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Prioritization of Supply Chain Capabilities Using the FAHP Technique

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Abstract: With the great challenges that the latest pandemic (COVID-19) has imposed on manufacturing companies, the need to overcome and cope with such situations is becoming crucial. Supply chain resilience is one of the main aspects that enables manufacturers to cope with change and uncertainty; therefore, it is essential to develop the capabilities necessary to do so. This study aimed to ensure supply chain resilience in light of the COVID-19 pandemic through prioritizing main supply chain capabilities. After surveying (30) experts in supply chain from leading manufacturing companies in Jordan, a Fuzzy Analytic Hierarchy Process (FAHP) analysis was conducted to prioritize main supply chain capabilities that were derived from the related literature. The results of this study showed that proactive capabilities, followed by reactive capabilities, were the most dominant capabilities that could ensure supply chain resilience, while efficiency-based capabilities were the least significant. Therefore, manufacturing companies should place their focus and emphasis on reacting to this pandemic in a more systematic manner.

Keywords: supply chain resilience; COVID-19; FAHP approach; manufacturing companies

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1. Introduction

A supply chain can be understood as a system connecting a diverse range of specialists. This system starts with the supplier and ends with the last customer, encompassing both the service and manufacturing processes, with the aim of maintaining the flow of information and goods. This support helps organizations to sufficiently determine the best way to meet their business requirements [1]. Subsequently, businesses become globalized, and companies begin to follow novel strategies. These strategies may include excellent streamlined customer responses and rapid-response programs. In addition, the market becomes dynamic, thus increasing the requirements for changes within the supply chain [2]. These changes depend on an increase in the supply chain's complexity [3].

In the context of the COVID-19 pandemic, supply chains have become more unpredictable and unstable; in light of this, they face diverse challenges [4]. Epidemic outbreaks begin on a small scale but quickly increase in size and spread across numerous geographic areas with a considerable level of uncertainty. This makes it difficult to completely comprehend the effects of epidemic breakouts on supply chains and take the necessary precautions to respond to them [5]. There are different possible reasons for these disruptions within a supply chain, which have been illustrated by different practitioners and researchers within the literature. According to Pereira et al. [6] and Ghadge et al. [7], the short life cycle of a product, the high variability in demand because of changing requirements, and customers' expectations are the most probable reasons for such changes. The PricewaterhouseCoopers/Massachusetts Institute of Technology (PwC/MIT) Forum of Supply Chain Innovation conducted a global supply chain risk management survey that presented plans for business continuity, which included fluctuations in the prices of raw materials, fluctuations in currency, and market changes in risk areas [8]. The American Production and Inventory Control Society (APICS) supply chain council published a report in the year 2015, which discusses a natural disaster and a lack of information sharing. The report indicates that there are many disruptions within a supply chain. Such disruptions are due to a lack of visibility, insufficient information technology communication, cyberattacks, and loss of skills, according to the Business Continuity Institute (BCI) supply chain flexibility report (2017). If any disruption occurs in a supply chain, it can have a negative effect on the economic performance of an organization. Consequently, to sustain themselves within this scenario of a changing market, it is essential for organizations to have resilient supply chains. According to [9,10], capacity can be increased to respond to unanticipated influences, while also having the power to quickly return to the original position, being ready to respond once again. Moreover, the capacity increase can result in a cost-effective situation after responding to and facing the difficulty. In the present study, the capabilities of a supply chain are prioritized based on their importance in the context of the COVID-19 pandemic, aiming to ensure the resilience of the supply chain.

The motivation behind this study was the disruptions within the supply chain caused by the COVID-19 pandemic, which highlighted the significance of supply chain resilience in dealing with such unpredictable events. Therefore, this study aimed to define the most important and necessary capabilities for ensuring supply chain resilience. The following are the main contributions of this study: First and foremost, this study combined theoretical and empirical aspects of research on supply chain capabilities to identify those most critical for ensuring supply chain resilience (SCRE). Second, this study sought to identify the most critical and necessary capabilities for ensuring supply chain resilience in the food sector. The proposed framework enables researchers to seek fundamental knowledge and conduct additional research on supply chain resilience in the face of uncertainty. This study also has practical value in that it provides guidance for decision makers, considering the trade-off between various capabilities and performance metrics. Third, SCRE is a new term in some developing countries such as Jordan. As a result, this study provides a good set of guidelines for understanding the establishment, evaluation, and improvement of SCRE. Fourth, this study employed empirical methods to analyze the factors that have significant impacts on the measurement of SCRE performance. Hence, organizations are better able to anticipate disruptions and respond to them, ensuring that their operations run smoothly and that their clients are satisfied. The remainder of the paper is structured as follows: Section 2 provides a literature review. Section 3 presents the methodology. The findings and discussion are covered in Section 4. Lastly, Section 5 summarizes the findings and suggests future work.

2. Literature Review

2.1. Supply Chain Resilience

Supply chain resilience has emerged as a topic of great concern for businesses due to the increasing frequency and severity of interruptions caused by multiple internal and external events [6]. The concept of resilience has been intensively researched in the field of supply chain management to understand how firms may more successfully prepare for and respond to crises [11]. There is no accepted definition of supply chain resilience. Yet, the expression is frequently used to describe a company's ability to withstand, recover from, and react to unanticipated disruptions while conducting business and meeting customer expectations [9,10]. A resilient supply chain is one that can adapt to changing conditions, whether those conditions are caused by pandemics, natural catastrophes, economic downturns, or other unpredictable circumstances [12]. After a significant series of disruptive events within global economies, several in-depth studies were carried out to improve our understanding of the ways that supply chains can more efficiently adapt to change [13–15]. When the term "resilience" appears in business vocabulary, researchers have investigated project attributes that contribute to supply chain disturbances as well as attributes that help enterprises to cope with and prevent those disturbances [16,17]. Resilience is also defined by the "four Rs"—robustness, recovery, review, and resourcefulness [18].

