Review of Supply Chain Flexibility Research and Identification of Research Trends during the Last Two Decades Using Content Analysis

Master Thesis

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Affidavit

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Abstract

In order to deal with supply chain disruptions, supply chain risk management practices were proposed over the years. What if the uncertainties pose the main threat in business? In this respect, academics propose the utilization of flexibility. Flexibility concept in supply chains address most of the sources of uncertainty such as demand volatility, machine breakdowns, and customer expectations for highly customized products. However, flexibility brings considerable costs. That is why most firms try to stay away from it even though they are aware of its contribution in handling uncertainties.

In this dissertation, the last three decades of flexibility research has been analyzed regarding the trends in types and focus of research. Furthermore, estimations for future trends based on the recent studies were given. Finally, the relationship between flexibility and firm performance is discussed and the reciprocal influence of flexibility and strategic decision making is addressed.

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1. INTRODUCTION

Supply chains experience great challenges nowadays, some of which are caused by inherent or external uncertainties. It has been difficult for companies to maintain competitiveness in volatile markets due to these uncertainties which arose especially during the last three decades.

Globalization, mass customization, new technologies in both manufacturing and information dissemination are among the sources of uncertainty. On top of that, environmental disasters cause disruptions in the flow of goods and information. In addition to these challenges, changes in consumption habits around the world reduced the life time of products in many sectors. Finding a way to cope with these changes is of utmost importance for global supply chains.

In order to deal with supply chain disruptions, supply chain risk management practices were proposed over the years. What if the uncertainties pose the main threat in business? In this respect, academics propose the utilization of flexibility. Flexibility concept in supply chains address most of the sources of uncertainty such as demand volatility, machine breakdowns, and customer expectations for highly customized products. However, flexibility brings considerable costs. That is why most firms try to stay away from it even though they are aware of its contribution in handling uncertainties.

In this dissertation, the last three decades of flexibility research has been analyzed regarding the trends in types and focus of research. Furthermore, estimations for future trends based on the recent studies were given. Finally, the relationship between flexibility and firm performance is discussed and the reciprocal influence of flexibility and strategic decision making is addressed.

2. THEORETICAL BACKGROUND

2.1 Concept of Supply Chain Management

A supply chain can be defined as the network of different parties which focus on the same target collectively: to fulfill the need of final customer. Material, information, and funds flow through the branches of this complex network in different directions. Every supply chain network consists of several parties such as manufacturers, suppliers, transporters, wholesalers, and retailers. Each party in this network is related to several tasks which are: development of new products, manufacturing operations, distribution, financing, marketing, and customer services.

The production of goods starts with the supplier of raw materials and these raw materials pass through several subsequent manufacturing processes before reaching the final customer. Goods obtain their final shape after the final process of manufacturing (e.g. assembly) and they are distributed through logistics channels to wholesalers and finally to retailers. Flow of information, material, and funds connect each stage of the supply chain (Chopra & Meindl, 2007). Beside the supply chains producing tangible goods for which the production stages described above are typical, there are also supply chains in which material movement is not that obvious such that flowing materials are intangible for example, a television channel entertaining the viewers. With respect to this matter, Waters (2007) explains that there is not only a flow of tangibles (e.g. materials) but also intangibles (e.g. information) in supply chains. He proposes the following definition for a supply chain: “A supply chain consists of the series of activities and organizations that materials move through on their journey from initial suppliers to final customers” (p.37).

2.1.1 Definition of Supply Chain Management

Today’s unstable market environment poses many issues companies trying to overcome while trying to maintain both their competitiveness and attractiveness in B2B and B2C relationships. Short product life cycles, complex and sophisticated customer demands to be considered in product development process, highly customized products, business conditions showing rapid changes, and not to mention the complex network of business partners spread all around the globe cause various challenges to deal with. Thus, a reasonable approach is that supply chain partners raise a mutual awareness and concentrate on a collective growth of all parties by utilizing coordination and maximization of the generated value overall. In order to raise the generated value, emphasis is put on the efficiency of operations between supply chain partners.

Al-Mudimigh, Zahiri and Ahmed (2004) emphasize the management of supply chain as a whole. They discuss several aspects of supply chain management. According to them, supply chain management contributes to eliminating of inefficiencies, embeds consistency, and provides flexibility as well as quality. Furthermore, they highlight the old and more fundamental topics in supply chain management as well as fresh subjects. The old and rather fundamental topics are: material and inventory logistics planning, and push and pull approaches in production systems. Issues being discussed currently include however, Enterprise Resource Planning (ERP), multi-echelon inventory, and synchronous flow manufacturing which are not examined in this paper. For more details it is recommended to read the paper mentioned above.

Effectiveness and efficiency in modern supply chains make deliveries at the right time, to right places and in correct amounts possible. Until 1990s, supply chain management endeavors have put emphasis on speeding up the flow of goods and services through the extension of intra-organizational integration of logistics, marketing, and operations management into inter-organizational cooperation. On top of that, the term „supply chain" has recently drawn the attention of politicians, general managers, and public since supply chain networks are now spread all over the world and economic impacts of disruptions reach remote locations in the world (Sidola, Kumar, & Kumar, 2009). Soon and Udin (2011) draw attention to important targets of supply chain management such as to provide a wider range of products, to procure components on a global basis, and to be able to distribute the products worldwide to achieve cost effectiveness and time-based competitiveness. While trying to achieve these targets, it is also important to improve customer responsiveness.

Several authors mentioned key aspects of supply chain management which encompass virtual organizations, agility, responsiveness, flexibility, mass customization, lean operations, just-in-time, and supply chain risk management (Bernardes and Hanna, 2009; Chen and Paulraj, 2004; Lambert, Stock and Ellram, 1998; Miles and Snow, 2007; Stevenson and Spring, 2007; Tang, 2006; van der Vaart and van Donk, 2004; Waters, 2007). In this paper, some of these aspects will be scrutinized considering their relevance to the main problem discussed here. For more details on the rest of these aspects however, it is recommended that the reader refers to the literature cited above.

2.1.2 Uncertainty in Supply Chains

As mentioned above, widely dispersed global supply chain networks are susceptible to many challenges such as risks, material and information flow disruptions, and uncertainties. Mahnam et al. (2009) argue that uncertainty plays the most important role in supply chain management and thus according to them managing a supply chain is quite troublesome. Authors relate this issue to the presence of various sources of uncertainty and complex reciprocal associations between supply chain partners. In order not to wander off the topic of this paper, only supply chain uncertainty is going to be discussed here.

In one of the earlier papers, Pagell and Krause (1999) highlight the three main drivers of a firm's external uncertainty: the rapid changes in technology, competitors around the globe, and demanding customers. These three sources of uncertainty will be scrutinized with regard to the literature.

Uncertainty and/or variability have been discussed by many authors during the last two decades. Van der Vorst and Beulens (2002) define supply chain uncertainty as follows: "Supply chain uncertainty refers to 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 […] and information processing capacities; is unable to accurately predict the impact of possible control actions on supply chain behavior; or lacks effective control actions" (p.413). Authors also indicate that the real issue in management and control of complex networks is uncertainty where they refer to a statement from an earlier work (Davis, 1993). Furthermore they state that uncertainty - like a spreading plague - has impacts on the network such as inefficient processing and non-value adding activities. Finally, they highlight two main issues describing uncertainty: the unforeseen amount of customer demand and thus the amount of products to have in stock; and the delivery reliability of suppliers in terms of timeliness and accordance with specifications.

In a more recent study, Stevenson and Spring (2007) claim that companies which were confident in order winning with the help of low cost standardized manufacturing earlier, had to utilize flexibility in order to stay competitive and they attribute the competitiveness in the present manufacturing climate to sophisticated customers demanding customized products in short lead times. A similar perspective was put forward by Kumar, Shankar, and Yadav (2008) where they describe the present business environment with awaked customers, customized products, short product life cycle, and short lead-time.

Merschmann and Thonemann (2011) state, that increasing uncertainties play an important role in today's business environment and these uncertainties stem from global scatter of customers, sourcing, manufacturing, and distribution; and customer demands which lean towards better service and more customized products compared to the past. Authors also mention that the companies are forced to shorten product life cycles, enhance the variety of product, and accommodate to technological developments faster as a result of the competitive pressure. Another recent study by Yi et al. (2011) embodies the idea that uncertainty has a significant impact on current business environments as a result of the widening of product varieties and global marketplace becoming more volatile.

While companies reaching various customers from different places and cultures, and also working with suppliers from distant corners of the world or outsourcing their activities overseas, manage to achieve growth and profit opportunities, they also face significant challenges considering the needs and expectations of customers from many local markets, and the complexity of managing a global network of supplies and information. In a study about European companies, Skjoett-Larsen (2000) highlights their need to be adaptive in terms of their products which fulfill the varying customer demands from different parts of the world in order to maintain international competitiveness. In the same study, globalization is considered among the anticipated seven most important challenges for European companies in the upcoming years.

A global company aims at expanding the target market and thus improving its business while trying to utilize scale economies in purchasing and production by pursuing focused manufacturing and assembly operations in order to obtain a cost reduction. However, uncertainties are highly noticeable such as non-homogenous markets which entail the need to have local diversifications in many product categories and the danger of extended lead times or increased costs due to the complexity of logistics network in global supply chains (Christopher M. , 2005).

Considering the hazards of uncertainties for the global supply chains mentioned above, it is obvious that they should not be neglected. During the last decades authors have discussed how to identify and deal with them. Thus, in order to identify the sources of supply chain uncertainty, authors have developed several models during the last two decades. In the study of Davis (1993), a model was proposed which incorporates three sources of uncertainty: supply, manufacturing process, and demand. The supply uncertainty is associated with the variability in supplier performance or defective and/or late delivery of raw materials. Uncertainty related to manufacturing processes originates from manufacturing problems such as machine breakdown. Last but not least, demand uncertainties root in either volatile demand or defective estimations. According to this model, uncertainties in demand and supply side trigger the uncertainty in manufacturing process. As a result, the customer orders may not be fulfilled in time. In addition, the author asserts that demand uncertainty is more crucial than to the others. This model also lays the groundwork for the following studies. Based on this model, Mason-Jones and Towill (1998) added control uncertainty as a fourth source. Control uncertainty is related to the general ability of an organization to utilize the information flow and decisions in order to obtain a production plan and raw material requirements from customer orders. Moreover, parallel interaction was introduced by Wilding (1998) as another source of uncertainty which is one of the corners of "supply chain complexity triangle" (a model proposed by the same author) and is related to the interaction between a customer and its multiple potential suppliers (e.g. order revisions with other suppliers if a first-tier supplier is not able to supply the required material or component). The two other corners are: amplification (related with the bullwhip effect) and deterministic chaos (related with control systems).

Attempting to combine the model of Davis (1993) with the complexity triangle model of Wilding (1998), Prater (2005) proposed a distinction between micro and macro uncertainty. While micro-level uncertainty refers to a rather specific type of uncertainty and requires specific actions, macro-level uncertainty corresponds to more general types of uncertainty such as: General variation, foreseen uncertainty, unforeseen uncertainty, and chaotic uncertainty. The macro-level uncertainties are broken down into micro-level uncertainties such as long-term planning, deterministic chaos, and general non-deterministic chaos etc. The aim of such a distinction is to allow researchers and practitioners address different types of uncertainty more accurately and thus, utilize their sources (e.g. IT implementation) according to the problem they face. The author explains that with an analogy about a physician who requires specifity to diagnose an illness.

Eliot, Hendry, and Stevenson (2012) analyze the previous research on supply chain uncertainty sources and come up with a synthesis of the previously developed models. In their own model they categorize 14 different types of uncertainty in three groups. The first group encapsulates uncertainties whose scope is limited with the focal company and called "internal organization uncertainty". In this first group, following uncertainties are considered: product characteristics, manufacturing process, control/chaos, decision complexity, organization/behavioral, and IT/IS complexity. Second group is called "internal supply-chain uncertainty" which emerge in the internal environment of supply chain (i.e. within the control range of focal firm or supply chain partners) and includes end-customer demand, demand amplification, supplier, parallel interaction, order forecast horizon, and chain configuration/infrastructure/facilities. The name of the last group is "external uncertainties" arising from the factors outside the supply chain and encompasses environment (e.g. government regulation, behavior of competitors, and macroeconomic issues) and disasters such as earthquakes or hurricanes.

Another source of uncertainty arises due to technological changes and innovations especially in the context of ICT. With the help of internet, there is a fast flow of information through e-business and e-commerce channel between supply chain partners or manufacturers and customers. The ability to communicate worldwide with suppliers and customers through fast channels creates a time-based competition since distances between these parties becomes insignificant. Lancioni et al. (2003), found out in their study where they investigate the impact of internet technologies on 100 US firms from transportation industry, that through employing interactive websites firms succeed in stimulating their supply chain's strength since they manage to integrate Internet into their supply network and thus gain considerable advantages over firms in smaller size. However, this is only viable for the largest 10 firms in their study and small and medium sized companies mostly are put in the position of a follower in uncertain markets.

Regarding the manager's opinions on this matter, Patterson et al. (2003) conducted a survey in order to test their model about the determinants for supply chain technology adoption. One of the respondents pointed out: "With almost daily technology advancement […], organizations need to synchronize by adopting and implementing new electronic commerce and supply chain technology in order to protect market share, not to mention improve market penetration".

Another perspective was provided by Vijayasarathy (2010) who investigated the moderating effect of uncertainty aside from process innovation and partnership quality on technology use and resulting performance in supply chains. In an empirical study involving 276 manufacturing organizations, the author found that competitive uncertainty which was defined in the same study as "unpredictability in price and supply of inputs and competitors' actions" diminishes the positive effect of technology on performance. Laws, economic policies of the countries the organizations operate in, and the predictability of competitors are considered as the main sources of uncertainty. Organizations which operate in countries with more stable economic conditions and policies, and whose competitors act more predictably benefit from greater returns from the use of technology in the supply chain.

Georgiadis (2011) identify five sources of uncertainty which they categorize in two groups. Demand, prices, and availability of production resources constitute the external factors while promotion of new products and improvement of product quality are considered as the internal causes of uncertainty. The authors focus mainly on demand uncertainty which is strongly related to high demand volatility and commonly known as the essential cause of “bullwhip effect” according to the authors. They also claim that supply chains operate in a dynamic environment which means consumption patterns and product cycles varying with time cause product demand fluctuations. Therefore, authors emphasize that firms are compelled to prepare themselves for the demand fluctuations and to foresee the upcoming changes in demand.

Zhang et. al. (2011) who investigate the effect of demand and material price uncertainty on performance of the supply chain, highlight the difference between supply and demand uncertainties in supply chains. According to them, the changes in supply prices can be estimated with high accuracy since they only show small alterations compared to demand variations. The reason behind this is that there is a long-term involvement between the company and procurement market which makes it easier to predict volatility of supply price than demand variability. Regarding this fact, companies mostly aim at gathering large amount of information for forecasting demand.

In one of the studies about supply chain planning under demand uncertainty, authors point out the variability of demand as a key source of uncertainty in supply chains. Companies which do not succeed in finding out the sources and magnitude of product demand variations in the medium term (defined by the authors as 1-2 years) by utilizing deterministic planning models, may face very high inventory charges and thus high production costs or lose a portion of market share due to unfulfilled customer demand. This issue results in high motivation towards studying process planning and scheduling under uncertain demand. Especially, short-term scheduling of batch plants is a common research subject recently (Gupta, Maranas, & McDonald, 2000).

Considering business environment volatilities involving incessant variations and increase in customer expectations, Gupta and Maranas (2003) emphasize that it is crucial to have an efficient and flexible supply chain. Uncertainties are classified in two groups (short- and long-term) by the authors according to the duration of their effects on the system. The short-term uncertainties they mention encapsulate day-to-day processing variations cancelled or rushed orders, and equipment failure while raw material or final product price fluctuations, seasonal variations in demand, and production rate changes are considered as long-term uncertainties.

