual model that links supply chain uncertainty, supply chain flexibility strategies, and the objectives pursued by companies along the supply chain is proposed. The elements of the conceptual model were synthesized from the literature. Figure 1 depicts the model, showing uncertainties as the factors that drive the need for supply chain flexibility (left), the two categories of strategy, i.e. four types of buffering (above), eight proactive strategies (below), and three objectives (right). More details will be given below.

3.1. Supply chain uncertainty

Uncertainty has been considered as a major factor behind the need for supply chain flexibility. We classify uncertainty in the supply chain context as upstream (supply) uncertainty, internal (process) uncertainty, and downstream (demand) uncertainty.

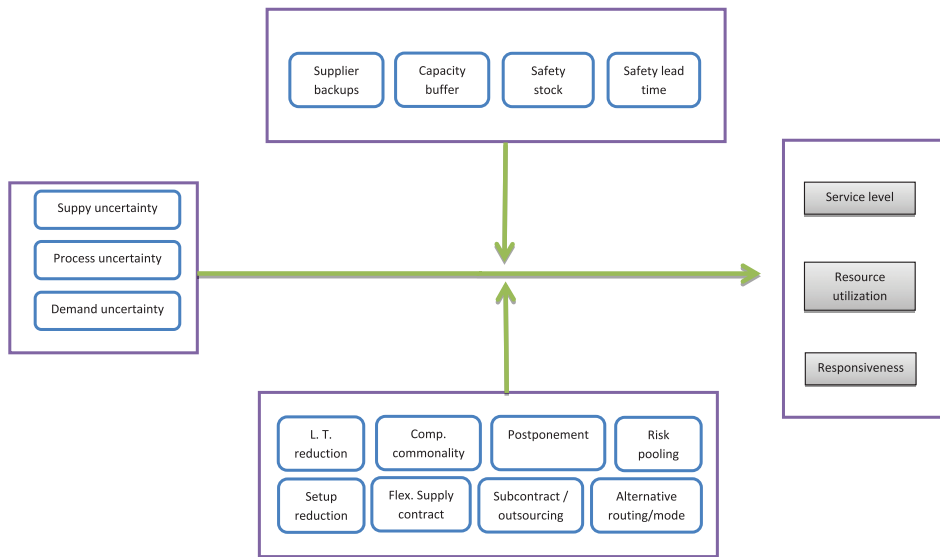


Figure 1. The conceptual model.

- *Supply uncertainty*. This is related to the uncertainty of materials' supply. Supply uncertainty may be manifested in the form of uncertainty regarding material availability/supply capacity, material price (Tang, 2006; Zhang, Shang, & Li, 2011), alternative sourcing availability (Pujawan, 2004), and supply lead time (Mohebbi & Choobineh, 2005; Osman & Demirli, 2012; Ramasesh, 1991; Thomas & Tyworth, 2006). When supply is uncertain, a higher level of flexibility is required to achieve better customer service levels. For example, when the price of a certain material suddenly increases, the ability to change the production schedule in order to produce alternative products or to use a substitute material is helpful in maintaining the efficiency and effectiveness of the supply chain.
- *Process uncertainty*. Process uncertainty is related to the probabilistic nature of machine availability (Ho, 1989; Van Kampen, van Donk, & van der Zee, 2010), yield (Gurnani & Gerchak, 2007; Ho, 1989; Schmitt & Snyder, 2012; Tang, 2006), quality (Ho, 1989; Murthy & Ma, 1991; Wu, Blackhurst, & O'grady, 2007), and processing times (Cao, Patterson, & Bai, 2005; Schmitt, 1984). Uncertainty in internal operations may also be related to such factors as labor issue, instable availability of working capital, and problems with information technology. The more uncertain the internal processes, the higher the level of flexibility needed. For example, when the reliability of a manufacturing process is low, a capacity buffer is necessary to keep the system flexible.
- *Demand uncertainty*. This refers to the probabilistic nature of demand quantity, types, timing, and locations. Demand uncertainty could be in the form of errors in the demand forecast (Schmitt, 1984), changes in customer orders (Pujawan & Smart, 2012; Van Kampen et al., 2010; Wong, Boon-Itt, & Wong, 2011), uncertainty about the product specification/mix that the customers will order (Li, Sikora, Shaw, & Tan, 2006; Van Donk & van der Vaart, 2005), and competitor actions regarding

marketing promotion (Wong et al., 2011). An empirical study involved 106 manufacturing companies by Pujawan and Smart (2012) suggested that most manufacturing companies experience order volatility from customers. Manufacturing companies, especially those producing innovative products, are facing shrinkage in product life cycle and increasing competition in the market. This ultimately creates demand uncertainty and forcing supply chain players to markdown product prices. Supply chain flexibility is important to cope with the dynamic nature of demand. For example, when demand for a product is highly uncertain, companies may have to increase the inventory buffer so that the sudden increased demand can be satisfied. Alternatively, the use of multiple transportation modes to cope with differing degrees of demand urgency may be important to improve customer service levels under highly uncertain demand.

