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Preface

First of all, I want to thanks God who has always replied to my prayers and who gave me the chance to successfully carry out my studies at this advanced level.

My thesis is dedicated to my parents, specially to my mother who endlessly support me by her prayers, love and advices.

I am really thankful to my worthy supervisor, Associate Professor Svein Bråthen for his continuous guidance and supervision. This work has been possible due to his precious help and guidance.

I am thankful to all my friends and fellows who made my stay in Molde very pleasant. I would like to thank specially Ali, Daouda, Guy, Issouf and Karthika for all the support and help they provided me during the last two years.

I would like to express my thanks to Molde University College who granted me a scholarship and helped me to realise my dream to study in a prestigious University, and to the Norwegian government for financing my studies in Molde under the quota scheme programme.

This thesis is part of my master degree studies at Molde University College. It is a mandatory requirement for the completion of the programme.

Summary

This thesis has a descriptive rather than an explanatory approach. It has been written around a theoretical framework related to flexibility in the supply chain. The aim of this thesis is to explore and develop new types of flexibility that can give rise to further development.

First, we define the concept of supply chain management. Then, we emphasize the importance to measure supply chain performance since it is the main driver for the future actions of managers. After that, we realized an extensive literature review on supply chain flexibility and the impact of uncertainty and risks in the supply chain. Then, we elaborate our research framework based on the supply chain operations reference (SCOR) model and developed ten flexibility types that will bring more flexibility in the supply chain if they are correctly applied by managers seeking to improve flexibility in their operations. Finally, we provide some guidelines concerning further research in the area of supply chain flexibility.

Keywords: Supply chain management, Flexibility, Uncertainty, Performance measures.

Contents

I- INTRODUCTION

According to the Council of Logistics Management (CLM), Logistics is defined as "the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to consumption (including inbound, outbound, internal, and external movements) for the purpose of conforming to consumer requirements". Logistics is vital for the success of most companies doing business, and it requires a lot of resources. There are lot of papers directed toward the strategies to use in order to succeed when doing business by an efficient allocation of resources. However, a lot of researches have to be done in order to bring more improvements in the logistics area. Supply chain management is one of the most important and interesting topic, and it has driven tremendous benefits for all business entities that have started to implement it.

Scope of study

In our study, we will focus on the importance of flexibility in the supply chain. The unit of analysis will be the supply chain; however the relationship between buyers and suppliers will also analysed. Our main objective in this thesis is to explain and develop types of flexibility that are needed in the entire supply chain. From all the literature reviewed, it appears that flexibility in the supply chain deserves to be studied in depth both theoretically and practically. Our work is theoretically oriented and is just an attempt to provide our understanding of the topic and propose the flexibility types that we think are the most important in supply chains.

First, we will provide definitions and provide a literature review on supply chain flexibility, identify the most important types of flexibility present in supply chains, and then make suggestions about how managers can develop strategies in order to build the right capabilities inside their organisations so that they can deal with the numerous challenges of the 21st century.

II- SUPPLY CHAIN LITERATURE AND THEORY REVIEW

II.1- supply chain concept and development

According to Lambert et al. (1998), "supply chain management is the integration of key business processes from end user through original suppliers that provides products, service, and information that add value for customers and other stakeholders." this concept that emerged as little as a dozen years ago is getting more and more attention from companies' managers. As global competition increased, it is virtually impossible to think of a company and its value offering without considering the supply chains to which it is linked.

Businesses are getting more involved in how their suppliers and customers do business. They recognise the necessity to look beyond the borders of their own companies to their suppliers, suppliers' suppliers and customers' customers to improve the overall customer and consumer value. They have changed their focus from what is happening inside their companies to manage and monitor processes across external companies. They are putting more focus on process that has an impact on enhancing supply chain management performance such as where raw materials come from and how many suppliers are able to provide those raw materials, how their suppliers' products are designed and assembled, how products are transported and stored and what consumers really need.

A typical supply chain network structure, with all business processes occurring across it, is represented in figure 1. As we can see, all the supply chain members have to work together in a way that all processes are integrated and managed smoothly. From the figure 1, we see that the processes occurring at the first tier suppliers' level (vertical arrows) are not integrated with the other processes (horizontal arrows). This can create disruptions and bring severe problems to the whole chain. Then, it is the role of the supply chain managers to identify those processes and make them go smoothly with the other processes. Now it is clear that the processes of sourcing, making and distributing products and services to customers are becoming the most effective and efficient way for businesses to stay successful. It is central to the practice of supply chain management. This requires supply chain competencies which are developed around quality and service, operations and

distribution, and design effectiveness. The goal of supply chain competencies is to satisfy customer requirements.

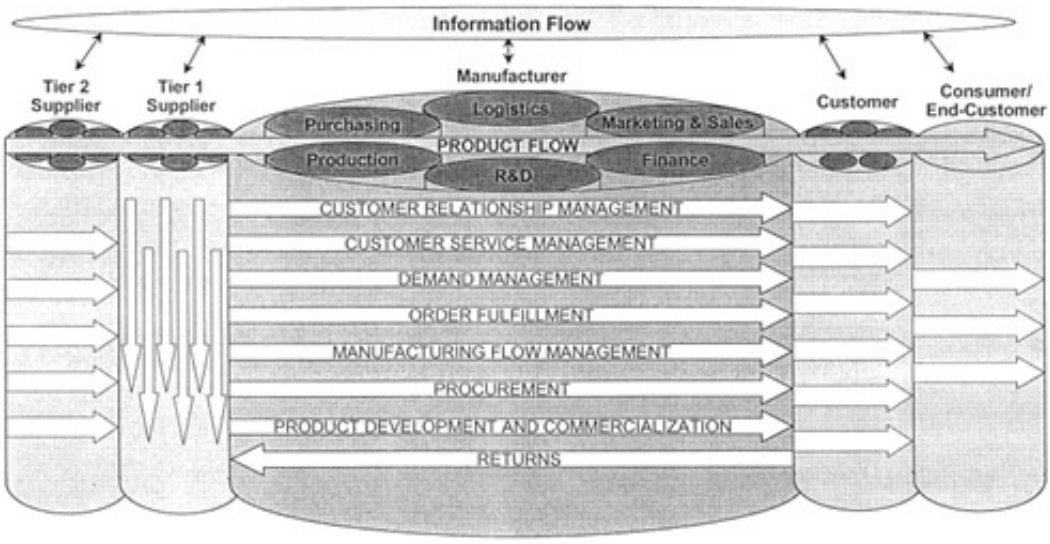

Fig 1: Supply chain management: Integrating and managing business processes across the supply chain (Cooper et. al, 1997)

It is said that the purpose of supply chain is to get products and services where they are needed when they are desired. Formally, supply chain is an integrated effort aimed at helping create customer value at the lowest total cost. This requires that supply chain members synergize their activities and resources towards accomplishing common goals for the supply chain as a group that aims to benefit all, and not just a few among the group (Solvang, 2001).

The missions of a supply chain are therefore to:

- Satisfy customer ever-changing requirements with the purpose of creating increasing customer value.
- Pursue increasing profitability for all supply chain members.
- Protect the supply chain members against potential disruptions.

Those can be attained by only balancing the approach to satisfy customer requirements and supply chain cost expenditure. Also, there are four different kinds of process links occurring between supply chain members and the focal firm: managed, monitored, not-managed and non-member process links (Figure 2).

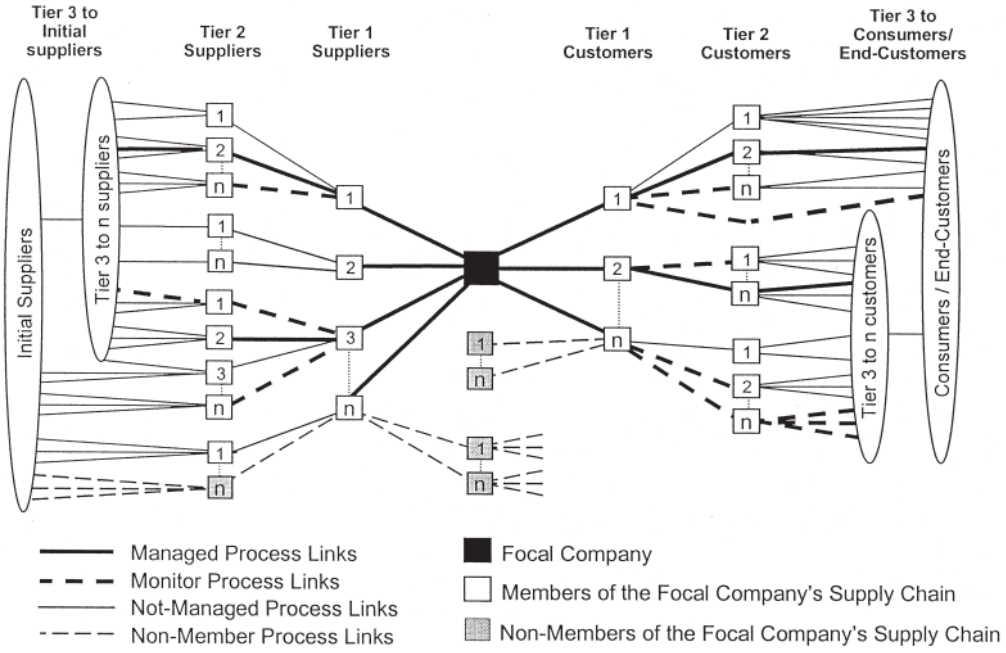

Fig 2: Types of intercompany business process links in a supply chain environment (Lambert et. al, 1998).

- Managed process links: where the focal company integrates a process with one or more customers/suppliers. This must be in collaboration with other member companies of the supply chain.

