

# Supply Chain Flexibility Configurations: Perspectives, Empirical Studies and Research Directions

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**Abstract---**This paper investigates the current developments in research and practice in the field of supply chain flexibility through content analysis of the published literature. We had scrutinized a wide range of research publications from national and international journals and conferences of high repute. As diversity and uncertainty in the environment increases the companies are responding by adding flexibility as a dimension to their operational strategies. The review examined various perceptions, notions and definitions of flexibility, drivers and sources found in manufacturing and supply chain literature and compared the stated objectives, articulated needs and fundamental beliefs underlying the concepts, from a flexibility decision-performance-synchronization perspective. The objective of this study is to encourage and provide researchers and academicians globally with future research directions in the field of supply chain flexibility and its impact on business performance.

**Keywords-**Supply chain management; flexibility; optimization; uncertainty

## 1. Introduction

Since second world war, when the study of operations research began, academicians had spent years of research effort on the topic of optimizing supply chains that is, reducing the overall supply chain costs using different mathematical optimization methods. Many supply chains have now been sufficiently optimized using operations research theories and companies have started to realize that their supply chains are lean but not flexible enough to accommodate the uncertain demand. The topic of flexible supply chains which started to draw academic and industry attention in the 1980s is a relatively younger discipline; the lack of tactical approaches for building a flexible supply chain is one reason to examine the topic. Yet, there is little agreement on how to define flexibility, how to achieve flexibility or what the costs are and benefits of more or less flexibility actually are, if any. For

example, some researchers have viewed flexibility primarily in terms of programmable machines and capabilities for mixing models in production [22]-[23]. Others had viewed this in terms of versatility of people and skills [27]. Now Figure.1 clearly demonstrates the real world benefits of employing flexibility in supply chains. Substantial changes in managerial practices are affecting dramatically the way firms compete. Increasing demand volatility, shorter product life cycles, global sourcing, just-in-time, e-business and mass customization increase the turbulence in business environment. In order to cope with this, firms have to focus on the competitive dimension of flexibility [18]. Although research in flexibility has been mostly conducted within firms (that is manufacturing flexibility), many researchers argue that it should be studied from a supply chain perspective. After all, competition occurs often between supply chains rather than between firms [7]. There is no commonly accepted definition of flexibility; with the existing definitions covering only the limited aspects [6]-[25]. For example, [26] defines flexibility at the internal production level as the ability of the manufacturing system to cope with changes such as product, process, load and machine breakdown. [17] Summarizes the current definitions of flexibility as:

- The ability of a manufacturing system to cope with environmental variations.
- The ability of the enterprise to respond with agility to variations in market conditions.
- The ability of the enterprise to respond to variations more quickly with lower cost and less negative effects on system effectiveness.

According to [42] flexibility is the ability of a business process to effectively manage or react to changes with little penalty in time, cost, quality or performance. [15] Explains the flexible ability of a company in terms of three distinctive components:

- *Adaptable*: Adjust the supply chain's design to meet the structural shifts in markets, modify supply network strategies, products and technologies.
- *Alignment*: Create incentives along the partners within the supply chain for better overall performance.
- *Agility*: The ability of a supply chain to respond to short term changes in demand or supply

quickly and handle external disruptions smoothly.

Flexibility reflects an organization's ability to effectively adapt or respond to change [39]. The importance of flexibility is clearly shown by [9] through the studies based on the problems faced by General Motors and Boeing when trying to implement a production ramp-up in 1990s and their suppliers were unable to adjust their capacity. Flexibility is not free [14] and different environments can suggest different approaches to flexibility. Collins and Schmenner [37] maintain that flexibility can be operationalized in terms of an explicit statement of customer and end user requirements that are to be met by manufacturing for example, the customization of products, shorter delivery lead times etc. The potential breadth of these requirements contrasts with those defined by [35], who informally interviewed managers from 10 manufacturing firms to provide a basis for the development of a framework that would be useful in analysis of manufacturing flexibility. The paucity of operational measures for manufacturing flexibility was also the focus of work by Gerwin [18]. [23] considers a different minimum ordering quantity contract under which the buyer decides whether to order the prefixed contract amount or order more than this amount at the beginning of each period. The buyer will be charged an incremental cost for the excess amount ordered. The key theme in 2000s is that the supply chain management reinforce the holistic best supply chain practices (manufacturing, distribution, supplier, technology, information technology and organizational development) to create business value through flexibility within the supply chain nodes [37]-[38].