Resilience can be perceived from the perspectives of flexibility and redundancy, encouraging leaders to develop "flexibility DNA". This new DNA is developed during periods of distributed authority, communications, passion for the mission being pursued, conditioning to disruptions, and deferral from experience [15]. Even though these viewpoints are different, everyone differentiates resilience from conventional risk management [19]. The resilience concept, unlike traditional risk analysis, uses strategies that do not require exact quantification or whole enumeration to create possibilities or representative future assumptions [20]. Strategic resilience imperatives stimulate supply chains to become more adaptive and less brittle to change. This adaptability can refer to the visibility of changes in supply and demand throughout the supply chain and the design of the supply chain. Adaptabilities working to embed a resilient culture and to place focus on business procedure management for enhancing capabilities throughout the supply chain are other strategic resilience imperatives [21]. However, the authors of [20] recognized a research gap regarding linked vulnerabilities and threats against the strategies required to overcome them. The authors of [22] defined resilience as being derived from the foundations of life as well as the social sciences, and this definition is adapted by the Council on Competitiveness (2007) as "the capacity for an enterprise to survive, adapt and grow in the face of turbulent change". Resilience is understood as consisting of two constructs. The first construct is "vulnerabilities", which are the fundamental factors that render a project susceptible to disruptions, and the second construct is "capabilities", which are attributes that allow an enterprise to overcome and anticipate these disruptions [20]. The authors of [23] generated a methodology to develop the best disturbance management strategy according to many flexibility levels, derived from the fact that mitigation and contingency events are not free. In addition, Pettit et al. [13] developed capability and vulnerability constructs including 21 factors that contain 111 sub-factors. They proposed that these 21 factors can be estimated and used for the evaluation of a supply chain's current resilient state, and recommendations for resilience improvement can be prioritized through adjusting a company's capability portfolio by aligning the vulnerability pattern so that it remains within the Balanced Resilience Zone [23]. Responses to vulnerability are diverse and encompass capabilities throughout the entire enterprise, in addition to the synergistic or conflicting capabilities of supply chain members [24,25]. The aim of managers is to create capability portfolios that can balance the intrinsic vulnerabilities within the supply chain, resulting in a balanced form of resilience that is hypothesized to improve firm performance [13].

Reactive and proactive supply chain resilience (SCRE) capabilities can be understood through the lens of the Dynamic Capability View (DCV) [26]. Consistent with the DCV, firms must include capabilities for adapting, integrating, and reconfiguring their resources, in addition to capabilities for quickly addressing changes in environments. To accelerate similar changes, organizations must be proactive in scanning for environmental changes. They must also obtain the adaptability and flexibility that is essential for matching their proactive capability with their supply chain. This flexibility includes adapting to environmental changes to prevent potential vulnerabilities within the supply chain, according to the DCV. Successful companies working within the market ought to reconfigure their capabilities and resources quickly so as to recover competencies in turbulent times [26]. Moreover, supply chains must have the reactive capacity to reconfigure capabilities and resources in order to recover rapidly from disruptions. In their study, the authors of [13] outlined the "balanced resilience" concept, which is basically the balance between rising resilience capabilities and rising costs as a concept for controlling vulnerabilities. Ponomarov and Holcomb highlighted the significance of capability or resource specificity, in addition to their sufficient measurement, for sustaining profitability through the development of resilience balance [27]. According to the concept put forward by the authors of [13], it is important to balance managerial and supply chain vulnerabilities. Prioritizing robust capability factors in the textile sector, the authors of [28] discovered that readiness is the most crucial capability for resilience, followed by response and recovery. Government support has been one of the main causal elements aiding the global supply chain during the COVID-19 pandemic, and cost optimization is the main factor affecting the supply chain [29].

While the existing literature offers a framework for supply chain resilience capabilities, there exists a number of gaps in the literature, which lacks a comprehensive view of resilience capabilities, as well as studies being conducted in developing countries and those examining such capabilities empirically based on a pandemic such as the COVID-19 pandemic.

2.2. Fuzzy Analytic Hierarchy Process (FAHP) Method

Supply chain resilience has become increasingly important in the wake of the COVID-19 pandemic. To ensure that supply chains can continue to function effectively in the face of disruptions, it is important to identify and prioritize capabilities that are most critical for resilience. The development of a Fuzzy Analytic Hierarchy Process (FAHP) model can assist in this process by providing a systematic framework for evaluating and prioritizing supply chain capabilities [30]. Many studies have proved that the FAHP method is effective for many practical problems. In [31], Ooi et al. showed that FAHP achieved the best performance balance for criteria referring to various categories, including physicochemical properties, safety, health, and environmental aspects. The FAHP approach's assumption is that all involved criteria are independent from each other. Nevertheless, practically, the relationship between criteria is generally complex, and there might be interdependencies [32,33]. To control quality, a relevant element and method are required [34]. A fuzzy model can be used with different multi-criteria decision-making (MCDM) methods [35]. According to Chiu et al. [36], a FAHP model is a good reference for decision makers, as the fuzzy AHP method is applicable as a quality control method and is suitable for multi-criteria decision-making problems [37]. With the FAHP method, decision makers can make more realistic, flexible, and efficient decisions according to the available criteria and alternatives [38]. The most recent articles on multi-criteria decision-making tools, which primary focus is on resilience supply chain management, are included in Table 1 below.