- Monitored process links: they are not as critical to the focal company as the managed process; however it is important to the focal company that the process links are integrated and managed appropriately between other member companies. Thus the focal company, as frequently as necessary, simply monitors or audits how the process link is integrated and managed.

- Not-managed process links: these are links were the focal company is not actively involved in, nor are they critical enough to use resources for monitoring. In other words, the focal company fully trusts the other members to manage the process links appropriately, or because of limited resources leaves it up to them.

- Non-member process links: these are links between members of the focal company's supply chain and non-members of the supply chain. Those links can often and will affect the performance of the focal company and its supply chain.

It is very important that companies understand and work through or around other members' links in order to achieve higher performance for the whole supply chain.

II.2- Supply chain performance

The performance of the supply chain has been widely covered in the literature. These studies are Chibba (2007); Koh & Demirbag et al. (2007); Saad and Patel (2006); Shepard and Günter (2005); Gunasekaran and Patel et al. (2004); Chan and Qi et al. (2003); Morgan (2004); Petroni and Panciroli (2002); Lambert and Pohlen (2001); Tracey and Tan (2001); Christopher and Towill (2001); Gunasekaran and Patel et al. (2001); Hoek van (2001, 1998); Lambert and Pohlen (2001); Otto and Kotzab (2001) and Beamon (1999).

These studies highlight the need to measure the performances and efficiency of the integrated supply chain. But why do we need to measure performance?

James Harrington (1991) partially answered this question by stating that "measurement is the first step that leads to control and eventually improvement. If you cannot measure something, you cannot understand it. If you cannot understand it, you cannot control it. If you cannot control it, you cannot improve it". As we see, the purpose of performance

measurement is to analyse, evaluate, control and improve the activities of a company in order to achieve its goals and objectives. It is in the late eighties and early nineties that performance measurement as a concept was formed. Performance measurements can be defined as the set of measures that provide an assessment of the performance of a system.

However, carrying out performance measurement properly demands a comprehensive understanding of the concept. Measurement is an act of cognition of reality (Solvang, 2001), then it requires good understanding of the subject under study. Most of the time, we measure something by comparing it with some references that we already know. With the latest development of technology, we are even able to provide measurement for very complex phenomena. Obviously, it is quite intuitive that we give the same meaning to measurement and quantification (Berka, 1983). However, this quantitative perspective of measurement is not necessarily suitable for every situation. It happens that some conditions cannot be measured due to the lack of knowledge, equipment or the qualitative nature of the object to be measured. In this situation, comparative measurement or classificational measurement may be of great usefulness (Berka, 1983). In the case of supply chain, performance measurement can help to identify weaknesses and provide solutions for improvements. The performance and efficiency of a supply chain can best be described by customers. Products or services provided by supply chains that have high performance and are efficient are getting more and more business share due to level of satisfaction that they provide to their customers. Petroni and Panciroli (2002) argued that customers usually retain suppliers who achieve the highest aggregate score on price, quality, flexibility of production and delivery times. De Toni, Nassimbeni et al. (1994) claimed that an efficient high quality supply chain is dependent on the achievement of a high-level performance in terms of cost, quality and time-to-market. Hayes and Wheelwright (1984) presented methods for addressing operational strategy by means of four generic competitive priorities; quality, cost, delivery and flexibility, which are the dimensions on which a company chooses to compete within a target market. Their original formulation was applicable to all functions. Hill (2000) also addresses competitive priorities such as price, cost reduction, delivery reliability, delivery speed, quality conformance; flexibility i.e. increased demand, product range and design, which he terms order-winners or qualifiers. As we can see, flexibility is a very important element when it comes to measure the performance of companies.

In our study, we will only focus on the flexibility dimension and try to provide more insights about how a firm can improve its performance through offering a high level of flexibility. Important questions will be: "What type of flexibility can we identify in the supply chain business processes? And, how flexibility should be handled so that companies can prosper in their businesses?"

Before to provide the answers of the previous interrogations, a review of literature on flexibility in the supply is indispensable.

III- REVIEW OF LITERATURE CONCERNING FLEXIBILITY IN THE SUPPLY CHAIN

A guideline for the literature review was to find an answer to questions regarding the importance of flexibility in the supply chain. The emphasis on theory was decided since our objective was to identify and explain new types of flexibility required in the supply chains. The aim of this third part is to present the available literatures on supply chain flexibility and to expose the findings suggested. There is a growing body of literatures related to flexibility in the supply chain. Considering their relevance, we review some of them with the objective to understand clearly the situation at the time we are writing.

Past literatures confined the study of flexibility to intra-organisational component and to production environment (Slack, 1987; Gerwin, 1993; Sethi and Sethi, 1990; Upton, 1994; D'Souza and Williams, 2000). Before managers did not have a comprehensive view of flexibility because they were focusing more on internal (machine) flexibility than on total flexibility system (Slack, 1987; Upton, 1994). But with the recent business development, companies have adopted a holistic view of their activities and are more interested to look beyond their traditional boundaries (Lummus et al. 2003). Now, companies are more than ever focusing on their core competences while outsourcing the rest of activities to external entities. This has risen the need for managers to consider not only their sole company

performances but also all their partners' performances when assessing their efficiency in the market place. Flexibility in supply chains may well represent a potential source to improve the company's efficiency and may be a significant measure of supply chain performance (Vickery et al., 1999).

Swamidass and Newell (1987) published one of first articles related to the importance of flexibility in the manufacturing environment. Their study was realized among mature U.S. industries facing severe recession and increasing competition from abroad (mainly from Japanese industries). They found that manufacturing flexibility improves performance in uncertain environment and they argued that as perceived environmental uncertainty increases manufacturing flexibility also increases. This observation led some authors to describe flexibility as a strategic weapon against competitors when the degree of environmental uncertainty increases (Gerwin, 1993; Lau, 1996). So, companies that are flexible have the ability to increase the level of environmental uncertainty in their industry by providing some additional services that their competitors are not able to do, giving them a serious competitive advantage. They also found that manufacturing managers have an important role to play in order to increase the performance of the companies regardless of the business environmental conditions.

Upton (1994) who studied flexibility with an emphasis on the manufacturing system presented a framework aiming at improving companies' flexibility. However, he acknowledged that confusion and ambiguity in the definition of flexibility can jeopardize the strategic competitive capability managers can get from it. He used the example of three different companies which were looking to develop their flexibility capabilities but which have various understanding on the concept of flexibility. Then, he urged managers to allocate more efforts in identifying with precision the types of flexibility with which they are concerned before to take decisions. He continued to argue that each type of flexibility should be composed of three different elements: range, mobility and uniformity. This view is also supported by Zhang et al. (2003) and Sánchez and Pérez (2005) who further explained that the importance of components of flexibility varies from supply chain to supply chain. This situation has created the need for managers to make a perfect assessment of the supply chain they are operating in if they want to succeed in their business.

Duclos et al. (2003) defined supply chain flexibility as the flexibility within and between all of the partners in the chain, including departments within and between an organization, and the external partners, including suppliers, carriers, third party companies, and information system providers. Sánchez and Pérez (2005) defined flexibility as a complex and multidimensional concept, difficult to summarize. They carried a study among automotive suppliers in Spain. Built upon the concept of flexibility competencies (dimensions of flexibility defined internally) and flexibility capabilities (dimensions of flexibility perceived by the customers) developed by Zhang et al. (2003), their research revealed that there is a positive relationship between a superior performance in flexibility capabilities and firm performance. They argued that companies enhance more the basic flexibility capabilities (at the shop floor level) than aggregate flexibility capabilities (at the customer-supplier level). Their study also showed that aggregate flexibility capabilities were more positively related to firm performance than basic flexibility capabilities, revealing that firms should focus more on aggregate flexibility capabilities if they want to improve their competitiveness. Another finding supported by their study is that the greater uncertainty is perceived by managers, the greater an emphasis is put on supply chain flexibility. They concluded their paper saying that the level of interdependence between companies may have an impact on the need for flexibility in the supply chain. Then, they argued that the high interdependence companies in the supply chain are in need of lower flexibility because of the use of formal agreements.

Lummus et al. (2003) extended the concepts of manufacturing flexibility and flexible organizations to the supply chain. They started by reviewing the previous literature on flexibility (Lau, 1996; Sethi and Sethi, 1999; Fisher, 1999; Vickery et al. 1999; Vokurka and O'Leary-Kelly, 2000; etc) and proposed a set of propositions to drive research on the concept of supply chain flexibility. They argued that the supply chain extends beyond the enterprise which means supply chain flexibility must also extends one firm's internal flexibility. They also described the concept of flexibility as a subset of agility, the ability of an organization to thrive in a continuously changing, unpredictable business environment. They explored the characteristics of flexible supply chain and their relative importance. For them, a flexible supply chain is one with the ability to respond to changes in customer demand while improving the supply chain performances. However, they

encouraged further empirical investigations in order to validate their model of supply chain flexibility.

Lee (2004) realized a study among more than 60 leading companies that were interested in building speed and efficiency in their supply chain. He argued that while those two factors are important for supply chains, they are not sufficient. He developed the concept of "triple A in the supply chain", meaning that managers should build agility in their supply chains, adapt to ever changing needs of customers and align their interest with those of all their supply chain members. He used the example of the Seven-Eleven Japan Company as a firm that successfully applied "the triple A" concept in its supply chain. He also argued that modular supply chain design and contingencies give the supply chain a degree of flexibility and potential source of competitive advantage. Then, he further explained that proactive supply chains are expected to be more responsive than reactive supply chains. Accordingly, he recommended that managers should design their networks with both flexibility and reduced uncertainty in mind in order to be better prepared against any disruption. An important option to mitigate uncertainty is to create flexibility by using multi-purpose resources which allows to reallocate capacity across different products and help to increase service levels and capacity utilization (Francas et al., 2007).