## 2. Literature Review

Authors have adopted content analysis method for literature review. Content analysis is an observational research method that is used to systematically evaluate the symbolic content of all forms of recorded information. This method also helps to identify the literature in terms of various categories, thereby creating a realm of research opportunities [45]. Content analysis was also used by Byrd and Davidson (2003) to examine the impact of information technology on supply chains; and by [13] in which the research on the transportation industry in U.S. This paper reviews the literature on supply chain flexibility that has been available in various academic journals and conferences of national and international repute. The aim is to collect, classify and synthesize the existing solid knowledge related to supply chain flexibility, thus to help researchers and practitioners develop flexible supply chains. We adopted a quite structural survey mechanism. At the initial stage of this research, we collected papers containing supply chain management, flexibility, agility, responsiveness, simulation, uncertainty and risk mitigation in their titles published in various major journals during the years from 1991 to 2011. The Journals include American Journal Of Engineering And Applied Sciences, International Journal Of Enterprise Network Management, Journal Of Global Strategic Management, International Journal Of Business Insight

Transformation, Operations Research, African Journal Of Business Management, Studies In Informatics And Control, International Journal Of Applied Engineering And Research, Industrial Marketing Management, Journal Of Studies On Manufacturing, Global Journal Of Enterprise Information System, European Journal Of Operational Research, International Journal Of Production Economics and Journal Of Operations Management. Keywords such as 'flexibility', 'supply chain management', 'supply chain performance measurement', 'postponement', 'supplier flexibility', 'plant flexibility', 'limited flexibility' and 'simulation' were used to find the related literature. In this research more than 50 journal publications have been reviewed. The review is intended for researchers wishing to understand deeply the existing theory on supply chain flexibility, with a view of identifying key areas for future research, as well as the practitioners to outline a clearer supply chain flexibility roadmap.

## 3. Framework for Supply Chain Flexibility

Recently, a considerable amount of work has been done by various academicians and researchers of high repute in the years from 1991 to 2011 and the efforts of such a hard working personalities is a boon to the society in general and supply management in particular. The supply chain flexibility framework has been divided into flexibility types, flexibility strategies, simulation, models and theories and their corresponding authors as shown in table 1.

**Table 1.** Frame work for supply chain flexibility.

CONTENTS	AUTHORS
<b>Flexibility Types</b>	Zheyu Liu (2009), Zhejun Gong et al. (2006), J. Gosling et al (2009), Wallace J. Hopp et al. (2010), Eric P. Jack et al. (2002), Nyoman Pujawan (2011), Domenico Aprile et al. (2005), Manu Goyal et al. (2010).
<b>Flexibility Strategies and Configurations</b>	Zhen Li et al. (2010), Christopher Tang et al. (2008), E lcio M. Tachizawa et al. (2010), Stephen C. Graves et al. (2003), Jing Jing Zhou et al. (2009), Claudio Garavelli (2003), Jiri Chod et al.(2005).
<b>Simulation</b>	Subhash Wadhwa et al. (2009), Anuj Prakash et al. (2010), Claudio Garavelli (2003), Thananya Wasusri et al. (2004), Guilherme E. Vieira and Osmar Cesar Junior (2006), Razman Bin Mat Tahar and Ali Asghar J. Adham (2010)
<b>Models and Theories</b>	Zhejun Gong et al. (2006), Saadettin et al. (2010), Yang Huaizhen et al. (2009), Bing Wu et al. (2008), Arawati Agus (2011), Wang Gui Hua (2009), Robert S. Collins et. al (1998), Balram Avittathur, Paul Swamidass (2006), Jing Jing Zhou et al. (2009), Ugur Bac et al. (2011), P. Fredrikson et al. (2005).