Table 1. Multi-criteria decision-making (MCDM) techniques for supply chain management.

Reference, Authors, and Year	MCDM Technique	Main Findings
[39] Gupta et al. (2019)	Fuzzy AHP, TOPSIS, MABAC, and WASPS	This study used a weighted sum and product model in WASPAS. The outcomes for choosing green suppliers were consistent across the three hybrid models (Fuzzy AHP and TOPSIS; Fuzzy AHP and WASPAS; and Fuzzy AHP and MABAC).
[40] Alkahtani et al. (2019)	Fuzzy AHP and TOPSIS	This study explored a mechanism for assessing the chosen approaches. The following aspects were taken into consideration when conducting the evaluation: group decision support, computational complexity, number of criteria, and alternative providers. The results show that AHP outperforms Fuzzy TOPSIS in terms of computational complexity, whereas Fuzzy TOPSIS is best suited for guaranteeing decision-making agility.
[41] Belhadi et al. (2022)	Fuzzy systems and wavelet neural networks	This study aimed to identify trends in AI approaches for creating various SCRes strategies. This paper offers an integrated multi-criteria decision-making (MCDM) strategy driven by AI-based algorithms, including fuzzy systems, wavelet neural networks (WNN), and evaluation based on the distance from the average solution (EDAS).

Table 1. *Cont.*

Reference, Authors, and Year	MCDM Technique	Main Findings
[42] Ayyildiz (2021)	Interval-valued intuitionistic FAHP	In this study, the importance of performance attributes was determined using the Fuzzy Analytic Hierarchy Process. The hierarchy levels were used to identify the most crucial performance attributes. The findings show that organizational characteristics are crucial for creating more resilient supply chains. For supply chain resilience, integrated systems are highly important.
[43] Murat et al. (2020)	AHP into VIKOR under intuitionistic fuzzy theory	The primary goal of this study was to use a quantitative approach to examine whether blockchain technology can be used in the logistics sector. A multi-criteria decision structure was provided, and AHP was integrated into VIKOR under the intuitionistic fuzzy theory. The study's conclusions imply that while security, visibility, and audit are the most crucial factors, transportation, material handling, warehousing, order processing, and fleet management are the most practical logistics operations for potential blockchain deployment.
[44] Wu et al. (2023)	Interval Type-2F-PT-TOPSIS	This study assessed the degree of robustness of the coal industrial chain and supply chain. An integrated method combining Interval Type-2 Fuzzy Prospect Theory and the Technique for Order Preference by Similarity to an Ideal Solution (Interval Type-2F-PT-TOPSIS) was proposed.
[45] Sathyan et al. (2023)	Fuzzy DEMATEL, Fuzzy AHP, and Fuzzy TOPSIS	The Fuzzy AHP–Fuzzy TOPSIS conclusion suggests that automakers should pay particular attention to management's commitment and strategic decision making, wait times for deliveries of vehicles, and demand forecasts. The suggested framework offers strategic objectives to direct various supply chain participants and decision makers in the automobile industry toward increased supply chain responsiveness.
[46] Giri et al. (2022)	Fuzzy DEMATEL	This study developed the DEMATEL approach based on Pythagorean fuzzy sets and used it to address the supplier selection issue in sustainable supply chain management. Based on information gathered from a group of professionals, the proposed method was mathematically presented.
[47] Sohrabi et al. (2022)	A combined metaheuristic-based robust fuzzy stochastic programming	To account for uncertainties in the real world, a hybrid resilient fuzzy stochastic programming approach was used in this study. The suggested model was put into practice for blood platelets. The outcomes demonstrate that the proposed RFSP model performs better than the Nominal model. In addition to lowering shortages and waste, it is also effective in minimizing overall system expenses and environmental damage.
[48] Rabbani et al. (2022)	Stochastic programming	In this study, a reactive strategy was modified to deal with network disruptions and failures, and a robust stochastic programming solution was extended and solved using a genetic algorithm to address uncertainties in the real world. A real-world case study was used to validate the model's efficacy and applicability. Additionally, the model's effectiveness and dependability were demonstrated according to its application in novel settings.

Table 1. *Cont.*

Reference, Authors, and Year	MCDM Technique	Main Findings
[49] Shokouhifar et al. (2022)	A multivariate time-series deep learning model	A multivariate time-series deep learning model based on long short-term memory is proposed in this paper to forecast blood donation/demand. The proposed model was used to achieve resilient blood inventory management so as to address the uncertainties that arose during the COVID-19 pandemic. The proposed method can be used to assist decision makers in managing blood supply chains during COVID-19 outbreaks and similar pandemics in the future by prioritizing blood transfusions.

