EVALUATING SUPPLY CHAIN RESILIENCY STRATEGIES IN THE INDIAN PHARMACEUTICAL SECTOR: A FUZZY ANALYTIC HIERARCHY PROCESS (F-AHP) APPROACH

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ABSTRACT

Over the years, aggressive competition and globalization have resulted in tremendous progress in the development and management of supply chains. There are many high-performing supply chains that have benefitted from globalization. However, globalization of supply chains has also resulted in exposure to increased risks and frequent disturbances at various stages. One way to address these disturbances is to make supply chains resilient in nature. This paper identifies and prioritizes a set of important resiliency strategies for supply chains using the Fuzzy Analytic Hierarchy Process (F-AHP). Responses from 23 experts from the Indian pharmaceutical sector have been analyzed. We found that supply chain agility, visibility, and collaboration were the three most important resiliency strategies that a pharmaceutical organization should follow to address the vulnerability within their supply chain. The findings will serve the supply chain managers and the policymakers in designing resilient supply chains through the better understanding of strategies and formulation of action plans, while also introducing MCDM techniques into resiliency studies.

Keywords: Multi-criteria decision-making (MCDM); supply chain resilience; resiliency strategies; Fuzzy Analytic Hierarchy Process (F-AHP); Analytic Hierarchy Process (AHP); Indian pharmaceutical sector

1. Introduction

The rapid shrinkage in the product and technology lifecycle, coupled with ever-changing (and unforeseen) customer preferences has forced organizations to change their operational processes. Organizations are no longer considered isolated islands, but rather as inter-connected networks functioning in harmony to achieve common objectives. One way to achieve this is to design and maintain an efficient supply chain that would serve as an important means for achieving a competitive advantage. However, in addition to the shortening life-cycle of products and technology, continuous and uncertain changes in customer demands and preferences have also resulted in extremely complex supply chains. This has led to more vulnerable supply chains. It has been observed that supply chains have been on the receiving end of a number of natural and manmade emergencies, like floods, earthquakes, fire, terrorist attacks and so on. As a weapon to combat these disruptions, organizations have started designing their supply chains in a manner that can respond to these disruptions, and also actually recover to their original state, or even better, which is known as supply chain resiliency (Christopher & Peck, 2004; Ponomarov & Holcomb, 2009). Resiliency ensures an uninterrupted supply of goods and services to an organization as well as their customers, even after suffering an unforeseen disruption, which can lead to revenue generation and a competitive advantage. In addition, it leads to reduced customer perception of assumed risks fostering risk resilient growth (Ambulkar et al., 2015; Ganguly et al., 2018a). The concept of resiliency stretches beyond just recovery and into the domain of flexibility, adaptability, maintenance, and recovery, becoming an important and sustainable component of success among organizations (Ponomarov & Holcomb, 2009; Hamel & Välikangas, 2003; Stoltz, 2004).

Supply chain resiliency is defined as an organization's ability to react to negative effects caused by disturbances that occur across supply chains (Barroso et al., 2010). Shuai et al. (2011) compared resiliency to cell biology and stated that it is just like cell elasticity i.e. the ability of a cell to come back to its original structure after being subjected to certain stress. A resilient supply chain exposed to disturbances can mutate to adapt to the internal and external environment. Furthermore, resiliency has become a critical component in present-day supply chains in order to combat external and internal vulnerabilities, along with being restored to a stage of equilibrium, and in the process ensuring higher efficiency and performance levels (Longo & Oren, 2008). Therefore, a resilient supply chain has the ability to thrive and survive in the face of unexpected and turbulent changes. The importance of supply chain resiliency has astronomically elevated in the last two decades, and organizations are trying to design various supply chain resiliency strategies to stay ahead of their competitors. The resiliency strategies have been broadly categorized into two types – proactive and reactive strategies – depending on the nature of the supply chain and the organization in general. Tukamuhabwa et al. (2015) stated that most of the supply chain strategies highlighted in the literature are proactive rather than reactive in nature, and therefore are expected to continue 'operations as normal.' They further argued that although proactive strategies are desirable to minimize vulnerability in supply chains, managers might be reluctant to justify investments in strategies to mitigate potential disruptive events that may not eventually occur. As a result, a careful trade-off between the selection of proactive vis-à-vis reactive supply chain resiliency strategies should be considered as part of the supply chain resiliency strategy selection for an organization.

As observed from the extant literature, substantial academic and practitioner-based research is available on identification and discussion of supply chain resiliency strategies. The strategies discussed are from a proactive and a reactive perspective, and from an organizational and an individual level. However, during the literature review we observed

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that though there were multiple research papers discussing strategies for supply chain resilience, limited research work has identified and discussed the relative importance of a set of critical strategies that might aid an organization in improving the efficiency of its supply chain, especially in the context of the Indian pharmaceutical sector. The current research attempts to shed some light on this issue and tries to bridge this gap through initially identifying a set of critical strategies (separating the vital few from the trivial many) associated with supply chain resiliency, and subsequently prioritizes through assessment of their relative criticality.

The pharmaceutical supply chain is considered a "systemic network of a set of complex processes, operations and organizational structure which is involved in the discovery, development, and manufacturing of medications" (Ganguly et al., 2018a). The Indian pharmaceutical sector is one of the largest producers of generic pharmaceutical drugs in the world and a major contributor to the Gross Domestic Product (GDP) in the country. Since the operational process of Indian pharmaceutical companies is comprised of sales and distribution of generic as well as branded drugs, efficient procurement and inventory management, logistics and distribution have become important ingredients for the pharmaceutical companies for operational efficiency. Additionally, the growing importance of reverse logistics, coupled with recycling, disposal, scheduling, and planning has elevated the importance of the supply chain among the pharmaceutical companies, thereby making it important for the pharmaceutical companies to design and develop efficient supply chains which are resilient in nature (Narayana et al., 2014).