### 3.1. Flexibility types

The study of various types of flexibilities in supply chain has been a subject of growing interest today. In order to cope with the changing market conditions like uncertain supply and demand many supply chain experts are incorporating various types of flexibilities in their supply chains depending upon the performance characteristics desired. Zheyu Liu [45] found that higher the level of relational closeness, higher is the level of both physical supply flexibility and purchasing flexibility; however relational capacity only enhances the purchasing flexibility. An economic evaluation model of supply chain flexibility was studied by [41]. In this they concluded that the improvement of the most important factors gives greatest contribution to the system flexibility (labor flexibility, machine flexibility, routing flexibility) and however the improvement of unimportant factors provides less contributions to system flexibility. J. Gosling et al. [24] had argued that an agile and flexible supply chain is a way of coping with high levels of uncertainty in the construction industry and had considered sourcing flexibility and vendor flexibility for their study. A very good research work was done by Wallace J. Hopp et al. [42] to study the impact of variability on the optimal placement of logistics and process flexibility in a multi product, multi echelon supply chain. Sources of volume flexibility and their impact on the performance of supply chain was studied in depth by Eric P. Jack et al. [14]. Nyoman Pujawan [27] had identified four main parts of flexibility such as flexibility of the product delivery system, product system, product development and sourcing or supplier system. In each of these parts four flexibility measures (volume, types, speed and cost) are defined. Domenico Aprile et al. [11] studied the process flexibility of each supply chain firm and the logistics flexibility concerning the possible connections between suppliers, assemblers and markets. Two types of production flexibilities (timing and quantity) has been discussed by Joseph Milner and Panos [22]. They investigated that for many manufacturers production quantity flexibility can be provided through dynamic expansion of production capacity, for example, by adding a third shift.

In contrast, production timing flexibility requires investment in flexible capital, for example flexible manufacturing systems. Manu Goyal et al. [26] studied two flexibilities (volume and product) and discovered that the value of product flexibility always decreases in demand correlation whereas the value of volume flexibility can increase or decrease in demand correlation depending on whether the products are strategic complements or substitutes. They further highlighted that adding volume flexibility to product flexibility never hurts performance whereas adding product flexibility to volume flexibility is not always beneficial even when such an addition is costless. The authors have categorized supply chain flexibility in 13 types in competitive business environment which are listed in table 2.

**Table 2.** Flexibility types

<b>Product Supply Flexibility</b>	<b>It is the ability of a firm to provide a variety of inbound materials and supplies for production quickly and effectively.</b>
<b>Purchasing Flexibility</b>	It is the ability of a firm to make agreements to buy a variety of inbound materials and supplies quickly and effectively through cooperative relationship with suppliers.
<b>Vendor Flexibility</b>	It is related to individual vendors that support manufacturing, warehousing or transport operations.
<b>Sourcing Flexibility</b>	It is the ability to reconfigure a supply chain network through selection and de-selection of vendors.
<b>Logistics Flexibility</b>	It is the ability to ship products to different locations.
<b>Process Flexibility</b>	It is the ability to produce different types of products.
<b>Volume Flexibility</b>	It is the ability of a firm to adjust production upwards and downwards within wide limits.
<b>Routing Flexibility</b>	It is the ability of manufacturing cells to handle machine breakdowns and finish the appointed tasks.
<b>Machine Flexibility</b>	It is the ease with which a machine can change the process among different jobs.
<b>Labour Flexibility</b>	It is the ability to change the number of workers, tasks performed by workers and other worker responsibilities.
<b>Product Flexibility</b>	It is the ability to manufacture multiple products on the same capacity and to reallocate the capacity between products in response to realized demand.
<b>Quantity Flexibility</b>	It is the ability to procure, produce or deliver in different quantities.
<b>Timing Flexibility</b>	It is the ability to procure, produce or deliver at different times.

### 3.2. Flexibility strategies and configurations

There is not a single approach to achieve supply chain flexibility but the different environments can suggest different approaches to achieve flexibility. The various flexibility strategies are mainly used to mitigate a particular risk exposure. However the focus on various flexibility configurations has become a necessity in the network-based businesses nowadays because each and every business either local or global shares a common structure in order to increase competitiveness in such a complex and turbulent marketplace. Studies have concluded that, given a service level the quantity of the common material under postponement strategy is significantly less than the quantity of common material without using postponement strategy [46]. Christopher Tang et al. [8] had focused on how firms can use various flexibility strategies as defensive mechanisms for

mitigating the supply chain risks. Elcio M. Tachizawa et al. [13] conducted analysis that how the different sourcing practices are combined to form particular supply chain flexibility strategy (integrated, domestic, offshore). To do this a survey among Spanish purchasing professionals was conducted. Stephen C. Graves et al. [37] had identified two phenomena; stage spanning bottlenecks and floating bottlenecks which reduces the effectiveness of a flexibility configuration and had also developed a flexibility measure 'g' and subsequently showed that increasing this measure 'g' results in greater protection from these supply chain inefficiencies.