2.3. SC Resilience and COVID-19

Across the globe, activities have been impacted by the COVID-19 pandemic, with severe interruptions in supply chains (SCs). Businesses are anticipated to be impacted indefinitely; as a result of this, it is doubtful that SCs will return to their pre-COVID-19 state [50]. There is much research on the relationship between the pandemic and supply chain and how to achieve SC resilience. One study proposed framework and listed the main causes of SCN, such as the COVID-19 pandemic, and then grouped the reasons according to their relative importance [11]. Another presented information on supply chain resilience and made the case for the distinction of agrifood supply chains based on a number of significant factors that must be taken into account when evaluating resilience [30]. Other authors drew attention to the emergence of five key areas in the context of COVID-19 in which AI can improve supply chain resilience [51], while the authors of [52] used artificial intelligence to build supply chain resilience, enabling a supply chain to endure major disruptions such as COVID-19. The authors of [53] examined how changes resulting from the pandemic have impacted efforts to promote resilience, while [54] outlines the difficult situations that China's retail supply chains have had to address, evaluates the impact of the pandemic on supply chain resilience, and analyzes the pandemic's effects on SCs in terms of difficulties, concerns, actions, and solutions, with the aim of enhancing SC resilience. The authors of [12] also suggested using the combined ANP–TOPSIS framework to rank the answers based on these complex interrelationships.

3. Materials and Methods

The current study adopted a descriptive correlational research design and consisted of two parts: The first included collecting experts' opinions on the main supply chain resilience capabilities, in which they were asked to rate the priority of each capability based on the current situation in light of the COVID-19 pandemic. The second part included prioritizing supply chain resilience capabilities considering the COVID-19 pandemic and the sub-factors for supply chain resilience capabilities using the FAHP approach. The methodology followed in this research is summarized in Figure 1 below, outlining the fuzzy AHP method adopted to determine the weights of the capabilities and sub-capabilities.

3.1. The Study Tool

The study tool was a questionnaire that was developed based on the studies described in [55]. The questionnaire consisted of main capabilities and sub-capabilities that were extracted from related studies, as shown in Table 2 below.

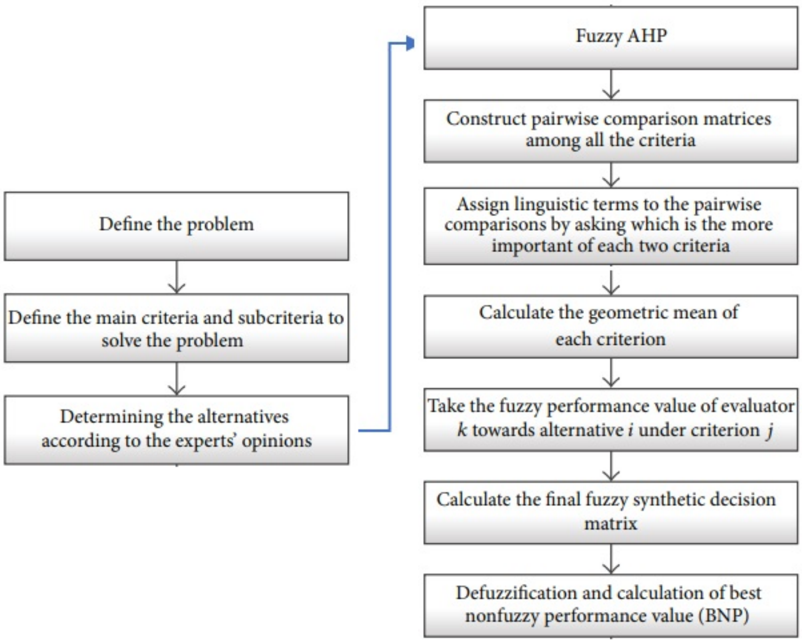

Figure 1. The steps of the methodology.

Table 2. The main capabilities and sub-supply chain capabilities.

Capability	Sub-Dimensions	Symbol	Reference, Authors, and Year
Efficiency-based capabilities	Contingency planning	CP	(Ambulkar et al., 2015 [55]; Pettit et al., 2010 [20]; Sheffi, 2007 [56]; Magableh, 2021 [50]; Chang et al., 2019 [57])
	Control-oriented approaches	COA	(Fisher, 2011 [22]; Garmestani et al., 2008 [58]; Han et al., 2019 [59])
Adaptive capabilities	Adaptive capacity	AC	(Garmestani et al., 2008 [58]; Lam and Bai, 2016 [60])
	Flexibility	F	(Pettit et al., 2013 [13]; Swafford et al., 2006 [61]; Rajesh, 2016 [62])
	Redundancy of function	RF	(Holling and Gunderson, 2002 [63]; Magableh and Mistarihi, 2022A [11])
	Self-organization and attractors	SOA	(Nilsson and Gammelgaard, 2012 [64]; Ivanov, 2018 [65])
Collaborative capabilities	Social capital	SC	(Johnson et al., 2013 [66]; Adobor and McMullen, 2018 [67])
	Inter-firm trust	FT	(Hendry et al., 2019 [68]; Chunsheng et al., 2019 [69])
	Social memory	SM	(Westley, 2002 [70]; Magableh and Mistarihi, 2022B [12])
	Visionary leadership	VL	(Lima et al., 2018 [71]; Yu et al., 2020 [72])
	System learning	SL	(Fertier et al., 2021 [73]; Stone and Rahimifard, 2018 [74]; Lima et al., 2018 [71])
Proactive capabilities	Disaster Readiness	DR	(Pettit et al., 2013 [13]; Hobbs, 2021 [30])
	Reserve capacity	RC	(Pettit et al., 2010 [20]; Hosseini et al., 2019 [75]; Thomas and Mahanty, 2019 [76])
	Integration	I	(Braunscheidel and Suresh, 2009 [77]; Chunsheng et al., 2019 [69])
	Market strength	MS	(Pettit et al., 2013 [13]; Kim and Bui, 2019 [78]; Dubey et al., 2019 [79])
	Financial strength	FS	(Lopez and Ishizaka, 2019 [80]; Kumar and Anbanandam, 2019 [81])