Beside the demand and raw material or supply uncertainties, uncertainties related to commodity prices and costs are also mentioned in the literature (Liu & Sahinidis, 1997). Chen and Lee (2004) focus on two types of uncertainty which are demand related and product price related uncertainties in their study, where they adopt scenario-based approach to model demand uncertainty and consider product price variations as fuzzy variables. They claim that various members of a supply chain have different (incompatible with other members' choices) preferences on product prices and analyze this issue. One of the targets of the optimization model in their study is to "elevate customer service levels, the safe inventory levels, the product-prices satisfaction levels, and the robustness of all considered objectives to product demand uncertainties as much as possible" (p.1133).

One of the issues drawing the attention of researchers is the robustness of the supply chain which plays an important role regarding the uncertainties in the environment, since the severity of inefficiency in performance caused by uncertainties is considerable. Thus, if enterprises are not able to prepare themselves in terms of creating a robust supply network against the unpredictable variations in their surrounding the consequences may be devastating. (Mirzapour Al-e-hashem, Malekly, & Aryanezhad, 2011).

A different approach for categorization of supply chain uncertainty research regarding the recognition of uncertainties is mentioned by Mirzapour Al-e-hashem et al. (2011). The authors proposed four approaches in uncertainty research: (1) Stochastic programming approach where some parameters are considered as random variables with known probability distribution, (2) Fuzzy programming approach where variables are considered as fuzzy members for the solution, (3) Stochastic dynamic programming approach which encapsulates implementation of random variables in dynamic programming as an essential part of all multi-stage decision making approaches, and (4) Robust optimization approach which is based on building scenarios to represent the occurrence of uncertain parameters. The target of this approach is finding a robust solution that provides responses closest to optimum for changing inputs. Since these approaches are not directly related to supply chain flexibility research, they are not scrutinized in this paper. However, it is important to have a brief overview considering that these terms are used quite commonly in the literature.

Wong and Boon-itt (2008) indicate that the occurrence of environmental uncertainty is related to the lack of reliable information about the environment which is necessary for effective decision making and forecasting the results of decision choices, and also related to unforeseeable changes in the environment. Authors examine the environmental uncertainty in three categories considering its sources which are supply uncertainty, customer uncertainty, and technology uncertainty. They assert that supply uncertainty is pertinent to how unreliable and unforeseeable suppliers are, considering the information flow, design, quality of their products, and their delivery performance. If the suppliers are reliable in terms of the information they provide, their designs, quality of products, and delivery performance; authors assert that their predictability is higher and thus, there is a low supply uncertainty. Customer uncertainty has a similar definition which is concerned with the reliability and predictability of information, needs and demands whereas the technology uncertainty is identified as unpredictability of upcoming changes and complexity of process/product technologies.

One major issue while defining effective supply chain inventory policies is identified as uncertainty since the supply, demand, information delays related to manufacturing and distribution processes, and also inventory and backorder costs are considered as uncertain by the researchers (Giannoccaro, Pontrandolfo, & Scozzi, 2003).

Petrovic (2001) highlights the sources of uncertainty in a study where a simulation tool is proposed for the analysis of supply chain behavior and performance taking the presence of different types of uncertainty into account. The author mentions that supply chain uncertainties result either directly from random events, imprecision in decision mechanisms, or from lack of certain evidences of these random events on supplier side, production or manufacturing processes' side and customer side. Pointing out the tendency in the literature to focus mainly on demand uncertainty, the author emphasizes the presence of supply side uncertainty which is described as the difference in quality and quantity of raw materials and/or product components from the requests of a customer, as well as production/manufacturing process uncertainties such as the difficulty in specifying the time needed for order processing, production and transportation operations with accuracy.

Another study focusing on supply and demand side uncertainties was carried out by Petrovic, Roy, and Petrovic (1998). The authors emphasize the common issue of supply chains that there are uncertainties on both upstream and downstream sides of supply chains. They assert that researchers have mainly focused on demand uncertainty on customer side but the existence of supply side uncertainty due to the deviations from the predefined requests in quantity and quality of raw materials provided by an external supplier cannot be denied.

Researchers put emphasis on the incompetence of companies to know customer demand, price, and manufacturing capacity accurately and on the ruinous effect of performance inefficiencies such as delays due to the lack of robust supply chain designs regarding these uncertainties. Thus, the ways to deal with uncertainty in supply chains are studied. One of the proposed methods for handling the challenges induced by uncertainties is agile manufacturing. An agile company is considered to have the capability to survive and maintain its operations in an uncertain environment where opportunities may come on the scene unexpectedly and vary constantly (Pan & Nagi, 2010).

Wagner and Bode (2008) scrutinize the supply chain risks, their sources and how to manage them. Authors find associations between risk sources and uncertainties. They categorized the risks to five groups which are (1) demand side; (2) supply side; (3) regulatory, legal and bureaucratic; (4) infrastructure; and (5) catastrophic risks. According to authors, one of the sources of demand side risks is the uncertainty in customer demands which results in disruptions in distribution of products to customers since the estimations of the company do not match the actual demand or there is a weak coordination between supply chain partners. Moreover, they assert that administrative, legislative, and regulatory authorities cause uncertainties in terms of sanctions related to supply chain-relevant policies and laws such as trade and transportation laws, which have an impact on the generation and operation of supply chains.

In terms of the strategies to deal with uncertainties, proactive mitigation strategies are proposed in the literature. Lin and Wang (2011) find the reactive approach towards the uncertainties in the sources of supply chain disruptions pessimistic and suggest instead mitigation strategies which can be utilized proactively. In their study, they establish supply chain disruption mitigation strategies and examine a specific supply chain network design while taking the supply disruption and demand uncertainty into account in a build-to-order supply chain. The mitigation strategies they propose consist of postponement with downward substitution, centralized or decentralized stocking and supplier sourcing base. Furthermore, the supply chain network design considered in this study involves an integration of supply-side, manufacturing and demand-side operations so that the overall anticipated operating cost is as small as possible.

In a recent study providing a framework to establish a foundation for organizations to develop decision-support systems and scrutinize the important tradeoffs regarding the uncertainties in the environment the following aspects are highlighted. Despite the fact that firms ideally would pursue both an efficient supply chain and the ability to deploy good forecasts, it results in a fair amount of profit loss. On top of that, uncertainty in demand due to exogenous factors such as state of the economy experiencing unexpected big changes like from a positive outlook to a downturn or abrupt decline, hampers the decisions on how much emphasis and resources should be devoted to either forecasting accuracy or how efficient the supply chain is expected to be (Crnkovic, Tayi, & Ballou, 2008).

A rather elaborate identification of sources of uncertainty is provided by Mahnam et al. (2009). Authors argue that there are three main sources of uncertainty which are: supplier reliability which means its tardiness in delivery and as authors claim it influences the ability of the supply chain to satisfy demand; manufacturing process which involves machine failures and transportation reliability; and customer's demand in terms of quantity and composition. Moreover, authors also indicate that uncertainties can be come across in projections about cost elements of inventory such as backorder costs. It is mentioned that uncertainty is modeled in many studies with the aim to develop inventory strategies by utilizing probability distributions which are based on the analysis of former practices and cases. Nevertheless, authors assert that factors such as market turbulence and diminishing product life time due to the rise of innovation level, data from previous experiences either does not exist or is not dependable (Giannoccaro, Pontrandolfo, & Scozzi, 2003).

Developing a framework which encapsulates the impact of plant location decisions, supply chain uncertainty, and manufacturing practices on a firm's operational competitiveness; Bhatnagar and Sohal (2005) highlight the idea formerly introduced by Levy (1995) that the decision about the location of a plant may increase the supply chain uncertainty in different ways. They shed light on the result of choosing a location in a country where the transport infrastructure or power infrastructure are insufficient. In a country with poor transport infrastructure, supplier uncertainty is considered to be an issue, whereas in a country with poor power infrastructure, production process may be exposed to disruptions and thus process uncertainties arise.

In addition to the sources of uncertainty revealed in the literature, there is a considerable endeavor to find out strategies to manage supply chain uncertainties. In their literature review Eliot et al (2012) categorized the studies focusing on strategies for the management of uncertainty in two groups. The first group involves strategies which aim at reducing uncertainties at the source (e.g. a suitable pricing strategy to reduce demand fluctuation of a product). The second group involves strategies focusing on coping with uncertainty instead of an effort to deal with the sources. This type of strategy mainly concentrates on ways of minimizing the impact of uncertainties by adapting to unexpected situations. In case of a demand fluctuation, advanced forecasting techniques can be developed by the organizations utilizing this strategy in order to reduce the forecasting errors regarding the future demand uncertainties. Thus, there is no change in the source of demand uncertainty but the effect of demand variations are going to be less severe due to more precise projections. Authors scrutinize some approaches as examples of these two strategies. Examples of reducing strategy are: Lean operations, product design, process performance management, a good decision support system, collaboration, shorter planning period, decision policy & procedures, ICT system (e.g. use of protective software), pricing strategy, redesign of chain configuration and/or infrastructure. The coping strategy covers the following approaches: postponement, volume/delivery flexibility, process flexibility, customer flexibility, multiple suppliers, strategic stocks, collaboration, ICT system (e.g. computer based information systems to provide transparency among supply chain partners and faster information flow), lead time management, financial risk management, quantitative techniques (e.g. operations research techniques for forecasting, simulation etc.). Authors make it obvious that flexibility is an important part of the coping strategy.

Sawhney (2006) confirm the above mentioned assertion about the significance of flexibility to deal with uncertainties with these words: "Traditionally, flexibility, in its reactive use, has been viewed as a coping mechanism against uncertainty, in an organization's internal or external environment". In the same study, the term uncertainty in supply chain encapsulates equipment breakdowns, variability in task times, queuing delays, reject/reworks, nonattendance of workers, defective handling of material, demand variations, product mix, and actions of competitors. The author also put emphasis on the entailment that the interaction between flexibility and uncertainty in value chains should be comprehended thoroughly as it is likely that uncertainties are passed along to different entities in the supply chain due to interdependencies between supply chain partners such that a delay in the delivery of a supplier may result in slow down of material flow along the entire chain.

Considering the authors' opinions discussed above, globalization, changes in customer's expectations and needs, and lastly technological developments and innovations constitute the three common sources of uncertainty in business environments recently. Now that the supply chain uncertainty is defined, its sources are introduced, and the methods to deal with uncertainties are mentioned; it is time to introduce the supply chain flexibility which is the main focus of this work and to discuss its role in the supply chain management. Thus, in the following section the origin of supply chain flexibility is taken into consideration and how it is used to cope with uncertainties is scrutinized.

2.2 Concept of Supply Chain Flexibility

As discussed previously, uncertainty can be a huge issue for most supply chains. The adversities to be handled in supply chain management, do not only involve dealing with unexpected and unwanted events, but also embody opportunities to take advantage of. Therefore, organizations strive for more responsive and agile supply chains in order to perceive the sources of uncertainty and how severe that uncertainty could impact the supply chain, and also to respond to the changes whether inside the supply chain (e.g. supplier uncertainty and process uncertainty) or in the environment (e.g. demand uncertainty, economic conditions of countries, and regulatory enforcements like laws). It should be noted that an uncertainty is not necessarily detrimental to value chain activities, but it can also generate opportunities which brings high profits and/or a bigger portion of market share if firms can recognize them promptly and know how to approach properly.

There is a fierce competition in current international customer-driven markets where companies show great endeavor to provide more variety, better service, higher quality, and more reliable/faster delivery which became indispensable parts of competitiveness due to demands of customers today. Researchers highlight the three primary strategies to follow which are low cost, high quality, and advanced responsiveness in terms of the flexibility and timeliness in product delivery (Duclos, Vokurka, & Lummus, 2003). According to the authors, the reason behind the emphasis put on responsiveness is that beginning from 1970s, product and service quality gain interest of buyers on top of low price products which appeared after mass production paradigm emerged. Regarding the tendency towards customized products with shorter life cycles, manufacturers realized that they should focus on reducing the cycle time and handling the tradeoffs between efficiency and flexibility instead of trying to maintain a cost efficient large volume production strategy. Swamidass and Newell (1987) highlight that companies became aware of uncertainties in the environment triggering two mechanims of manufacturing strategy: manufacturing flexibility and role of manufacturing managers in strategic decision making which in turn affect business performance. Saleh, Mark, and Jordan (2009) state their opinion about flexibility with these words: “Flexibility is […] recognized as a critical attribute of a system, a process, or an organization; it is needed in order to cope with uncertainty and change and implies an ability to change and adapt to a range of conditions” (p.307).

In the following subsections, first the origin of supply chain flexibility is scrutinized in order to understand how and under which circumstances the idea of flexibility has emerged in supply chains whereas what kind of role flexibility has considering the different actors in a supply network.

2.2.1 Origin of Supply Chain Flexibility

Lavington (1921) was one of the pioneers who discussed in his/her book the immobility of invested resources and risks associated with it. The author emphasizes that these risks increase with more specialized and/or fixed resources considering the changing environment and the inability to redirect the resources in order to adapt the changes and meet the fluctuations in customer demands. In case of a demand increase the adaptability of machinery will be weak due to immobility of resources. Thus, the organization cannot benefit from opportunities or deal with emergencies (in case of demand decrease) rapidly or do not handle them at all.

Another early study carried out by Stigler (1939) where flexibility was mentioned, discusses the production theory. The author makes a comparison between flexible and non-flexible plants where he demonstrates the difference between these two plant types on a cost curve which is a function of production output. The curve of a flexible plant is rather flat compared to the non-flexible plant which means a flexible plant can be attuned to fluctuations in output without a big cost penalty. However, he also draws attention to the cost of utilizing flexibility with these words: “But flexibility will not be a free good: a plant certain to operate at X units of output will surely have lower costs at that output than a plant that is designed to be passably efficient from X/2 to 2X units per week (pp. 310-311). The specific dimension of flexibility discussed by Stigler was later entitled as ‘volume flexibility’ in manufacturing.

A distinction between flexibility and rigidity for organizations was highlighted by Feibleman and Friend (1945). They define the flexibility as the “capacity of an organization to suffer change without severe disorganization” and refer to rigidity as the lack of this capacity. With this regard, authors make an analogy from the nature as they point out the similarity between a flexible organization and a river whose route and dimensions may be altered without damaging its foundation. A rigid organization however, is similar to a vase which cannot be deformed without shattering.

Regarding the emergence of flexibility concept in the literature, Upton (1995) puts the flexibility concept to the place where quality was 10-15 years ago. According to the author, quality was a vague concept but still obviously crucial, considering its positive impact on competitiveness. Similarly, flexibility is considered as a rather new concept researchers recently began to examine. It has different meanings for different practitioners. While flexibility is perceived as the ability to change or adapt at the plant level, from a marketing perspective a manager may interpret flexibility as the ability and/or cost of shifting from one product to another or widening the range of products overall. From a manufacturing perspective, it can also be seen as a variation in the production volume in order to meet the fluctuations in demand.

Despite the fact that low cost and high speed are considered as the two most important targets of supply chain management, they alone are insufficient for companies which strive for sustainable competitive advantage. Lee (2004) illustrates this with the state of supply chains in US between 1980 and 2000 when excess inventories resulted in price markdowns and thus unsatisfied customer in terms of availability of products although these supply chains became faster during the same period of time. On the contrary, authors point out that some other companies did not experience such an issue since they do not only have cost-efficient and high speed supply chains but they are also agile, adaptable, and aligned. These three aspects constitute the Triple-A Supply Chain model - proposed by the author - which has been referred to in quite a few studies during the last decade.

Agility is described by Lee (2004) as the target to act rapidly according to the variations in external environment such as supply and demand changes and disruptions. Adaptability which is the second ‘A’ in the model is portrayed as the ability to adjust the supply chain according to structural alterations happening in markets in terms of strategic, product related, and technological aspects. The last A in the model represents alignment which denotes the coordination and cooperation of supply chain partners with the same targets such as to meet the demand of final customers.

Each of the three aspects is related with flexibility in different ways. Christopher and Towill (2001) identify agility as a business-wide capability which has influence on organizational structures, information systems, logistics processes and mindsets. They also highlight that flexibility is a crucial property of agile organizations. For example, agility encapsulates both the speed to deliver or receive goods in supply chains and the flexibility which determines the punctuality and the capability to adjust supply chain speed, production volumes, and changing the product mix (Prater, Biehl, & Smith, International supply chain agility - Tradeoffs between flexibility and uncertainty, 2001).