The multi-criteria decision-making (MCDM) model of Fuzzy Analytic Hierarchy Process (F-AHP) is used to assess the relative criticality of the identified strategies, thereby adding to the novelty of the current investigation. F-AHP, which stemmed from the basic AHP model, allows the experts to use fuzzy ratios in place of exact ratios (Saaty, 1980, 1990, 1994; Buckley, 1985; Buckley et al., 2001). The basic advantage of F-AHP over its traditional counterpart (AHP) is that it allows the respondents to provide vague or imprecise replies when comparing two alternatives in a hierarchical analysis (Buckley, 1985). The AHP's subjective judgment, selection and preference of decision-makers often cannot reflect the human thinking style. Additionally, the fact that the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications might lead to an unbalanced scale of judgment. Therefore, avoiding these risks on performance, fuzzy AHP, a fuzzy extension of AHP, was developed to solve hierarchical fuzzy problems. (Özdağoğlu & Özdağoğlu, 2007). Buckley (1990; 1992; 1995) used the application of fuzzy AHP in decision making with great success and Buckley et al. (2001) enlisted a three-step process for calculating fuzzy AHP which includes finding the crisp solution, fuzzifying the crisp solution, and using the fuzzified crisp solution to determine the solution to the fuzzy problem. Considering the risks associated with a conventional AHP analysis, the authors decided to use fuzzy AHP as the preferred technique in the current study.

Beginning with a review of concepts of supply chain resiliency and F-AHP, this paper subsequently goes on to identify a set of strategies that are expected to improve supply chain resiliency of pharmaceutical organizations. The identified strategies are then prioritized using F-AHP to assess their relative criticality. The findings of this study are expected to serve as an important roadmap towards understanding the relative importance

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of the strategies that can be subsequently adopted as part of the organization's operational planning process.

2. Review of the extant literature

2.1 Resilient supply chains

The concept of resilience, which stems from the Latin word *resilīre* meaning 'to spring back or rebound,' is the ability of a substance or object to spring back into shape (Ganguly et al., 2018a). Resilience is concerned with the ability of systems to absorb changes and return to an equilibrium state after a temporary disturbance (Ponomarov & Holcomb, 2009). Although the concept of resilience originated from the domain of pure science, it has subsequently filtered down to other domains of engineering, social sciences, and business management (Clapham, 1971; Holling, 1973). A supply chain is one of the latest inductees into this group. Earlier studies in supply chain resiliency were conducted in the UK in the early 21st century, following the (in)famous fuel protests in 2000 that caused considerable disruption in transportation (Pettit et al., 2010). The concept of supply chain resiliency was subsequently studied and crystallized by Christopher and Peck (2004), who were the first to develop a framework for a resilient supply chain. Christopher and Peck (2004) further suggested that resiliency in a supply chain can be created through a basic set of principles and can serve as one of the most powerful strategies in combating supply chain disruptions. Around the same time, Sheffi & Rice Jr. (2005) concluded that a resilient supply chain not only aids an organization in managing risks, but also helps it to be better positioned than the competition and even gain an advantage from disruptions. Over the years, the importance of supply chain resiliency has grown exponentially, especially in the face of globalization and persistent uncertainties. Recently, there has been a lot of focus on supply chain resiliency, especially in the context of supply chain disruption and sustainability. Resiliency has also been a key focus in evaluating the robustness of a supply chain with the idea that there are certain features that if engineered into a supply chain can improve its resilience (Yadav et al., 2011; Soni et al. 2014).

Integrating resiliency into supply chains helps them efficiently and effectively recover from disruptions. It should be noted that resiliency does not guarantee elimination of risks, but ensures speedy and efficient recovery following a disruptive event. Furthermore, a resilient supply chain does not always translate into a low-cost supply chain, but is definitely more capable of coping with uncertainties (Carvalho et al., 2012). Therefore, resilience allows an organization to manage disruptions in the supply chain and continue to deliver their products and services to customers (Ambulkar et al., 2015). Sheffi & Rice Jr. (2005) argued that resiliency is a major weapon for competitive advantage in the face of unforeseen disruptions, and building redundancy and flexibility into the system can be useful strategies in combating the same. Pettit et al. (2010, 2013) proposed two important constructs for resiliency – vulnerabilities and capabilities. They termed the optimal balance between the two as the 'zone of balanced resilience'. Therefore, the goal of a resilient supply chain is to recover to the desired state of the system that has been disturbed within an acceptable time and at an acceptable cost as well as to reduce the impact of a disturbance by changing the impact of a potential threat (Haimes, 2006). As a result, a resilient supply chain needs to have the ability to use the lowest possible amount of resources during the recovery process, and the supply chain that incurs the lowest resiliency cost will be considered the most resilient supply chain (Vugrin et al., 2011).

Over the years, researchers and industry executives have conducted numerous studies concerning strategies to develop resilient supply chains. The strategies discussed by the researchers range from increasing supply chain visibility (Calvalho et al., 2012b; Glickman & White, 2006; Kraft et al., 2018; Pettit et al., 2010, 2013; Zhang et al., 2011) and flexibility/agility (Christopher & Holweg, 2011; Ganguly et al., 2018a, 2018b; Pettit et al., 2013; Rice & Caniato, 2003; Sheffi & Rice Jr., 2005; Tang 2006; Tang & Tomlin, 2008) to greater knowledge management (Christopher & Peck, 2004; Rice & Caniato, 2003; Ponis & Koronis, 2012; Ponomarov & Holcomb, 2009; Urciuoli et al., 2014) to appropriate supplier selection (Mascaritolo & Holcomb, 2008). However, while reviewing the strategies associated with designing a resilient supply chain, we observed that while being very generic in nature, researchers also did not separate the strategies from the 'trivial many' to a set of the 'vital few.' Additionally, prior research has also overlooked prioritizing the identified strategies to assess their relative criticality which, if listed, would aid the policymakers in formulating a better action plan for developing a resilient supply chain. The current study attempts to focus upon this important, but undiscussed issue.

2.2 An overview of the Indian pharmaceutical sector

The Indian pharmaceutical sector, which holds an important position in the global pharmaceutical industry, is one of the key drivers of growth in India. According to a report by PwC India in 2018, the Indian pharmaceuticals market is the third-largest in terms of volume and thirteenth-largest in terms of value, along with being the global leader in providing generic drugs to the world. As a result, the importance of the pharmaceutical sector in India has attracted enormous interest from academicians and practitioners alike.