Table 2. *Cont.*

Capability	Sub-Dimensions	Symbol	Reference, Authors, and Year
Reactive capabilities	Response	RES	(Sheffi and Rice Jr, 2005 [82]; Modgi et al., 2022 [51])
	Recovery	R	(Sheffi and Rice Jr, 2005 [82]; Munoz and Dunbar, 2015 [83])
Design quality capabilities	Node Density	ND	(Choi and Krause, 2006 [84]; Kim et al., 2015 [85])
	Complexity	COM	(Colicchia et al., 2010 [86]; Ozdemir et al., 2022 [53])
	Criticality	CRI	(Craighead et al., 2007 [87]; Rajesh, 2017 [88])

Before starting the ranking task, the respondents were asked to answer three questions regarding their position, experience, and the type of industry in which they were working.

3.2. Sample and Population

The study population consisted of all working experts in Jordanian manufacturing companies. The study sample consisted of (30) experts in supply chain management within 10 of the leading manufacturing companies in Jordan. The sample was selected based on the convenience sampling technique.

The characteristics of the study sample are illustrated in Table 3 below, indicating that most of them (60%) were logistic and supply chain experts, and the majority had less than 30 years of experience.

Table 3. The characteristics of the study sample.

Characteristics		N (%)
Position	CEO	4 (13.3%)
	Brand expert	2 (6.7%)
	Logistic expert	9 (30%)
	Sales and operation planning	3 (10%)
	Data analysts	2 (6.7%)
	Managing director	1 (3.3%)
	Supply chain manager	9 (30%)
Experience	10 to less than 20 years	13 (43.3%)
	20 to less than 30 years	14 (46.7%)
	More than 30 years	3 (10%)
Type of industry	Pharmaceutical industry	5 (16.7%)
	Food industry	21 (70%)
	Energy industry	4 (13.3%)

It is apparent that the food industry predominates, accounting for more than half of the local market share, according to existing statistics [89]. This is due to the fact that Jordan's primary focus is the food sector and its lack of significant industries in other areas. The pandemic also had the most significant effect on the food industry supply chain [89,90].

3.3. FAHP Approach

The AHP approach was used to prioritize the supply chain resilience capabilities considering the COVID-19 pandemic. The AHP offers a framework that can be used to deal with multi-criteria situations that involve intuitive, rational, quantitative, and qualitative aspects [39,40]. The following steps were followed to calculate the weights of each capability and sub-capability. In this subsection, the FAHP method is outlined. The model is constructed based on decision makers' preferences and the problem's characteristics. The procedure used for the proposed method is derived from [91,92] and described below.

3.3.1. Structure a Hierarchy Model to Prioritize Capabilities

This phase involved formulating the FAHP hierarchy model, consisting of the goal, main capabilities, and sub-capabilities. The goal of this model is to identify the most important capabilities for ensuring supply chain resilience. This goal is on the first level in the hierarchy, as shown in Figure 2 below.

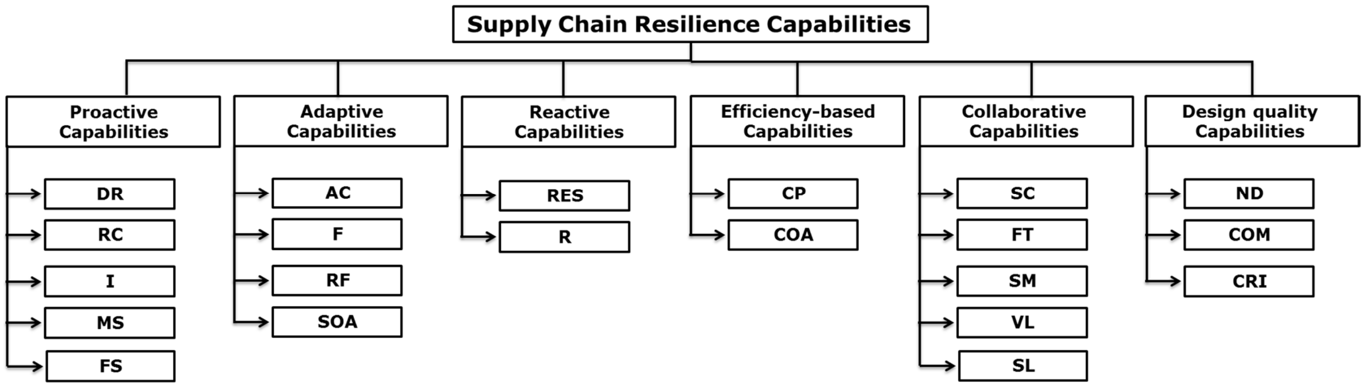

Figure 2. The AHP hierarchy model.

3.3.2. Develop the Pairwise Comparison Matrix

In this step, the pairwise comparison matrix was developed, and each of the capabilities was given a numeric rating based on the experts' rankings. Intermediate numeric ratings of 8, 6, 4, and 2 were assigned, and the reciprocal rating was assigned where the second alternative was preferable to the first. The values were assigned when comparing an alternative with itself [90]. The pairwise comparison matrix has a strong position in the consistency framework, and it can be used to analyze the overall priority sensitivity, defined as follows [93]:

$$a_{ij} = \frac{w_i}{w_j},\ i,j = 1,2,\ldots..,n \tag{1}$$

where n denotes the number of criteria compared; W_i denotes the weight for the i criterion; and a_{ij} is the ratio of the weights of the (ith) criterion and j, where i is the row and j is the column.