The theory of operational research was used by Jing Jing Zhou et al. [25] to see the usefulness of flexibility in mitigating the supply chain risks and a limited flexibility can achieve nearly all the benefits of total flexibility at lower costs. [9] Had proposed a simulation model to evaluate the performance of different flexibility configurations (no flexibility, limited flexibility, total flexibility) of a supply chain. Jiri Chord et al. [21] analyzed the effects of two key drivers of flexibility (demand variability and demand correlation). They had shown that with the additional flexibility gained from responsive pricing, the firm can maximize the benefits of favourable demand conditions and mitigate the effects of poor demand conditions and hence profiting from variability. Positive demand correlation, on other hand remains undesirable under responsive pricing.

The authors have identified five types of flexibility strategies which are explained in table 3 and the three types of flexibility configurations are shown in figure 2.

Table 3. Flexibility strategies.

<b>Flexible Supply Strategy Via Multiple Suppliers</b>	<b>Both Intercom Japan and Li and Fung can make use of multiple suppliers to reduce supply cost risks.</b>
<b>Flexible Supply Strategy Via Flexible Supply Contracts</b>	To reduce the supply commitment risks, Canon agreed to allow HP to adjust their order quantity upward or downward by no more than few percent.
<b>Flexible Process Strategy Via Flexible Manufacturing Process</b>	To reduce production cost, Texas Instrument (TI) organized their LCD watch manufacturing facility according to an assembly line. This assembly line was efficient for producing high volume of a few models of LCD watches at low cost but when Seiko introduced many different models of LCD watches; TI was unable to use this inflexible assembly line to compete on cost and product variety.
<b>Flexible Product Strategy Via Postponement</b>	HP delayed the point of differentiation until the last stage of the process would offer HP the highest level of product flexibility for mitigating demand risks.
<b>Flexible Pricing Strategy Via Responsive Pricing</b>	When the supply of certain components from Taiwan was affected by earthquake, Dell's response was to lower the price of certain products so as to make shift the demands of online customers to other Dell computers.