The pharmaceutical sector in India has been viewed through multiple research lenses. Athreye et al. (2009) studied the dynamic capabilities of four large Indian pharmaceutical firms for international collaboration and R&D and innovation. Kale & Little (2007) studied the process and stages involved in the Indian pharmaceutical sector's transition from an importer to generic exporter to innovator. Chittoor & Ray (2007) studied the internationalization strategies of 40 Indian pharmaceutical firms and their use of conventional market exploitation and exploration strategies towards becoming third world multinational corporations. A study of changing patent laws and the stringent regulatory environment in India and China by Grace (2004) found that the enhanced IP protection laws result in revenue losses and increased emphasis on export in profitable regulated markets. Similar outcomes were evidenced by Greene (2007) during the study of the Indian pharmaceutical industry and their effect on the American pharmaceutical market post-2005. Saranga (2007) used the DEA to analyze how inefficient Indian pharmaceuticals firms can manage buyers, vendors and other peer groups post-2005 due to the new Intellectual Property Protection laws. Kar & Pani (2014) studied supplier selection and evaluation using AHP for 188 Indian firms across 12 industries including pharmaceutical industries with attributes applicable to all firms. However, no research work has discussed supply chain resiliency for the Indian pharmaceutical sector, and the

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current study is expected to understand the same using Fuzzy Analytic Hierarchy Process approach.

2.3 Selection of Fuzzy AHP for the study

Fuzzy AHP's ability to identify and prioritize attributes has been used extensively within various decision-making processes in the different areas of management research. Junior et al.'s (2014) comparison and sensitivity analysis of F-AHP and F-TOPSIS found that F-AHP performs better in terms of time complexity and allowing inclusion of sub-criteria into a hierarchical structure. Further, F-AHP performs better in terms of modeling uncertainty with an objective of supplier elimination (Junior et al., 2014). Triantaphyllou & Lin (1996) stated that F-AHP fairs only second to Fuzzy Revised AHP, and is better than F-TOPSIS and other MCDM methods, and more capable of managing human decision-making ambiguity in a complex environment and with real-life data. Further, a comparative analysis of F-AHP and F-TOPSIS for the selection of facility location by Ertuğrul & Karakaşoğlu (2008) found that both provide similar and consistent ranking of criteria. However, F-AHP has more flexibility in terms of a hierarchical spread of attributes. A study to identify an operating system by Balli & Korukoğlu (2009) found that F-AHP is a useful technique for the evaluation of complex multi-criteria alternatives with subjectivity, while TOPSIS is more tuned towards ranking alternatives. Similar observations have been made by Tadic et al. (2009) while evaluating quality goals in an organization and use of F-AHP was found less mathematically cumbersome and more attuned to weight linguistics and qualitative attributes as opposed to TOPSIS. We will build upon these previous studies by substantiating the use of F-AHP in scenarios where qualitative decision-making judgements are to be taken to provide weights for the attributes.

2.4 Overview of Fuzzy AHP

The Analytical Hierarchy Process (AHP) is a multi-criteria decision-making technique for prioritization of alternative attributes when multiple attributes influence the decision-making process (Saaty, 1980; Ganguly & Merino, 2015). It (AHP) attempts to achieve consistent pairwise judgments through use of the properties of reciprocal matrices and allows one to rank the actions, criteria, objectives or any attribute relevant to the decision (Hughes, 2009). The initialization of the AHP analysis requires the construction of a hierarchy describing the problem statement and then deconstructing it in a hierarchical structure. There are no limitations regarding the number of levels in the hierarchy breaking down the analysis structure in attributes and sub-attributes to substantiate the problem statement and its characteristics (Dave et al., 2012). The problem statement or the objective resides at the top of the hierarchical tree, followed by attributes and sub-attributes. The bottom level consists of alternatives providing the selection set. Elaboration of the AHP model is done after the construction of the hierarchy. Through a set of pairwise comparison of attributes at the same level, a matrix of relative importance is developed. The pairwise comparisons require the respondents to compare the siblings based on their relative importance to each other. The relative importance is based on a numerical scale with siblings on each side of the scale. This allows the respondent to weigh the pair and provide the relative importance for one of the siblings or select neutrality.

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Though the ease of use of the AHP has made is one of the most widely used decision-making techniques, the use of a 9-point scale is considered one of the major shortcomings of the method, as it sometimes is not able to cater to the uncertainty in the decision-making process (Kilincci & Onal, 2011). The AHP lacks the ability to allow decision-making in uncertain situations when preferences are not objective in nature due to information asymmetry, complexity and other uncertain attributes of the environment (Nieto-Morote & Ruz-Vila, 2011). As a result, fuzzy numbers and scales have been developed to consider this issue in decision-making. Over the years, fuzzy sets have been subsequently extended to type-2 fuzzy sets, intuitionistic fuzzy sets, hesitant fuzzy sets, Pythagorean fuzzy sets, and neutrosophic sets, while new extensions of fuzzy AHP have been proposed by various authors accordingly (Kahraman, 2018).

Introduction of fuzziness within the AHP technique allows this uncertainty to be considered, and the improved technique is called Fuzzy-AHP (F-AHP). This insertion of fuzzy theory into the traditional AHP allows one to account for the vagueness in the respondent's judgment (Ayhan, 2013). Due to the fuzzy characteristic of F-AHP, determination of weights based on pairwise comparison becomes slightly complex for computation (Nieto-Morote & Ruz-Vila, 2011). The refined method uses triangular fuzzy numbers along with linguistic variables for alternative comparison for priority derivation of different selections (Kilincci & Onal, 2011). Using the triangular fuzzy numbers as a replacement for the 9-point scale of the traditional AHP, F-AHP successfully deals with the uncertainty of the decision-making process. The F-AHP uses the extent analysis method for the pairwise analysis and calculates synthetic extent values for the same (Kilincci & Onal, 2011). After finalization of the weights, the normalized weights are calculated. Further, priority weights of the final alternatives are computed through the use of varied weights of criteria and attributes. The alternative with the highest value is chosen as the preferred one, or is the most important attribute, whatever the case may be. The comparison between AHP and F-AHP method has been provided in Table 1.