3.3.3. Develop the Normalized Matrix

According to [91], the normalization matrix was established by dividing each value in a column of the pairwise comparison matrix by the sum of that column, as follows:

$$a_{ij} = \frac{a_{ij}}{\sum a_{ij}},\ \forall_{i,j} \tag{2}$$

Through this process, one can ensure that the matrix is consistent and accurately reflects the weight given to each criterion or alternative.

3.3.4. Develop the Priority Vector

By calculating the mean of each row of the normalized matrix, the priority vector was created [92]. The preference problem's priority vector illustrates the relative weighting of each alternative. The alternative with the highest priority is regarded as the ideal option.

3.3.5. Calculate the Consistency Ratio

According to [94], the multiples of the entries were added using the priority of the corresponding (column) alternative to obtain the weighted sum for each row of the pair-wise comparison matrix. After this step, each row's weighted sum was divided by the associated alternative priority. The consistency must be near to perfect to provide a decision that is almost certainly valid. After determining the λ_max value, the consistency index (CI) of the (n) alternatives was computed, as shown in Equation (5). The value of the eigenvector, which is the weighted value of the criterion, must first be recognized using the following equation:

$$w_i = \frac{\hat{a}_i}{n}, \forall_i \quad (3)$$

where w_i is the eigen vector, and $\hat{a}_i$ is the sum of the matrix normalization values, which is divided by the number of criteria (n). The maximum eigenvalue is the number of times that the number of columns is multiplied with the main eigenvector. It can be determined using the following equation:

$$\lambda maks = \left(\sum GM_{11-n1} \times \overline{X}1\right) + \cdots + \left(\sum GM_{1n-ni} \times \overline{X}n\right) \quad (4)$$

After obtaining the maximum lambda value, the value of CI can be determined:

$$CI = \frac{\lambda max - n}{n-1} \quad (5)$$

where the maximal lambda is the largest eigenvalue in the n-order matrix, and CI is the consistency index. The matrix is consistent if the value of CI is zero. The limit of inconsistency is checked using the consistency ratio if the obtained value of CI is larger than 0 ($CI > 0$). To compute the consistency ratio, the random index RI was determined as shown in Table 4 below.

Table 4. Average random consistency index (RI) as a function of the pairwise comparison matrix size.

Size of Matrix	3	4	5	6	7	8	9	10
RI	0.525	0.90	1.12	1.248	1.342	1.406	1.450	1.485

Then, the consistency ratio was calculated as in [95]:

$$CR = \frac{CI}{RI} \quad (6)$$

3.3.6. Set up the Triangular Fuzzy Number (TFN)

The FAHP scale has three values: lower (lower, L), middle (median, M), and highest (highest, H; upper, U). Hence, each fuzzy set is split into two, except for the identical comparison set on the TFN scale, as shown in Figure 3 below.

3.3.7. Calculate the Weight Value of the Fuzzy Vector

This phase involves calculating the fuzzy synthesis value once the AHP comparison value has been converted to a FAHP scale value. The method for calculating the fuzzy synthesis value is as follows:

$$Si = \sum_{j=1}^{m} M_{gi}^{j} X \frac{1}{\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]} \quad (7)$$

where Si is the fuzzy synthesis value, and $\sum_{j=1}^{m} M_{gi}^{j}$ is the summation of the cell value in that column starting with column j in each row i in the matrix. Then, the defuzzification ordinate value (d') and v were obtained using the following formula to calculate V':

$$V(M2 \geq M1) = \begin{cases} 1, & ,if\ m2 \geq m1 \\ 0, & ,\ if\ l1 \geq u2 \\ (m_2 - u_2) - (m_1 - l_1)' & ,\ etc \end{cases} \tag{8}$$

The value of the fuzzy vector weight (W') was calculated using the following formula:

$$d'^{(Ai)} = \min V\ (Si > Sk) \tag{9}$$

Then, the ordinate values were collected as shown below:

$$\sum W' = (vsk1,\ vsk2,\ \ldots,\ vskn) \tag{10}$$

The normalization of the vector weight values was obtained using the following equation:

$$W' = (d'(A1),\ d'(A2),\ \ldots,\ d'(An)T \tag{11}$$

3.3.8. Ranking and Selection of Capabilities

Each capability weight value was calculated by the weight of the criteria element and directed to obtain the decision result.