Stevenson and Spring (2007) published a timely review of literatures on supply chain flexibility (Table 1). They provided a more complete definition of flexibility in the context of supply chains. For them, flexible supply chains are able to adapt effectively to disruptions in supply and changes in demand whilst maintaining customer service levels. They argued that flexibility is built into supply chains to hedge against the demand uncertainty, and supply chain flexibility encapsulates components of flexibility inherent at the inter-firm level together with those at the intra-firm level. While they showed that different types of flexibility are more important in some environment than in others, they argued that there are strong dependencies among flexibility types. Finally, they presented four categories of research literature which brought new contributions to the existing supply chain flexibility literature (the literature that links flexibility to elements external to the firm, the literature related to flexibility in supply chain relationships, the literature related to flexibility in the design of supply chains; and the literature that make a link between flexibility and the role of inter-organisational information systems).

Winkler (2009) developed a conceptual model with the aim to improve supply chain flexibility. First, he defined supply chain flexibility as the ability of a system to perform proactive and reactive adaptation of its configuration in order to cope with internal and external uncertainties. For him, basic flexibility and supply chain flexibility are important elements to the company's financial performance. He proposed that building up and using certain strategic supply chain networks can improve the flexibility of supply chains. Then, the networks' members should focus on their core competencies and align their objective with the other networks members. This can only be possible by a high level of cooperation in the network. He further argued that those strategic supply chains networks are expected to provide the networks with high structural, technological and human flexibility potentials. He stated that a high level of integration of resources of all partners in the network is imperative if they want to achieve common competitive advantages. This can be reached by the use of trusting agreements. He continued arguing that it is insufficient to improve flexibility in only one single company of a supply chain. Rather, an improvement in the flexibility of an entire supply chain is necessary to achieve remarkable performance results. While this article can be considered as a new contribution to the topic of supply chain flexibility, it did not provide any empirical study that tested the validity of its arguments.

Stich and Wienholdt (2009) presented a framework for production system that includes the whole value chain of a company. They carried their research in the context of a project called "Integrative Production Technology for High-Wage Countries" undertaken at RWTH Aachen University, Germany. They developed a configuration logic that enables companies to configure their production systems in a way that customer specific products can be produced at the costs of mass production. They described elements of the subsystems of the production system that need to be flexible in order to build flexibility in the production system (production technologies, the production processes, the product and its architecture, etc). This resulted in providing a high level of flexibility to their operations. They also presented a holistic description model for production systems. Further, they discussed the complexity that exists in production systems with an emphasis on its drivers. Complexity drivers are defined as all influence factors and elements that lead to arise of the complexity level within the production system (Meyer, 2007). They

asserted that managers should identify and classify complexity drivers in order to reduce their impact and have a better control of future behavior of the production system.

Hallgren and Olhager (2009) participated in a large-scale project (HPM) that has the objective to investigate high performing plants in order to understand the practices and principles behind superior performance. The data collected from the research was coming from three industries (electronics, machinery and automotive) located in seven countries dispersed around the world. They found in their research that flexibility configurations based on high or low levels of volume and mix flexibility combinations show significant differences both in terms of operational performance and in terms of emphasis put into different flexibility source factors (total preventive maintenance, statistical process control, design for manufacturing, modular product design, set-up time reduction, advanced manufacturing technology and multi-trained employees). They also argued that plants exhibiting high levels of flexibility generally perform better than those showing low levels of flexibility on all four operational performance measures, i.e. cost, conformance quality, on-time delivery, and delivery speed. Another result of their study is that volume flexible plants generally perform better than mix flexibility plants; however the difference between the performances of the two types of plant is only significant for on-time delivery. Also, they said that volume flexibility is the most important element in high flexible plants. However, adding mix flexibility to volume flexibility is expected to improve the flexibility of the plant specially for delivery speed. Finally, they concluded that flexibility is not achieved through a single factor but it is the result of a mix of the previous flexibility source factors.

Arias-Aranda et al. (2009) conducted a research build upon the relationship between flexibility and outsourcing. For them, operations flexibility can help companies to deal with risks created by outsourcing decisions and provide outsourcing benefits to services firms at the same time. They showed that higher levels of flexibility in the information systems, markets, expansion and personnel dimensions are directly related to higher outsourcing benefits. The relationship between flexibility and suppliers has also been studied by Tachizawa and Thomsen (2007). They conducted a multiple case study in Spain with manufacturing companies coming from various sectors (automotive, apparel, electronics and electrical equipment). Their results showed that manufacturing companies

independently of their industry need flexibility in their upstream supply chain in order to be better prepared against uncertainty and supply disruptions. First, they explored the relationship between drivers and sources of supply flexibility. Then, they concluded that when the main driver of flexibility is uncertainty in the production schedule and just-in-time purchasing (mix and delivery uncertainty), companies can increase supply flexibility by implementing a strategy aimed at "improved supplier responsiveness". Furthermore, they added that when the drivers of flexibility are low component commonality, demand volatility and low forecast accuracy (volume and mix uncertainty), companies appear to increase supply flexibility by implementing a "flexible sourcing" strategy. Finally, they suggested that it exists a positive relationship between supplier searching and switching costs and the supply flexibility strategy (the higher these costs, the more likely the firm is to adopt the "improved supplier responsiveness" strategy).

Table 1: Summary of the literature* on supply chain flexibility (up-dated version from Stevenson and Spring, 2007)

Research focus	**Authors(s)**
Examples of manufacturing flexibility literature (that bridges the gap to supply chain flexibility)	Lau (1994), Fawcett et al. (1996), Lau (1996), Koste (1999), Narasimhan and Das (1999; 2000), Das (2001), and Olhager and West (2002), Pujawan (2004), Wadhwa and Rao (2004), Kumar and Deshmukh (2006), and Yang et al. (2007)
Building/refining conceptual models of supply chain flexibility	Duclos et al. (2003), Lummus et al. (2003), Wadhwa and Rao (2004), Lummus et al. (2005), Kumar et al. (2006), Reichhart and Holweg (2007), Gong (2008), and Winkler (2009).
Measuring supply chain flexibility	Beamon (1999), Vickery et al. (1999), Gupta and Nehra (2002), Giachetti et al. (2003), Pujawan (2004), Swafford et al. (2006), Bhagwat and Sharma (2007), and Gong (2008).

Quantity and timing flexibility in supply contracts	Bassok and Anupindi (1997), Eppen and Iyer (1997), Lariviere (1999), Li and Kouvelis (1999), Tsay (1999), Tsay and Lovejoy (1999), Barnes-Schuster et al. (2002), Das and Abdel-Malek (2003), Sethi et al. (2004), Giunipero et al. (2005), Milner and Kouvelis (2005), Tang (2006), Yazlali and Erhun (2007), Fotopoulos et al. (2008), Lian and Deshmukh (2009),and Xu and Nozick (2009)
Flexibility considerations in supply chain design and simulation	Barad and Sapir (2003), Bertrand (2003), Garavelli (2003), Graves and Tomlin (2003), Tiger and Simpson (2003), Wadhwa and Rao (2003), Terzi and Cavalieri (2004), Aprile et al. (2005), Shen (2006; 2007), Tang and Tomlin (2008), Caniëls and Roeleveld (2009), and Winkler (2009)
Empirical analysis of supply chain flexibility (using long-distance questionnaires)	Suarez et al. (1995), Suarez et al. (1996), Narasimhan and Das (1999), Vickery et al. (1999), Narasimhan and Das (2000), Scannell et al. (2000), Prater et al. (2001), Jack and Raturi (2002), Young et al. (2003), Zhang et al. (2003), Pujawan (2004), Claycomb et al. (2005), Giunipero et al. (2005), Gosain et al. (2005), Lummus et al. (2005), Sánchez and Pérez (2005), Swafford et al. (2006), Avittathur and Swamidass (2007), and Hallgren and Olhager (2009)
Empirical analysis of supply chain flexibility (using interviews/in-depth field studies)	Golden and Powell (1999), Pérez and Sánchez (2001), Jack and Raturi (2002), Fredriksson and Gadde (2005), Krajewski et al. (2005), White et al. (2005), Reichhart (2007), Tachizawa and Thomsen (2007), and Baker (2008)

Related concepts (e.g. supply chain agility, resilience and responsiveness)	Buzacott and Yao (1986), Fisher et al. (1994), Fisher and Raman (1996), Gunasekaran (1999), Naylor et al. (1999), Suri (1999), Cagliano and Spina (2000), Christopher (2000), Hoffman and Mehra (2000), Perry and Sohal (2001), Power et al. (2001), Van Hoek et al. (2001), Catalan and Kotzab (2003), Yusuf et al. (2004), Corsten and Kumar (2005), Holweg (2005), Storey et al. (2005), Lin et al. (2006), Agarwal et al. (2007), Gunasekaran et al. (2008), and Ponomarov and Holcomb (2009).

* It is possible to find other articles using proper keywords and date of publication but they do not provide relevant information that can be useful for the corresponding research focus.

From our literature review, it appears that supply chain flexibility is a topic that is gaining a lot of interests and new contributions. Our work has the objective to bring new insights into the topic based on what have been done so far in the existing literature. However, before to develop our arguments on supply chain flexibility types, we think that it is important to start our work, built on uncertainty and risks in the supply chain since they are the main reasons why companies need more flexibility in their operations.