3.2. *Classification of strategies for supply chain flexibility*

Flexibility is a strategy to deal with uncertainty facing the supply chain. As mentioned in the literature review, various strategies to increase flexibility have been evaluated by different authors. Koste and Malhotra (1999) mentioned that flexibility can be either reactive or proactive in nature. The reactive nature of flexibility addresses the environmental uncertainty, both internal and external, faced by an organization, while the proactive nature of flexibility allows an organization to redefine market uncertainties or influence what customers have come to expect from a particular industry. In the following subsections, we will list the strategies that belong to the above two classifications.

3.2.1. *Reactive or buffering strategies*

Basically, companies make no attempt to influence the level of uncertainty but, rather, react to it in an attempt to maintain their service level to customers or to maintain efficiency through, for example, better capacity utilization. These are the type of strategies which companies use to buffer themselves:

- *Safety stock.* Safety stock is one of the most common approaches to increase flexibility under the existence of demand and supply uncertainty. With safety stock, a company can reduce the probability of inventory shortage to an acceptable level. According to Van Kampen et al. (2010), safety stock also increases responsiveness. We argue that safety stock is a reactive strategy because this approach merely responds to the current level of uncertainty, without any attempt to proactively reduce it.
- *Capacity buffer.* One way to cope with uncertainty is to have flexible capacity. However, in many situations it is costly or even impossible to dynamically adjust the capacity level. Hence, to achieve flexibility, companies may set capacity higher than average demand so that they can avoid substantial shortages during peak periods. A capacity buffer could be used as a substitute of or a complement to safety stock. As mentioned by Manuj and Sahin (2011), some companies prefer to maintain surge capacity in the form of extra assembly lines that are staffed when necessary rather than maintain buffer inventory.
- *Supplier backups.* Working with a single supplier is risky. Companies often maintain multiple suppliers, which will guarantee availability but in most situations

will increase costs. The use of multiple suppliers to improve supply flexibility has been discussed in the literature, including for example Das (2011) and Manuj and Sahin (2011).

- *Safety lead times.* In dealing with uncertainty, companies often add a safety lead time to the actual cycle time (Raturi & Jack, 2004). While increasing inventory and adding costs, safety lead time enables companies to increase materials' availability and thus become more flexible in responding to demand. Van Kampen et al. (2010) suggested that adding safety lead time increases mix flexibility.

3.2.2. Proactive or redesign strategies

These are the type of strategies in which companies attempt to increase supply chain flexibility through proactively redesigning products, processes, and the supply chain network as well as proactively negotiating more effective relationships with trading partners. The following strategies belong to this classification:

- *Component commonality:* one of the obvious strategies related to product design that can improve flexibility is the use of component commonality. There has been wide discussion of the possibility that use of common component could increase efficiency as well as responsiveness when a manufacturing company offers a large product variety or when uncertainty in demand exists (Mohebbi & Choobineh, 2005). Large component commonality also increases supply chain flexibility. The use of component commonality to increase supply chain flexibility has been discussed by Pujawan (2004).
- *Postponement:* design or redesign of processes, both in terms of the manufacturing shop floor and in administrative processes, could significantly improve flexibility. Manufacturing or logistics postponement are examples of process design that improves supply chain flexibility. Increased component commonality and the use of postponement as strategies for better flexibility have been discussed in the literature (Barad & Sapir, 2003; Das, 2011; Kumar, Shankar, & Yadav, 2008; Pujawan, 2004; Tachizawa, 2007).
- *Risk pooling:* When demand is highly uncertain and involves multiple sales regions, a supply chain often designs a network for risk pooling. Reducing facilities or centralizing stocks to fewer facilities reduces risks as well as improves flexibility in allocating stock to multiple destinations or sales regions. In line with this idea, Stevenson and Spring (2009) argued that consortium purchasing among several independent firms or the use of centralized procurement among firms in the same group are among strategies to overcome the problem of buyers having minimum power and having to accept large minimum order quantities.
- *Subcontracting/outsourcing:* The use of external capacities through subcontracting and outsourcing is also a strategy used to be flexible in dealing with uncertainty. As suggested by Stevenson and Spring (2009), outsourcing is a tactic to obtain purchasing flexibility because it can reduce the risks of capacity utilization and amortization, especially when demand is uncertain, irregular, low, and/or temporary.
- *Flexible supply contract:* proactively negotiating supply contracts to alleviate minimum order quantities or to obtain a commitment from suppliers to supply materials or services in the case of a significant increase in demand are among the

strategies that could improve supply chain flexibility. Flexible procurement contracts can provide supply flexibility (Tang & Tomlin, 2008), ensure stability for the supplier, and help the buyer respond to demand fluctuations (Stevenson & Spring, 2007).