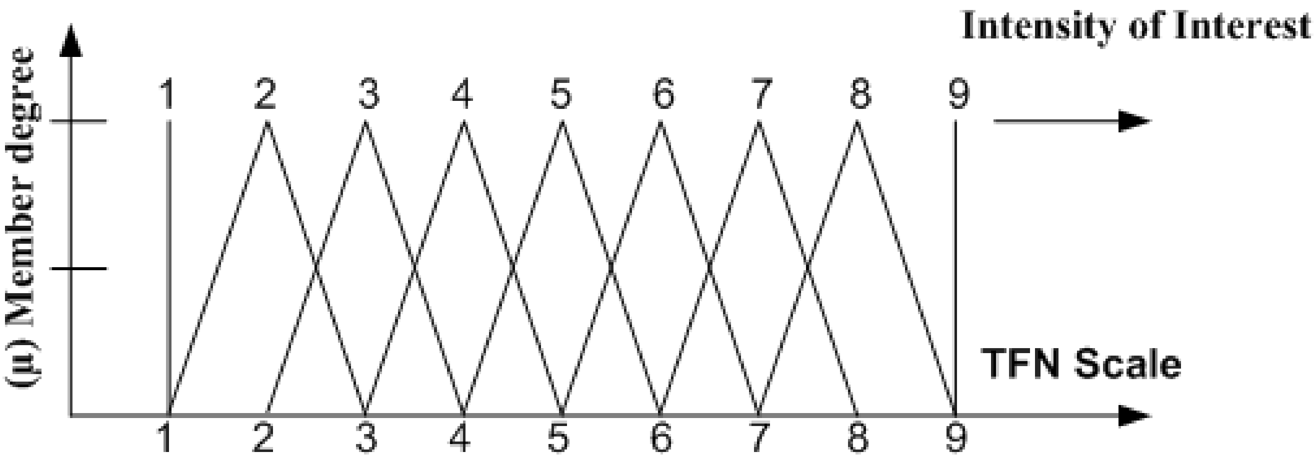

Figure 3. Fuzzy triangle set.

4. Results and Discussion

By gathering the opinions of experts in the field and using the AHP approach to prioritize the main supply chain resilience, we found that proactive and reactive capabilities are equally important, as shown in Table 5. According to [96], proactive strategies and reactive strategies are the most frequently used strategies for preventing disruptions in a supply chain. The reasons for our results can be seen in the strategic steps for each capability, where the associated risk factors, together with the facilities, are considered in the proactive model when dealing with the disruptions. Moreover, in the case of reactive capabilities, the disruptions are incorporated into the location routing facility, and the total cost, together with the related consequences, is optimized.

Table 5. Weight values for the main supply chain resilience capabilities.

	Proactive Capabilities	Adaptive Capabilities	Collaborative Capabilities	Proactive Capabilities	Collaborative Capabilities	Design Quality Capabilities	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weights
Proactive Capabilities	(1, 1, 1)	(7, 8, 9)	(4, 5, 6)	(1/5, 1/4, 1/3)	(2, 3, 4)	(1/3, 1/2, 1)	(1.39, 1.97, 2.91)	(0.15, 0.29, 0.61)	0.31
Adaptive Capabilities	(1/9, 1/8, 1/7)	(1, 1, 1)	(5, 6, 7)	(2, 3, 4)	(4, 5, 6)	(1/6, 1/5, 1/4)	(0.93, 1.22, 1.57)	(0.09, 0.183, 0.33)	0.18
Reactive Capabilities	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(1, 1, 1)	(6, 7, 8)	(5, 6, 7)	(2, 3, 4)	(1.09, 1.43, 1.83)	(0.12, 0.21.0.38)	0.20
Efficiency-based Capabilities	(3, 4, 5)	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/3, 1/2, 1)	(0.28, 0.38, 0.61)	(0.03, 0.05, 0.12)	0.05
Collaborative Capabilities	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(3, 4, 5)	(1, 1, 1)	(6, 7, 8)	(0.58, 0.75, 1)	(0.062, 0.11, 0.21)	0.11
Design Quality Capabilities	(1, 2, 3)	(4, 5, 6)	(1/4, 1/3, 1/2)	(1, 2, 3)	(1/8, 1/7, 1/6)	(1, 1, 1)	(0.59, 0.99, 1.46)	(0.062, 0.14, 0.31)	0.15

4.1. *Supply Chain Resilience Proactive Capabilities*

Table 6 represents the normalized weights for the proactive capabilities, where it can be noted that financial strength is ranked first, followed by reserve capacity, while market strength is ranked in the last place.

Table 6. Weight values for the proactive capabilities.

	DR	RC	I	MS	FS	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weights
DR	(1,1,1)	(1/8,1/7,1/6)	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/9,1/8,1/7)	(0.14,0.16,0.211)	(0.012,0.016,0.27)	0.087
RC	(6,7,8)	(1,1,1)	(4,5,6)	(4,5,6)	(1/4,1/3,1/2)	(2.21,2.76,3.46)	(0.18,0.28,0.44)	0.265
I	(3,4,5)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)	(1/6,1/5,1/4)	(0.71,0.89,1.12)	(0.06,0.09,0.14)	0.079
MS	(5,6,7)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1/9,1/8,1/7)	(0.38,0.45,0.54)	(0.032,0.045,0.07)	0.043
FS	(7,8,9)	(2,3,4)	(4,5,6)	(7,8,9)	(1,1,1)	(4.45,5.57,6.64)	(0.37,0.57,0.84)	0.522

4.2. *Supply Chain Resilience Adaptive Capabilities*

Self-organization and attractors were identified as the governing capabilities among the adaptive capabilities. According to [97], a supply chain can adopt a new network structure to restore and realize its complete function quickly through self-organization ability that adequately reveals the resilient response plan for the supply chain. Table 7 represents the normalized weights for the adaptive capabilities, where it can be noted that self-organization and attractors rank first, followed by redundancy of function, while adaptive capacity ranks last.

Table 7. Weight values for the adaptive capabilities.