IV- UNCERTAINTY AND RISKS IN THE SUPPLY CHAIN

Uncertainty is defined as “the lack of certainty, a state of having limited knowledge where it is impossible to exactly describe existing state or future outcome, or where it exists more than one possible outcome” (Hubbard, 2007). In the same verve, Williamson (1979) described uncertainty as the inability to predict contingencies that may occur. Those contingencies can create opportunism, which is defined as the self interest seeking while guile. Since we are more interested about uncertainty in the supply chain, the definition of Van der Vorst and Beulens (2002) give us more insights about the problem. They defined Supply chain uncertainty as “the decision making situations in the supply chain in which the decision maker does not know definitely what to decide as he is indistinct about the objectives; lacks information about (or understanding of) the supply chain or its environment; lacks information processing capacities; is unable to accurately predict the impact of possible control actions on supply chain behaviour; or, lacks effective control actions (non controllability)”. Going in the same way, we can say that uncertainty in the supply chain can have its origin from many sources: supplier’s behaviour, technology availability, manufacturing abilities, network structure, customer’s needs and market dynamics. However, we cannot talk about uncertainty without considering the risks that can result from the situation. From many literatures, risk is defined as a state of uncertainty where some possible outcomes have an undesired effect or significant loss. There are many definitions of risk that vary by specific application and situational context. One is that risk is an issue, which can be avoided or mitigated (wherein an issue is a potential problem that has to be fixed now). Risk is described both qualitatively and quantitatively. In most texts, risk is described as a situation which would lead to negative consequences. However, risk can yield to a situation of economic gains. In general, risk is simply defined as the product of the probability of the occurrence of an event and the negative impact of that event on the system (greater loss and greater event likelihood result in a greater overall risk); while at the same time, uncertainty is defined as the probability of the occurrence of an event. This is further argued by Hubbard (2007). For him, Uncertainty is the lack of complete certainty, that is, the existence of more than one possibility. It can be measured as a set of probabilities assigned to a set of possibilities (example: "There is a 60% chance the salmon market will double in five years"). Risk is defined as a state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome.

Risk can be measured as a set of possibilities each with quantified probabilities and quantified losses (example: "There is a 40% chance the proposed oil well will be dry with a loss of $12 million in exploratory drilling costs"). In this sense, Hubbard argued that one may have uncertainty without risk but not risk without uncertainty. We can be uncertain about the winner of a contest, but unless we have some personal stake in it, we have no risk. If we bet money on the outcome of the contest, then we have a risk. In both cases there is more than one outcome. The measure of uncertainty refers only to the probabilities assigned to outcomes, while the measure of risk requires both probabilities for outcomes and losses quantified for outcomes. Since uncertainty is the unavoidable part of risk, companies have to put in place mitigation plans so that the impact of the event occurrence being minimized or eliminated. As to quote an old adage, “uncertainty is the only certainty in life”. In order to build sustainability in their business, companies have to bear in my mind that something unexpected can happen at any time. Preparation and response are the main tools to deal with uncertainty. To state the obvious, risk is given and we have to deal with it. However, companies can make their ability to deal with risk their biggest competitive weapon. This can be done by building a resilient supply chain, understanding risks, evaluating options and designing flexibility into it (Roy, 2006).

From our point of view, we think that since flexibility is used to react when there is uncertainty, it would be wise to start to identify all kind of uncertainties that can affect the supply chain. Uncertainty is composed of both external and internal uncertainty.

External uncertainties in a supply chain come from various sources: customer demand fluctuation (e.g. customer requiring different quantities of products in different periods), the turbulence generated by market competition (e.g. companies that have to launch new products to the market continuously), natural disasters (e.g. the Kobe earthquake, the severe acute respiratory syndrome SARS, foot and mouth disease, birds flu, and others), terrorist incidents (e.g. the attack on September 11, 2001 or ships hijacking in the gulf of Aden), industrial or direct action (e.g. the fuel price protest in September 2000 that rapidly affected almost every supply chain in the United Kingdom), unexpected accidents (e.g. a fire at a component supplier can have such a serious impact on the original equipment manufacturers that they are forced to shut down operations, or crash of delivery planes), operational difficulties (e.g. if one supplier experiences a production or supply related

problem, then every downstream organization will be affected), etc (Yu et al, 2009). External uncertainty, which is the most frequent type of uncertainty, is really difficult to predict and therefore requires the organisation to set up proactive measures able to deal with it when it occurs and mitigate the risks created from the situation.

On the other hand, internal uncertainty in a supply chain is mostly related to the turbulence that can occur either at a member location or between supply chain members when working together. Those turbulences can be undue arrival of supplied goods, machine failure, information system failure, breakdown of material handling devices, transport vehicle breakdown, poor managerial decision, bankruptcy of a critical supplier, workers absenteeism, etc. Internal uncertainty can result in a total disfunctionnement of the company. For example, the failure of the information system can create the lack of correct, accurate and up-to-date information, resulting in big losses for the companies affected.

The table below shows situations where some supply chains had been hit by unexpected events and the responses of the firms that have to deal with the situations.

Table 2: Comparison of disasters resulting in significant Supply Chain disruption and firm responses (modified version from Griffy-Brown, 2003)

Events / Crisis	Impact	Response / Management
Hurricane Mitch in Honduras, Guatemala and Nicaragua (November 1998)	Flooding destroyed banana plantations, thus damaging 10% of the worldwide crops.	Chiquita: leveraged alternative source of bananas to maintain deliveries. Dole: suffered revenue declines and struggled to find alternative sources of supply
Earthquake in Taiwan (September 1999)	Power outages and damaged equipment halted supply of components to PC manufacturers.	Dell influenced demand toward products with available components through direct sales model. Apple faced products backlogs due to component shortages and inability to alter product configurations.

A Philips manufacturing facility in Albuquerque, New Mexico, was destroyed by fire (March 2000)	Destruction of supplied radio frequency chips (RFCs) for cellular telephone giants	Nokia's response was quick and two-fold: use other Philips plants to supply chips and make alternative suppliers to produce the missing chips by quickly redesigning it. Ericsson, however, reacted much more slowly. No action was taken and the company relied exclusively on the Albuquerque plant for the RFCs
Outbreaks of mad cow and foot and mouth disease in England (Spring 2001)	Destruction of cattle caused shortage of European hides to leather goods manufacturers.	Natale, Gucci and Wilson leather were locked into supply contracts; Naturalizer, Danier and Justin Boot relied on inventories. Etienne Aigner shifted purchases to other regions, but faced stiff cost increases.
Terrorist attacks on the United States (September 11, 2001)	Increased security crippled transportation networks, thus causing cross-border shipment delays to US auto manufacturers	Daimler Chrysler, Continental Teves used alternate modes of transportation and implemented contingency plans. Ford was forced to close five plants for several days.

In order to mitigate the effects of uncertainty and risk in the supply chain, companies' efforts should be directed toward preparing and finding solutions that can best accommodate with all the various types of uncertainty and risks that can occur in the supply chain. In his work, Sandvik (2008) has provided managers with tools to better assess and manage risk in the supply chain. Built around the Global Supply Chain Framework (GSCF), he derived a supply chain risk assessment framework composed of supply chain processes, structure and components risks. He further argued that supply chain risks should be assessed according to human behaviour unpredictability, dependencies established in the supply network, and skills and qualities of each actor in the supply chain. For him, management of supply chain risk should involve actions to reduce such behavioural unpredictability and network dependencies, while increasing the skills and qualities of the supply chain actors with respect to risk identification, risk

avoidance and risk situation handling. It is for this sake that we think that building high flexibility in the supply chain is of vital importance.

V- RESEARCH METHOD

Our flexibility assessment is developed based on a literature review where multiple perspectives on flexibility from supply chain management, marketing theory and organisation theory have been integrated into a composite supply chain flexibility framework. Relevant contributions were identified through library searches and key word searches in the Norwegian Libraries' system Bibsys, Proquest, ScienceDirect and Google Scholar™ databases. Search words were used either alone or in combination to find contributions which could bring added insight about flexibility in from different theoretical perspectives. Key word searches typically included words such as supply chain management, risk management, supplier's development, organisation theory or marketing, and words such as flexibility, agility, framework, relationship, uncertainty, performance, etc. A large number of research contributions were identified from this procedure and contributions were further selected based on a qualitative assessment of the title and abstract of each identified contribution.

VI- FLEXIBILITY IN THE SUPPLY CHAIN

a- Supply chain Flexibility: concept and definitions

Flexibility is described as a reactive mean to cope with uncertainty. The ability to adapt effectively to disruption in supply and changes in demand whilst maintaining customer service levels (Stevenson and Spring, 2007). It can also be defined as the ability to change or react with little penalty in time, effort, cost or performance (Upton, 1994). In short, flexibility is the ability to react successfully to uncertainty. As we can see, uncertainty in the supply chain is a major driver for flexibility.

With the globalisation of the economy and the fact that customers are demanding more value for their money, companies have to adapt and find better ways to satisfy their customers. Then, flexibility in their operation is of vital importance. It is a key competitive weapon in current world war of business survival (Upton, 1994). Also, since the trend in the business is now oriented towards companies participating in supply chains where collaboration and cooperation are key issues; companies are more interested to be members of flexible supply chains (Bowman, 2000).

It has been documented that flexibility is a value added that appears at the last stage of a successful relationship between two parties, meaning that we cannot provide flexibility to all our customers since flexibility is a result of a successful relationship and requires that the parties which are interacting know more about each other. However, the emergence of agile supply chains, defined as an efficient supply chain able to exploit profitable opportunities in volatile market has shown that companies can present their flexibility abilities as an entrance ticket to be member of agile supply chain without having to be involved in long relationships with the other supply chain members. This observation shows that there is diverse understanding of the concept of flexibility depending on which setting the company is operating in. For example, in an agile supply chain setting the company will have to exhibit special skills in order to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services (Gunasekaran, 1998).