- *Lead time reduction*: reducing lead time is an important strategy to enable better flexibility. With a shorter lead time, companies will be able to better respond to demand uncertainty. Proactively reducing lead time may be done through re-designing procurement processes, changing supplier selection criteria from cost focus to speed focus, or developing suppliers for better lead time management.
- *Setup time reduction*: long production setup is a major cause of inability to create volume and mix flexibility. Significantly reducing setup time requires systematic effort within a manufacturing company. Vonderembse, Uppal, Huang, and Dismukes (2006) suggest that reduction of setup time will allow the economic production of small quantities, thereby achieving cost reductions, flexibility, and internal responsiveness. Having suppliers with short setup times would create supply flexibility and thus should be considered as an important criteria when selecting suppliers (Wu & Shen, 2006).
- *Alternative routing/mode*: when a customer places a sudden order, companies may have to use alternative transportation modes to speed up shipment. In another situation, when problems occur on a certain route, the company's flexibility to use alternative routes is important. The use of alternative transportation routing/modes to create flexibility has been mentioned in the literature (see e.g. Kumar et al., 2008; Morlok & Chang, 2004; Pujawan, 2004).

3.2. Objectives of supply chain flexibility

Although supply chain flexibility is often costly to achieve, it is rewarding to have appropriate levels of flexibility for companies working under uncertain environments. A study conducted by Merschmann and Thonemann (2011) involving German companies suggests that in uncertain environments companies with highly flexible supply chains perform better than companies with less flexible supply chains, while the opposite holds true under certain environments. As widely discussed in the literature, flexibility is viewed as a system's ability to cope with internal and external variation (Gong, 2008) or to cope with environmental uncertainty in an attempt to improve market responsiveness (Das, 2011), maintain customer service levels (Kumar et al., 2008), and achieve better resource utilization. Hence, we define here three objectives of supply chain flexibility that companies aim to achieve:

- *Higher service level*. Service level is a measure of a company's ability to satisfy customers' demand. It is normally measured in terms of percentage of customer demand satisfied without a backlog. When demand and supply are both uncertain, a flexible supply chain system is necessary to maintain a high level of service. As pointed out by Kumar et al. (2008), flexibility is the strategy by which the supply chain aims to maintain customer service levels by absorbing disturbances in supply and sudden changes in demand. There are many other works that address the linkage between flexibility and service level, including for example Alfredsson and Verrijdt (1999), Mohebbi and Choobineh (2005), and Van Hoek (2001).
- *Resource utilization*. Supply chain activities normally involve a variety of resources, such as those used for production, storage, material handling,

transportation, and administrative activities. Resource utilization is generally a measure of how much of the available capacity of resources is being used for productive outputs. Under uncertain operating environments, it is often difficult to obtain high levels of resource utilization. However, when appropriate supply chain flexibility is in place, there is an opportunity to better utilize the resources along the supply chain. Some earlier publications mention how flexibility may improve resource utilization. Ndubisi, Jantan, Hing, and Ayub (2005) stated that there is a relationship between resource utilization and volume flexibility. Pramod and Garg (2006) suggest that as any flexibility level increases, the system utilization increases.

- *Responsiveness*. Responsiveness is a very important capability which companies need to have in doing business. In an uncertain environment, responsiveness can only be achieved if there is sufficient level of flexibility throughout the supply chain. Flexibility in responding to changes in demand reflects responsiveness to changing customer needs and wants (Duclos et al., 2003). Kumar et al. (2006) stated that there is a need to make operations more flexible in an environment with unpredictable changes, and thereby increase responsiveness. Further, Yi, Ngai, and Moon (2011) suggest that better supply chain responsiveness can be achieved in two ways: reducing uncertainties and improving supply chain flexibility.

4. Case studies

We conducted a case study involving four manufacturing companies in Indonesia. According to Kähkönen (2011), case study is an appropriate research method for gathering rich empirical data and thereby to gain a deep understanding of the phenomenon in question. The objective of the case study was to gain more insights into supply chain flexibility in practice, and particularly the strategies which companies adopt to achieve better flexibility. We selected case companies with different supply chain characteristics, i.e. one is representing the engineering-to-order model, the other one is representing make-to-stock model, and the other two are somewhere in between of the above two models. A list of open-ended questions were prepared before interacting with each case company. In each case, we interviewed 3–5 people in 2–4 meetings involving those in charge of procurement, planning, manufacturing, product development, engineering, and marketing functions. In addition to the interview, we also collected and analysed pertinent data that could support our understanding of supply chain flexibility. We will provide details of each case in this section. Cross-case analysis will be conducted to compare uncertainty typology facing each case company and strategies they applied to create better supply chain flexibility.

4.1. Case 1: company A

This company is in the business of producing new ships and repairing old ones. As a project-based company, design, procurement, and production respond to customer orders. The company serves many domestic customers, but only three of them are considered major customers. The production facility is located on the coast of East Java. The size of the production facility limits its capacity. They can produce up to two new ships and repair up to 100 ships each year. The company employs around 550 permanent and 600 subcontracted workers.