Table 1
Comparison of AHP vis-à-vis F-AHP scales (Adapted and modified from Ayhan, 2013)

AHP Scale	**Definition**	**F-AHP scale**
1	*Equally important*	(1,1,1)
3	*Somewhat important*	(2,3,4)
5	*Fairly important*	(4,5,6)
7	*Strongly important*	(6,7,8)
9	*Extremely important*	(9,9,9)
2,4,6,8	*The intermittent values*	(1,2,3), (3,4,5), (5,6,7), (7,8,9)

Following the above F-AHP scale, if *attribute A* is strongly preferred over *attribute B*, then it is denoted by the fuzzy triangular scale as (6, 7, 8) and its inverse as (1/8, 1/7, 1/6)

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and so on. Based on this scale, the relative prioritized weights at each level of the hierarchy is determined, which is subsequently used to arrive at the final alternative.

2.5 Prior efforts in using AHP and Fuzzy AHP in supply chain research

AHP and Fuzzy (F) – AHP have been used extensively for various kinds of attribute-based analysis in supply chain management. A study done by Mardani et al. (2015) found 23 (6%) supply chain management papers out of 393 papers reviewed between 2010 and 2014 used AHP, second only to the number of papers in the research area of energy, environment and sustainability. Identification of attribute weights for both qualitative and quantitative attributes has been used for prioritizing suppliers in a resilient supply chain (Rajesh & Ravi, 2015). López & Ishizaka (2017) have analyzed threats to supply chain resilience arising from offshore outsourcing location decisions using AHP along with fuzzy cognitive maps, and they conclude that offshoring might lead to reduced flexibility, financial strengths and recovery capacity of supply chains. Wang et al. (2017) used AHP to analyze the resilient nature of the green construction supply chain. Their study found that product quality, commodity cost, legal environment, new technology, service distance and level of informalization etc. had higher weights than time, quantity and service flexibility. Ho et al.'s (2015) literature review of supply chain risk management identified the AHP as one of the top five techniques along with mathematical modeling, news vendor model, simulation and game theory. Risks in operations areas like machine and equipment failure, design risks and skilled labor scarcity were found to be the most critical ones for green supply chains rather than supplier based, demand forecasting, financial or product recovery for an F-AHP study by Mangla et al. (2015). A study of the supply chain for petroleum products from a disruptions perspective using F-AHP found transparency, flexible transportation, secure communication networks, and human resource management as the most weighted attributes from the overall supply chain resiliency perspective (Ghasemzadeh et al., 2017). An analysis of 288 peer-reviewed articles published between 2000 and 2017 from the supply chain resilience perspective found the AHP as one of the most used techniques among MCDM after mathematical modeling (Kochan & Nowicki, 2018). Use of AHP for supplier selection based on supply chain resiliency in south-east Asian countries like China, Vietnam and Hong Kong found that robustness, reliability, and rerouting are the most important attributes (Hosseini & Al Khaled, 2016).

Adebanjo et al. (2016) studied lean supply chain management in healthcare services operations using F-AHP and found that operational performance and financial factors are the important attributes describing 96% of the initiatives for lean management. Ayhan (2013) analyzed the supplier selection problem for a gear motor company using F-AHP, and the study found quality and origin of raw material as the two most important attributes, others being cost, delivery and after-sales services. Chen & Yuan (2013) used AHP to select outsourcing destinations in east and south-east Asia, and found that based on analysis of costs, human resources, the business environment, and the policy and legal environment, China, Philippines, and Singapore are the best destinations with cost considerations being the major driving factor (0.44) and the other three attributes scoring nearly equal weights (0.18-0.19). Kahraman et al. (2003) used F-AHP to understand the perspective of purchasing managers of white goods in supply chains in Turkey for supplier selection, and found that Supplier Criteria (0.43) and Product Performance (0.37) outweigh Service Performance (0.20). Among the sub-attributes Financial Performance

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of Supplier Criteria (0.70) and Professionalism (0.95) in Service Performance outweighed other sub-attributes. Patil & Kant (2014) have developed a Fuzzy AHP-TOPSIS method to provide ranking for solutions for overcoming knowledge management barriers in supply chains. Application of AHP for selection of building material suppliers among 10 USA-based suppliers found that tender price (0.25) and life-cycle cost (0.17) were the most weighed attributes among 10 attributes (Plebankiewicz & Kubek, 2015). Supplier selection among 7 regional contractors for a clothing company in Turkey based on the minimum and maximum order quantity, under or over achievement and other mathematical programming constraints found that product quality (0.51) and delivery capability (0.24) have higher values than service capability (0.19) and product discount (0.06). For the selection of a lead-free equipment supplier, the use of F-AHP found that product compatibility, response and maintenance time, and upgrades and expansibility share nearly 50% of the attribute weights among seven attributes (Tang & Lin, 2011). A study for supplier selection in the Indian manufacturing context using F-AHP found that quality (0.41) and cost (0.25) are the most valued attributes as opposed to delivery, service, long-term relationship and flexibility (Yadav & Sharma, 2015). A study of the garment industries in Bangladesh using Quality Function Deployment and AHP to mitigate supply chain vulnerabilities and develop a resilience index found that the most resilient strategies are building backup capacity, relationship with buyers and suppliers and quality control (Chowdhury & Quaddus, 2015). The AHP has been used to assess the supply chain risk and manage it based on ranking the severity, and its magnitude has been developed by Dong & Cooper (2016). Rathore et al. (2017) used grey-AHP and grey-TOPSIS to develop a risk assessment methodology and have applied this to the food product supply chain. However, in spite of MCDM and AHP establishing themselves as important tools in the domain of supply chain research, their utilization in the area of supply chain resiliency has been sparse. The current study is expected to shed some light on this important but sparsely discussed issue.

3. Research model and methodology

The basic foundation of the current investigation lies on two concatenate research questions which are provided below:

RQ1: What are the important strategies required to design a resilient supply chain?

RQ2: How can an organization prioritize the identified strategies to assess their relative criticality, so that they can design a resilient supply chain more effectively?