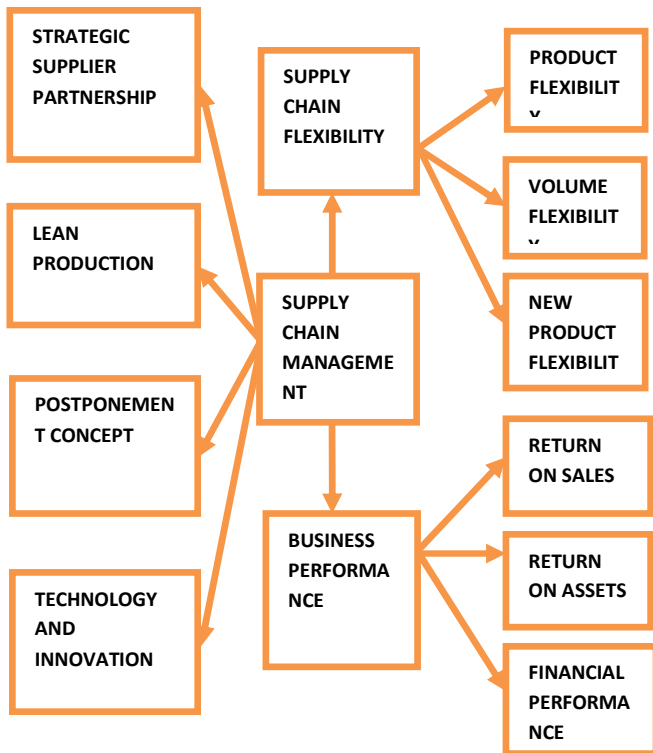
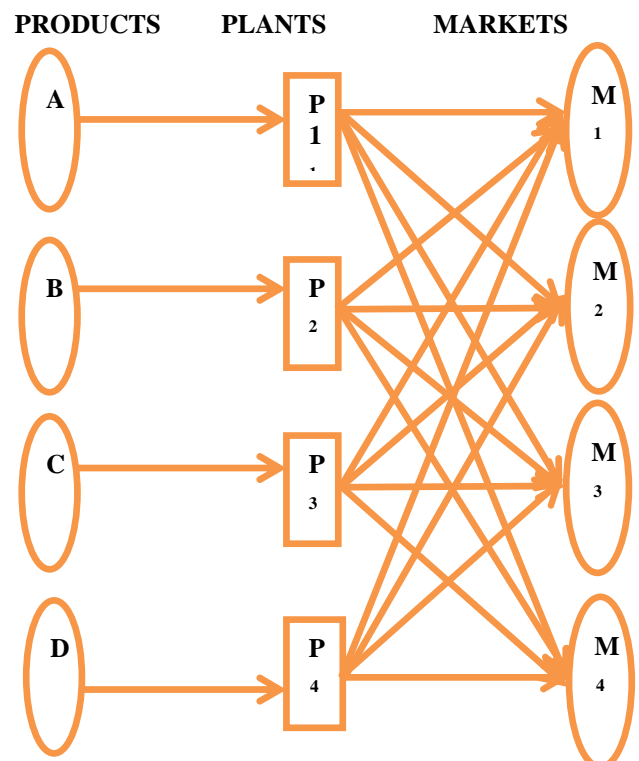
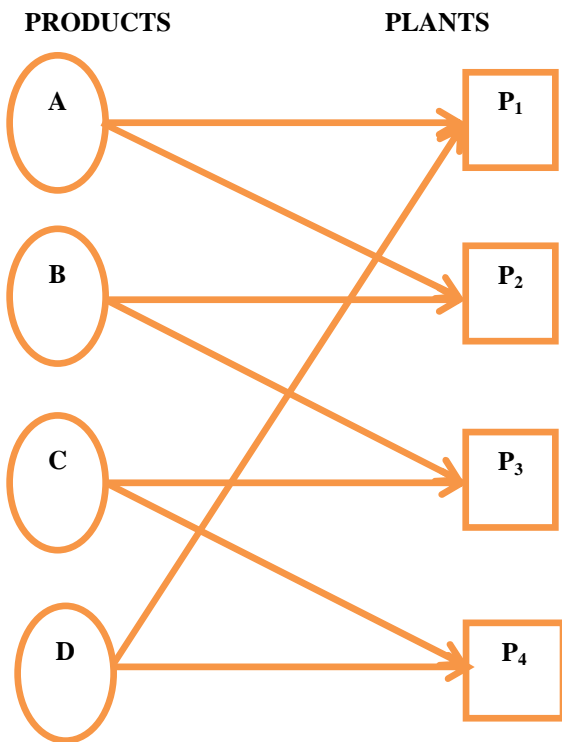


Figure1. Impact of supply chain flexibility.

(a) No Flexibility.





(c) Total Flexibility.