For every product, customers will be involved at the early stage of developing the product specification. The raw material will not be ordered until the design and specifications for the end product are agreed on by the customer. Each product is composed of more than 10,000 components. However, there are only four major types of component: plate, pipe, engine, and electricity. In each of these major types, there are about five different variants. The majority of materials, about 80%, are obtained from overseas suppliers with 2–6 months' lead time. To avoid lateness of material supply, the company sets a lead time buffer of about four weeks. The company has about three suppliers for each type of component. The relationship with customers and suppliers for each project is contractual in nature rather than a partnership type. If a supplier is unable to supply the quantity ordered, an alternative supplier should be used.

The production process consists of five stages. It begins with body construction, pipe fitting, installation of machinery or engine, electrification and, finally, running tests. The duration of a project building a new ship is somewhere between 4 and 20 months, depending on the product type, size, and complexity. Substantial changes in the design at the production stage rarely happen. There are usually only minor revisions which do not significantly affect the production schedule and costs.

Unavailability of material will lead to production rescheduling. Interestingly, delays in the supply of materials are not because of problems with the suppliers, but quite often because of poor cash availability at the company. For ship production, capacity constraints can be relaxed by hiring more subcontracted workers, although it is not always easy to adjust the level of the workforce. However, for ship repair, space availability is a major constraint which cannot be adjusted. The uncertain nature of internal operations and materials supply leads to poor levels of on-time delivery to customers.

4.2. Case 2: company B

Company B is a supplier of packing items such as plastic bottles and tubes for the consumer goods industry. The company operates three factories in Indonesia with fixed production capacities, employing around 1000 people in total. Currently, they supply packing items to about 10 major customers. They have two types of product, exclusive and V-item, with about 100 variants. Exclusive products are those specific to a certain customer, whose design or patent is owned by the customer. V-item is a nonpatented product and can be sold to any customer. However, most of the products produced by this company are exclusive to certain customers. For exclusive products, the customers are involved in product design and innovation. All changes are based on customer requests.

The production process is fairly simple, with only a few steps, including molding, printing, and stamping. Even though the process is very simple, the level of process uncertainty is high due to machine breakdowns, high setup time, and defective products. Materials can be categorized into resin, master bed, and art work. There are around 20 varieties for resin, 50 for master bed, and 100 for art work. Supply of materials is not considered a problem since they can be obtained easily from local or overseas suppliers. The company has about 10 active suppliers with three to eight weeks' lead time and 80–90% on-time delivery. The relationship with the customer is generally transactional in nature. However, the company collaborates with mold suppliers to ensure that new models are built according to the customer's requirements.

Customers have high bargaining power. Demand uncertainty is passed on to the company, where orders could fluctuate by up to 40% from the initial figures they

submitted to the company. This is the major cause of uncertainty facing the company and triggers much of the production rescheduling. Some customers even change their orders one day before the delivery due date. The high flexibility needed with regard to customers' rescheduling or changing orders is possible because the company keeps high levels of inventory buffers and has relatively short supply lead times for most materials.

4.3. Case 3: company C

This company produces circuit breakers for several industry sectors, such as telecommunication, transportation, watercraft and special vehicles, and industrial equipment. The company operates two factories in East Java with around 250 employees. The majority of products are sold to four major customers, all of which are located overseas. Customers' geographic area influences product variety. The majority of the materials are supplied by one main supplier. The company produces up to 4500 product variants; all of them belong to nine major product types. Variety is created through different product attributes such as ampere, mounting, number of poles, thread neck design, hardware, types of terminal, push button, color of push button, and auxiliary contact.

A representative of the company stated that this type of industry has very few competitors, because they deal in a very special product which needs extremely high performance and accuracy. Difficulty in obtaining replaceable materials and alternative suppliers, coupled with uncertain supply, results in a very high inventory buffer of materials.

Production processes for one type of product are different from those for other types and the processing times vary significantly. Even variants within the same product type could have different processes. Some types of product have less than 20 variants, but some could have thousands.

Each product consists of 11–45 components, with about 10–20% common components across different finished products of the same type. To speed up production time, subassemblies are prepared before the company receives customer orders. However, the final assembly is normally done after the receipt of orders from customers. The number of machines will determine production capacity and each machine is dedicated to a single product type only. This creates a low level of production capacity flexibility. On the other hand, the company absorbs demand fluctuation by working overtime hours.

Demand is lumpy for all product variants. The company sets no constraint on minimum order quantity. The order quantity from customers could be very large for some product variants; for other variants, customers sometimes order very small quantities, and even only one unit. This lumpiness creates much idle capacity and poor on-time delivery. To avoid having a large idle capacity, the company produces some regular products whose demand is quite certain in anticipation of customer orders. However, it results in high inventory of finished goods. The company did not set time-fencing mechanism for orders. As a consequence, there is frequent production rescheduling. On the positive side, the changeover time for producing different product variants within the same type is very short.