Based on the two aforementioned research questions, the objective of the present study was to identify and prioritize a set of strategies that might result in an organization designing a resilient supply chain. The research process started with identifying a set of resiliency strategies and was initially done through a thorough review of the available open literature in the field. Approximately 70 research papers were reviewed on resiliency and supply chain resiliency and an initial laundry list of a set of strategies associated with supply chain resiliency was developed. This set was subsequently narrowed down, through interviews with the subject matter experts, to validate their authenticity as well as filter out the important ones. The subject matter experts, who are pivotal to a successful AHP analysis, were identified after careful scrutiny and consisted of Indian industry professionals having more than 15 years of experience in the domain of supply chain including, being a part of multiple supply chain related projects. In addition, their knowledge regarding supply chain resiliency and disruptions was also taken into consideration as part of the selection process. The discussions and interviews with the SMEs were conducted formally and informally by the authors through telephone, Skype and face to face. Salient points arising out of the discussions were duly noted and subsequently used to finalize the set of resiliency strategies. Furthermore, the data gathered through the interviews of the experts was subsequently analyzed to remove ambiguity and discrepancies. It was observed, that although the experts were interviewed separately, a distinct pattern emerged regarding the relative importance of the strategies in their opinion. Therefore, the top seven strategies, as identified by all the experts were taken as the final set of resiliency strategies and were used for further analysis and prioritization.

Once the final set of strategies was identified, the next stage was to use the experts to prioritize them in order to assess their relative criticality while not compromising the accuracy of the information. A set of 23 subject matter experts in the supply chain field were identified and given an AHP based questionnaire for prioritization of the identified strategies[1]. The questionnaire was designed with a self-administered survey in mind and the experts were briefed about the format of the AHP questionnaire as it varied from its traditional Likert scale counterpart. The data was gathered in the form of a survey questionnaire and was designed for prioritization of the identified risks. The survey was administered to the experts separately and individually in order to eliminate a possible response bias. In this context, it should be mentioned that before the survey was sent out to the targeted experts, a pilot survey was conducted on a small group of four to five industry experts with considerable experience in supply chain management. The purpose of the pilot study was to reveal deficiencies, if any, in the design of the survey before it was deployed within the main study. Some of the issues that were revealed by the pilot study were addressed prior to sending out the final survey questionnaire. The subsequent sections of the paper discuss the identified strategies along with using Fuzzy AHP to prioritize them.

4. Identifying the resiliency strategies

In the present-day business scenario, where the competition is often not between organizations, but rather between their supply chains, a major cause of concern for an organization is the failure of its supply chain. Disruptions have become fairly frequent in supply chains, especially with rapid globalization and increased complexity of the supply chains. The purpose of the current study, as mentioned previously, was to identify and prioritize a set of strategies that would aid an organization in the design of a resilient supply chain. The initial set of strategies was identified based on a thorough review of the extant literature in the field, coupled with discussions and deliberation with experts associated with the production planning and controls and operations. The initial set of strategies were further refined into a final set through additional discussions with the

[1] Since AHP is an expert based decision-making technique, the number of survey respondents was low. Therefore, the number of respondents in the current study was 23, which can be considered a fairly acceptable number for the AHP.

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experts to arrive at a final, condensed set. The final set of the identified strategies are discussed below.

4.1 Increasing supply chain visibility

Christopher & Peck (2004) have defined supply chain visibility as the ability of an organization to clearly see through its supply chain. Pettit et al. (2010) conceptualized visibility as the knowledge an organization can have regarding the status of its operating assets and the environment. Having clear visibility of a supply chain enables an organization to have a clear idea about the entire supply chain, therefore helping detect signals of future disruptions (Tukamuhabwa et al., 2015). In turn, this helps the organization avoid any unnecessary intervention and ambiguous/ineffective decisions in situations of possible disruption, along with quickly responding to disturbances based on real-time assessment (Glickman & White, 2006; Pettit et al., 2013). Greater visibility of a supply chain can also help an organization disclose supply chain resiliency information to its customers, along with having a positive impact on the organization's social responsibility (Kraft et al., 2018). Furthermore, greater visibility in the supply chain is required to increase the level of responsiveness of a supply chain, both from the demand and supply context, which is often considered a key component to combatting disruptions (Williams et al., 2013). Since disruptions in supply chains are considered one of the precursors to resiliency, supply chain visibility was considered one of the key strategies to achieve supply chain resiliency.

4.2 Supply chain agility

For organizations to thrive and grow in the current market, being agile is one of the fundamental aspects needed for success. Agility is the capability of an organization (and its supply chain) to efficiently function in an unpredictable environment marked by continuous (and often uncertain) changes in the business environment by reacting quickly (Cho et al., 1996; Gunasekaran, 1999). This has become one of the most powerful weapons for organizations and their supply chain. Supply chain agility can be considered as the ability to respond quickly to unpredictable events through rapid changes in business processes and systems (Christopher & Peck, 2004; Erol et al., 2010). Agility and velocity (which is the speed with which a supply chain can adapt) pertaining to both positive and negative changes in the external environment have become the ability of a supply chain to exploit unexpected emergencies (Peck, 2005; Ponomarov & Holcomb 2009; Jüttner & Maklan, 2011). Therefore, agility is concerned with the continuous search for the most appropriate response to manage uncertainty and unpredictability within the business environment and requires the presence of agile partners both upstream and downstream in the supply chain (Ganguly et al., 2018b; Christopher & Peck, 2004). Since agility of a supply chain involves adapting to unforeseen changes (which might even include disruptions) in a cost effective and timely manner, this is often considered as one of the key strategies to achieve resiliency.

4.3 Creating supply chain redundancy

As a convention, most organizations think of surplus capacity and inventory as a waste, and therefore an undesirable option (Christopher & Peck, 2004). However, contrary to the common belief, redundancy has often been considered a deliberate strategy to achieve resiliency in supply chains. Redundancy can be stated as "the strategic and selective use of spare capacity and inventory that can be used to cope with disruption…" and involves

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use of multiple suppliers, excess inventory and additional facilities, among others (Tukamuhabwa et al., 2015). Sheffi & Rice (2005) argued that resiliency can be enhanced by building redundancy into the supply chain, where significant redundancy can aid in a faster recovery after disruption. Strategic deployment of additional inventory or capacity at a certain point (which they termed as 'pinch-points') can be beneficial to creating a supply chain that is resilient in nature (Christopher & Peck, 2004). An organization can ensure redundancy through holding extra inventory and having multiple suppliers and locations, all with the objective of dealing with disruptions (Christopher & Peck, 2004; Tomlin, 2006). Therefore, redundancy is a capability that can be employed to ensure resilience, regardless of the need for resiliency emerging from demand volatility, or due to supply and/or internal disturbances (Purvis et al., 2016).