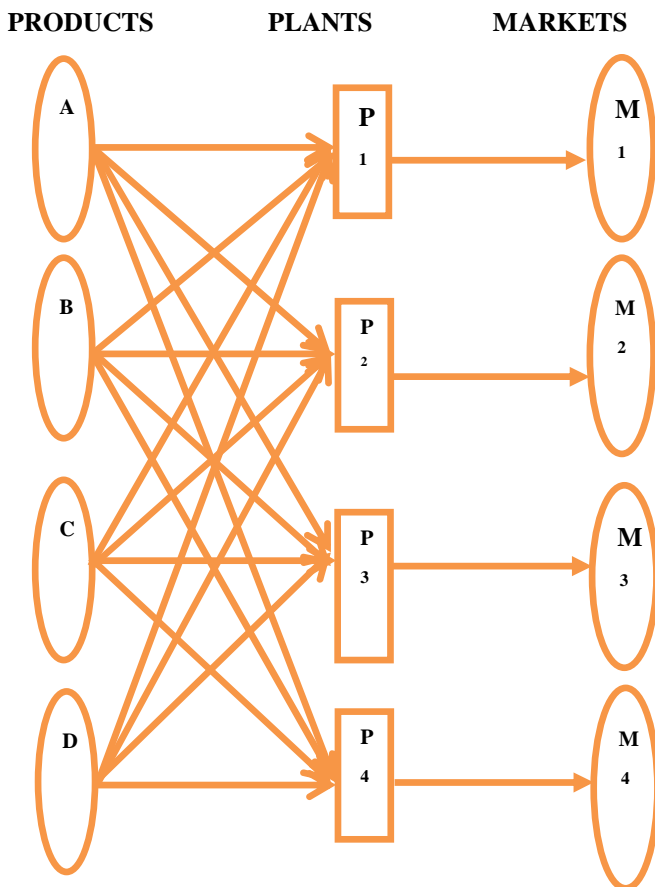


Figure 2. Flexibility Configurations

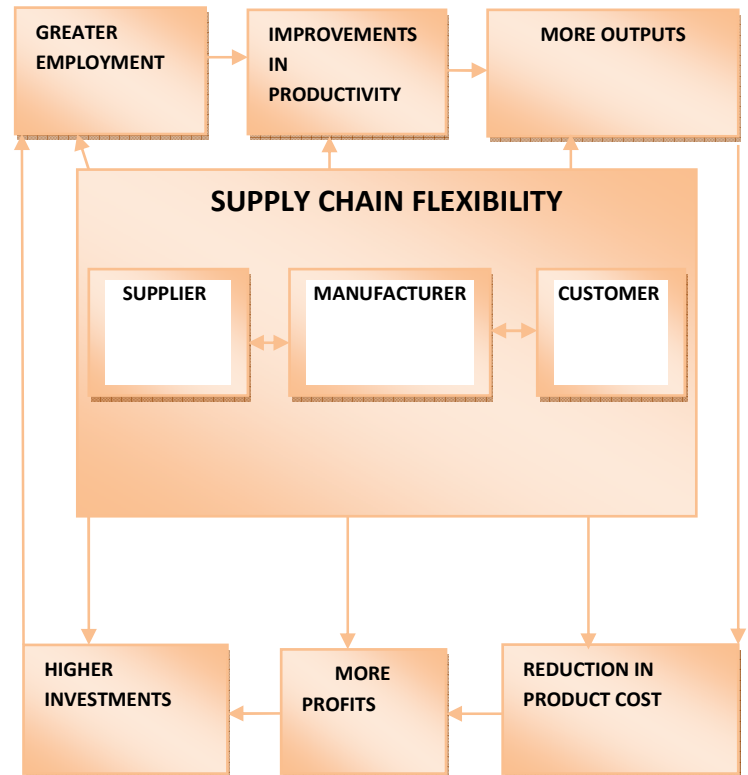


Figure 3. Impact of Flexibility on Business Performance

3.3. Simulation

Simulation has become a standard tool in business. In manufacturing, simulation is used to determine the production schedules, inventory levels and maintenance procedures to plan capacity, resource requirements and processes; and more. In services, simulation is widely used to analyze waiting lines and schedule operations. Often when a mathematical technique fails, we turn to simulation. There are very few authors which had used simulation in general and ARENA simulation software in particular to study flexibility in supply chains. Thananya Wasusri et al. [39] had developed a simulation model representing key supply chain operations namely fabrication, dyeing and garment. Simulation is used to investigate those uncertainties and the significant factors affecting operational and customer performance. The simulation results show the major impact from synchronized sourcing and production plan. Subhash Wadhwa et al. [36] demonstrated in their work the importance of simulation for the improvement of decision making and controlling of flexible manufacturing systems. Anuj prakash et al. [6] studied the impact of horizontal collaboration in flexible supply chains by using ARENA simulation software. [21] Had proposed a simulation model to evaluate the performance of different flexibility configurations (no flexibility, limited flexibility, total flexibility) of a supply chain. Guilherme E. Vieira [18] had developed a conceptual model that can be used in the

creation of certain types of supply chain simulation projects. The supply chain considered is composed of four elements: suppliers, manufacturer, retailers and the consumer market. Razman Bin Mat Tahar [30] simulates a production facility that manufactured car based on simulation model. The amount of products and the time saving showed the difference between before and after using simulation. The obtained data from the model can be applied to select the line produce to achieve optimum product. Finally, by introducing the model the company could explore new policies, operating procedures and organizational structures without disrupting ongoing operations.