4.4. Case 4: company D

Company D produces pharmaceutical products, operating three plants. All are located in the West Java Province of Indonesia, with about 400 workers. Every plant is dedicated to a certain type of product. Currently, they only serve the Indonesian market. The

company supplies products to about 100 customers, but only three are considered major customers. There are four types of product – tablet, capsule, syrup, and dry syrup – with 64 product variants. The main product itself cannot be modified; however, the company usually changes the product package once a year.

Raw materials originate overseas but the import process is managed by a local distributor. Supply of materials from local distributors requires two to three days of lead time. It can take up to six months to receive special materials that do not have a local distributor. This company has around 30 suppliers for main materials and 28 for packaging items, many of which are considered as backup suppliers. The policy of the management is to have at least three suppliers for each type of material. Relationships with suppliers are more transactional than partnership in type. One supplier can supply several types of main materials for different finish goods.

Materials are categorized into four: main material, supporting material, primary packaging, and secondary packaging. In total, there are about 200 types of material where 50 are categorized as main materials, 100 are supporting materials, 9 are primary packaging items, and 64 are secondary packaging items. The product structure is generally very simple. A product consists of one to four main materials, one primary packaging item and one secondary packaging item. Product variations are created by different product weights, packaging, or product composition. Some materials can be used in more than one product variant within the same type.

There is high process similarity across different products. However, the batch quantity differs significantly. Production capacity for each product type is fixed, but there is a possibility to increase production volumes through the use of overtime hours. Even though the production lines are dedicated to certain product types, a changeover is needed when there is a change in product variants to be produced. The changeover time is about 2–3 h for cleaning and about half a day for changing a mold. The company responds to this long changeover time by freezing order and production schedule for one month.

In general, demand for most products is quite stable and little affected by segments and the geographical area of a market. On the other hand, there is uncertainty associated with supply of materials, mainly due to high competition to obtain them. In addition, the warehouse capacity is quite small, which limits the company's ability to do forward buying for materials. The company normally buys sufficient materials to satisfy the production schedule for a month, even though they can actually predict material requirements for three months. For materials that have long lead times, this creates a major material availability problem.

5. Cross-case comparisons and analysis

In this section, we will compare the uncertainty typology of each case company and the strategies adopted to achieve better supply chain flexibility.

5.1. *Typology of supply chain uncertainty*

Table 1 shows the comparisons between four companies in terms of uncertainty typologies. The four cases represent different types of operations: the first is a project-based or engineering-to-order company, and is followed by make-to-order, assembly-to-order, and make-to-stock companies. With the exception of Case 4, all companies are facing highly uncertain demand. Demand uncertainty may be associated with frequently revised orders

Table 1. Typology of supply chain uncertainty.

	Case 1	Case 2	Case 3	Case 4
Type of operations	Engineering to order	Make-to-order	Assembly-to-order	Make-to-stock
Level of uncertainty				
• Demand	Highly uncertain	Highly uncertain, customers frequently change orders, high mix uncertainty	Highly uncertain product mix, high product variety, demand fluctuating over time	Low demand uncertainty (orders received well in advance)
• Supply	Highly uncertain supply lead time	Low supply uncertainty, relatively short lead time	Highly uncertain supply lead time and material price	Low supply uncertainty for most materials
• Process	Moderately uncertain, very high complexity	Highly uncertain in terms of cycle time, yield, availability	Moderately uncertain: low process similarity, high variability in processing time	Stable process, low uncertainty

by customers (as in Case 2) or the inability of the company to forecast what products they are going to sell in the future (as in Cases 1 and 3).

From the supply side, Cases 1 and 3 are facing high supply uncertainty while the other two cases are fortunate to have low supply uncertainty. In Case 1, supply uncertainty is mostly due to the long lead times (4–6 months), but in Case 3, uncertainty is associated with lead time as well as the price. In both of these cases, most suppliers are located overseas, while for Cases 2 and 4 most materials are obtained from local suppliers.

In terms of operations processes, only Case 1 deals with highly complex processes; the other three involve simple production processes. On the other hand, process uncertainty in Case 2 is high where the company is unable to predict the cycle time accurately. In addition, yield and production system availability are uncertain. It is often the case that the production system fails and requires unplanned maintenance. In Case 3, process uncertainty is relatively lower, although processing time varies greatly depending on the types of product being produced.

From the typology of uncertainty of the four case companies, it is obvious that the company in Case 4 is operating under a stable and low level of uncertainty where not much flexibility is needed. The other three cases are facing different types of uncertainty and require flexibility in the supply chain.

5.2. Flexibility strategies adopted

The way in which a supply chain creates flexibility to handle demand uncertainty differs from case to case. Table 2 shows which strategies are adopted by each case company. Low, moderate, and high refer to the intensity of the strategies being used. The ratings are given subjectively by the authors after obtaining information from each case company. An ‘X’ sign means there is no clear evidence of the use of that strategy by the respective case company. For example, the company in Case 3 uses safety stock with a high level of intensity but there is no evidence of it using backup suppliers. From the

list of strategies presented in the framework of Figure 1, all four cases are more focused on buffering rather than the proactive or redesign strategies. For example, safety stock and safety lead time are used by all four cases, although with differing levels of intensity. On the other hand, the proactive strategies are less intensively adopted to improve supply chain flexibility. Based on this fact, we arrive at a proposition:

Proposition 1: The flexibility of companies tends to be of a more reactive than proactive nature.