In this regard, Engelhardt-Nowitzki (2012) emphasize that the ability of a company to act rapidly is one of the core competences nowadays considering the unforeseeable markets. To be more concrete, authors assert that the velocity of each partner in a supply chain to make adjustments in manufacturing processes and in flow of supplies according to the speed of environmental shifts such as demand requirement changes is quite significant. If members of a value chain lack this ability, problems may arise due to unreliable delivery, sales loss, inappropriate and ill-timed improvisation, not to mention other inefficiencies.

Adaptability, the second 'A' in the triple-A model is described by Engelhardt-Nowitzki (2012) as "the disposition of a company to structurally transform a supply chain, or a certain part of it, according to changing requirements far from its current operational state". Adaptability and flexibility are related in a manner that supply chains get to solve their problems with multiple ways. Members of a supply chain can increase their adaptability with flexibility in decision making such that - as Chan et al. (2009) stated - "they are not restricted to achieving one goal at a time, but are able to flexibly arrange their activities in order to consider multiple goals concurrently" (p.107). Authors also emphasize that adaptability can be considered as a pro-active approach to achieve a higher performance for supply chains without the permission to share information between partners owing to safety reasons (e.g. a supplier practicing adaptability with an approach to conjecture the inventory information of other supply chain entities) and how flexibility can contribute, if a supplier has a flexible range of delivery quantity pre-determined by a contract between supply chain partners.

Chan and Chan (2010) propose an adaptive coordination strategy between the members of a decentralized (i.e. members cannot access to sensitive information about each other) and multi-product manufacturing supply chain which is exposed to uncertainties related to customer demand, supplier production volume, and the utilization of that volume. While authors mainly compare the impact of two different coordination mechanisms which are flexible- and adaptive coordination, they also point out that supply chain entities become more adaptive if there is no restriction to handle one issue at a time but they rather have the capability to aim at multiple goals at the same time which refers to the presence of flexible options.

As for alignment, Lee (2004) put emphasis on the accessibility of supply chain partners to forecasts, plans, and sales information which is one of the main concerns in supply chain flexibility. One of the dimensions of flexibility which is called spanning flexibility, is related with information dissemination among the entities of supply chain. Zhang et al. (2006) describes the spanning flexibility as rapid and accurate dissemination of information along the partners of supply chain so that knowledge about plans, requirements, and status of participants is shared. By utilizing such information sharing, strategies either to improve supplier performance or satisfaction of customers can be developed. Thus, firms can coordinate their activities and customer-supplier relationships are developed where trust is built among them. Spanning flexibility and all other dimensions of flexibility will be discussed in one of following parts of the paper.

Bernardes and Hanna (2009) propose a hierarchical association between flexibility, agility and responsiveness based on their literature review. As they interpret the results of their literature review, they come up with the idea that flexibility is an ‘ex-ante’ capability, or simply put, a preparation for transformations to adapt to environmental or internal changes due to uncertainties within certain boundaries which are defined beforehand. It is important to note that the main idea is to generate diversity to be able to approach things in different ways. That being said, authors assert that flexibility is not an end but instead a means to reach that end, thus it can be considered as an enabler or potential behavior and not a performance indicator.

Agility, on the other hand, incorporates a property allowing the organization to restructure the existing options for tailoring unforeseen environmental conditions. Moreover, agility does not have pre-defined boundaries or limited number of options to absorb a change in the environment; it rather pertains to a fundamental change in the system in a short time. According to authors, flexibility is a complementary element that supports agility.

Last but not least, responsiveness is described by the authors as the behavior or actions of a system based on the utilization of certain capabilities in order to deal with changes which occur due to stimulants in the environment. In this context, flexibility provides the means to respond to changes as various dimensions of flexibility represent specific internal components of a broad system which can be used to improve the system responsiveness (Matson & McFarlane, 1999). Nevertheless, a system should be able to utilize its flexibilities against disturbances in order to be responsive. In short, the responsiveness is the end to achieve by utilizing a capability to target sources of uncertainty, whereas flexibility is an attribute of the system which is associated with the availability of options.

Since the roots of the flexibility concept and its relation with the three main components of sustainable competitiveness (triple-A) are covered, it is time to focus more on the role of flexibility in supply chain management.

3. A FRAMEWORK OF FLEXIBILITY RESEARCH TRENDS

3.1 Definition and Categorization of Supply Chain Flexibility

This section of the paper provides a literature review on supply chain flexibility regarding the publications from the last three decades. First, several definitions of flexibility provided by many authors during this 30-year period are discussed in different contexts such as manufacturing, logistics, and general supply chain management. Additionally, there are a lot of studies where supply chain flexibility is categorized in several dimensions, thus various flexibility taxonomies are scrutinized. Last but not least, some measurement methodologies for the valuation of different flexibility dimensions will be reviewed.

3.1.1 Definitions of Flexibility Emerged During the Last Three Decades

Upton (1995) identifies flexibility as a way to obtain competitive advantage in new forms since there is a consensus among industries that keeping costs low and providing high quality products are not sufficient for success considering the fierce, low-cost competition between companies. In this regard, the author also assert that a flexible manufacturer aims at quick response to changes in customer orders, achievability of a wide range of products, or introduction of brand new products without much effort.

The reason why there are lots of different descriptions of flexibility in the literature is that researchers cannot agree on a single definition. Shewchuk and Moodie (1997) draw attention to the multi-dimensional nature of flexibility and claims that it is considered in the literature as a physical feature, an element of decision making, an economic indicator, and also a strategic asset.

In manufacturing context, Viswanadham and Raghavan (1997) consider flexibility among the performance measures (i.e. lead time, customer service, dependability, cost, quality, and flexibility) of business processes. In order to consider a business process flexible, this business process should be able to manage or respond to a change quickly, cost-effectively and without sacrificing quality or performance. Accordingly, they define flexibility with these words: “Ability to meet customer requirements under various environmental uncertainties in various dimensions such as delivery time, schedules, design and demand changes etc” (p.149). Authors also introduce the common definition they came across during their literature survey which is: “a system’s capability to cope effectively with a wide range of environmental changes and internal variations without deterioration in system performance in terms of cost, quality, lead time and on-time delivery”.

In a study focusing on the development of a dynamic equilibrium model to counterpoise the capabilities and requirements or the manufacturing flexibility and the external uncertainty; Newman, Hanna and Maffei (1993) claim that manufacturing flexibility is the most evident solution for external uncertainty and they define the flexibility in manufacturing context as the adaptability of a manufacturing system to the variations in environmental circumstances and changes in process requirements.

Aside from defining the flexibility, some researchers shed light on the ambiguity of the concept of supply chain flexibility (De Toni & Tonchia, 1998). Authors attribute the vagueness of flexibility to its multidimensionality and thus the presence of different perspectives to describe it. In this regard, they also assert that there are different view angles from which researchers focus one or more of the following dimensions: on the endogenous (manufacturing flexibility) or exogenous side (the perception of customer) of the flexibility; limits of flexible capabilities in manufacturing system (supervision of supplier’s flexibility); performance of flexibility in terms of its potential benefits or current effectiveness; and the reactive adaptability or proactive alteration capability regarding the uncertainties.

Based on their literature review, De Toni and Tonchia (1998) emphasize that the definitions of manufacturing flexibility in the literature either address to the context of the firm or to other disciplines where more general definitions of flexibility exist. They distinguish three different ways to define flexibility first of which views flexibility as a representative feature of the relation between a system and its environment such that flexibility is assumed to filtrate the effects of external disruptions on the system which are symbolized by their scale, frequency, authenticity, and exactness. The second definition model taken from the study of Mariotti (1995) refers to the ‘degree of homeostatic control’ which means the internal stability; and ‘dynamic efficiency’ of a system. What is meant by this is a system which is able to measure, control and manage in order to maintain a stable internal state during external variations. According to the third and last definition model flexibility is simply considered as the capability to adapt or change. The adaptability proposed in this definition is evaluated by the range of alternative states to obtain and also the time requirement of adaptation. These two aspects which are mentioned in the literature quite often and called ‘range and response’ of flexibility will be scrutinized in more detail throughout the following parts of this paper.

Manufacturing flexibility is considered by researchers as a significant source of competitive superiority whereas hard to acquire and manage (Kathuria R. , 1998). In terms of managing manufacturing flexibility Gustavsson (1988) point out that flexibility is not a commodity to be simply paid for and utilized immediately. Instead, it has to be planned and managed attentively. According to Kathuria (1998), who discusses the relevance of 14 managerial practices in order to increase flexibility, manufacturing flexibility encapsulates a skill set for a manufacturing plant that includes launching new designs and products in short time, tuning the capacity according to the requirement quickly, product customization, dealing with the alterations in product mix and changes in the timetable of deliveries rapidly. Details about this study will be discussed later in this paper.

Supply chains, where more than one product is processed, both the capacity of agents and the utilization of this capacity are decisive in terms of dealing with uncertainty in demand. Considering this matter, Tomlin discusses (Tomlin, 1999) the allocation of resources such that they are either devoted to one product or can be utilized in a common process for multiple products. In latter case this resource is considered as flexible. Thus, the author describes flexibility as an enabler to handle demand uncertainty since the distribution of resource capacity can be performed taking the existing demand into account. In other words, the author asserts that a flexibility decision is about determining the role of a resource on processing different products.

Koste and Malhotra (1999) draw the attention to the changes in customer expectations in last decades. According to them, customers demand a wide variety of high quality products and services for low price. Therefore, organizations are forced to find out new perspectives and means to meet these needs without falling behind their rivals in terms of both time and cost effectiveness in order to stay competitive. Emphasizing the multidimensionality of flexibility in manufacturing context, authors mention that flexibility can either be reactive, in which case endogenous and exogenous uncertainties are handled; or it can also be proactive such that the organization manages to address market uncertainties from a completely different perspective or to orient the expectations of customers from a specific industry.

In a literature review about manufacturing flexibility, Beach et al. (2000) identify manufacturing flexibility as a key strategic objective of manufacturing companies. While manufacturing and engineering management play a significant role in reaching corporate goals, manufacturing flexibility is regarded as a part of operational management and thus is related with process technology. Considering this fact, authors put forward the assertion that manufacturing flexibility has mostly a reactive nature since process technologies are adapted in response to uncertainties. Moreover, being under the scope of operational management, the development of manufacturing flexibility should be encouraged in the decision making process on the strategic as well as operational level. In order to do this however, the acquirement and management of manufacturing flexibility should be grasped thoroughly by the developers of flexible capabilities.

One of the studies focusing on routing flexibility in manufacturing context proposes a graph-based model to illustrate different manufacturing operation sequences and to contribute to planning of manufacturing operations and machines. In this study, Borenstein (2000) assess flexibility as a significant attribute of current manufacturing systems similar to quality and cost which have been considered as main concepts of manufacturing. The reason behind this assertion is that flexibility provides the opportunity to be more competitive in dynamic markets. Hence, organizations invest millions of dollars in flexible manufacturing technologies which are referred to as the Flexible Manufacturing Systems (FMS) in the literature.

D’Souza and Williams (2000) endorse the idea of Olhager (1993) that researchers agree on primary grounds of competition which are cost, quality and responsiveness. As mentioned earlier, responsiveness is closely related with flexibility in addition to speed. The ability to respond to changes in competitive environment properly is a crucial objective to be successful in global markets. Based on this fact, authors emphasize the necessity of an in depth comprehension on the flexibility construct. While cost and quality are rather simple concepts to understand since they can be predefined, measured and compared with predefined standards. However, flexibility is not so simple to be determined. In their study, authors include a number of definitions proposed in the literature one of which belongs to Olhager (1993): “In the short run, flexibility means the ability to adapt to changing conditions using the existing set and amount of resources. In the long run, it measures the ability to introduce new products, new resources and production methods, and to integrate these into the existing production system”. They recognize the common idea in different definitions of manufacturing flexibility as they claim manufacturing flexibility is viewed as the ability of the manufacturing function to respond to alterations in its surroundings without sacrificing too much from firm performance. Moreover, authors also identify that many researchers mention the time, cost and required effort to achieve the adjustments to environmental changes.

Vokurka and O'Leary-Kelly (2000) point out that in order to handle the competitive pressures companies develop some improvement programs such as just-in-time manufacturing, mass customization techniques, time-based methods of competition, agile manufacturing, and manufacturing flexibility. In other words, authors emphasize the assertion of Hayes and Wheelwright (1984) that manufacturing flexibility is among the primary elements of the competitive strategy of a business. Furthermore, authors illustrate the fact that manufacturing flexibility attributes not only to a single variable but rather to a general class of variables. In other words, manufacturing flexibility has lots of different dimensions which is the topic in following section of the paper.

From the perspective of changeover performance, McIntosh et al. (2001) define flexibility as "an ability to commence economic manufacture of any quantity of a given product, from a specified product range, at any chosen time, by any chosen personnel" (p.21). Authors also mention that this definition considers an ideal case which means it is possible to manufacture batch sizes of one unit. The definition they provide is pertinent to designate measurable criteria such that practitioners can keep track of the present changeover performance. Furthermore, authors underline the distinction between environmental change and market change while describing flexibility as an ability to cope with either of these changes. Similar to the dimensions of supply chain uncertainty described in preceding section of the paper, author describe environmental change as being not directly related with customer demands but influenced by variables such as macro-economic conditions, disruption in labor, technological changes or supplier bankruptcy.

As mentioned before in the discussion about the origins of supply chain flexibility, Prater et al. (2001) highlight two main components of agility which are speed and flexibility. Based on the understanding of supply chain agility as the ability to excel in a volatile business environment which shows unforeseeable changes, by reciprocating these changes in a timely manner; authors define flexibility as the adjustability level of time required to ship or receive goods while speed stands simply for a measure of time to ship or receive material/goods. In this respect, they scrutinize flexibility in three main attributes of production which are sourcing flexibility, manufacturing flexibility, and delivery flexibility.

In their study about the sources of volume flexibility and their effects on firm's performance, Jack and Raturi (2002) shed light on a common description for flexibility in studies they came across during their literature review. According to that, flexibility is portrayed as a response to uncertainty in the business environment. Aside from this description, they point out an argument between researchers about the vagueness of manufacturing flexibility sources which is grounded on the fact that the sources of manufacturing flexibility embodies capabilities which may never utilized. Thus authors refer to Gerwin (1993) who refuses to describe flexibility solely as an adaptive response and proposes a distinction between required, potential, and actual flexibilities. Required flexibility denotes the strategic designation of the type and degree of that specific type of flexibility, whereas potential flexibility can be evaluated considering the present capabilities of the plant for appropriate external conditions. Lastly, the actual flexibility is based on the implementation of these capabilities and the experienced results.

There has been an argument in the literature about whether manufacturing flexibility should be considered as a competitive priority which Olhager and West (2002) discuss in their study about the integration of flexibility into Quality Function Deployment (QFD) approach. They propose an analogy between productivity and flexibility, and assert that productivity does not represent a competitive priority instead it is considered as an enabler to attain cost efficiency and thus low product price. Since both flexibility and productivity are included among properties of manufacturing systems, flexibility is meant to be approached the same way which as a contributing factor to competitive priorities. This assertion stems from the idea of Slack (1990) who claims that flexibility is a second-order competitive attribute due to the fact that it is not flexibility which wins the orders, but other attributes such as delivery time or reliability instead.

Barad and Sapir (2003) mention the lack of research on flexibility in the context of distribution and marketing. Aside from a broad description of flexibility as an element of a system technology to be implemented in dealing with the variety of environmental requirements; authors put emphasis on the fact that time-based strategies have an impact on the attitude of mind in logistics channels. Thus, they elicit the consideration of flexibility as “a powerful system ingredient that enables stable performances under changing conditions” (p.156). They also argue that progress on flexibility as a strategic objective has a positive influence on system responsiveness to changes.

Bertrand (2003) highlights the emergence of flexibility as a recent performance indicator which arose during the last two decades on top of cost, quality and reliability for operational systems. The author draws attention to the change in markets of most sectors of industry since 1980s in terms of inclination in competition towards product differentiation and innovation as a result of saturated markets. Due to this fact, both the amount of product variants and the rate of new product introduction became higher. Based on these assertions, the author scrutinizes the three main sources of flexibility in manufacturing which are: technological variety enabling a variety of products to be manufactured, available production capacity determining the volume of products to be delivered, and the timing/frequency of production which is related with work-in-process inventory and duration of lead times and constrained by economical issues caused by change-over and set-up costs.