Christopher and Peck (2004) went further and defined supply chain agility as the ability to respond rapidly to unpredictable changes in demand or supply. For them, two key ingredients of agility are “visibility” (defined as the ability to see from one end of the pipeline to the other; it implies a clear view of upstream and downstream inventories, demand and supply conditions, and production and purchasing schedules for example) and “velocity” (defined as the elapsed time from when the focal firm places orders on its first tier suppliers to when it delivers to its customers; or how rapidly can the supply chain react to changes in demand, upwards or downwards?). On the other side, a company operating in a lean supply chain will just focus on determining and eliminating all kinds of wastes and seek to improve outputs in the supply chain. Resulting from the lean philosophy

developed by the Japanese company Toyota, lean supply chain has brought tremendous benefits to many industries such as the construction and the automotive industries. According to the lean philosophy, there are seven wastes at the roof of all unprofitable activity within the organization. The seven wastes consist of defects, overproduction, transportation, waiting, inventory, motion and processing.

Fig 3: The Seven sources of waste (principles of lean manufacturing).

From all those sources of wastes, the one that deserves most consideration in order to achieve a lean system is overproduction. The main reason for that is because it includes in essence all other sources of wastes. Focusing on eliminating overproduction was the main driving force for the Toyota Just-in-time system. By tackling overproduction first, Toyota was smart enough to eliminate all the other sources of waste, improve its operations and become a very successful company in the automotive industry. From the above situation, it is clear that flexibility can be seen from different perspectives. However from all papers that have addressed flexibility, generic principles arise and can be considered with high value: flexibility is multi-dimensional; different elements of flexibility are more important in certain environments than in others, and flexibility is a capability that does not have to be demonstrated since it measures potential behaviour, whereas other operational objectives are actually demonstrated by the system's operating behaviour and performance (Stevenson and Spring, 2007; Slack, 1983).

Flexibility, which is defined as the ability to cope with uncertainty, is considered as a major determinant of competitiveness in the marketplace. It is vital to the success of the

supply chain since the supply chain exists in an uncertain environment. It can be used to measure the degree to which the supply chain can respond to random fluctuations in the demand and supply changes. Flexibility can improve the company's competitiveness and position in his industry, particularly for the decision-making process of implementing technologies (Jaikumar, 1986; Alvarez Gil, 1994). To this regard, some scholars (Brill and Mandelbaum, 1989; Gerwin, 1993) think that a flexible operations system requires the management and control of different flexibility dimensions by analyzing the total system flexibility.

However, enhancing a flexibility dimension does not necessarily lead to a flexible operations system since the system can require more than one dimension before to deliver the expected results (Gupta and Somer, 1996). Because flexibility is viewed as a reaction to uncertainty (Riley and Lockwood, 1997), in a global scenario, not only manufacturing, but also supply chain logistics and management can be an important source of competitive advantage, since material and information flows strongly affect business performance.

b- Supply chain flexibility types.

Previous researchers (Vickery et. al, 1999) and (Beamon, 1999) have already tried to identify supply chain flexibility types. While the first approach was critised as being based on customer-focus perspective, the second was taxed to being based only on the flexible manufacturing system (FMS). However, from our point of view, those two studies were the most direct and relevant contributions for the identification of supply chain flexibility types. They have provided us with approaches that we have used in order to go further in our work.

The types of supply chain flexibility defined by Vickery et al. (1999) were based on their conviction that flexible supply chain should be customer-oriented. They identified five types of flexibility based on an empirical analysis of the business environment of supply chains:

- Product flexibility (customization): the ability to handle difficult, non standard orders; to meet special customer specification; and to produce products characterized by numerous features, options, sizes or colours.

- Volume flexibility: the ability to rapidly adjust capacity so as to accelerate or decelerate production in response to changes in customer demand.

- New product introduction (i.e., launch flexibility): the ability to rapidly introduce large numbers of product improvements/variations or completely new products.

- Widespread distribution (i.e., access flexibility): the ability to provide widespread and/ or intensive distribution coverage.

- Responsiveness to target market (target market flexibility): the ability to respond to the needs and wants of the firm's target market.

The problem with this study is that the research was based on the researchers' experiences rather than a systematic analysis on supply chain environmental uncertainty. This fact leaded to question the completeness of the set of flexibility types needed. Also, several types of flexibility were overlapping each other in terms of uncertainties they are dealing with (Solvang, 2001). An example was the product flexibility that was overlapping the volume flexibility in the sense that the supply chain ability of handling difficult, non standard orders was found in the two types. This served as bias to calculate the flexibility of the entire supply chain.

On the other hand, the types of supply chain flexibility defined by Beamon were based on the flexible manufacturing system concept (FMS). She emphasized on identifying types of flexibility corresponding to different uncertainties of supply chains. The four types of supply chain flexibility she defined were:

- Volume flexibility: the range of volumes in which the organization can run profitably; how much of a demand can be met considering only the range of volumes that are profitable.

- Delivery flexibility: the ability to move planned delivery date forward; the ability to accommodate rush orders and special orders.

- Mix flexibility: the range of product types that may be produced during a particular time period, or the response time between product mix changes.

- New product flexibility: the ease with which new products are introduced into the system.

In her analysis, she pointed out that each type of flexibility aimed at handling only one type of supply chain uncertainty, raising no suspicion about bias to calculate the flexibility of the entire supply chain. However, there is still doubt concerning the completeness and sufficiency of her approach in dealing with all types of supply chain environmental uncertainty. This is mainly due to the fact that her study is derived only from an exploration on flexible manufacturing system rather than an analysis on supply chain uncertainty.

Our framework is organized around and inspired from the Supply Chain Operations References Model (SCOR), a diagnostic tool for the Supply Chain Management. It allows the users to know the various processes involved in a business and the important elements that lead to customer satisfaction. The SCOR model has been developed in 1996 by the Supply Chain Council and is organized around five business processes: Plan, Source, Make, Deliver and Return (figure 4). The SCOR model is a cross-industry, standard supply chain model that forms analytical tools for the supply chain on the basis of process, performance evaluation and best practice. It is a standard supply-chain process reference model that enables effective communication among the supply chain partners, by using standard terminology to better communicate and learn the supply chain issues and using standard metrics to compare and measure their performances (Supply-Chain Council,

2008). The model describes the business processes required to satisfy customer's demands. It also helps to explain the processes along the entire supply chain and provides a basis for how to improve those processes. It can help to develop critical metrics that are used to assist managers for their decision-making. It can also be applied in developing action-oriented metrics that effectively measure the progress of supply chain projects.

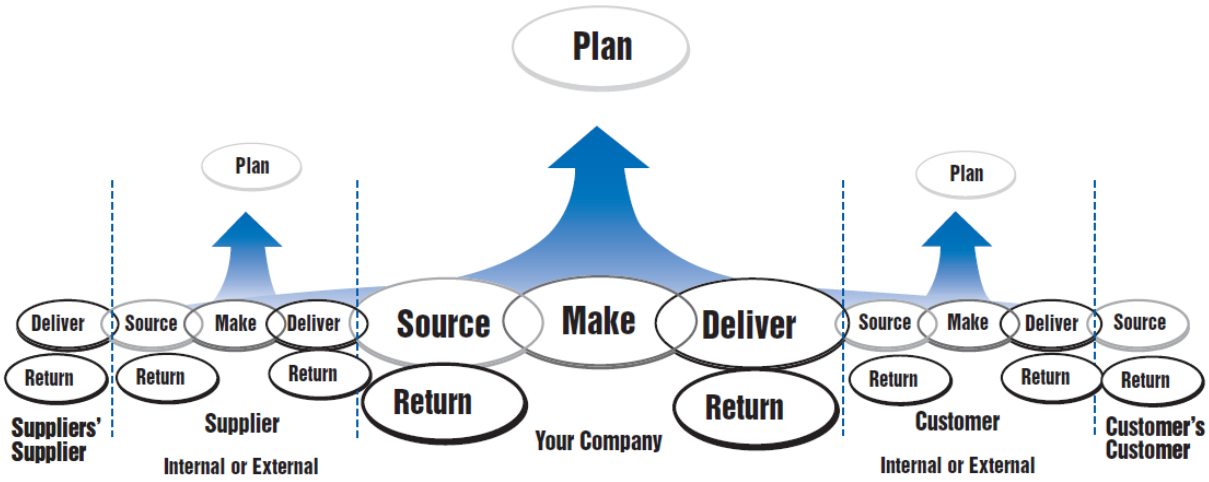

Fig 4: Supply chain operations reference model (source: Supply-Chain Council, 2008)

From figure 4, we can see that all processes are geared towards keeping customer in mind since the entire process is customer satisfaction centric. The SCOR model is based on three important factors: process modeling, performance measurement and best practices sharing. These factors design a comprehensive model for the business to successfully carry out their Supply Chain Management functions.

For the sake of our research, we will focus on the first process (process modeling) and derive the flexibility types that are needed to make the supply chain flexible (figure 5).

Then ten types of supply chain flexibility have been identified in our study according to the sources of uncertainty and our understanding of the different needs of companies. These types are:

- Production technology flexibility,
- Production process flexibility,
- Product flexibility,
- Volume flexibility,
- Delivery time flexibility,
- Labour flexibility,
- Contract flexibility,
- Network flexibility,
- Strategy flexibility,
- Routing flexibility.

Our model is described below. It shows where the identified supply chain flexibility types should be applied in order to increase the overall flexibility of the system.