The use of buffers to increase flexibility has been discussed extensively. For example, Caputo (1996) pointed out that buffers could be considered alternative or complementary factors to technological flexibility. Any strategy to increase flexibility has cost implications. The choice of positioning a buffer as an alternative or complementary way of achieving flexibility depends on the cost benefits of the two solutions. However, as suggested by Christopher and Lee (2004), buffers are built up as a result of no confidence or low visibility across the supply chain. Manuj and Sahin (2011) also warned that the use of buffers, especially capacity buffers, could be very costly if not planned carefully.

Although all four cases are using some type of proactive strategy, they are concentrating on internal operations rather than working with supply chain partners. For example, all four cases seem to use some level of component commonality. Increasing component commonality is possible with changes in product and process design. The objective is to reduce the number of components a company has to manage while maintaining the ability to produce a large product variety. All four case companies are adopting component commonality as a strategy to achieve better flexibility. The use of common components, along with the postponement strategy, has long been considered an effective way of increasing flexibility. Gunasekaran and Ngai (2005) pointed out the commonality of components is an important strategy to achieve flexibility, especially in the context of a built-to-order supply chain. Likewise, manufacturing postponement has long been used as a hedging strategy against the proliferation of product variety (Feitzinger & Lee, 1997; Yang, Burns, & Backhouse, 2004).

Table 2. Flexibility strategies adopted.

	Case 1	Case 2	Case 3	Case 4
Type of operations	Engineering to order	Make-to-order	Assembly-to-order	Make-to-stock
<i>Strategies/enablers</i>				
Safety stock	Low	High	High	Moderate
Safety lead time	High	Low	Low	Low
Capacity buffer	Low	High	Low	X
Backup supplier	High	Low	X	High
Lead time reduction	X	X	X	Low
Setup time reduction	X	X	High	X
Component commonality	Moderate	High	Moderate	Low
Postponement	High	High	Moderate	X
Risk pooling	X	X	X	X
Flexible supply contract	X	X	X	X
Subcontracting/outourcing	High	X	X	X
Alternative routing/modes of transportation	X	X	Low	X

Lead time reduction, flexible supply contracts, and subcontracting/outsourcing are not popular strategies among the four cases, although the company in Case 4 has been able to reduce supply lead time through the use of local suppliers. Obviously, when a company is undertaking any of these three strategies, the focus should be shifting from internal operations to supply chain collaboration. Supply lead time could not be effectively reduced without the involvement of suppliers. Likewise, flexible supply contracts would require the supplier to alleviate ‘minimum order quantity’ or to ensure security of supply in case of increasing demand and to enable speeding up delivery in case urgent deliveries are emerging. This then leads us to the following proposition:

Proposition 2: The flexibility of companies tends to focus more on internal operations rather than on collaborating with external parties.

As mentioned in the literature review, authors have recognized the importance of better coordination and collaboration to increase supply chain flexibility (Pujawan, 2004; Vokurka & O’Leary-Kelly, 2000). However, it should be noted here that Proposition 2 above suggests that efforts to increase supply chain flexibility have not been undertaken in accordance with supply chain principles. The move from manufacturing flexibility to supply chain flexibility should be interpreted as a need for collective efforts of supply chain members to create flexibility and, hence, responsiveness to end customers (Das, 2011; Kumar et al., 2008). Literature on supply chain flexibility suggests that reasons for the need for flexibility are both internal and external (Gong, 2008). Therefore, flexibility cannot be created without involving trading partners.

5.3. Flexibility attributes, problems, and objectivess affected

Table 3 presents the most obvious flexibility attributes, dominant problems that hinder flexibility and impacts of insufficient flexibility. In Case 1, as is usually the case for ETO companies, there is high flexibility in producing different products. However, the problem is mostly in the form of the supply of materials which have long lead times and the problem of cash availability that often results in delayed procurement of materials. In Case 2, the company attempts to provide very high flexibility to customers, so order revisions are allowed. With a long setup time, such volatile demand can only be satisfied with high inventory, both in the form of materials as well as finished products. In Case 3, the company also attempts to provide high flexibility to its customers, who may even order only a single unit. This is very well supported by the internal production system, where changeover time is very short on one side and there is moderate level of component commonality on the other side, but there is a big challenge from the supply side because of the long lead time. As a result, the company has to keep a high level of inventory buffers.

5.4. The impacts of power structure in supply chain relationships

Power structure in a supply chain seems to affect supply chain flexibility configuration. Although some studies have indicated that competition has shifted from company vs. company to supply chain vs. supply chain in the past two decades, each member in the chain is still exercising their power in the relationship (Crook & Combs, 2007). The power structure in a supply chain determines the parties that have to keep higher inventories, work with higher capacity flexibility and alleviate ‘minimum order quantity’

Table 3. Dominant problem for each company that hinders supply chain flexibility.