In an effort to broaden the perspective on flexibility from the context of manufacturing to supply chain in general, Duclos, Vokurka and Lummus (2003) assert that the flexibility literature has not taken the cross-functional and cross-business structure of supply chain management into account, prior to their study. Their argument implies that flexibility should incorporate dimensions which involve all entities in this supply chain so as to satisfy customer expectations if the supply chain flexibility is supposed to be defined as a whole. Thus, in order to implement flexibility in supply chain management, flexibility is required both between the departments of an individual firm and between partners of a supply chain such as suppliers, carriers, third-party companies (e.g. third party logistics providers) and information systems providers.

Zhang, Vonderembse and Lim (2003) summarize the common notion in the literature on flexibility, describing it as an indispensible strategic requirement allowing firms to handle uncertainty. They concur with the assertion of Duclos et al (2003) about the necessity of cross-functional and cross-company efforts to avert the bottlenecks, raise responsiveness, and achieve a performance level such that a competitive advantage is obtained, while ensuring short delivery times for high-quality products which is the type of flexibility valued by the customer and is called ‘value chain flexibility’. The value chain flexibility mentioned by the authors includes the introduction of new products quickly, contribution to rapid product customization, reduction of lead times, performance improvement for suppliers, decrease in inventory levels, and timely deliveries of products.

Kara and Kayis (2004) see flexibility as the ability of an organization to perform adaptations in production to new circumstances and to maintain effective functioning in the face of imperative adaptations due to changes in the environment. According to them, the need for flexibility arises in order to handle two variables which are intrinsic uncertainties and variability of outputs. Moreover, the multi-dimensional nature of flexibility is emphasized in the same study and it is attributed to the fact that it can be perceived from different angles depending on the way to attain it and the type of uncertainty to deal with.

In an empirical study Karuppan and Ganster (2004) bring together two operational strategy theories namely: machine and labor flexibility, and scrutinize their effect on the relationship between mix flexibility and competitive priorities. An important assertion in their study is that there are authors emphasizing that flexibility, unlike quality and cost, cannot be managed formally; although the importance of flexibility as a strategic advantage is commonly acknowledged in the literature. Referring to Cox (1989) and Zammuto and O'Connor (1992), authors discuss that there is two issues leading to this problem which are lack of empirical research and pertinent to this issue also lack of measurability. Thus, flexibility is still considered to be an obscure concept for manufacturers; besides its measurement can be done specific to an industry or even to a particular case.

Another study encapsulating the appraisal of how manufacturing flexibility is beneficial at enterprise-level where authors point out the relevance of manufacturing flexibility in the face of demand uncertainty since flexibility enables manufacturing facilities to change the production plans cost-effectively. Thus, flexibility has a potential value with regard to long-term capacity organization (Chandra, Mark, & Grabis, 2005).

Considering the manufacturing organization as a part of the complete supply-distribution system which consists of acquisition, processing and distribution stages, Kayis and Kara (2005) describe flexibility in the context of a supply-distribution system: "flexibility at the acquisition-processing-distribution stages must be achieved to devise the best strategy for obtaining the right and desired output, satisfying the quick design changes, broader product line, fluctuating orders, multiple quality levels, quicker deliveries, and multiple price levels" (p.734). In order to achieve flexibility in each of the three stages, authors propose companies to utilize flexibility mechanisms not only within these stages but also in conjunction with the interactions between them.

As most of the researchers emphasize, determination of production volumes, customization according to customer expectations, and ensuring a good product mix became the most significant challenges in today's volatile markets. The need for flexibility becomes obvious to remain competitive and profitable at the same time. With respect to this matter, Llorens et al. (2005) delineate the complementary role of flexibility towards productivity which is considered as a fundamental attribute of manufacturing system. Thus, authors assert that flexibility should be regarded as a fundamental property, too. Furthermore, authors express the consensus in literature about the fact that flexibility and productivity are both required as much and companies should not compromise one of them for the sake of the other.

Aside from the studies where flexibility is introduced in the context of manufacturing, some authors Sanchez and Perez (2005) indicate the lack of a comprehensive view of flexibility and elucidates that researchers focus their attention more on machine flexibility and implementation of technology instead of scrutinizing total system flexibility. Regarding this comprehensive view of total system flexibility, authors provide a description of supply chain flexibility: “Supply chain flexibility is defined to encompass […] flexibility dimensions that directly impact a firm’s customers and are the shared responsibility of two or more functions along the supply chain, whether internal (marketing, manufacturing) or external (suppliers, channel members) to the firm” (p.682).

Some studies provide definitions which recognize the strategic role of manufacturing flexibility considering aspects related to customer requirements and marketing. Zhang et al. (2002) describe flexibility as being able to satisfy the wide range of customer expectations without enduring unnecessary costs, time loss, disruptions or sacrificing performance. Kumar et al. (2006) referring to Hyun and Ahn (1992), take this definition one step further and assert that flexibility as a strategic asset represents the ability of a company to change its positioning in the market in terms of product mix, to alter future plans, or to repeal the current marketing strategy if its customer base is not as attractive as before. Furthermore, author proposes a transition from manufacturing flexibility to supply chain flexibility, also addressed as total system flexibility or the flexibility which provides value to end customer.

3.1.2 Flexibility Taxonomies from Last Three Decades

Flexibility, still a vague concept for many practitioners and academics, brings along quite a few concerns which stem from unanswered questions about its fundamentals. Researchers cannot concur neither on its definition nor on its implementation which means fundamental aspects like: why it is a requirement, how it can be implemented and measured are not comprehended clearly. Oke (2005) relates the reason behind this ambiguity to the multi-faceted nature of flexibility and highlight the issue that it is not an easy task to obtain a proper conceptualization and understanding for flexibility which is important for practitioners soliciting guidance from academics. Considering the multi-dimensional nature of flexibility, authors have been trying to classify the dimensions constituting supply chain flexibility. In this part of the dissertation, several taxonomies of flexibility are introduced first, and their commonalities/discrepancies are discussed in detail later.

As Da Silveira (2006) mentioned, flexibility research has gained a considerable popularity in 1990s. The classification of flexibility is the aspect which drew most of the attention. There have been several types of categorization from different perspectives such as organizational, hierarchical, temporal or objective based criteria. Da Silveira (2006) scrutinizes different flexibility classifications in two groups first of which embodies comprehensive taxonomies where categories such as machine, material, production, volume, and routing flexibilities have been taken into consideration and every category is described by the ability to adapt in terms of the aspect mentioned in that flexibility type (e.g. adaptation in raw material requirements or changing production capacity). The second group includes categories which are generic clusters of more specific types of flexibility. In other words, taxonomies in the second group commonly consider three major types of flexibility which are volume (the ability to operate in different production capacities), mix (the ability to shift the product variety for a production period), and product flexibility (the ability to introduce new designs or modify existing products).

As mentioned in the last paragraph, there is hierarchical taxonomies of flexibility. A good example for this approach is demonstrated by Barad and Sapir (2003) who divided flexibility categories to three hierarchical levels: basic, system and aggregate. Basic flexibility types are: machine, material handling, and transportation network flexibility. System level flexibilities correspond to combinations of basic level flexibilities such as routing flexibility which benefits from versatility of machines, flexible material handling, and also transporting network flexibility in order to process a part by using alternative machines. Among the aggregate flexibilities, there are marketing (time/cost for introducing a new product) and expansion flexibility (ease of altering production capacity).

From a supply chain perspective, Kumar et al (2006) emphasize that all activities in a supply chain should contribute to the final goal of satisfied end customers. Therefore, authors recommend that this phenomenon should be kept in mind while establishing supply chain flexibility taxonomy and they propose five different types of supply chain flexibility by adopting an integrative, customer-oriented view. The five categories of supply chain flexibility are: Product flexibility (the ability of supply chain partners to introduce more customized products or modify existing ones in a cost-effective and timely manner), sourcing flexibility (the ability of supply chain entities to regulate the supply level without additional costs or delays in product delivery), delivery flexibility (the ability of the logistics system to manage the transportation of raw materials, components and final products between the partners cost-effectively and without causing additional delays), new product flexibility (the collaboration capability of entities to introduce entirely new products quickly with a cost-effective way), responsive flexibility (the capability of the entire chain to respond to the market changes in a short notice and in a cost-effective way).

Naim et al (2006) gather different categorizations from the literature and propose two main groups of flexibility types. Machine, process, operation, capacity, and routing flexibility compose the internal flexibilities; while product (or new product/changeover), mix (in terms of product and materials), volume, and delivery flexibilities constitute the external ones. This distinction is based on the difference between internal elements of business which characterize the behavior of the system and external elements which affect the opinions of customers and determine the perceived performance of the company. Moreover, authors focus the types of flexibility in logistics context. With the same taxonomy approach, they identify nine internal types of transport flexibility: mode (number of different transport modes available), fleet (capability of providing different vehicles for different products), vehicle (ability to adapt vehicles for different types of products or to provide various loading facilities), node (planning and implementation of new transport nodes), link (creating new links between nodes), temporal (the capability of determining sequence of infrastructure investment and the coordination requirement between users caused by this infrastructure), capacity (responsiveness to demand changes in traffic of goods), routing (adaptability to various routes), and communication (competence to manage a variety of information types).

One of the studies providing the fundamentals of many other flexibility taxonomies belongs to Sethi and Sethi (1990), who propose three main clusters of flexibility types. The first group is called ‘component or basic flexibilities’ and encapsulates the flexibility of important attributes of the system such as machine, material handling and operation flexibilities. Process, routing, product, volume and expansion flexibilities carve out the second group which is called ‘system flexibilities’. The last group includes program, production and market flexibility, and it is called ‘aggregate flexibilities’.

As discussed earlier, flexibility is an important strategic asset to deal with supply chain uncertainties. Nevertheless, it is also important to recognize which type of flexibility is relevant for different types of uncertainties. Gerwin (1993) discusses six different types of flexibility and elucidates the utilization of each different flexibility dimension regarding various uncertainties. These seven flexibility dimensions the author focuses on are: mix, changeover, modification, volume, rerouting, and material flexibility. In addition, flexibility responsiveness is discussed considering the aforementioned dimensions.

According to the author, mix flexibility is useful for achieving a diverse product range which is the main issue regarding the ambiguity about customer preferences. With the implementation of mix flexibility, firms become capable of processing a range of products or product variants by having low setup times. This approach is an alternative of focused manufacturing which requires to be specialized on certain tasks and count on the cost reduction. Changeover flexibility is described as being able to replace new products with the existing ones rapidly. It is relevant for industries where product life cycles are getting shorter and there is time challenge for introducing new products to the market. In order to respond to specific customer preferences for certain products, firms should enhance modification flexibility. Volume flexibility however, becomes prominent when the amount of total customer demand in the market is uncertain and a firm still wants to maintain its market share in a volatile demand. In case of long machine downtimes and process disruptions, the capability to reroute the manufacturing processes (e.g. shifting the sequence of machines) provides the flexibility to meet delivery due dates. Another source of uncertainty is the manufacturing input provided by suppliers. If there are disruptions or defects in raw materials, the same product quality cannot be offered if the company does not have material flexibility. Last but not least, the author emphasizes that companies should also deploy strategic adaptability to be able to adjust their objectives to changing circumstances in a short time. Thus, companies should not only implement the corresponding dimension of flexibility but they also need to take heed of flexibility responsiveness.

From the perspective of strategic options to deal with product competition, Sanchez (1995) introduces the general concept ‘strategic flexibility’ and adopts a collective approach on several flexibility options which support new product development endeavor of a company. The flexibility dimensions are grouped in two main categories: resource flexibility and coordination flexibility. The idea behind this approach is that firms are supposed to find and attain flexible resources and coordinate the flexibilities inherent in these resources. Strategic flexibility (a collective perspective on many flexibility capabilities), is established on two fundamental aspects one of which is the possession of resources that provide alternative strategic routes to follow while responding to changes in customer preferences considering the product specifications, and the other is the coordination capability on alternative uses/flexibilities peculiar to available resources to obtain maximum gain from them. According to this categorization, the first group ‘resource flexibility’ includes technology flexibility, product development flexibility, production flexibility, distribution and marketing flexibility, and feasible product strategies; whereas the second group ‘coordination flexibility’ represents such aspects like: flexibility to redefine the firm’s product strategy, flexibility to restructure the firm’s resource chain, and flexibility to redeploy the restructured chain of resources.

Viswanadham and Raghavan (1997) argue that there are four basic flexibility categories namely: mix, volume, new product, and delivery time flexibility. Authors emphasize that different competitive circumstances require different types of flexibility. For example, they describe mix flexibility as the capability of producing different products concurrently and highlight its relevance in a situation where a company is not only concentrated on one product line but is also able to compete in a number of different market segments. Secondly, volume flexibility refers to the ability to adjust the production level and also to change the composition of product mix quickly which becomes crucial against volatility in demand. New product flexibility however, represents having the possibility to make changes in product mix by introducing new products or removing existing ones which is important when the market is technology intensive. Lastly, delivery time flexibility is defined as the ability to decrease the cycle (order-to-delivery) time.

An important study which sheds light on different methods used in the literature to classify flexibility was performed by De Toni and Tonchia (1998). Authors categorize the taxonomy logics in flexibility research to four groups. First of them is horizontal classification which focuses on setting boundaries to the analysis and encapsulates either the stages of manufacturing or in a broader view, the phases comprising the ‘value chain’. Moreover, flexibility dimensions are scrutinized in the context of upstream (design and procurement) or downstream activities (distribution and customer service). Similarly, this classification logic also provides a distinction between internal (product design, production flexibility) and external flexibility (distribution and purchasing flexibilities). Vertical/hierarchical classification is the second on their list of classification logics. In this type of classification, flexibility dimensions are divided into certain layers such as flexibilities at micro level which corresponds to resources of a system or flexibilities at macro level which is regarded as aggregate flexibilities related to the whole system. The third logic is called temporal classification which takes the time span into account during which a specific type of flexibility is effective. For example, Merchant (1983) (cited in De Toni and Tonchia (1998)) proposes seven different flexibility types starting with the ‘instantaneous flexibility’ which stands for choosing the most adequate work center to perform the required operation during the manufacturing cycle of a component and closing with the 'long-term flexibility' which represents the ability to adapt the system to new product types or a range of components. Another classification logic considers the object of variation. It is the most common type of classification in flexibility literature. In this classification rationale, authors address uncertainty sources and categorize flexible capabilities in terms of the objects which show variations and require a certain flexibility dimension to be handled. As the simplest example, De Toni and Tonchia (1998) illustrate the categorization proposed by Skinner (1985): process flexibility (to deal with variation in set-up times), product flexibility (to provide a product variety) and volume flexibility (considering the possibility that customers could vary the order amount). Last but not least, there are classifications which follow a mix of the aforementioned classification logics (e.g. temporal and by the object of variation).

With a hierarchical perspective on flexibility dimensions, Sanchez and Perez (2005) provide a bottom-up categorization of flexibility dimensions which they divide into three levels: aggregate, system, and basic flexibilities where aggregate level consists of launch, sourcing, response and access; system level includes delivery, transshipment, and postponement; and basic level encorporate product, volume, and routing flexibilities. Logistics and process capabilities establish a connection between these levels as illustrated in Figure 3.1.