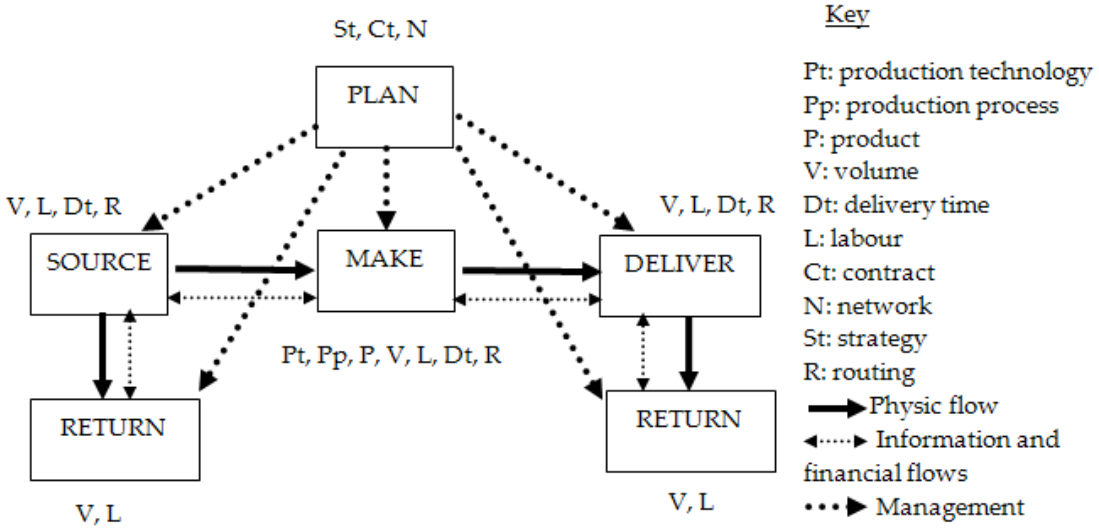

Fig 5: Supply chain flexibility framework.

In the following section, we will describe each of the flexibility types listed above. The approach that we will use is organized around five steps; that is first, defining the flexibility type concerned, then describing under what circumstance they are important, what are the obstacles to get this flexibility type, the disadvantages associated to them, and finally we will make recommendation about some technique to develop those flexibility types when needed.

1- Production technology flexibility

Production technology flexibility is defined as the ability to use different technologies for production depending on the environment uncertainty or market condition. It can also be identified as machine flexibility, which is defined as the ease of making the changes (on the machine) required to produce a given set of parts types (Brown et al, 1984).

Production technology flexibility refers also to various types of operations that a machine can perform without requiring an unreasonable effort in switching from one operation to other. This can well be expressed in the case of National Bicycle, a subsidiary of the Japanese giant Matsushita Electrics. This company was facing a lot of problems due to the technology used to produce their bikes which were known under the brand name Panasonic Bicycle. The company had variety of products: kids' bikes, bikes bought by students and other seeking for low cost transportation and sport bikes that affluent customers buy for recreation. The company was using tube cutting machine in its production and because of the rigidity of the technology used, all the other production processes were requiring set up cost when switching from on model bike to another. As an example, during the welding process, the tubes that would comprise the frame were held in place by fixtures, which needed to be adjusted each time a different frame geometry was produced. Because of the long set up times that were occurring, it was efficient to produce bikes in large batches (50,100, 150, etc.) depending on the popularity of the model in order to realize economies of scale. Then, the whole supply chain was constrained by the production technology, making difficult to cope with customers demand for variety. The main problem was the long and uncertain lead time (several months) required for replenishment during the sale season. Then, in an effort to grow sales and reduce inventory

risk on their sport bicycle (fashion items), National introduces a radical change in their production. They were able to offer a new service to their customer through the reengineering of their production processes enabled by their introduction of a new production technology. National built a new factory and was utilizing computer controlled welding robot and highly skilled workers to produce and deliver a custom bike to the customer within two weeks after placing an order (Fisher et. al, 2000). The introduction of the new production technology reduces the lead time and enabled national to provide a wide range of bicycle model to their customers. This situation led them to success because they were able to set up two supply chains corresponding to their needs. The problem with this flexibility type is that it is the result of a long process and requires huge investments in research and development (R&D).

2- Production process flexibility

Production process flexibility is defined as the ability to change or modify work processes so that the final product can meet the customer requirements; the ability to reorganize the order in which different kinds of works are processed. It encompasses bringing innovative procedures into the production processes so that the manufacturability of products is simplified. This can be described also as the easiness to make a product due to major improvements in the production processes. Production process flexibility can also be seen in the case of a production facility that can produce multiple products. It is a critical design consideration in multiproduct supply chains facing uncertain demand. The challenge here is to determine a cost-effective flexibility configuration that is able to meet the demand with high likelihood (Grave and Tomlin, 2003). An example of this flexibility type is expressed in the case of Toyota which modified the layout of its production facilities so that the workers were able to perform multiple tasks. A key to Toyota's competitive advantage has been its robust and flexible product-creation process. In this company, production process flexibility has been applied in the case of the development of hybrid vehicles. When designing the Prius, Toyota required it to be built using existing production lines and manufacturing processes. Because of the high degree of flexibility in Toyota's production process, this required less compromise than one might imagine. The benefit of this flexibility conveyed two key advantages:

- ✓ Getting an innovative product to the market quickly - Since all the technology needed to produce the Prius already existed, Toyota could get the product to the market almost immediately.
- ✓ Minimizing risk - If consumers rejected the hybrid, the company could just go back to using its production lines for its traditional models. If consumers loved the Prius, Toyota could switch production accordingly.

The Toyota Prius story illustrated a design principle called reuse. Engineers no longer had the authority or "carte blanche" to use any materials or designs they wanted, but rather were restricted to using as many existing designs or components as they could. The savings in design time and cost were dramatic. By introducing production process modularity, Toyota was able to provide a wide range of products. The core of the product architecture modularity idea is the breaking down of the product into standardized components or group of components, which is called modules. Standardization of modules yields not only the economies of scale, but it also provides an opportunity to increase product variety. It provides the companies with the ability to react quickly to customers' demand, since parts of the required elements for production were already available in inventory. It also helps the companies to reduce their inventory holding costs. For those who were thinking that economies of scale were reducing flexibility because of production in large batches, found that component commonality was the right strategy in order to still benefit from economies of scale while increasing the flexibility of the products. Production process flexibility is hard to get and is a result of extensive improvements made by the engineering forces. It also requires huge investment in research and development because of the innovative procedures that are used by companies to achieve this type of flexibility.

3- Product flexibility

Product flexibility is defined as the ability to customize product to meet customer specifications. Vickery et al. (1997) defined product flexibility in a supply chain framework as the ability to handle difficult, non-standard orders, to meet special customer specifications, and to provide services characterized by numerous features and options.

Sethi and Sethi (1990) defined product flexibility as "the ease with which new parts can be added or substituted for existing parts. In other words, product flexibility is the ease with which the part mix, currently being produced, can be changed inexpensively and rapidly. Gerwin (1982) defined two types of flexibilities related to product flexibility: part flexibility (the addition or removal of new components to a system) and design-change flexibility (design changes to a particular component in a system). Furthermore, he defined two types of flexibility, which are related to products based on the uncertainty faced by manufacturing managers: changeover flexibility, that is the ability of a process to deal with additions to and subtractions from the mix over time (Uncertainties in the length of product lifecycles lead to changeover flexibility); and modification flexibility, that is the ability of a process to make functional changes in the product. These minor changes are due to the uncertainties in the customer needs, which arise at the beginning of the lifecycle for a standardized product or throughout the lifecycle for a product that can be customized. Browne et al. (1984), explained product flexibility as the ability to change in producing a new product or set of products very economically and quickly. They measured product flexibility as the time required to switch from one part mix to another, not necessarily of the same part types. Moreover, they explained that this flexibility type can be achieved by having an efficient and automated production planning and control system; and machine flexibility, where machine flexibility is the ease of making the changes (on the machine) required to produce a given set of parts types. Product flexibility can be built by introducing techniques such as component commonality into products. Those techniques can help the companies to provide more variety to customers while minimizing the costs associated to production and inventories. Challenges associated with this flexibility type can be found in the product design stage where engineers have to incorporate technical capabilities and layers so that the product can be upgraded or modified according to the new needs of the customers.

As we can see, the three first flexibility types are close to each other. However, they present some special characteristics that create the need to consider them separately.

4- Volume flexibility

Volume flexibility is defined as the ability to operate profitably at different customer demand sizes. The ability to adjust capacity to meet changes in customer demand quantities. It is also defined as the ability to effectively increase or decrease aggregate production in response to customer demand (Cleveland et al., 1989). Volume flexibility can also be seen when it comes to change the delivery quantity with profitability. This is when there is no changes in types of products ordered, in planned due date, in states of internal material arrival, or in internal resource. The focus here is only in the changes in quantity to be delivered to the customers. However, we think that we should have a focus on the return on investment (ROI) and capital cost when it comes to operate in low volume level; that is when the quantity decreases. In this case, excess capacity is not necessary and the supply chain is usually able to delivering the new quantity. This situation can lead to increasing unit cost (since advantages gained from economy of scale can be affected); increasing inventory of raw materials, parts and subassemblies, which have been ordered in accordance with the original quantity; and increasing price of raw materials and/or components when assigning reduced order to suppliers who may require a compensation for their losses (Solvang, 2001). This last point had been the interest of many researchers: Lian and Deshmukh (2009); McKone and Tumolo (2002). In the case of quantity increase, the company has to find redundant capacity (production capacity, raw materials, parts, workers, etc.) as its primal objective. If the redundant capacity is large enough to deal with the change that means the company has the volume flexibility required. However, when redundant capacity does not exist or is not sufficient, a chain will usually apply three countermeasures (Solvang, 2001). The company will expand volume capacity within current chain. The second is to add new members. The third is the combination of the previous two. When any of these three countermeasures manages to create the capacity needed, we can conclude that the supply chain has volume flexibility. Companies that have this flexibility type should have the ability to work with less tied up capital so that change in volume does not affect the financial performance of the company. In the other hand, Companies that rank high in volume flexibility usually require close coordination with their supply chain members, especially in the face of increasing demand. In the planning stage, we can say that some companies build volume flexibility by appropriately placing and sizing their capacity and inventory reserve; that is to maintain excessive flexible capacity in existing plants. Volume flexibility directly impacts supply chain's performance by preventing out-of-stock conditions for products that are suddenly in high demand or by preventing high inventory levels.