	Most obvious flexibility attributes	Problems	Impacts
Case 1	<ul style="list-style-type: none"> • Ability to produce various types of products 	<ul style="list-style-type: none"> • Problems with cash availability that prevents the company to obtain sufficient materials in due time 	<ul style="list-style-type: none"> • Poor on-time delivery (only about 70%) • Idle resources because of waiting for materials
Case 2	<ul style="list-style-type: none"> • No frozen schedule, customers are allowed to change orders any time 	<ul style="list-style-type: none"> • Long setup time • Frequent breakdown 	<ul style="list-style-type: none"> • Large inventory buffer (up to 6 weeks demand) • Fluctuated capacity utilization
Case 3	<ul style="list-style-type: none"> • No limit on minimum order quantity, some customer orders have a quantity of one unit • Ability to produce a very large number of products variants 	<ul style="list-style-type: none"> • There is only one very dominant supplier that limits supply flexibility • Long supply lead time 	<ul style="list-style-type: none"> • Poor on-time delivery reliability to customers • High inventory of raw materials (about 3–4 months)
Case 4	<ul style="list-style-type: none"> • None looks obvious in Case 4 	<ul style="list-style-type: none"> • Limited warehouse capacity that prevents forward buying for materials 	On-time delivery of about 90% which is quite low for highly predictable demand Lost sales

restrictions. The party that holds more power may require its trading partners to share information but reciprocate (Mishra, Raghunathan, & Yue, 2007), and hence tends to pose more uncertainties for others.

Differences in power structure and flexibility configuration are also exhibited by the cases observed in this study. In Case 2, customers are demanding high flexibility for changing orders, but the case company is unable to pass this risk on to the suppliers. The uncertainty on the part of the customers has to be absorbed by the case company. This is worsened by the fact that the case company is facing long setup times and uncertain processes. Although the supply lead time is relatively short, there is a need for the company to keep high material inventories and maintain a high level of capacity buffers. Figure 2 illustrates the power structure and flexibility configuration of Case 2. The solid arrows connecting the company with the suppliers and the customers indicate the power direction. The single direction arrow from customers to the company indicates the dominating power of the customers, while the two-way directions between suppliers and the company indicates balanced power between the two. The dashed

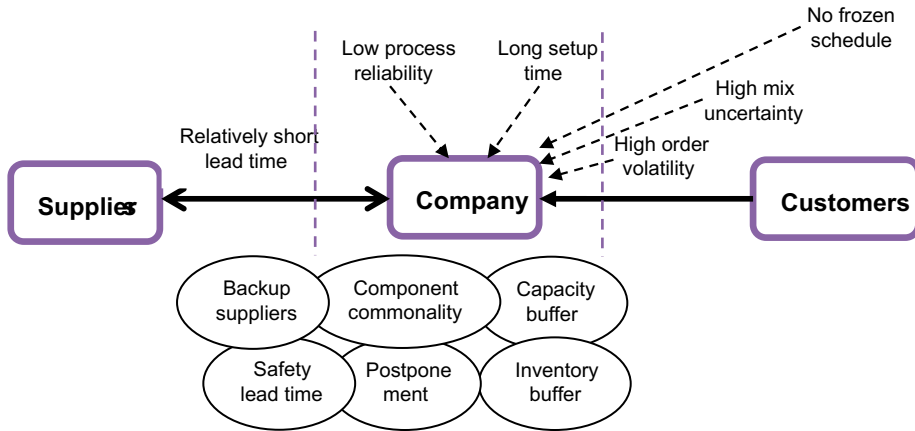


Figure 2. Illustration of power structure and flexibility configuration for Case 2.

arrows represent challenges that foster the need for better flexibility and the circles are strategies for achieving better flexibility.

The company in Case 3 seems to be positioned between dominant, inflexible suppliers and demanding customers. As a consequence, the company has to absorb uncertainties regarding inventory of materials. As presented in the two tables above, the company in Case 3 is facing customers that require high product variety and a very wide range of order quantities, from as small as one unit to as large as thousands of units. Facing this uncertainty, the case company has to be flexible in producing different lot sizes and different product types. The company has been responding to this need by reducing setup costs, postponing the assembly process until orders are received, and increasing component commonality. On the other hand, the company is very much dependent on one very large, powerful supplier with long lead times, and hence there is little choice but to keep high inventory buffers, add buffers to the lead time and switch the transportation mode to air freight in case urgent delivery is needed. Figure 3 illustrates the power structure and flexibility configuration of Case 3. Hence, we suggest the following proposition:

Proposition 3: The power structure and typology of uncertainty in the supply chain will govern the type and configuration of supply chain flexibility.

6. Concluding remarks

6.1. Summary

In this paper, we have presented a conceptual model that links the uncertainties, the two classifications of strategies for improving supply chain flexibility and the pertinent objectives. We classified the strategies into reactive or buffering and proactive or redesign strategies. Four case studies have been analysed to obtain insights into uncertainty typology and the strategies each case company is adopting to have better supply chain flexibility. Our case studies suggest that each company may be facing different uncertainty typology and choosing different flexibility strategies.