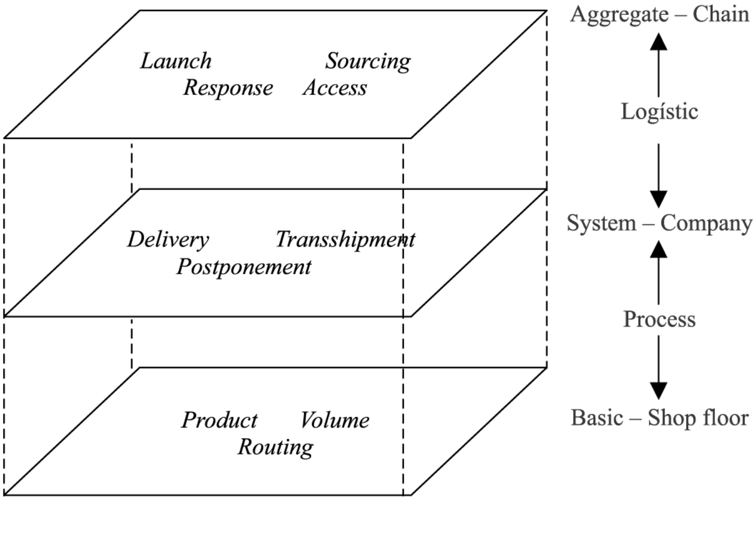

Figure 3.1 – Supply chain flexibility dimensions (Sanchez & Perez, 2005)

Parker and Wirth (1999) illustrate eight flexibility dimensions in manufacturing context: machine, process, product, routing, volume, expansion, operation, and production flexibility. Machine flexibility represents the range of different operations to be provided by the same machine without deterring the process while switching to another operation. Process flexibility refers to the ability to switch manufacturing from one product to another within shortest time possible. Product flexibility is described as being capable of adjusting the mix of current products manufactured. Routing flexibility is the ability to make changes in the route of a part following certain manufacturing process steps. Volume flexibility defines the boundaries of production volume where profitability is maintained. Expansion flexibility is related to the possibility and ease of increasing capacity in need of larger volumes. Operation flexibility focuses on swapping the sequence of manufacturing operations and finally, production flexibility encompasses the ability to produce different part types which incorporates seven other flexibility dimensions.

Aside from the most common dimensions of manufacturing flexibility such as machine, process, product, routing, volume, and expansion, Gupta and Goyal* (1989) introduce ‘process sequence flexibility’ which is described as “the ability to interchange the ordering of several operations for each part type” (p.121).

In addition to different taxonomies, researchers also focused on the elements of flexibility dimensions described in those taxonomies. Koste and Malhotra (1999) discuss four common elements for evaluating all flexibility dimensions. These elements are: range-number (the amount of options in terms of operations, products etc.), range-heterogeneity (differences between the available options), mobility (monetary or temporal utilizing these options), and uniformity (the measure of how close the outcomes of alternative options are). Authors also add four new dimensions to the taxonomy of Parker and Wirth (1999). First of them is labor flexibility which corresponds to the number (range-number element) and diversity (range-heterogeneity element) of operations a worker is capable of realizing. Regarding the other two elements of this flexibility dimension, the time requirement for a worker to be transferred to a different operation represents the mobility element and uniformity represents how close the performance of the same worker is for the tasks he/she is assigned to. The second dimension they add is material handling flexibility which is described as having alternative routes parts/materials may follow between process hubs. The third dimension is new product flexibility defined as the ability to introduce a diversity of new and innovative products. The last dimension, modification flexibility, added by the authors corresponds to making alterations in product specifications which does not affect the fundamental functions of that modified product, in order to meet particular customer needs. The elements or attributes of flexibility are particularly discussed in the following part of the paper, where measurement of several flexibility dimensions is scrutinized.

D’Souza and Williams (2000) predicate their flexibility taxonomy on Gerwin’s (1993) classification. Authors mention four dimensions of flexibility: volume, variety, process, and materials handling. They preserve the volume flexibility dimension same as once described by Gerwin (1993) since they conceive that it is a crucial primary flexibility dimension. Moreover, they recognize that material flexibility actually embodies two different aspects. First of these aspects is the ability of the system to process the materials not matching the predefined specifications and the material handling flexibility of the system in general. The latter aspect was not mentioned by Gerwin (1993) but discussed in the study of Koste and Malhotra (1999) and authors predict that it will be an area of research interest. Aside from that, authors combine mix and modification flexibilities under ‘variety flexibility’ which is described by the authors as “the ability of the manufacturing system to produce a number of different products and to introduce new products” (p.580). Mix and modification flexibilities play a complementary role in this dimension. Moreover, flexibility dimensions representing characteristics of manufacturing process like changeover and rerouting flexibility, are encapsulated within ‘process flexibility’ which is the fourth and last dimension of D’Souza and Williams’ (2000) taxonomy and refers to the ability to adapt to changes in production timetable or disruptions like machine malfunction. The four flexibility dimensions are divided to two categories in terms of their drivers. Volume and variety flexibility belong to externally-driven flexibilities, while process and materials handling flexibilities are considered as internally-driven flexibility dimensions.

In a broad multi-disciplinary literature review about flexibility and flexible engineering systems, Saleh et al. (2009) work on establishing a basis for quantitative assessment of flexibility while approaching the concept as an engineering attribute. In their study authors address flexibility in different contexts of production. They discuss about four types of flexibility in manufacturing systems which are volume, routing, expansion, and product mix flexibility while they propose two different dimensions of flexibility in the context of engineering design which are flexibility in the design process and flexibility of a design itself (or flexible systems). Flexibility in the design process is described as a method of handling uncertainty in requirement specifications in the initial phases of design process in order to obtain a design as close to customer expectations as possible, insofar the resources of the developer allow to get. Flexibility of a design (or flexible systems) represents a feature of the system such that additional design parameters, design margins and specific design architecture such as platform or modular architectures, are embedded in system’s design. In addition, authors emphasize that these attributes embedded in the system are not supposed to bring immediate benefits, however they provide the capability to modify the system provided that design requirements can change in the future.

From a supply chain perspective, Vickery et al (1999) identify five flexibility dimensions which are important in terms of satisfying the needs of end customer. First of them is product/customization flexibility and represents a value-adding element of the system such that it enables companies to overcome off-spec customer orders, special customer requests and also to manufacture highly customized products in terms of many different characteristics (color, size etc.). For this type of flexibility authors highlight the importance of cooperation between several functions of a company such as product design and development, engineering, and marketing. The remaining types of flexibility mentioned in their taxonomy are volume, launch, access flexibility and responsiveness to target markets. Among these flexibility dimensions, launch and access flexibility are concepts which are not that common in flexibility research compared to the ones discussed above in this section of the paper. Launch flexibility is described as an enabler to achieve the competitive advantages of being a pioneer in a market such as large market share or high profitability by integrating several value activities in the supply chain and thus being able to introduce novel products or cater for varieties of existing products. Access flexibility refers to the width and depth of distribution coverage of a supply chain. This aspect is important for supply chains to provide product availability in a wide area.

Duclos et al (2003) shed light on the issue that cross-functional and cross-business nature of supply chain management is not covered properly in flexibility literature. Thus, flexibility in the supply chain covers the dimensions required by all supply chain partners to satisfy demands of customers. From this point of view, authors identify six components of supply chain flexibility: (1) Operations system flexibility, which represents the ability to organize both assets and operations in order to respond to changes in customer trends in terms of product specifications, volume and mix of products; (2) Market flexibility, which refers to the ability to deploy mass-customization and establish close relationships with customers; (3) Logistics flexibility, which is described as the capability of performing product deliveries cost-effectively while customer and supplier locations change; (4) Supply flexibility, which is defined as the ability to restructure the supply chain such that supply of components or material is in accordance with customer demand; (5) Organizational flexibility, which refers to the ability to line up the skills of workers to the needs of supply chain to achieve the final goal of customer satisfaction; and (6) Information systems flexibility considered as being able to adjust the information system structure to cover the information needs emerge from changing customer demand.

As one may observe, the majority of work in flexibility research focus on the interior of a firm such that most of the flexibility dimensions proposed in the literature, correspond to internal functions of a company such as manufacturing. From a broad perspective over the flexibility literature, Stevenson and Spring (2007) observe that there are three important principles which are viable in supply chain context, to be extracted from several classifications of flexibility: multi-dimensionality, dependence on environmental conditions (i.e. particular conditions raise the importance of particular flexibility types), and dispensability of demonstrating flexibility. Furthermore, authors build a bridge between internal flexibility dimensions and supply chain flexibilities as they make analogies between the components of manufacturing and supply chain entities. They remark that internal attributes of flexibility can be related to external ones beyond the boundaries of the firm: “This is a logical step as many of the components of flexibility identified at the shop floor, plant or firm-level can be related to the supply chain (and network) level. For example, routing flexibility on the shop floor is comparable to the advantages of dual sourcing policies in the supply chain. Similarly, work centers on the shop floor can be compared to (external) suppliers and customers in the supply chain.”

Stevenson and Spring (2007) infer from a number of different flexibility taxonomies and propose a novel description of a flexible supply chain. With regard to that, a flexible supply chain incorporates five elements of flexibility: robust network (or rigid) flexibility, re-configuration flexibility, active flexibility, dormant (or potential) flexibility, and network alignment. Robust network flexibility corresponds to the diversity of circumstances the supply chain can handle; re-configuration flexibility means the ease of re-structuring or adapting the supply chain; active flexibility addresses the possibility of cooperating properly with partners in the chain in the face of environmental variations which embodies both reactive and proactive measures; dormant flexibility refers to the property of flexibility that it is considered as a contingent resource and it is not necessary to demonstrate this capability; last but not least, network alignment represents the capability to give more weight to the common goal of supply chain instead of individual objectives of supply chain entities.

In a study about the impact of operations flexibility in supply chains deploying build-to-order initiatives, six supply chain flexibility dimensions are proposed. First of them is called operations system flexibility which is described as the ability to regulate operations and assets in order to respond to arising trends in customer demands/expectations at all nodes of supply chain. The second dimension denotes market flexibility corresponding to the capability to utilize mass customization, design new and modify existing products. Third dimension is called logistics flexibility representing receive and deliverability of materials and products while the location of suppliers and customers may change due to globalization. Fourth flexibility category is supply flexibility that is related with restructuring the supply chain in order to align the specifications of supply with customer demand. Fifth flexibility dimension represents the ability to bring worker skills in line with the needs of the supply chain and from there to achieve customer demand properties. Last dimension of flexibility mention in this study corresponds to information systems flexibility defined as the adjustability of information system architecture considering the varying information needs of the firm as a result of uncertain customer demand (Coronado M. & Lyons, 2007).

On top of the most common types of flexibility addressed in the literature such as machine, material handling, operation, process, product, routing, volume, expansion, production, and market; Chou et al (2010) adds a new dimension called ‘program flexibility’. Authors describe this flexibility type as the “ability of a system to run unattended for a period of time” (p.712). This is a novel perspective related to automated processes which can run according to an initial input without the need of consistent interference from workers.

In an empirical study on a sample of 158 U.S. manufacturing plants, Malhotra and Mackelprang (2012) examine the interactions between manufacturing flexibilities and external supply chain flexibilities and investigate if a complementary relationship between two aspects of flexibility exists. With respect to this idea, authors propose the following flexibility dimensions: Inbound supplier flexibility (the capability of the supplier to provide materials responsively considering any variations in the demand of focal company), outbound logistics flexibility (robust delivery capability in the face of changes in production volume or product type of the focal company), and internal manufacturing flexibility which covers modification, mix, and new product flexibilities. According to the results of their delivery performance evaluation on the firms which utilize some or neither of these flexibility dimensions in their supply chain; authors come to the conclusion that supplier flexibility, flexibility of the focal firm and flexibility of logistic service providers may influence each other in a synergetic way which leads to higher delivery performance.

A small portion of the literature address the relationships between flexibility types and one example for these studies is carried out by Suarez et al (1995) who emphasize the need for a proper framework enabling managers to integrate flexibility to strategic planning in an empirical study of circuit board manufacturers. According to authors, achieving all flexibility dimensions at the same time is not a feasible thing to do since each of them necessitates different configurations on production technology, management techniques, supplier relationships, human resources, and product development endeavor. Due to this fact, they investigate if there is a complementary relationship or a trade-off between mix, volume and new product flexibilities. Their findings subsume a converse relationship between mix and volume flexibility where the lack of mix flexibility may result in higher volume fluctuation and thus the requirement for volume flexibility increases. Also, high mix flexibility provides cushion against the adverse effect of the volume fluctuation of one product type which could diminish the need for volume flexibility. While authors do not find a significant relationship between volume and new product flexibility, they find out that mix and new product flexibilities have a reciprocally constructive relationship. Examples for this relationship are: component reusability (e.g. modular design) which decrease new product design cycle-time and is at the same time crucial for mix flexibility; and incorporation of workers in group activities to contribute to problem solving.

3.1.3 Measurement of Flexibility Dimensions

One of the earliest publications as far as measurement of flexibility is concerned belongs to Buzacott (1982) (in Gupta and Goyal (1989)) who attributes the measurement of flexibility to the capability of handling a prospective change effectively, considering the loss or benefit if this change takes place.

In order to find out the relationship between environmental uncertainties, manufacturing strategy (i.e. flexibility and role of manufacturing managers in decision making), and economic performance of the firm; Swamidass and Newell (1987) address the measurement of uncertainty, flexibility and role of manufacturing managers in decision making in an empirical study. As for the measurement of manufacturing flexibility, authors evaluate the responses from participants of the survey on a ten-point rating scale (from most frequent or widest range to least frequent or narrowest range in the industry) about five attributes of flexibility which are: new product introduction, new production process introduction, product variety, product features, and research & development effort. Both chief executives and manufacturing executives are involved in the questionnaire. Considering the average rating given by chief executive and manufacturing manager, a single measure of each attribute of flexibility is obtained.

Gupta and Goyal (1989) indicate several different approaches to measure flexibility. One approach pertains to the measures based on economic consequences (e.g. losses due to low production volume caused by internal disturbances or demand fluctuations). In this respect, costs and opportunities for adding value can be measured regarding various dimensions of flexibility; and these 'partial measures' can be combined to a total flexibility measure which is the ratio of physical system output to the sum of measured costs of flexibility dimensions. Another approach refers to the evaluation of flexibility by considering particular performance criteria. For example authors propose the following measures for the assessment of machine flexibility: number of tasks a machine can perform, dimensional limits of the part processed by the machine, cost of changeover, and duration of changeover (i.e. non-productive time).

Another empirical study focusing on the assessment of flexibility by Dixon (1992), assess mix, new product, and modification dimensions of flexibility. The author perceives that it is more preferable to address a broader range of flexibility dimensions, however the longer a questionnaire is, the fewer amount of participants would respond. Aside from that, the assessment of mix flexibility is performed by considering the range (average number of different product specifications and changeovers between these specifications achieved by the respondent firm concurrently/during a month), cost, and time burden (brought by changeovers between different product specifications). With regard to the evaluation of new product and modification flexibilities respectively, questions target the number of new product introductions, and the number of modifications made on the existing product characteristics in one year period. Additionally, the lead-time of new and modified products as well as the cost of production shift from one product to another are assessed; which embodies new process equipment, employee training, productivity loss, operations scheduling, manufacturing methods and routes planning, and quality verification. Despite the observation provided by Slack (1983) that regarding the assessment of a firm's flexibility, both potential and realized flexibility should be taken into account; Dixon (1992) assumes it is more reliable to focus on the realized flexibility for the sake of objectivity.

Suarez et al (1995) focus on measuring mix, new product, and volume flexibility in their empirical study of PCB (printed circuit board) manufacturers. In order to measure mix flexibility, authors deploy four variables which are number of different board models, number of different board sizes used during assembly, density of components on manufactured boards, and range of final product categories where these boards are utilized. As for the new product flexibility, authors query the time length (in months) from the primary stage of a product's design to the introduction of the first batch to market. Shorter time means higher new product flexibility. Finally, authors use volume fluctuation data, information about cost per certain volume change and also the ratio of boards which require maintenance.

With the attempt to develop an instrument to facilitate the measurement of manufacturing flexibility, Gupta and Somers (1992) propose a model which encapsulates the measurement of nine components of manufacturing flexibility: expansion flexibility, material handling flexibility, routing flexibility, machine flexibility, market flexibility, product/production flexibility, process flexibility, programming flexibility, and volume flexibility. Referring to the literature, authors come up with 21 items to assess (e.g. time/cost required to introduced new products, number of new products introduced in a year, the rate at which a typical machine is considered as obsolete etc.) by implementing a five-point Likert scale (from 1-highly inaccurate to 5-highly accurate) in a questionnaire including 269 firms. Then, these items are associated with these nine flexibility components mentioned above. The purpose of their study is to establish a standard instrument for the measurement of manufacturing flexibility which is reliable and easy to implement.