### 3.4. Models and theories

The various models and theories has been developed by research scholars to elucidate the degree of flexibility required to mitigate the supply chain risks and outputs from these models can assist the firms in making the suitable production decisions under uncertain environment. An economic evaluation model of supply chain flexibility was studied by [47]. In this they concluded that the improvement of the most important factors gives greatest contribution to the system flexibility (labour flexibility, machine flexibility, routing flexibility) and however the improvement of unimportant factors provides less contributions to system flexibility. Saadettin et al. [34] had modelled the supply chain where the buyer has two options in each supply instance: (1) to place an order below the supplier specified minimum quantity and pay penalty or (2) place no order and loose the sales for the current period; these two options allow the buyer to substantially reduce inventory risk when demand is highly uncertain. The index system for the measurement of supply chain flexibility from the point of the whole value added system was proposed by Bing Wu et al. (2008). The findings of the study done by Arawati Agus [1] suggests that the supply chain management would be able to support and accommodate supply chain flexibility as well as increase the level of business performance as shown in the figure 3.

Wang Gui Hua [41] had used extension theory for the evaluation of supply chain flexibility. Adaptive Neuro Fuzzy Inference system was used by [19] to solve the problems arising during supply chain flexibility measurement. Robert S. Collins et al. [19] had conducted the empirical study of the rigid flexibility model by using made in Europe and made in Switzerland database and concluded that flexibility in manufacturing and thereby responsiveness in market requirements is achieved through simplicity in process and discipline in procedures. Option theory provides a useful way of linking flexibility to robustness was clearly stated by [35]. Paul Swamidass [28] had developed a regression model to conclude that the profitability is highest when an inflexible plant uses small inflexible suppliers. Profitability is above average when a flexible plant uses flexible small suppliers. In contrast, if there is a mismatch of plant flexibility with supplier flexibility, the profitability is below average. The empirical data is collected from U.S manufacturing plants operating in India and their small suppliers. A

mathematical model to evaluate supply chain performance and supply chain flexibility using some key performance indicators was attributed to Ugur Bac [40]. The theory of operational research was used by Jing Jing Zhou et al. [21] to see the usefulness of flexibility in mitigating the supply chain risks and a limited flexibility can achieve nearly all the benefits of total flexibility at lower costs. P. Fredrikson et al. [28] concluded that in order to customize at reasonable cost a supplier must combine the potential for flexibility offered by the principle of build-to-order production with elements of the rigidity associated with mass production systems.

### 4. Research Gaps in Literature Survey & Future Research Directions

Despite profound contributions by research scholars and academicians of national and international repute on the topic of supply chain flexibility. The literatures reviewed still have a wide range of gaps which are to be addressed in the upcoming years with focused dedication so as to enhance the concept of supply chain flexibility in order to bridge a gap between underdeveloped, developing and developed nations.

Authors hereby proposed some important directions in supply chain flexibility research:

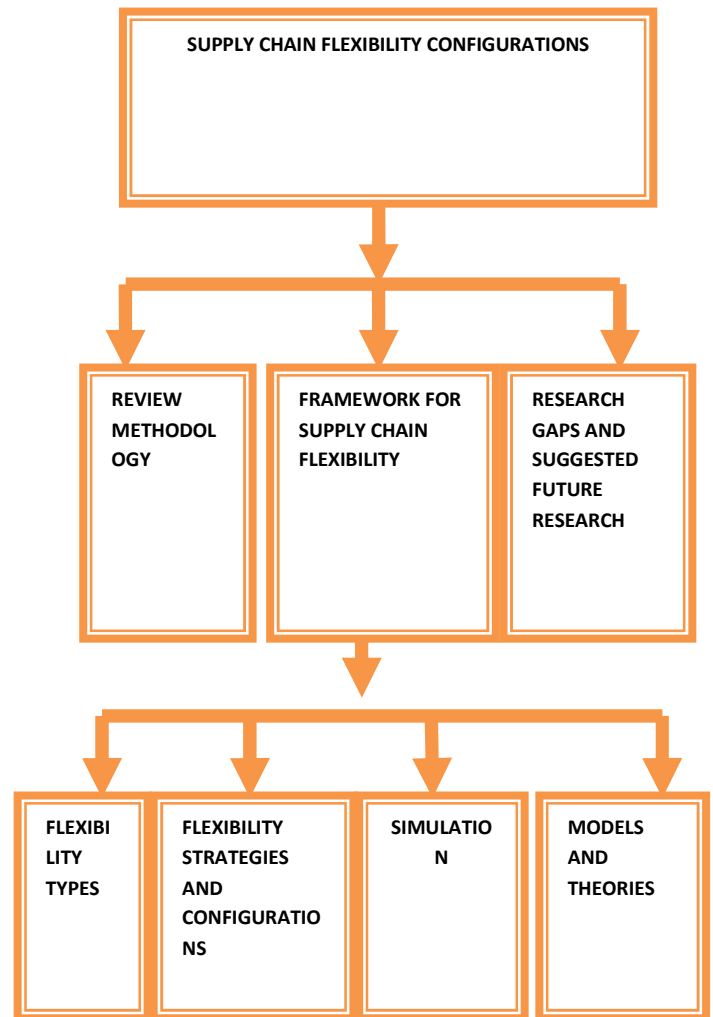
- A lot of work has been done on evaluating the impact of supply chain flexibility on firm performance but emphasis should also be laid down on the effect of supply chain flexibility on supply chain performance.
- All the previous work done on supply chain flexibility does not give same results when applied to different supply chains in other countries. So, to some extent there should be a focus on the generalized research applications rather than some particular product or company or country specific.
- Very few academicians had used simulation in general and ARENA simulation software in particular for studying supply chain flexibility. So, future researchers must focus on using ARENA simulation software.
- It has been shown by [43] the impact of vendor managed inventory (VMI) strategy for improving supply chain flexibility but nothing has been stated about the effect of supply chain flexibility on vendor managed inventory.
- Most of the research is limited to single stage production delivery system but as usually the multistage production system is the most common operational characteristic of many industries, so it requires expert attentions.
- In order to improve and verify the supply chain flexibility models; a wide range of empirical research of problems must be carried out for future research.

- A large number of models have been used for measuring flexibility but further research is required to compare the efficiency of the different models.
- It has to be investigated that how flexibility meets demand volatility and at the same time deal with external market disruptions or the long term and strategic perspective.
- In order to represent the large number of practical implementations; future research must be focused on consideration of flexibility in highly complex supply chains.
- A lot of research work has been done on studying different flexibility strategies but to examine the compounding effect of a combined strategy is a future research topic.
- Another useful avenue for future research is to compare volume flexibility responses of make-to-order (MTO) and make-to-stock (MTS) firm.
- How can vendor flexibility for a framework agreement supplier is developed will also guide the future research into this direction.
- For a supply chain cannot be created merely by a single manufacturing company within a chain, thus assessment should also include inter organizational flexibility.
- The degree of flexibility should match the requirements; otherwise a supply chain may be too low (under design) or too high (over design).
- Suppliers sometimes may provide too much flexibility which is not valued by customers to the greater extent; so the analysis of network flexibility needs to be further deepened to include the consequences of the ‘balancing problem’ [11].

**5. Conclusion and Discussion**

The above discussion shows that research in supply chain flexibility is multifaceted. The review shows that research publications in the field of supply chain flexibility are increasing especially after 2001 and therefore it shows the growing trend among the firms to incorporate flexibility strategies in their supply chains to get a competitive advantage. We have used content analysis method to show a holistic perspective of flexible supply chains from inputs to outputs and then to inputs again. This paper presents a comprehensive literature review of the journal papers on flexibility in supply chain management, published during 1991 to 2011. Figure 4 shows the various topics covered by our literature review on the basis of the previous work done by reputed researchers and academicians for studying flexibility in supply chain management. Different authors had developed different models and frameworks for studying flexibility in supply chain management. As stated at the outset of this paper, the literature on flexibility to date has been weak in terms of establishing

probable connections between flexibility in operations and firm’s strategy, competitive environment and business performance. This paper develops a new framework for implementing and managing supply chain flexibility based on the limited existing literature and gives a considerable comprehensive analysis of supply chain flexibility. A major implication of this research is that the thoughts and methods of practicing supply chain flexibility and the framework can help managers to implement and manage supply chain flexibility and it provides a very good starting point for researchers to conduct exploratory and confirmatory research on supply chain flexibility. Unfortunately, different theories of supply chain flexibility have led to diverse and separated application and so through this review paper we have tried our best to install convergence in such a vast topic so that more generalized research findings should come in the upcoming years by our world renowned supply chain experts, academicians and research scholars.



**Figure 4.** Topics covered in Literature Review.

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