We suggest three main propositions that need further testing. First, companies tend to use reactive rather than proactive strategies. This is somewhat understandable as

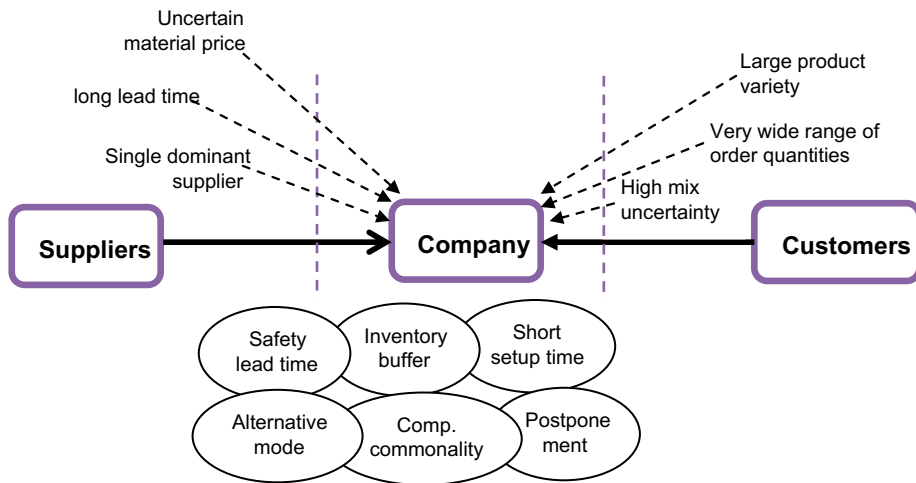


Figure 3. Illustration of power structure and flexibility configuration for Case 3.

reactive strategies are easier to carry out and require less time and resource investment, although it may not be better in the long term. We suspect that such a pattern is quite common in the manufacturing industry in general, and hence a follow-up study involving a larger number of companies is necessary. Second, companies seem to be more inward than outward-looking when there is a need for higher flexibility. There is not much evidence of collaborative improvement of flexibility across the supply chain network through, for example, flexible supply contracts, outsourcing, or supply lead time reduction. Companies tend to work more on their internal systems. However, this might be largely dependent on the power structure in a supply chain. A manufacturing company positioned between powerful customers and suppliers is normally unable to influence trading partners, and thus uncertainty has to be absorbed internally through safety stock, safety lead times, extra capacity, and other internal reactions.

6.2. Research implications

Obviously, there are a number of opportunities to extend this work. First, there is a need to do a larger scope study to confirm if the above three propositions hold true for a wider range of samples. In addition, uncertainty typology may affect the strategy applied. An interesting research question would be if any relationship exists between uncertainty typology and the flexibility strategies adopted by manufacturing companies. Finally, the strategies applied might be affected by common factors, leading to the following research question: would the choice between buffering and redesigning strategies be affected by any common factor?

Another avenue for future research is to find the balance between flexibility and schedule instability. Schedule instability is a subject that has been extensively discussed in the literature since as early as the 1970s (see e.g. an early paper by Steele, 1975) but remains a topic of ongoing research (see e.g. Pujawan & Smart, 2012 for a recent paper). A company offering high flexibility would not impose such policies as a long 'frozen schedule' and a large 'minimum order quantity'. However, being flexible with

customers may also mean much disruption to the production schedule. Such disruptions are normally called schedule instability. Quantitative models or empirical research trying to find the balance between schedule instability and supply chain flexibility is an important topic for future research.

6.3. Managerial implications

Managers would benefit from our findings in a number of ways. First, the conceptual model can be used as a general guideline for achieving better supply chain flexibility when dealing with uncertainties. Managers could adopt various strategies to achieve supply chain flexibility, including four buffering strategies and eight redesign strategies. With this model, managers should be aware of various options, but the appropriateness of each strategy would depend on each specific situation.

Second, it should be quite obvious that too much focus on buffering strategies may be counterproductive in the long term. Buffering strategies are normally easier to execute and require less effort and risk. The move toward more proactive or redesigned strategies needs not only time and money, but also leadership that focuses on long-term benefits and willingness to take up short-term risks. Managers should be motivated to initiate a more long-term focus on flexibility rather than reactively responding to uncertainties with buffering strategies.

Finally, managers need to be motivated to explore possibilities to work with external parties to create better supply chain flexibility. The ideas behind supply chain management that fosters better collaboration with supply chain partners are much easier to say than to do. It is likely that most supply chain managers understand the importance of having close relationships with trading partners, but the reality, at least from our case study, suggests that such close collaboration is not easy to operate. Managers are more internal rather than external-looking. Potentials to improve flexibility together as a chain are little realized. This again implies the need to explore possibilities to work more closely with trading partners to improve supply chain flexibility.

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