5- Delivery time flexibility

Delivery time flexibility is defined as the ability to deliver the requested products on a short notice and to handle delivery time changes with little penalty. Solvang (2001) defined delivery time flexibility as "the ability of a supply chain to meet changes in delivery time with profitability, without considering the change of product mix, planned quantity, states of internal material arrival, and internal resource". She argued that delivery time flexibility described a supply chain's ability of being capable to deal with change in due date. Delivery time can be either lengthened or shortened.

In the first case, a supply chain is usually capable to deliver within the new due date. The chain may revise its schedule and this may result in cost change in manufacturing and/or assembly. When the chain chooses to not revise its schedule, excess cost for stocking finishing products may be incurred.

In the second case, a little penalty will definitely occur due to the early delivery. However, a supply chain may or may not be capable to deliver within the new due date. Usually, when a supply chain is facing a shortened delivery time, it tries to revise the schedule and utilize redundant capacity first. If the redundant capacity is large enough to cover the needs, we say the company has the delivery time flexibility.

However, when the schedule is impossible to be revised, redundant capacity does not exist or is not sufficient, a chain will usually apply three counter measures. The first is to expand capability within current chain by acquiring more resources in order to provide the requested delivery. The second is to engage new members by bringing in new contractors to handle the job on its behalf. The third is the combination of the previous two. When any of these three counter measures manages to create the capacity needed, then we can conclude that the supply chain is flexible.

This type of flexibility mostly occurs with third party logistics providers who are sometimes asked with short notice to change the time of their delivery due to increase in demand or urgency.

6- Labour flexibility

Labour flexibility is defined as the adaptability of a firm's workforce (Huang and Cullen, 2001), the ability of the workers to have their working hours or schedules adjusted according to the company's current needs. This can be done by giving flexible working time or percentage of working time to permanent workers (flexible work organization); or by employing workers on temporary work or fixed-term contracts (flexible hiring and employment practices). Labour flexibility can also be defined as the extent employees can be transferred to different activities and tasks within the firm (skills flexibility). Here, polyvalence or multi-competences of workers can be of great value and set as entrance criteria when hiring new workers. In clusters, formally defined by Porter (1990) as "geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities", it is possible to identify another type of labour flexibility, labour pooling. Labour pooling is defined as the ability to share labour between companies belonging to the same geographic area. It brings costs savings due to a privileged access to specialized skills especially in an environment where firms have non-positive correlations in the temporal variations of their demands (Lublinski, 2003).

In this case, the workers shared by companies can either perform similar activities as before (case of the shipbuilding industrial clusters in Mid-Norway where a company can require to use the available workers of its neighbouring companies in order to respond to increase in demand); or perform activities that are different from their initial occupations (case of the north Italian industrial cluster, where workers of factories used to go to work in farms in periods of low manufacturing activities). In those two cases, industrial clusters allow companies to benefit from the labour forces that are present in the area. The challenges associated with acquiring this flexibility type are mainly related to the level of cooperation between the managing staff of the company and its workers, and between different companies managers belonging to the same cluster.

7- Contract flexibility

Contract flexibility is defined as the ability to insert formalised agreements in contracts that will allow a company to take decisions depending on his current economic situation without displaying opportunistic behaviour. It is also defined as the ability of partners to adjust their behaviours or the terms of the alliance agreement in response to changes in the environment or the needs of their partners. This can be done through open contracts with clauses indicating that the parties have the possibilities to discuss and review terms of trade according to the performances of each party. One good example of contract flexibility can be found in the case of rolling horizon planning (RHP) contracts described by Lian and Deshmukh (2009).

RHP contracts are specific supply contracts under which a buyer receives discounts for committing to purchases in advance. The further in advance the commitment is made, the larger the discount. As time rolls forward, the buyer can increase the order quantities for future periods of the rolling horizon based on updated demand forecast information and inventory status. However, the buyer will have to pay a higher per-unit cost for the incremental units. Such contracts are mostly used by automobile and contract manufacturers, and are quite common in fuel oil and natural gas delivery markets (Lian and Deshmukh, 2009). It provides a higher level of flexibility than normal contracts.

The authors explained the RHP contracts using a simple example (see Table 2). The buyer places orders for the first 4 weeks (planning horizon) at the beginning, and the supplier provides the ordered product quantities each week. The buyer may adjust (increase) the orders for the future 4 weeks at the beginning of each week. Assume that the regular unit cost of a product is \$5.00. The supplier sets the unit costs of \$5, \$4.50, \$4, \$3.50 for orders placed in the upcoming 4 weeks, respectively. If the buyer orders 20, 25, 15, 30 items for these 4 weeks, the weekly costs are \$100, \$112.50, \$60, \$105. Now, if the buyer adjusts the order to 26, 18, 31 for the 2nd, 3rd and 4th weeks at the beginning of the second week, he will have to pay the extra cost (26-25) × 5.00, (18-15) × 4.50 and (31-30) × 4.00 dollars for the 2nd, the 3rd and the 4th week, respectively. In that case, the additional units are more expensive than those ordered in the earlier period.

Table 3: rolling horizon planning for a 7 weeks period.

Period		1	2	3	4	5	6	7
1	$377.5	20	25	15	30			
		$100	$112.5	$60	$105			
2	$75		26	18	31	15		
			$5	$13.5	$4	$52.5		
3	$51.5			18	32	18	10	
				$0	$4.5	$12	$35	
4	$111.5				35	20	10	25
					$15	$9	$0	$87.5
Total	**$615.5**							

We can also get contract flexibility by using option contracts with suppliers. In operations management literature, an option is a contract in which supplier allows a buyer to purchase up to a given quantity of a product during a specified interval of time at specified price (Xu and Nozick, 2009). Contract flexibility creates multiples benefits to the buyer as well as to the supplier. It provides stability for the supplier and help the buyer respond to demand fluctuations. It also provides the buyer with the ability to cope with its downstream demand fluctuation; while at the same time, it helps the supplier to better capture the incoming demand from its customers and hedge against uncertain demand by charging extra money for the change that will occur at a later stage. Other contract flexibility examples can be found in Barnes-Schuster et al. (2002), Kouvelis (2005) and Krajewski (2005).

One problem associated with this flexibility type is the determination of the behaviours that are judged opportunistic since this is critical to the agreement. Another problem that

also arises is that there are many intangible elements of flexibility that cannot be formalised or captured in supply contracts (Stevenson and Spring, 2007). Then, it is the responsibility of contractual parties to incorporate those elements when drawing their contracts. Companies that want to acquire contract flexibility should have the ability to make good forecasts and have strong negotiation skills. It is also important for them to develop their ability to deal with different contract arrangements. The governance structure of the relationships and the nature of the dependence between the buyer and its suppliers are expected to play an important role in establishing this flexibility type.

8- Network flexibility

Network flexibility is defined as the ability for actors to enter or exit the supply network without having to invest or lose a lot of resources in the network; or the ease of changing supply chain partner in response to changes in the business environment (Vokurka and O'Leary-Kelly, 2000). It can be also defined as the ease of exit from an alliance that no longer satisfies the partners or meet their needs (Gosain et al., 2005). It should allow the new members to provide capacity and capability that will strengthen the network. Network flexibility is an important property that can help companies to build redundant capacity into their supply chain.

Also, since in a network, members are requested to exchange information and have a high level of communication, it is vital to possess an effective information system by the mean of information technologies. This information system will enhance the responsiveness of companies by allowing them to have a large overview and control of the on-going operations in the supply chain in real time. The information system is very sensitive to the sustainability of a supply chain because as soon as a failure happens anywhere in the system, this can cause failure everywhere in the supply chain, and sometimes lead to huge losses. It has been reported that Ford applied this flexibility type in its plant in Valencia, Spain. There, it has been put in place a system that enable Ford and its value chain members to integrate and exchange information in a real-time basis. The goal was to manage and control sequencing of parts and assemblies to line-side - optimising in near real time and taking into account in-bound logistics - against changes and events. This allows Ford to integrate its production and planning system with those of its suppliers

using web technologies. Then, it is possible for Ford's suppliers to access the web portal and see demand evolving (long term, mid-term and short term). Suppliers can see cars being manufactured, stocks, expediting notices, exceptions as they occur. The system uses SMS messages and email alerts, and includes workflow to ensure action. It has also been designed to cater for several levels of sophistication, according to supplier capabilities. However, this system is not in use in all Ford's plants since it requires a lot of resources to reach the stage of full utilisation (Manufacturing computer solutions, 2004). As we see, the benefits of supply chain collaboration and logistics integration can be huge, but may only be reaped if companies are really convinced that this will deliver greater benefits than doing it themselves or by engaging in traditional customer-supplier behavior that may be more adversarial than collaborative. It is also recommended that all the members belonging to the same supply chain set common strategic and operative measurements that will participate in the improvement of the supply chain. Then, network members should be more willing to share rich information (i.e. information needed by the other partners) if they want to benefit from all the advantages of the supply chain. This fact constitutes one of the biggest obstacles for achieving this type of flexibility. In his paper, Winkler (2008) stated that network flexibility results in superior financial performance for each partner in the supply network. It allows the creation of higher revenue with the same costs or helps to achieve existing revenues with lower costs. Network flexibility requires that supply chain members share data in order to improve their operations.