In an empirical study of North American manufacturers using advanced manufacturing technologies, Pagell and Krause (1999) collected data about the following four items implemented in their survey to assess the operational flexibility: (1) number of distinct parts/ product families manufactured in the plant, (2) average batch size for that plant, (3) number of new parts or products relative to the number of existing parts or product mix introduced in one year, and (4) number of parts or products relative to the number of existing parts or product mix are taken out of the portfolio.

Koste and Malhotra (1999) provide four general elements to define each flexibility dimension and to enable the development of general manufacturing flexibility measures in further studies. These elements were discussed in the preceding section of this dissertation: range-number, range-heterogeneity, mobility, and uniformity. As an example for the contribution of these elements to measurement of flexibility dimensions, authors illustrate several measurement aspects of machine flexibility gathered from flexibility literature and grouped under the four elements introduced in the same study. For instance, range-number element of machine flexibility includes the following measurement items: percentage of operations performed by the same machine or adaptability of the machine to different machining tools, while mobility element embodies the speed and ease of changing tools and thus operations for the same machine. It is obvious that there are both quantitative which can be evaluated objectively and qualitative measures which relies on subjective opinions.

There are other studies recognizing common attributes for various flexibility dimensions. One of these studies is performed by D’Souza and Williams (2000) who point out range and mobility as common elements of volume, variety, process, and material handling flexibilities. Authors deploy these elements to measure the four flexibility dimensions. Range attribute of volume flexibility determines the interval of profitable production volume whereas mobility represents the time requirement for making a certain amount of change in production volume with the cost brought by this change. For variety flexibility, range refers to how many different products are manufactured by each facility and how many new products are introduced for a given time period. Mobility attribute however, encapsulates the time and cost of introducing new products. In the context of process flexibility range describes how many different operations a machine can perform without causing prohibitive costs or time while switching between operations, whereas the mobility captures the time and cost of changing the product mix. Material handling flexibility is measured by the competence to link machines on the shop floor and to deliver parts through the system to appropriate positions which compose the range element; and also by the ratio of inventory cost to total production cost which indicates the mobility attribute.

From a normative perspective, Philips and Tuladhar (2000) investigate the characteristics ideally expected from a flexibility measure. First and foremost, authors emphasize that inefficiency measures cannot cover the whole scope of flexibility and thus cannot be solely taken as a flexibility measure. Moreover, a flexibility measure should not focus solely on the magnitude of a single flexible response to an environmental change but should rather capture the range of responses against a diversity of environmental changes. It is also mentioned that responses to unexpected events should be considered which is kind of information difficult to obtain from the executives of a firm. Time should also be taken into consideration by analyzing the particular flexibility over a period of time (longitudinally). In addition, the flexibility measure should enable a comparison between flexibility and efficiency in order to establish an association with organizational performance. Furthermore, in order to achieve a valid flexibility assessment, flexibility of a particular company should be compared with peer companies. Also, a flexible firm which demonstrates changes within the boundaries of a business model; should not be confused with an evolutionary firm which refers to changing the business model. Last but not least, a flexibility measure cannot test the optimality of the concept which as a matter of fact, cannot be determined at all.

Two common attributes of flexibility measures researchers agree upon are range and response (Gerwin, 1993; Barad and Sapir, 2003; Chou et al, 2010). Barad and Sapir (2003) describe ‘range’ as the extent of alternatives at hand, to adapt the system in order to continue operating smoothly. Authors assert that range can be measured by obtaining the number of alternative options and find a correlation between range and system effectiveness. Response, on the other hand, is a measure of difficulty or cost of adaptation to a change according to the authors and is related to system efficiency. As the reader may notice, response is a similar attribute as the mobility mentioned earlier in this section.

Another paper considering range and response elements of flexibility in the context of process flexibility was written by Chou et al (2010) who define range as: "the extent to which a system can adapt" and response as "the rate at which the system can adopt" (p.711). From the similarity of these definitions to the others mentioned before, it is clear that researchers are in a consensus about these common attributes of various flexibility dimensions. In their study, authors mainly focus on the response dimension considering the uniformity of production cost and compare this attribute with range. They state that improving either range or response is clearly beneficial for system performance whereas with limited resources at hand, one of them should be selected and pursued. Regarding this fact, authors come up with the assertion that improving response element is supposed to be the priority in utilizing resources and the range of options should be extended with the remaining resources, since a system with high response and limited range shows similar and even better performance than a system with high range and limited response capability according to the results of their mathematical model.

Koste et al (2004) describe two factors which determine the contribution of measurement attributes such as range-number, range-heterogeneity, mobility, and uniformity to flexibility. First of these factors encapsulating R-N and R-H elements, represents the 'scope' of flexible response regarding the diversity of available options an organization is able to obtain. The second factor is 'achievability' which encompass mobility and uniformity. Achievability is associated with cost/time penalties in both short and long term that result from deploying the flexible response. Considering the limited resources of a firm, one may observe that it is difficult to attain high level of both factors mentioned above at the same time. It should be taken into account that there may be a trade-off between these factors.

Mathematical model development is also a subject of interest in flexibility evaluation research. One example for this approach is the study of Gong (2008) who formulates the dimensions of supply chain flexibility with mathematical models which bring basic flexibility elements (labor flexibility, machine flexibility, routing flexibility, and information technology) of supply chain together under one roof. From there, the author also scrutinizes the association between flexibility factors and overall supply chain flexibility. In the study, the flexibility measurement of the supply chain system is grounded on improvement in current and prospective profit opportunities due to the implementation of flexibility. The reason behind this logic is that evaluating the cost of flexibility deployment is troublesome or not possible at all. However, cost is already considered inside the resulting profit. In order to measure total system flexibility which corresponds to product mix flexibility in this study, the researcher provides a comprehensive model involving some dimensions of flexibility mentioned above; and the influence of these dimensions on total system flexibility is analyzed with the objective of contributing to system flexibility decisions. The supply chain considered in this model, is structured in such a way that the flexibility of one agent depends on the flexibility of suppliers (or upstream agents in general). Thus, the total flexibility of the supply chain is also expected to be affected by flexibility of all partners and the relations between them. While information and labor flexibility are conceived to have an influence on all supply chain stages, routing and machine flexibility solely affect supply and manufacturing stage. Important to note is that uncertainty in customer demand is neglected in this study.

Machine flexibility has been one of the commonly addressed subjects among the studies focusing on measurement of flexibility dimensions. Wahab et al (2008) propose two domains of machine flexibility models which are called operational capability-based and time & cost-based machine flexibility. Authors develop a generic model for the measurement of machine flexibility by taking characteristics of manufacturing a part such as processing time and cost, the amount of different operations within the capabilities of a machine, and also the internal and external uncertainties (e.g. in machine-part assignment or demand respectively) into account. Their approach subsumes two stages. In the first stage, a super efficiency Data Envelopment Analysis Model is applied and in the second stage, a flexibility model is established. Data Envelopment Analysis is a method to find best practices as well as the inefficient practices compared to these best practices, from a set of observed decision making units. The structure of their two stage model is demonstrated in Figure 3.2.

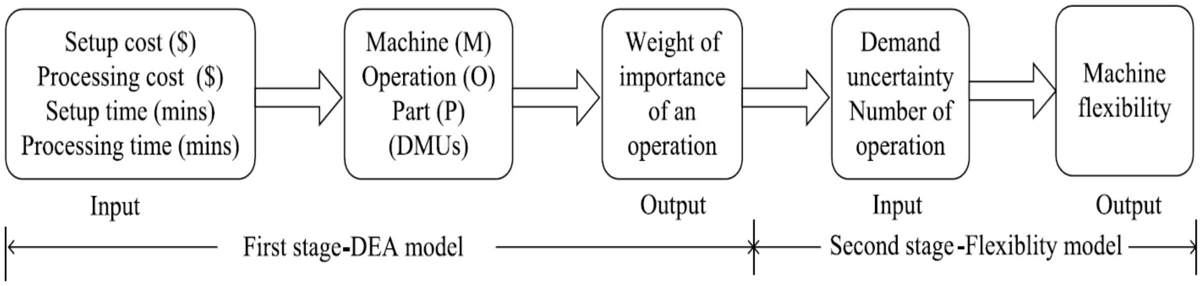

Figure 3.2 - Two stage conceptual framework for measuring machine flexibility (Wahab et al, 2008)

An important deduction from the results of this study would be that the marginal system machine flexibility cannot be improved directly from increasing number of operations a machine is capable to perform, whereas system machine flexibility is influenced from uncertainty in demand.

3.2 Analysis of Supply Chain Flexibility Research Trends

In the preceding parts of this section, various definitions of flexibility in different contexts of supply chain management, types of flexibility with respect to taxonomies proposed in the literature, and measurement practices were identified and discussed considering the last three decades of supply chain flexibility. Now that an overview of supply chain flexibility is covered, it is time to analyze the trends in the flexibility literature during these last three decades. In this section of the dissertation, 95 studies are firs categorized according to their publication date and types of research implemented in them. Afterwards, the timeline of research focus is discussed regarding the subjects of interest in these studies. Last but not least, estimations on the future trends of flexibility research are proposed.

3.2.1 Types of Former and Recent Research

The objective of this part of dissemination is to discuss what types of research have been used in studies during the last three decades. Three main types of scientific study are considered to categorize the flexibility research. These categories are conceptual, empirical, and exploratory research. To start with, the logic behind this categorization should be clarified. In this regard, it is important that the reader is properly informed about what is meant by these different categories of research.

Conceptual research encapsulates studies in which the authors choose to follow one of the following approaches: provide a literature review; describe a concept by developing a framework for implementation, taxonomy, or measurement; or contain development of a mathematical model. In the context of supply chain flexibilities, conceptual studies either present a basic understanding through definitions related with flexibility, its sources, and dimensions; provide frameworks for the taxonomy of flexibility dimensions; or include mathematical models to measure these dimensions. In conceptual studies, the proposed framework or mathematical model cannot be confirmed by real world cases which is only possible for empirical and exploratory research.

Empirical research refers to the kind studies where a number of hypotheses are built first, considering the ideas proposed in formers studies or on the basis of authors' own observations (particularly if authors are among the practitioners of that concept); and a survey on a considerable amount of participants (more than 10 at least) mostly chosen among the practitioners of the concept is conducted. In the empirical studies related to the main subject of this paper, participants are mostly chosen among managers from different functions of several companies such as manufacturing managers, marketing managers, or chief executive officers etc. The names of the participating organizations remain unknown due to high quantity and for the sake of objectivity.

The survey could be in the form of a questionnaire or interview including certain questions which are predefined. Each participant in the survey is expected to answer the same predefined questions. Afterwards, a statistical analysis is performed on the answers of the questionnaire and/or interviews. The objective of this type of study is mostly to find out if supporting or contradictory evidence for the hypotheses built prior to survey exists. Considering the subject of this dissertation, hypotheses look like: "Supply chain strategy has direct effects on the adoption of supply chain flexibility dimensions" or "Supply chain flexibility dimensions have direct effects on supply chain performance" (Fantazy, Kumar, & Kumar, 2009, s. 180, 181).

In addition to these hypotheses, some researchers prefer to develop a complete conceptual model prior to survey application. If that is the case, the variables in that model (e.g. a mathematical model) are assessed by utilizing the results of statistical analysis on the data gathered from the survey answers. From the assessment of these variables (or hypotheses), researchers come to a conclusion where they interpret the findings of their study. One important property of this kind of studies is that they provide objective results which are open to discussion and they also provide vision and new areas of research for the future studies since empirical studies shed light on the needs and problems of practitioners which may not be visible to academics and could also draw their attention until they take practitioners' experiences into account.

Exploratory research on the other hand, represents the endeavor to confirm the assertions of researchers with evidence from real world examples. Although it might look similar to empirical study so far, this type of research is limited to a small amount of case studies (not more than 10). A portion of exploratory studies include the name of participating firms in their case studies while some of them do not share them with the reader depending on the choice of the company. This is mainly due to security issues since sometimes they are expected to share classified information about their competitive strategies or information which may publish their weaknesses to rivals. Two important features of these studies are that they mostly do not intend to provide objective results since their results are not based on statistical evaluation on a large sample of participants, however more detailed information can be gathered since the size of the sample is a lot less than empirical studies. Thus, these studies establish a bridge between conceptual arguments and real world implications. Now that each category of research type is described, it is time to discover which types of research was chosen during the last three decades and why they were chosen.

Between the years 1980 and 1990, only 6 studies were carried out. 5 of these studies were based on conceptual research and the remaining one was an exploratory study. Moreover, no study that incorporates an empirical approach could be found (Figure 3.3). These two phenomena can be considered as the indication of the need of a basic understanding of this novel concept in management science. This means that the conceptualization of flexibility was the subject of interest during these years in order to facilitate the emergence of awareness about supply chain flexibility. Additionally, the lack of both empirical and exploratory study implies and not many companies were aware of this concept set aside there is almost no company utilizing flexibility in its internal operations or supply chain.

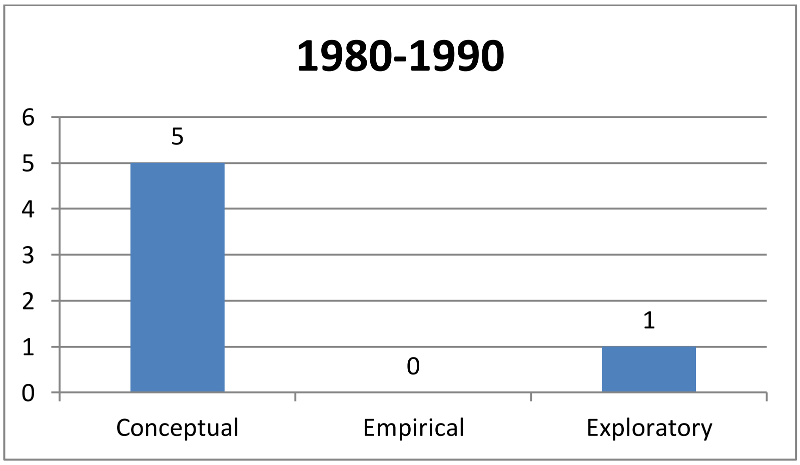

Figure 3.3 – Distribution of research types between 1980 and 1990

The only exploratory study was performed by Gustavsson (1988), who emphasizes the decrease in product life cycles and discusses the long-term benefits of flexibility in complex machining operations. In this respect, the author sheds light on the relationship between flexibility and productivity with the case study of a automotive manufacturer. The effect of flexibility on the operations of this company is illustrated by several capabilities such as 'the use of modules' which corresponds to the convertibility of machinery installations that have the necessary process capabilities to manufacture different parts and consist of standard components that can be replaced or combined into different machinery. Moreover, new product development is also facilitated if products are composed of standard modules. The studied company utilizes this aspect of flexibility in switch gear.