4.4 Supply chain collaboration

With increased competition and a turbulent business environment, more and more firms (and their supply chains) have started collaborating to reap greater benefits of operations. The fundamental reason supporting collaboration is that a single company cannot successfully compete by itself and therefore, collaboration involves joint ownership of decisions and collective responsibility for outcomes (Min et al., 2005; Gray, 1991). A high level of collaboration across supply chains can significantly help reduce disruptions (Christopher & Peck, 2004). The perspective of supply chain collaboration enables the supply chain partners to extract more relational rents for their own competitive advantage (Cao & Zhang, 2011). As a result, collaborating supply chain partners will ensure supply chain efficiency for their mutual benefit. Through collaboration, supply chain partners can work effectively with other supply chain entities and reduce vulnerabilities (Tukamuhabwa et al., 2015). Since reducing vulnerabilities is one of the fundamental aspects of a resilient supply chain, supply chain collaboration can be a useful strategy for ensuring a resilient supply chain. Supply chain collaboration as a strategy to address disruptions has been repeatedly stressed in the extant literature (Leat & Revoredo-Giha, 2013; Pettit et al., 2010, 2013; Ponis & Koronis, 2012; Ponomarov & Holocomb, 2009). Since resilience is key to addressing and mitigating disruptions in a supply chain, supply chain collaboration was considered to be an important strategy to achieve supply chain resiliency.

4.5 Knowledge management across supply chain

One of the fundamentals for success of supply chain collaboration is effective sharing of knowledge and information across the different entities of the supply chain (Christopher & Peck, 2004; Jüttner & Maklan, 2011). As supply chains have become more and more complex in nature, the difficulty in managing them has increased exponentially, resulting in an increased susceptibility to vulnerability. It has been observed that managers often do not have sufficient knowledge to address various issues within the supply chain. Lack of knowledge/information sharing is still a significant roadblock towards efficient functioning of a supply chain (Baily & Francis, 2008; Kong & Li, 2008). One of the avenues to address supply chain vulnerabilities is enabling the exchange of information among the members of that supply chain community (Christopher & Peck, 2004). Effective management and sharing of information/knowledge can enable the supply chain to be ready for any disruptive event through increased supply chain visibility, and therefore improvement in event detection and the organization's reaction (Jüttner & Maklan 2011; Manuj & Mentzer 2008). This makes knowledge sharing an important

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strategy for creating a resilient supply chain. Furthermore, Li et al. (2006) observed that if the information is shared downstream in a timely fashion, then disruptions upstream can be avoided or mitigated. Therefore, knowledge and understanding of supply chain structures, coupled with proper knowledge management and sharing can underpin a supply network's resilience (Choi & Hong, 2002; Scholten et al., 2014). On the contrary, failure to share information/knowledge among the intra and inter supply chain entities might lead to supply chain opacity, leading to compromised resiliency of the supply chain.

4.6 Inventory management

As mentioned earlier, injecting redundancy into supply chains can be used by organizations as a resiliency strategy. One way to increase supply chain redundancy is through inventory redundancy (Barroso et al., 2010). Barroso et al. (2010) further argued that building redundant inventory in supply chains can go a long way in maintaining continuous operation of the supply chains, thereby combating any possible disruption. Additionally, research has also shown that holding excess inventory is as an important strategy to maintain supply chain resiliency (McKinnon, 2014; Ole-Hohenstein et al. 2015). Boone et al. (2013) mentioned that the strategic alignment of inventory plays a very important role in achieving supply chain resiliency, an argument that supported the findings of Carvalho & Cruz-Machado (2011). Therefore, with subsequent discussions with the subject matter experts, it was decided to include this as a strategy for achieving supply chain resiliency.

4.7 Appropriate supplier selection

Since suppliers can be considered one of the major sources of external disruption in modern supply chains, appropriate selection of suppliers requires factoring in resiliency of the supply chains (Rajesh & Ravi, 2015). Supplier selection is a process through which an organization identifies and evaluates its vendors with the objective of signing a possible contract (Mital et al., 2018). Supplier selection often forms the backbone of successful supply chains and therefore, organizations need to pay careful attention to the supplier selection process. Proper selection of suppliers can enable an organization to achieve unprecedented success, while poor selection of suppliers can lead to failure (Rahman & Haldar, 2018). Effective selection of suppliers can aid an organization in building a resilient supply chain, which can lead to a reduction in disruptions and vulnerability (Hosseini & Khaled, 2016; Parkouhi & Ghadikolaei, 2017). It can also support a supply chain to successfully combat any disruption and even bounce back from it. Additionally, effective supplier selection can aid in financial stability, business continuity, supply chain reliability, and quality, among others (Tukamuhabwa et al., 2015). Figure 1 exhibits the overall hierarchical structure of the supply chain resiliency strategies.