9- Strategy flexibility

Strategic flexibility is defined as the ability to use managerial skills to overcome disruption in the supply chain. Sanchez (1995) defined strategic flexibility as "firm abilities to respond to various demands from dynamic competitive environments". He asserted that strategic flexibility depends both upon firms' resource flexibility and on firms' ability to flexibly apply those resources to alternative courses of action when necessary. This allows firms to have strategic options when dealing with dynamic environments. Strategy flexibility is applied in order to better control the demand of a specific item which is not available due to supply disruption. This flexibility type has been made possible mostly by the evolution of the supply chain in recent years, characterized by a move toward

modularization, customer relationship management (CRM) integrated application suites and information technologies. The evolution of technology and customer relationship capabilities provided an opportunity for managers to mitigate risks even in the worst of situations when supplies are missing, provided the supply chain system is contemporary and not too thin. This new conceptual strategy for mitigating supply chain disruption is to influence customer choice. Traditionally, companies were creating product lines that represented their best guesses about what buyers would want. There were generally some alterations possible at the purchase point, but choices were largely fixed. Customers were not used to variety or "mass customization," and companies could not produce a high level of variety. Traditional vertically integrated operations, using a standard supply chain, could not deliver custom products reliably or quickly.

However, since the mid-1990s, more and more companies have developed the ability to tailor in real time the options presented to the buyer and to promote certain features over others through their digital networks. This ability to dynamically influence customer choices is particularly powerful in times of crisis, and it is this ability that give rise to strategy flexibility. Price differentiation that consists of charging different prices to the same product is one of the strategies that derived from strategy flexibility. A good example of this flexibility type can be found in the airline industry with the strategy called “yield management”. Yield management is the broad term used for a set of strategies that enable capacity-constrained service industries to realize optimum revenue from their operations. The core concept of yield management is to provide the right service to the right customer at the right time for the right price. That concept involves careful definition of service, customer, time, and price. The service can be defined according to the dimensions of the service, how and when it is delivered, and how, when, and whether it is reserved. Timing involves both the timing of the service delivery and the timing of when the customer makes known the desire for the service, whether by reservation or by going into the company office. The ideal outcome of a revenue management strategy is to match customers' time and service characteristics to their willingness to pay, ensuring that the customer acquires the desired service at the desired time at an acceptable price, while the organization gains the maximum revenue possible given the customer and business characteristics. Another example of this flexibility type is seen in the way Apple and Dell dealt with the Taiwan earthquake in 1999. This earthquake cut power, damaged factory equipment and halted the supply of critical PC and laptop components for two weeks. In this case, the problem could not be resolved with alternative forms of transportation or

different sources of supplies. Apple faced shortages of semiconductors and other components that delayed production of its iBook and Power Macintosh G4 desktop computers during a period of growing demand. The company was unable to alter product configurations, but it decided to ship slower G4 computers than the customers had ordered and received a barrage of complaints. Dell on the other hand fared much better. Even though Dell's direct sales model meant that it held only five days of inventory, Dell was able to continue selling and delivering product. Dell used price incentives and promotions, adjusted in real time on Dell's online choice board, to influence customer choice. Dell directed demand toward the most accessible item of the company and was able to satisfy their customers. Dell's third quarter 1999 earnings actually improved 41 percent over the previous year, despite the supply-chain disruption. The successful strategy made in place by Dell showed how important is the ability to provide new strategies to deal with change in the environment. However, this flexibility type is not easy to develop since it depends of the companies' decision-making processes and the quality of the managerial decision.

10- Routing flexibility:

Routing flexibility is defined as the ability to use alternative contingency processes or alternative mode of transportation as a result of major disruption or incidents. This flexibility type has been identified as one of the best sources of flexibility in manufacturing systems. However, it may also be applied at the supply chain level. It is very important for companies to have routing flexibility in place in their supply chains, specially in the activity of moving physical goods between supply chain members. While such ability may seem obvious, the examples of Daimler Chrysler versus Ford indicate that unfortunately, even large, profitable companies may not have alternative contingency strategies in place. When the U.S. were victims of attacks on September 11, the situation immediately triggered tighter security at all U.S. customs checkpoints, thereby causing significant delays at border crossings for several weeks and disrupting critical shipments of parts and components. Ford suffered from not being prepared with alternative transportation routes for critical components. Consequently, Ford had to shut down five of its U.S. plants because the company could not get enough engines and drive-train parts

from Canada. The direct consequence of this situation was that Ford's production for the fourth quarter was 13 percent fewer vehicles than planned.

In contrast, Chrysler responded quickly to the restrictions on air travel after September 11. Chrysler's logistics staff in Michigan had analyzed its production flow by September 12 and realized they were likely to run out of an updated steering gear unit for the redesigned Ram pickup truck. The part was usually sent by air from a Thompson-Ramo-Wooldridge's plant in Virginia to the Chrysler assembly plant in Mexico. Chrysler turned to a truck service to minimize the delay in delivering the component. The same situation happened with Continental Teves, a large supplier to the auto industry, who similarly demonstrated exceptional supply chain management skills. Their crisis team composed of purchasing and logistics managers, immediately put together a list of all customers, parts, and suppliers outstanding. They identified where the parts were coming from and assessed which were considered critical and vulnerable to delay. By the afternoon of September 11, they knew which North American shipments required immediate action and expedited many of these by land. Continental Teves used existing contingency relationships with transport firms such as Emery to supplement air cargo delivery. Toyota, among other Continental Teves' customers, benefited from the company's ability to deliver with little disruption in the week that followed. As these events make it clear, manufacturers and suppliers must have the flexibility to expand their contingent shipping arrangements. In this regard, logistics software can help by tracking goods globally and providing guidance when disruptions occur. Those that ship via one mode of transportation should consider backup routes by other transportation modes. These steps may raise costs and affect production lead time, but determining the balance between flexibility and extra cost is one of the main challenges that managers should solve in order to benefit from the advantage of having a competitive supply chain (Griffy-Brown, 2003).

VII- DISCUSSING THE PROPOSED FRAMEWORK FOR FLEXIXIBILITY IN THE SUPPLY CHAIN.

According to our framework, we think that the flexibility types listed above can be applied as follow:

At the "plan" process, company managers should be more inclined to integrate resources and build more capabilities that will make the supply chains able to resist to any crisis or disruption. This can only be done by having a holistic view of the supply chain. The use of strategy, contract and network flexibility at the "plan" process is expected to strengthen the supply chain and prepare it to respond to change that may occur later. Also, since the "plan" process takes place before the beginning of all other processes, it is assumed to be part of the other processes. That means that the flexibility types needed for this process are also needed in all the four other processes.

At the "source" and "deliver" processes, we think that managers should build and develop volume, labour, delivery time and routing flexibility. At these stages, the sources of risk and uncertainty that we think can hit the supply chain are supply quality problems, incidents, natural disasters, late delivery, demand fluctuations, etc. Then, we recommend that companies integrate their operations and share information with other supply chain members so that the supply chain can be better prepared to deal with problems occurring at those two processes.

We think that the process that need to have a strong focus is the "make" process. It should be the primary focus of all supply chains since it is the process that requires a high level of flexibility. As we can see, this process requires that all the ten flexibility types identified in our framework to be applied. The "make" process is central for supply chain and it is at this stage (in most of the cases) that the most important part of the value of the products delivered is created. If carefully managed, the "make" process can be the driver of the whole supply chain flexibility.

Finally, we think that at the "return" process, volume flexibility and labour flexibility should be emphasized in order to efficiently carry out the activities related to the reverse logistics. Those activities come on support of the main activity of the companies and they require additional resources to integrate them to the existing systems. In many situations, the "return" process can constitute a challenging task for companies since they lack the knowledge to deal with that process.

In the table below, we summarise the elements of our framework and propose the flexibility types that should be used to hedge against the risks and uncertainties that can hit supply chains.

Table 4: Summary

	Risks & Uncertainties	Flexibility types
Plan	Crises.	Strategy Contract Network
Source	Supply quality problem, Late delivery, Natural disasters, Incidents (fire, terrorist attack, etc.), Demand fluctuation.	Volume Labour Delivery time Routing
Make	Market competition, New technology and innovation, Internal system failure, Demand fluctuation.	Production technology Production process Product Volume Labour Delivery time Routing
Deliver	Late delivery, Natural disasters, Incidents (fire, terrorist attack, etc.), Demand fluctuation.	Volume Labour Delivery time Routing
Return	Delivery failure, Product failure.	Volume Labour

VIII- CONCLUSION

In this thesis, we have addressed the issue of flexibility in the supply chain by developing a conceptual framework build upon the SCOR model, providing a review of the literature on supply chain flexibility and presenting types of flexibility that we believe can improve the overall flexibility and performance of supply chains.

From our literature review, we have seen a lot of papers that were focusing in identifying flexibility types in the manufacturing system. However, we think that when it comes to go a little further to the level of the entire supply chain, it is better to have a holistic view of the flexibility types and avoid categorizing them in way that they overlap each over. We think that many of the flexibility types that have been identified in some previous papers can be incorporated under other flexibility types since they present almost the same characteristics while some other flexibility types have to be defined separately.

Grounded in existent literature and our understanding of the concept of flexibility, this study has provided ten flexibility types: production technology, production process, product, volume, delivery time, labour, contract, network, strategy and routing flexibility. We think that they can participate to make companies more capable to deal with the numerous challenges of the new business environment by providing companies with a high level of flexibility in their supply chain.

Nevertheless, despite these contributions, it is important to reflect upon possible limitations of the study. Perhaps the main risk is that the literature review is not exhaustive, since only three online repositories were interrogated (Proquest, ScienceDirect and Google Scholar^{TM}). Whilst they are widely regarded as an excellent data sources, other databases could have been reviewed for completeness. Another limitation can be seen in the fact that we did not provide empirical testing to support our arguments. This later limitation can provide possible avenues for future research.

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