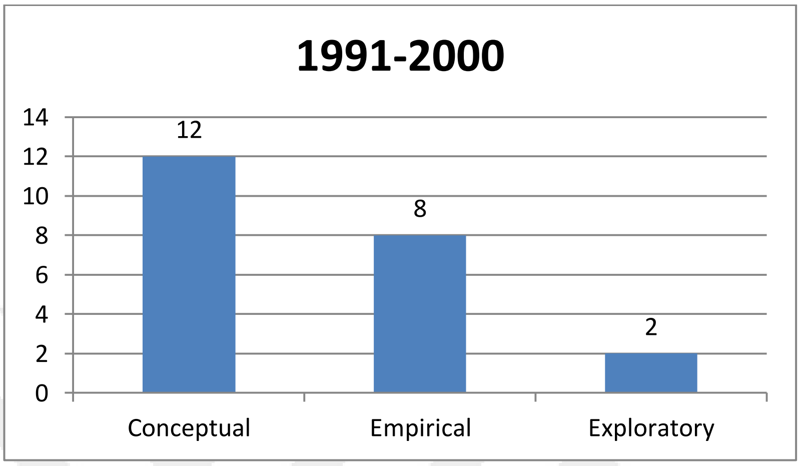

Figure 3.4 – Distribution of research types between 1991 and 2000

From the review of the next ten year period (1991-2000), 22 studies were found. The majority of these studies (12 out of 22, or 55%) are conceptual and some of which provide mathematical models (Gupta, 1993; Borenstein, 2000). An interesting finding is that there are a significant amount of empirical studies published between these years. 8 out of 22 studies (36%) are empirical, while the number of exploratory studies is limited to 2 (Figure 3.4). This distribution implies that academics still give weight to conceptual studies which shows that the concept of flexibility is still in the phase of development; and also that academic society recognized the inclination of business strategies towards the implementation of flexibility sources in several functions of their organization or supply chain. Other than that, there is not a big change in the number of exploratory studies

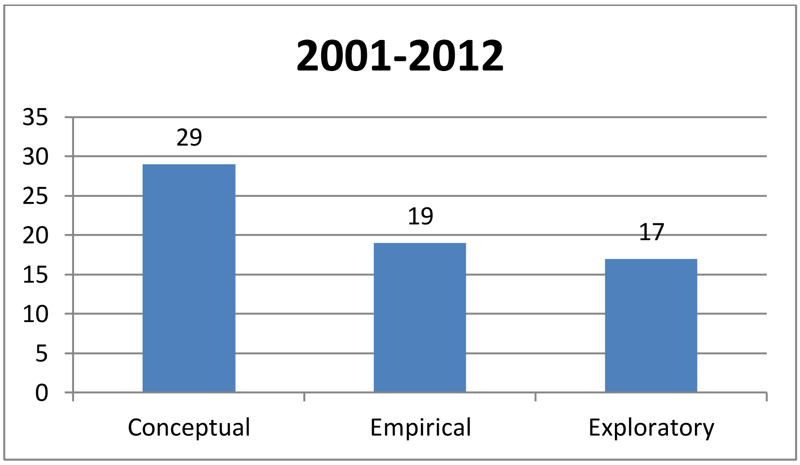

Figure 3.5 – Distribution of research types between 2001 and 2012

Considering the last decade, one can observe that the ratio of empirical and exploratory studies to all studies is changed considerably. 29 studies from a total of 65 (44%) are conceptual work, while 19 of the other studies (29%) are empirical and the remaining 17 studies (26%) are exploratory (Figure 3.5). These findings connote that there is a considerable change in the distribution of study types such that the percentage of exploratory studies has become 26% which is almost equal to the percentage of empirical studies. Moreover, the ratio of conceptual studies has dropped and now there is a more homogenous distribution among types of study. The deduction from these percentages could be that the concept of flexibility is closing to a maturity state since researchers can find more examples for case studies in exploratory research. Additionally, it is important to note that exploratory research fills the gap from reduced number of conceptual studies (not the actual number but based on the ratio to overall research) which indicates the increasing number of companies implementing dimensions of flexibility. Researchers obviously recognized the proliferation of flexibility especially among the larger organizations and thus, they aim at providing both a better understanding and ways of proper adoption of flexibility to small and medium sized companies.

3.2.2 Flexibility Research Timeline Assessment

In supply chain management context and during the last three decades, flexibility was first recognized as an ambiguous capability in manufacturing processes. Zelenovic (1982) discusses the utilization of flexible production systems in terms of automation and planning of production factors such as production means and working conditions. To achieve a higher degree of flexibility in these production factors authors propose several terms to focus on like: improving the motivation of employees and utilization of them for increasing system effectiveness; coordinating all actions which may cause progressive changes in process state; assigning workers to many different process functions; and managing the logistics function of the system in best possible way.

Similarly, Slack (1983) scrutinize the nature of flexibility in production management and admits that it is a vague concept which has not been comprehended yet. The main focus of the study is to clarify four main questions in the mind of flexibility researcher at that time. These questions refer to the position of flexibility with respect to manufacturing objectives; the meaning of flexibility in production context; how tasks, decisions and elements of production management may affect various dimensions of flexibility; and what kind of a measurement approach should be implemented to assess flexibility in manufacturing system. These two studies represent the vagueness of flexibility concept and both authors pursue the understanding of fundamental aspects of flexibility. Thus, for the studies between 1980 and 1990 the main subject of interest can be identified as the defining flexibility in addition to determining the role of flexibility in manufacturing. The first study, where external flexibility dimensions are considered and thus a correlation between flexibility and the supply chain management practices is illustrated was performed by Sethi and Sethi (1990) who propose three main clusters of flexibility types which are classified as basic, system, and aggregate flexibilities. While the first two clusters of flexibility dimensions is related to manufacturing context, the aggregate flexibilities encapsulate program, production, and market flexibility.

After 1990, empirical studies show up which either focus on measuring flexibility (Dixon, 1992; Gupta and Somers, 1992) or on the development of a flexibility categorization (Suarez et al, 1995; D’Souza and Williams, 2000). Besides, the majority of studies between 1980 and 2000 assess flexibility in the context of manufacturing focusing on dimensions such as mix, new product, volume, and routing flexibility (Sethi and Sethi, 1990; Zammuto and O’Connor, 1992; Suarez et al, 1995; De Toni and Tonchia, 1998; Koste and Malhotra, 1999; D’Souza and Williams, 2000).

Only Vickery et al (1999) provides a different perspective that proposes an approach towards the consideration of flexibility in the supply chain management concept from the narrow manufacturing flexibility context. Authors not only consider the responsiveness to target markets which corresponds to the contribution of flexibility in value creation but they also identify the novel concept of access flexibility. As mentioned by authors, access flexibility represents “the ability to effectively provide widespread and/or intensive distribution coverage" (p.19). Distribution coverage is not a capability to be obtained solely by the firm, it is rather dependent on the performance of logistics service providers or coordination abilities between two entities.

During the last decade however, both the total number of studies about flexibility and the portion of empirical and exploratory studies have significantly increased. Among the 95 studies in total, 65 papers were published between 2001 and 2012. These papers not only considered the manufacturing flexibility dimensions, but they also added new dimensions of flexibility in the context of supply chain management.

One of these new dimensions which became one of the subjects drawing attention of researchers is 'spanning flexibility' which corresponds to the ability to disseminate information among all partners of a supply chain. Zhang et al (2006) scrutinize organization and classification of spanning flexibility research with respect to competence and capability theory, as well as development of instruments to measure components of spanning flexibility, and finally the impact on customer satisfaction.

Moreover, there are also studies which address the assessment of other supply chain partners in order to facilitate the overall flexibility in the value chain. In one these studies, a framework is developed to determine the capability of a third party (3PL) logistics service provider (Naim, Aryee, & Potter, 2010). Authors also emphasize that logistics service providers should employ different types and degrees of transport flexibility in order to fulfill certain supply chain strategies. The developed framework is also tested in a case study where a supply chain triad is considered including a third party logistics provider a consigner and a consignee.

Considering the general properties and trends discussed in this paper, Figure 3.7 illustrates a timeline for the supply chain flexibility research. From 1980 to 1990, literature focused mainly on definitions and early taxonomies for this new concept, which authors mostly could not agree on. Afterwards, at the start of 1990s empirical studies showed up in order to determine the effects of flexibility on manufacturing, in terms of product, process, mix, volume, and routing flexibilities. So, taxonomies are established for flexibility in manufacturing context. Moreover, as empirical studies were carried out, mathematical models were developed and confirmed with empirical evidence in order to measure flexibility dimensions. Between 2001 and 2012, exploratory studies emerged as a result of increasing number of companies utilizing flexibility. Researchers were able to find companies for case studies to provide evidence for their frameworks. During the last decade, one of the subjects mostly discussed was the interaction between uncertainty and firm/supply chain performance, and the moderating effect of flexibility. Besides, the influence of flexibility on decision making and strategic choices was recognized and it is the topic drawing most of the attention nowadays.

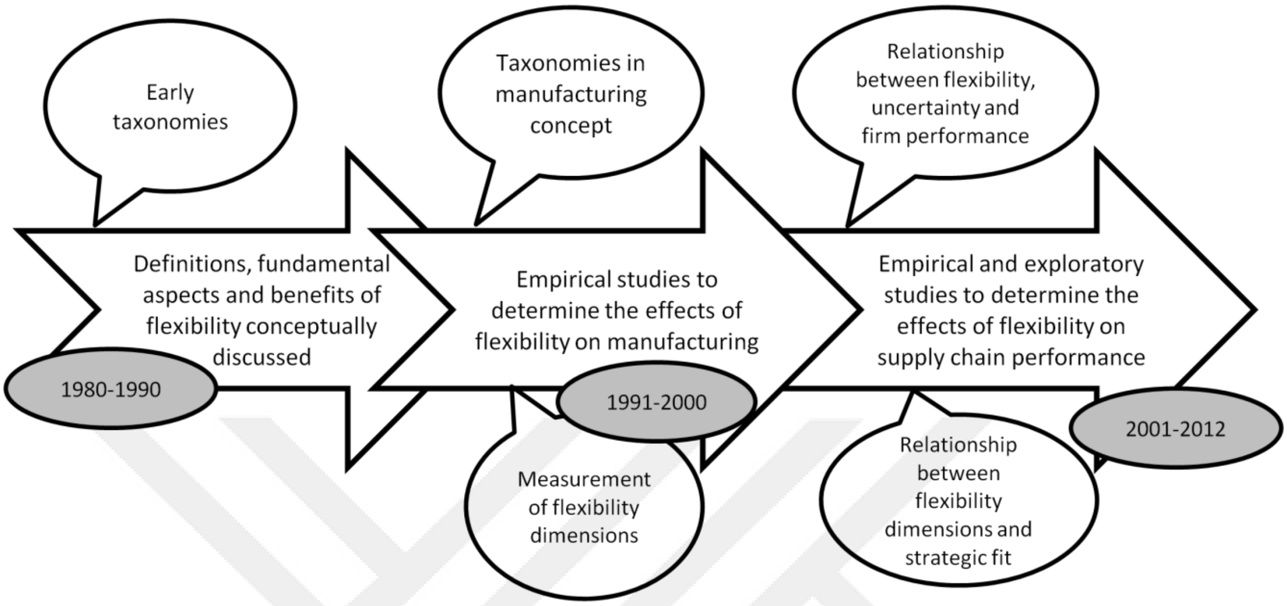

Figure 3.6 – Timeline of flexibility research

It is also important to know the location of studies, in order to facilitate further research in supply chain flexibility. In Table 3.1, the names of journals are given which contain the papers discussed here. For different time periods, different journals provided research papers related to flexibility. For example, in International Journal of Production Research Journal, four flexibility studies were published between 1980 and 2000 whereas Journal of Operations Management became one of the most prominent journals where valuable studies about supply chain flexibility can be found.

Table 3.1 – Number of papers found in each journal

Journal Name	1980-1990	1991-2000	2001-2012
Int. Journal of Production Research	2	2	-
Int. Journal of Operations & Production Management	1	-	10
European Journal of Operational Research	1	5	
Management Science	-	2	3
Industrial Management & Data Systems	-	1	2
Journal of Operations Management	-	6	9
Int. Journal of Production Economics	-	-	5
Industrial Marketing Management	-		
Expert systems with applications	-	-	2
Journal of Modeling in Management	-	-	2
Supply Chain Management: An International Journal	-	-	4
IIE Transactions	-	-	2
Journal of Manufacturing Technology Management	-	-	2
Other	2	7	13

3.2.3 Estimations on Future Research Trends

In the future, the number of empirical and exploratory studies should increase since the concept of flexibility is getting closer to maturity. The main focus in the latest studies carried out during the ten years imply that flexibility is going to reach the level of importance and will become an indispensible capability in order to compete against firms which have considerable share in global markets. Nowadays, almost any company is trying to appeal customers in distant countries. Due to the information technologies and rapid distribution channels, product life times in many industries reached almost one day. Considering all these factors and the trends in the last three decades, the role of flexibility in overall supply chain will be addressed more often and new dimensions such as spanning (information dissemination) and responsiveness to customer demands will become the focal research topics in following years.

Moreover, industries such as grocery retailing and textile where shortest lead times are observed, should be addressed in terms of the benefits of flexibility. There is also a lack of longitudinal studies which observe the effect of flexibility over a certain time. In the future studies, these sectors should be analyzed and longitudinal studies need to be implemented in order to achieve a time dependent performance indication within the flexible global supply chains.

4. UTILIZATION OF SUPPLY CHAIN FLEXIBILITY

4.1 Effects of Flexibility on Supply Chain Performance

As discussed earlier, uncertainty is a significant issue for the entire supply chain since globalization induces the endeavor to reach customers at the other end of the world which increases the physical distance between supply chain partners while information technologies smoothen out the interfaces within the business system which involves product development, manufacturing, logistics, and retailing (Viswanadham & Raghavan, 1997). Regarding this matter, this part of the dissertation focuses on the utilization of flexibility in supply chain considering its relationship with uncertainty and its impact on performance of either a single firm or the entire supply chain.

4.1.1 Relationship between Uncertainty, Flexibility, and Performance

Researchers have drawn attention to the fundamental change in manufacturing priorities throughout the last decades from mass production towards mass customization (Sethi and Sethi, 1990; Viswanadham and Raghavan, 1997; Stevenson and Spring, 2007; Sidola, Kumar and Kumar, 2009). Flexibility is considered as an indispensable part of mass customization as it plays a role in the enhancement of certain performance measures like lead time, quality, and timely delivery which contribute to competitiveness in the face of turbulent markets demanding highly customized products in massive amounts. Viswanadham and Raghavan (1997) identify the uncertainties which the manufacturing system handles with the help of flexibility. These uncertainties include resource changes, design and demand changes in the product, technological developments, and socio-political changes. Unfortunately, most of these uncertainties cannot be handled by eliminating their sources but only dealt with by either reducing the detrimental effects of environmental changes or adapt to these changes and even turn them into opportunities, where the contribution of flexibility comes into effect. Nevertheless, it should be noted that business processes of an enterprise may become complex, costly, and time-consuming to adopt, should flexibility be implemented. Flexible capabilities may require redundant capacity, time, and space that induce additional costs.

With respect to the influence of managerial practices on performance and the moderating effect of flexibility, Kathuria and Partovi (1999) emphasize that workers can contribute the conventional duties of managers such as problem solving, performance monitoring etc. if the plant is pursuing manufacturing flexibility. For achieving a higher performance authors suggest that manufacturing managers integrate flexibility to work force management by fostering their employees to work cooperatively in self-managing teams, monitor their self-performance, and derive solutions for sudden problems. Moreover, following aspects are crucial in work force management of firms pursuing flexibility: supportive behavior and periodical appreciation for workers' efforts, encouragement for getting in touch with other departments when product design changes or new products are underway, and develop capabilities in order to adapt to changes in volume and delivery timings.

Considering the results of trend analysis on the last three decades of flexibility research presented in the last part of this paper, it is clearly visible that there is a considerable amount of empirical studies in flexibility literature some of which was attempting to find out the relationship between uncertainty, flexibility, and performance. One of these studies performed by Pagell and Krause (1999), illustrates these relationships from the perspective of advanced manufacturing technology users among North American manufacturers through the results of a mail survey. Interestingly, the results of the quantitative analysis do not confirm a relationship between environmental uncertainty and the degree of operational flexibility. Moreover, there is also no evidence to validate the beneficial influence of the alignment between external and internal environment on performance. Thus, authors interpret that companies in complex environment do not always need to improve flexibility to increase competitiveness or there may not be any indication of performance improvement.

Supply chain agility as an important skill against environmental uncertainties was described in the paper previously. In this regard, Prater et al (2001) assert that complexity and uncertainty are factors increasing the vulnerability of a supply chain. In other words, they have a potential detrimental effect both on the position of the firm in the market and on its operations. Agility is considered as a significant attribute of strategy and a determinant factor of survival which is positively influenced by flexibility. Authors highlight that there is a trade-off between vulnerability and supply chain agility in a way that factors increasing agility may also end up raising complexity and uncertainty. This assertion is viable for example in a case when supply chain is extended over several geographic regions to compete in niche markets and establishing business relationship with new supply chain partners. Based on this assertion, authors state that flexibility and complexity are both determinant elements of external vulnerability of supply chain and thus also designate the feasible degree of agility. If environmental vulnerability increases, agility should be reduced in order to keep the complexity and uncertainty under control. This relationship is demonstrated in Figure 4.1.