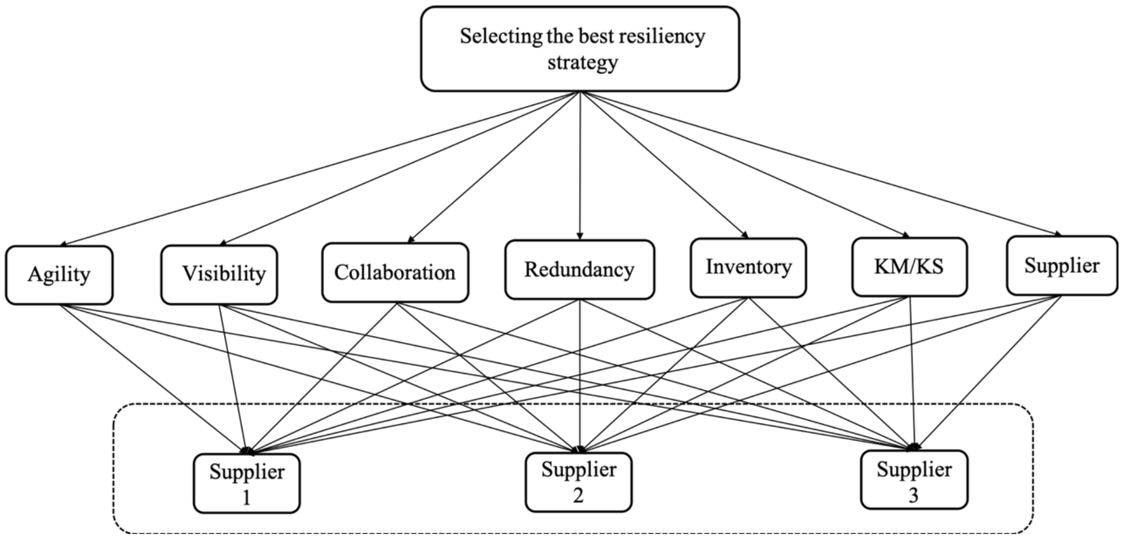

Figure 1 Basic AHP structure for the resiliency strategies

6. Using Fuzzy AHP to prioritize supply chain resiliency strategies

The current study applies the following steps as a part of the F-AHP analysis which are adapted and modified from the study conducted by Badri & Abdulla (2004) and Ayhan (2013). The steps involved are as follows:

1. Defining the problem/objective of the study (in the context of the current study, it was ranking the important strategies associated with supply chain resiliency).
2. Identifying the attributes for supply chain resiliency and structuring the AHP hierarchy (Figure).
3. Constructing a pairwise comparison matrix of the attributes with the objective of determining their impact on the overall object of the study.
4. Identifying the experts for comparing the identified strategies' criteria or alternatives in order to obtain pairwise judgments among the identified attributes in step 2; since there was more than one expert, preferences of each experts are averaged.
5. Calculating the geometric mean of the fuzzy comparison values of each criterion following the method adapted by Buckley (1985).
6. Determining the fuzzy weights of each of the criterion and calculating the vector summation of the triangular values.
7. Calculating the inverse (-1) power of the summation vector and replacing the fuzzy triangular number, to make it in an increasing order.
8. Determining the fuzzy weight of criterion and multiplying each with this reverse vector.
9. Based on the survey responses, prioritized weights of the identified attributes are obtained and consistency among the judgments tested.
10. Determine the final prioritized set of attributes related to the overall objective of the study and chose the best alternative among a portfolio of alternatives

The first step of the survey consisted of designing the AHP hierarchy as exhibited in Figure 1. Once the AHP structure was determined, the next step consisted of experts comparing the identified strategies to determine their relative criticality. The scale used in the questionnaire was the AHP scale provided in Table 1. Also, although mentioned earlier, it would be worthwhile to reiterate that though the standard AHP scales were used in the survey, the data was subsequently converted to the Fuzzy triangular scale (refer Table 1) before analysis, in order to facilitate the Fuzzy AHP calculations. The identified strategies were compared to the overall objective of the study. Table 2 shows the pairwise comparison matrix of the identified supply chain resiliency strategies as provided by one of the respondents[2].

Table 2
Pairwise comparison of the resiliency strategies

	Visibility	Agility	Collaboration	Redundancy	Supplier Selection	Inventory	KM/KS
Visibility	(1.1.1)	(1/4,1/3,1/2)	(6,7,8)	(4,5,6)	(6,7,8)	(4,5,6)	(6,7,8)
Agility	(2,3,4)	(1.1.1)	(2,3,4)	(4,5,6)	(6,7,8)	(6,7,8)	(7,8,9)
Collaboration	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1,1,1)	(4,5,6)	(6,7,8)	(4,5,6)	(5,6,7)
Redundancy	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)
Supplier Selection	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(3,4,5)
Inventory	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1,1,1)	(4,5,6)	(1,1,1)	(4,5,6)
KM/KS	(1/8,1/7,1/6)	(1/9,1/8,1/7)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1,1,1)

After the initial prioritization of the identified strategies, the next step was to determine the geometric mean of the fuzzy comparison value for each of the strategies. The geometric mean is calculated using Equation 1:

$$\tilde{r_i} = \left[\prod_{j=1}^{n} \tilde{x}_{ij}\right]^{\frac{1}{n}} \qquad (1)$$

Where,
$\tilde{r_i}$ = Geometric mean
$\tilde{x}_{ij}$ = Weights of the attributes and or sub − attributes
n = Number of attributes / sub-attributes

Calculating the geometric means was followed by the fuzzy weights of the attributes, which is subsequently followed by de-fuzzying and normalizing the weights. The fuzzy weights were determined by multiplying the geometric mean ($\tilde{r_i}$) with the reverse Fuzzy Triangular Numbers (FTNs), arranged in ascending order, as illustrated in Equation 2.

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[2] It should be noted here that Tables 2 & 3 exhibit the results of one of the respondents out of the 23 respondents surveyed. The primary reason for this is that the AHP response matrix for all the respondents surveyed has the same structure with different values. The final table (Table 4) exhibiting the final, prioritized values, is an average of all the survey responses.

ISSN 1936-6744
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$$w_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots\ldots..\oplus \tilde{r}_n)^{-1} = (aw, bw, cw) \quad (2)$$

The determined fuzzy weights were then subsequently de-fuzzied and normalized, thereby accounting for the final set of attribute and sub-attribute weights[3]. The findings have been provided in Table 3.

Table 3
Geometric mean and normalized weights of the resiliency strategies

	Geometric Mean ($\tilde{r}_i$)			Fuzzy weights (w_i)			M_i	N_i
Visibility	2.63	3.12	2.63	0.255	0.325	0.331	0.304	**0.259**
Agility	3.28	4.05	4.77	0.318	0.421	0.601	0.447	**0.380**
Collaboration	1.47	1.75	2.08	0.143	0.182	0.262	0.196	**0.167**
Redundancy	0.57	0.69	0.82	0.055	0.071	0.103	0.077	**0.065**
Supplier Selection	0.30	0.36	0.43	0.030	0.037	0.055	0.041	**0.034**
Inventory	0.66	0.76	0.87	0.064	0.079	0.110	0.084	**0.072**
KM/KS	0.21	0.24	0.30	0.020	0.025	0.037	0.028	**0.023**
Total	7.95	9.60	10.30					
Inverse (power of -1)	0.126	0.104	0.097					
Increasing order	0.097	0.104	0.126					

M_i = Non-fuzzy weights and N_i = Normalized weights

Table 3 provides the prioritized weights of the identified strategies to achieve supply chain resiliency. As mentioned earlier, this is the response of one of the 23 experts surveyed as a part of this research project since the AHP response matrix is the same across all the respondents, but with different values. Table 4 details the average of all the experts surveyed as a part of the study along with the rankings of the strategies.

[3] For a detailed explanation of the Fuzzy AHP process and the Fuzzy Triangular Distribution please refer to Ayhan (2013) and Singh and Prasher (2019).

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Table 4
Ranking of the resiliency strategies along with their normalized weights over the entire set of respondents (N=23**)**

Resiliency strategies	Mean normalized weights	Rank
Agility	0.346	1
Visibility	0.277	2
Collaboration	0.175	3
Inventory management	0.078	4
Redundancy	0.072	5
Supplier selection	0.031	6
Knowledge management/sharing	0.021	7

Finally, it's necessary to mention that although the AHP structure exhibited in Figure 1 includes the alternatives, as the current study intends to prioritize the resiliency strategies, the last level of the hierarchy (the alternatives – supplier 1, 2 & 3) was considered to be beyond the scope of the current study and therefore was omitted. Additionally, it should also be mentioned that following the methodology suggested by Leung and Cao (2000a, 2000b), a consistency test for the pairwise judgments was performed and consistencies were within the permissible limits. The following section provides a detailed discussion of the findings.

7. Results and findings

The results provide a glimpse into the supply chain resiliency attitudes in the Indian context. It was found that there are similarities as well as contrasts with the global context. While the highest weights for Agility and Visibility were in line with the global research, a low value for Knowledge Management was in contrast with the global research. The top three resiliency strategies identified were Agility, Visibility, and Collaboration, contributing towards nearly 0.80 of the attribute weights. The highest weight was for Agility (0.37), which is consistent with the understanding that agile supply chains are also agile during external shocks, making them more resilient. This is consistent with the findings of Wieland & Wallenburg (2013) who discuss agility from the customer care perspective while adding robustness as a measure for agility of supply chains. The second highest attribute weight was for Supply Chain Visibility (0.28). This is consistent with the findings of Brandon-Jones et al. (2014) whose confirmatory factor analysis study found factor loading of 0.90 for inventory-based visibility and 0.73 for demand-based visibility covering 264 different organizations. Collaboration was the third highest weighted attribute with a weight of 0.18; this is also consistent with the qualitative research work done by Scholten & Schilder (2015). Inventory management (0.08) and Redundancy (0.07) have a minor share in attribute weights, which are in line with the global literature. However, the low weights for knowledge management/sharing (0.02) contrast the Indian context with global context (Li et al., 2006; Scholten et al., 2014). Overall, the authors found that if a supply chain focuses upon Agility, Visibility, and Collaboration during normal phases, it can be considered a resilient supply chain during disruptive phases and will be able to cope with the negative externalities.

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MCDM and F-AHP have been used extensively in various aspects of supply chain management e.g. facility location, supplier selection, quality control etc. However, research using F-AHP on resiliency strategies are relatively sparse. Through this study, the authors intend to provide inroads for F-AHP and other MCDM techniques into the area of supply chain resiliency. This is of critical importance considering the current global economic trade volatility where changing business scenarios guided by cut-throat competition and continuous uncertainties have made decision-making an extremely complex and confusing process.

Further, the decision-making process in organizations has stretched its boundaries from being just economic in nature to including a plethora of non-economic factors of business operations. As a result, MCDM has started playing a huge role in current day decision making. The current study, using supply chain resiliency strategies as an illustrative example, attests to the importance of MCDM (and F-AHP) in the business decision-making process.

8. Limitations of the current study

While F-AHP is a robust tool for relative importance, the consistency index remains an issue for large groups of data, grouped data sets or an attribute matrix size of more than 4 (Saaty, 1990; 1994). However, our study used data points where consistency ratios were less than 0.20, and hence is within the control limits considering the data size of 23 for a seven-attribute comparison matrix. This is also in line with the recommendation of Wedley (1993) where 0.2 or less is acceptable for large attribute matrix sizes. A comparison of F-AHP and F-TOPSIS for supplier selection for an automotive company by Junior et al. (2014) also uses a CI of less than 0.20 considering it under control limits. Further, in other areas of research, Ho et al.’s (2005) study of property-specific attributes for office building quality uses a tolerance range of 0.1 to 0.2 for CI when having a large data size. In addition, the consistency is also aligned with other similar studies in the area of supply chain management by Adebanjo et al. (2016), Büyüközkan et al. (2011), Kahraman et al. (2003), Kilincci & Onal (2011), Yadav & Sharma (2015), and Singh & Prasher (2019).

This makes the result and outcome of the study more robust, but at the same time it also means that a few of the samples have been left out thereby reducing the number of responses. Further, the study focuses on identifying resiliency attributes for a supply chain, however, the resiliency varies based on the criticality and type of disruptions. The current research analyzes the information procured from various industry experts based on their experience in their respective sectors; this can be done at the sectorial level.

9. Conclusion and further research

The authors have identified the relative importance for various supply chain resiliency attributes, thereby providing managers with specific strategic areas in which to work for improvement. Improvements regarding Agility, Visibility, and Collaboration have already been incorporated by most supply chains to improve efficiency and other

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production-based indicators. The study provides a new dimension by further emphasizing these attributes from the resiliency perspective. This will allow firms or supply chains to work better during disruptions and might lead to improved market share. Hence, the study should not only be seen as a research work analyzing relative importance, but also as a way of identifying how resilient the existing supply chains are when they have already focused on the above-discussed attributes.

This study has considered only the Indian pharmaceutical industrial sector and has discussed disruptions without typology or criticality of the disruptions. Further research can be done for supply chains of other industrial sectors with industry-based supply chain resiliency measures. Also, industries can be studied for resiliency strategies based on the disruption typology and geographic differences while keeping the attributes unchanged.

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