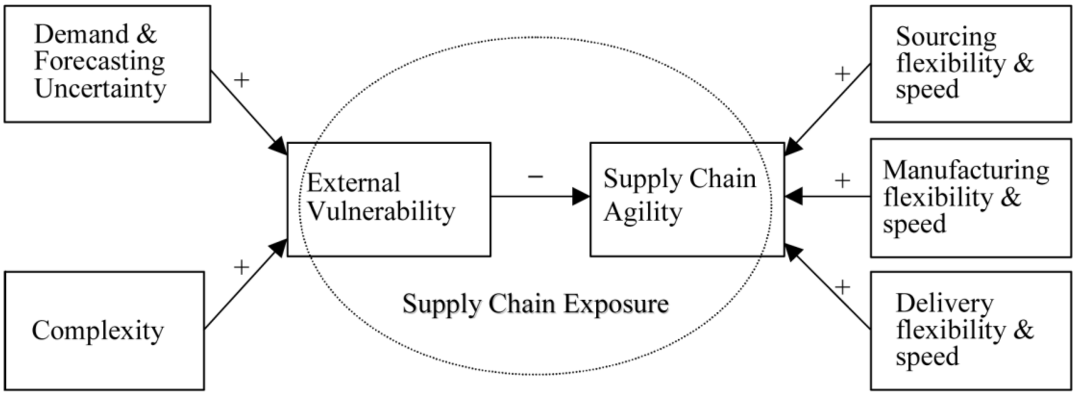

Figure 4.1 - Supply chain exposure and affecting parameters

In terms of the impact of specific flexibility dimensions, Jack and Raturi (2002) focus on the relationship between volume flexibility, its sources and firm performance in a study where three case studies were carried out. Authors shed light on the particular sources of volume flexibility which contribute to performance as well as competitive advantages. These sources are categorized according to whether they provide short- or long-term capabilities and also whether they are inherent to the firm or not. With respect to performance assessment of participants, authors adopt three indicators: delivery, financial, and growth performance. The results of the study indicate that internal buffers (inventory and production capacity) and labor flexibility (overtime and cross-training) are the aspects to count on in short-term; whereas external sources like network of plants and outsourcing arrangements as well as internal sources such as plant capacity enhancements, major workforce level adjustments or shift changes, and major changes in planning and control systems comprise the prominent factors in volume flexibility development over the long-run. Furthermore, first company which utilizes several short- and long-term sources of volume flexibility experienced a considerable inclination in sales over the last 10 years. Second company highly relying on volume flexibility capabilities, was maintaining low inventory buffers on top of conducting operations at a 60% capacity. The company also established outsourcing arrangements with suppliers. As a result, its performance has been satisfying over more than a century. On the other hand, the last company lost a portion of both profitability and sales which was related by the company representatives to over-reliance on overtime and lack of focus on other sources of flexibility such as workforce flexibility and outsourcing arrangements. In general, the study reveals the positive influence of volume flexibility on delivery and financial performance but does not provide evidence for any contribution to growth performance.

There are also studies providing empirical evidence on the impact of several flexibility dimensions to performance. In this regard, Sanchez and Perez (2005) come up with the following aspects which are deduced from the results of a survey over 126 Spanish automotive suppliers. Growing uncertainties as perceived by participating managers are associated with a higher emphasis on overall supply chain flexibility. On top of that, the most important outcome of their survey is that aggregate flexibility has the most significant impact on firm performance in terms of ROI (return on investment), ROI growth, market share, market share growth, ROS (return on sales), and ROS growth. However, system level flexibilities are not significantly associated with market share and ROS while basic level flexibilities do not show a statistically significant relationship with any of the performance indicators. Despite this fact, surveyed companies were focusing more on basic and system level flexibilities rather than aggregate level. Moreover, only certain types of flexibility capabilities such as product responsiveness, sourcing, postponement, and routing flexibility illustrate potential responses to environmental uncertainty.

In order to provide a general approach for the implementation and management of supply hain flexibility, Kumar et al. (2006) propose a framework which contains three main stages: (1) required flexibility identification process which considers the joint effect of environmental uncertainty, marketing and manufacturing strategies, and customer and supplier characteristics; (2) implementation & shared responsibility which encapsulates four flexibility dimensions (new product, sourcing, product, and responsive flexibility) and their relations; and (3) feedback & control which represents a comparison of required and actual flexibility types. Authors draw attention to the awareness on required flexibility types and put forward the concept of ‘fit’ which can be determined by the comparison of required and actually implemented types of flexibility. According to authors, if these two aspects match, business performance of supply chains can be improved.

Another study connecting uncertainty, flexibility and performance performed by Pramod and Garg (2006) incorporates the analysis of machine, volume, and product variety flexibilities under demand uncertainty. Five levels of flexibility (from no flexibility to total flexibility) are used to build their experimental environment in addition to a variable called traffic density corresponding to the ratio of mean processing time and mean inter arrival time. Traffic density is inversely related to volume flexibility (i.e. low traffic density means high volume flexibility). Authors also assess two performance indicators that are system utilization which represents the proportion of value adding time to total functioning time of a machine and throughput time which refers to the time required for the entire manufacturing process of a part starting with its entry, ends with its exit. Results of their simulation indicate that system utilization and throughput time increases with increasing traffic density. The reason behind the increase in system utilization is higher mean processing time. Throughput time however, is affected by the clashes between parts processed by the same machine causing more waiting time. Moreover, depending on the number of different part types, system utilization declines, though this is not the case for fourth and fifth flexibility levels (total flexibility and the highest before that). Interestingly, fourth flexibility level demonstrates the best performance (even better than total flexibility) which is followed by second and third flexibility levels. Thus, authors assert that partial flexibility can bring better results compared to both no flexibility and total flexibility.

Swafford et al. (2008) scrutinize the correlation between IT (information technology) integration, flexibility and supply chain agility, and how their relationship impacts competitive business performance. Their framework demonstrating this relationship is shown in Figure 4.2.

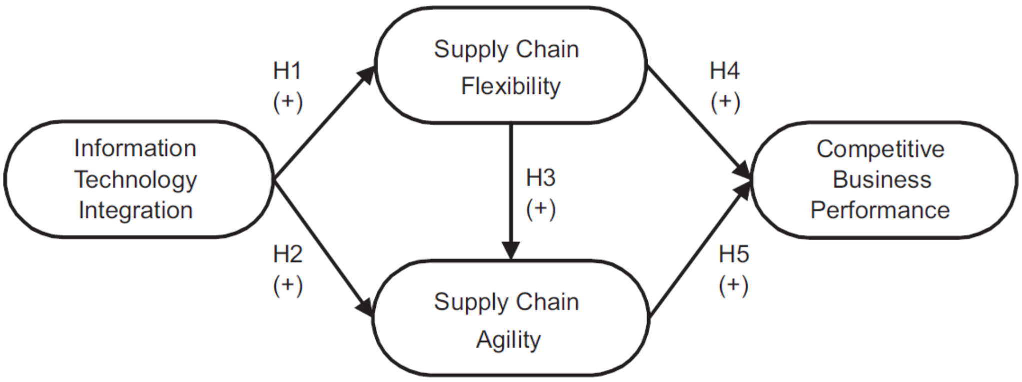

Figure 4.2 – Conceptual framework of supply chain agility (Swafford, Ghosh, & Murthy, 2008)

The arrows indicate the interactions between the four aspects. Authors put forward four hypotheses to describe these interactions. These hypotheses (from H1 to H4) refer to the positive impact of one of the aspects on the other pointed by the arrow. In order to emphasize the importance of IT integration, authors mention the positive effect of access to material availability information in terms of daily production scheduling on an organization utilizing mass customization. With the use of empirical data on their framework, they find out that (1) IT integration affects supply chain flexibility that leads to a higher agility and eventually a better competitive business performance is achieved. (2) Flexibility and supply chain agility differ from each other, and flexibility is an antecedent of agility since it improves the supply chain agility. (3) An organization pursuing both IT integration and supply chain flexibility can achieve a greater supply chain agility than a company focusing only on IT integration since information technologies enable dissemination of data within different functions (e.g. product development, procurement, manufacturing etc.) and results in shorter lead times. Shorter lead times enable a greater flexibility which in turn increases agility.

While flexibility is crucial against uncertainties and its beneficial influence on firm performance has been discussed and supported by many authors with empirical evidence; it is obviously not free. Considering the fact that the utilization of flexibility brings new costs to business, company size plays an important role in achievability of flexibility. Focusing on the moderatin effect of uncertainty on the relationship between supply chain flexibility and performance, Merschmann and Thonemann (2011) point out that flexibility and environmental uncertainty should be matched in order not to over-invest in a redundant capability or not to stay behind the competitors who may even find opportunities in the uncertain environment if they possess the right amount and type of flexibility. The results of their empirical study involving German manufacturers show that companies operating in environments with low uncertainty and adopting low supply chain flexibility achieve a greater performance than companies in the same environment utilizing a higher degree of flexibility. The opposite of this assertion also holds since highly uncertain environments require a higher degree of flexibility and a company that succeeds in deploying a high flexibility performs better than others.

4.1.2 Examples from Real World Supply Chains

General Electric Lightning (GE) was among the first Western firms to seize the opportunity of operating in Eastern Europe. So, GE bought 75% percent of Tungsram which is a Hungarian lightning company in order to cater light bulbs to European market. The company created a single warehouse out of several facilities scattered around Europe. Starting to operate in foreign markets over a single warehouse, a complexity arose which required flexible delivery scheduling since each affiliate in different locations of Europe had established special delivery plans with its local customers so far. As a result, an agility dimension emerged which is related to customized goods and services which complicated the operations of GE. Thus, the company had to renounce just-in-time delivery approach in order to realize scheduled delivery such that customers could change their orders up to two days before the delivery. To summarize, GE tried to reduce the complexity of operating in foreign markets and having to outsource transportation of goods by unite the scattered warehouses. However, this strategy forced GE's hand to increase lead time but provide a more reliable delivery. Hence, external vulnerability was dealt with by providing reliability to customers in terms of delivery timing which reduced external exposure. This example shows us that flexibility (in this case product customization and delivery flexibilities) and may require trade-offs between different capabilities (Prater, Biehl, & Smith, International supply chain agility - Tradeoffs between flexibility and uncertainty, 2001).

Hopp et al. (2010) present three examples of flexible capabilities from global supply chains: (1) Dell implements a sourcing mechanism which embodies procurement of multiple mother boards from the same supplier; (2) Hewlett Packard (HP) performs the assembly of voltage adaptors to its printers in a distribution center located in Europe, considering the standard voltage values specific to different countries; and (3) General Motors (GM) provides tools for stamping processes which enable the manufacturing of several parts for a diversity of car models.

4.2 Interaction between Flexibility & Strategy

Since the relationship between flexibility and firm/supply chain performance was discussed and illustrated with real world examples, now it is time to address how this relationship influences strategic decision making. In this context, Llorens et al. (2005) address the influence of manufacturing flexibility at system level on the process of strategic change such that it can be a determinant factor to consider in strategic change decisions and can also affect strategic fit in particular, which refers to how close the actual strategic change is to the necessary one. Strategic change is identified by Kraatz and Zajac (2001) as "the means through which organizations maintain co-alignment with shifting competitive, technological, and social environments which occasionally pose threats to their continued survival and effectiveness" (p.632). Strategic fit on the other hand, represents the capacity of the organization to reconfigure and thus adapt itself to the requirements imposed by environmental conditions in terms of financial measures.

Llorens et al. (2005) put emphasis on the impact of organizational competences on strategic change planning and deployment in a way that they determine the desirability of strategic change. They indicate that manufacturing flexibility is an asset for developing organizational competences that facilitate the management of reactive or proactive strategic options to meet the requirements of the environment. In this respect, authors highlight the need for an analytical approximation in order to assess the impact of manufacturing flexibility on strategic change and fit over a period of time. In order to find evidence for their assertion, a broad trans-national study was conducted on 403 European companies. The findings of their study illustrate that deployment of the appropriate level of manufacturing flexibility as well as a considerable amount of financial endowments lead to a higher performance. Also, the achievability of a proper fit in manufacturing flexibility is closely related to elements like metaflexibility which refers to the learning capability or ability to find solutions to paradoxes resulting from competitive, dynamic and complex environments, and financial endowment.

Ling-Yee* argue that core competencies do not suffice to obtain a considerable competitive advantage. However, managers can plan and organize production activities in certain ways to align these competencies with customer preferences in order to extend their competitiveness. In this respect, authors point out that manufacturing competence influence range dimension of flexibility since it enables rescheduling orders and material input without causing a significant burden in terms of cost and time while marketing competence provides the ability to anticipate total customer demand, coordinate distribution activities so that response time is reduced and deliveries are realized on time; and thus it has a positive impact on response flexibility. Moreover, assembly outsourcing competence is considered to ensure a cushion against the pressure on product variety and rapid delivery. Therefore, the latter competence dimension is assumed to contribute to both range and response attributes of flexibility. Authors also highlight the moderating effect of strategic positioning on the competence-flexibility relationship. With respect to this matter, they come up with the conclusion that low-cost manufacturing and long-term contracting strategies weaken the firm’s ability to obtain flexible capabilities from its core competencies, whereas private ownership and direct exporting strategies catalyze the improvement of manufacturing performance through manufacturing flexibility.

In flexibility literature, studies focusing on the interaction between strategy and flexibility are mostly based on empirical evidence from questionnaires, interviews or field surveys. A recent empirical study from Fantazy et al. (2009) containing an analysis on the results of a questionnaire survey and personal interviews with a group of small and medium-sized Canadian manufacturers illustrates that strategy decisions directly influence flexibility and flexibility directly influences performance. Considering three main supply chain strategies (innovative strategy, customer oriented strategy, and follower strategy), authors note that “Firms should invest resources and time to develop appropriate flexibility dimensions to fit into their strategies. Innovative strategy firms must invest time and resources in developing new product flexibility. While customer oriented strategy firms are required to invest heavily in developing sourcing, product, and delivery flexibility; follower strategy firms need no investment in any specific type of flexibility" (p.186).

A novel perspective on strategic decisions in supply chain management incorporates the idea of strategic supply chain networks which is based on a selected group of supply chain partners comprising a collective identity that embodies an internal role differentiation and assignment of responsibilities. This is a virtual organization since each member of such a network is independent despite its presence in this group; and all participants follow a certain objective. With regard to this subject, Winkler (2009) asserts that strategic supply chain network can contribute to supply chain flexibility since its potentials and resources enable the improvement of all flexibility parameters simultaneously. Authors identify these parameters as transparency, simplicity, responsiveness or agility, and reliability. Structural potentials, potentials in manufacturing and logistics technologies, and potentials in information technologies and human resources are the significant dimensions of supply chain strategic network that contribute to these flexibility parameters by the utilization of a target oriented management approach.

5. SUMMARY AND CONCLUSIONS

In the face of shorter product life cycles, specific and volatile customer demand, rapid technological developments; not only companies but also supply chains are exposed to many uncertainties both in the external and internal environment. If firms lack the appropriate and rapid responses in these environments, they cannot maintain their competitiveness in the long-term.

The globalization attempts make this adversity even more obvious to organizations which become aware of the threats especially during the last three decades. However, the question about how to handle uncertainties and prevent its sources does not have a simple answer. Researchers discovered flexibility as one of the capabilities crucial to cope with uncertainties. Flexibility can be supported by the internal competences and supply chain partners of the company.

However, it is not easy to implement this novel and vague concept since companies either do not have the necessary resources or they do not possess the sufficient knowledge to provide variety in products, change the production capacity as they please or access to distant locations in the world where they could increase their profitability and market share. Therefore a vast amount of flexibility studies were published for last thirty years and this dissertation has covered the last three decades of flexibility research by analyzing the trends in definitions, taxonomies, common subjects of interest and research types.

In addition to the analysis of research trends over the last three decades, estimations on the future subjects of interest and types of research are discussed. Last but not least, the relationship between firm/supply chain performance and flexibility is assessed according to the relevant literature.

In terms of the weaknesses of this dissertation a couple of issues can be recognized. The sample size of the reviewed literature could be larger especially for the first two decades of the overall time span. Since there are only 6 studies between 1980 and 1990, it is hardly possible to reach appropriate conclusions considering the much larger amount of studies written during the last decade. Furthermore, a more specific categorization in research types could have revealed a wider range of reasons behind the distribution of research over the last thirty years.

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