	AC	F	RF	SOA	Fuzzy Geometric Mean Value	Fuzzy Weight	Normalized Weights
AC	(1, 1, 1)	(1/5, 1/4, 1/3)	(4, 5, 6)	(1/9, 1/8, 1/7)	(0.55, 0.59, 0.73)	(0.11, 0.14, 0.19)	0.14
F	(3, 4, 5)	(1, 1, 1)	(1, 4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(0.59, 0.72, 0.89)	(0.12, 0.17, 0.23)	0.17
RF	(1/6, 1/5, 1/4)	(2, 3, 4)	(1, 1, 1)	(5, 6, 7)	(1.14, 1.38, 1.63)	(0.23, 0.32, 0.43)	0.33
SOA	(7, 8, 9)	(4, 5, 6)	(1/5, 1/6, 1/7)	(1, 1, 1)	(1.54, 1.61, 1.67)	(0.31, 0.37, 0.44)	0.36

4.3. *Supply Chain Resilience Reactive Capabilities*

Response was identified as the leading reactive capability. Supply chain response focuses on minimizing disruptions with minimal influence in the shortest time possible [13]. The capacity for quick response to the needs of the market in critical circumstances is a significant SCRE determinant [82,98]. Therefore, supply chains must be able to respond quickly so as to return to stronger or normal positions. Jüttner and Maklan stated that the ability of an organization to respond quickly to environmental forces may be a unique capability [99]. Table 8 represents the normalized weights for the reactive capabilities, where it can be noted that response ranks first, followed by recovery.

Table 8. Weight values for the reactive capabilities.

	RES	R	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weights
RES	(1, 1, 1)	(7, 8, 9)	(7, 8, 9)	(0.77, 0.98, 1.26)	0.957
R	(1/9, 1/8, 1/7)	(1, 1, 1)	(0.11, 0.125, 0.14)	(0.01, 0.015, 0.019)	0.042

4.4. Supply Chain Resilience Efficiency-Based Capabilities

Contingency planning was found to be the governing capability among the efficiency-based capabilities. This result can be attributed to the fact that contingency planning capability involves selecting the processing intensities subject to disruptions in the supply chain structure at different structural constancy intervals [100]. Several studies have discussed contingency plan deployment to reinforce supply chain resilience [101–104]. Table 9 represents the normalized weights for the efficiency-based capabilities, where it can be noted that contingency planning ranks first, followed by control-oriented approaches.

Table 9. Weight values for the efficiency-based capabilities.

	CP	COA	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weights
CP	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	(0.44, 0.9, 1.78)	0.90
COA	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.05, 0.09, 0.22)	0.10

4.5. Supply Chain Resilience Collaborative Capabilities

Social capital was found to be the governing capability among the collaborative capabilities. In their study, the authors of [105] argued that internal social capital arises as a complex resilience-enhancing resource manifested through cognitive, relational, and structural components. Table 10 represents the normalized weights for the collaborative capabilities, where it can be noted that social capital ranks first, followed by visionary leadership, while system learning ranks last.

Table 10. Weight values for the collaborative capabilities.

	SC	FT	SM	VL	SL	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weight
SC	(1, 1, 1)	(6, 7, 8)	(4, 5, 6)	(2, 3, 4)	(5, 6, 7)	(3.94, 5.01, 6.05)	(0.38, 0.58, 0.92)	0.535
FT	(1/8, 1/7, 1/6)	(1, 1, 1)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(0.18, 0.25, 0.34)	(0.017, 0.028, 0.05)	0.082
SM	(1/6, 1/5, 1/4)	(3, 4, 5)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1, 2, 3)	(0.59, 0.885, 1.17)	(0.057, 0.102, 0.178)	0.096
VL	(1/4, 1/3, 1/2)	(4, 5, 6)	(2, 3, 4)	(1, 1, 1)	(3, 4, 5)	(1.57, 2.11, 2.78)	(0.15, 0.24, 0.42)	0.233
SL	(1/7, 1/6, 1/5)	(1, 2, 3)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1, 1, 1)	(0.31, 0.45, 0.67)	(0.029, 0.052, 0.101)	0.051

4.6. Supply Chain Resilience Design Quality Capabilities

Several studies [106–108] have identified supply chain design issues relevant for resiliency. The results of this study revealed that node density was the governing capability among the design quality capabilities. Node density is expanded when there are disturbances in the markets and sources of the supply chain [16]. Craighead et al. and Falasca et al. emphasized that an enlarged supply chain density generates more vulnerabilities and reduces resilience [87,106]. For this reason, node density is a significant supply chain design quality attribute. Table 11 represents the normalized weights for the design quality capabilities, where it can be noted that node density ranks first, followed by complexity, while criticality ranks last.

Table 11. Weight values for the design quality capabilities.

	ND	COM	CRI	Fuzzy Geometric Mean Value	Fuzzy Weights	Normalized Weights
ND	(1, 1, 1)	(1, 2, 3)	(6, 7, 8)	(1.57, 1.93, 2.21)	(0.37, 0.55, 0.76)	0.538
COM	(1/3, 1/2, 1)	(1, 1, 1)	(2, 3, 4)	(0.90, 1.11, 1.41)	(0.22, 0.32, 0.49)	0.326
CRI	(1/8, 1/7, 1/6)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.42, 0.47, 0.54)	(0.1, 0.13, 0.19)	0.134

The following chart (Figure 4) demonstrates the ranking of the main capabilities and sub-capabilities, where the black bars denote the main supply chain resilience capabilities. From Figure 4 and the above calculations (Tables 5–11), it is clear that the effects of the different types of potential capabilities and sub-capabilities are established. The main capabilities are ranked as follows: proactive, reactive, adaptive, design quality, collaborative, and efficiency-based capabilities. In addition, we can see that the most influential sub-capabilities include contingency planning, response, node density, social capital, financial strength, self-organization, and attraction capabilities. These findings are in line with the estimates of the group of experts who, in the study, aimed to achieve future resilience of the supply chain and avoid impacts of disruptions, such as the COVID-19 pandemic.

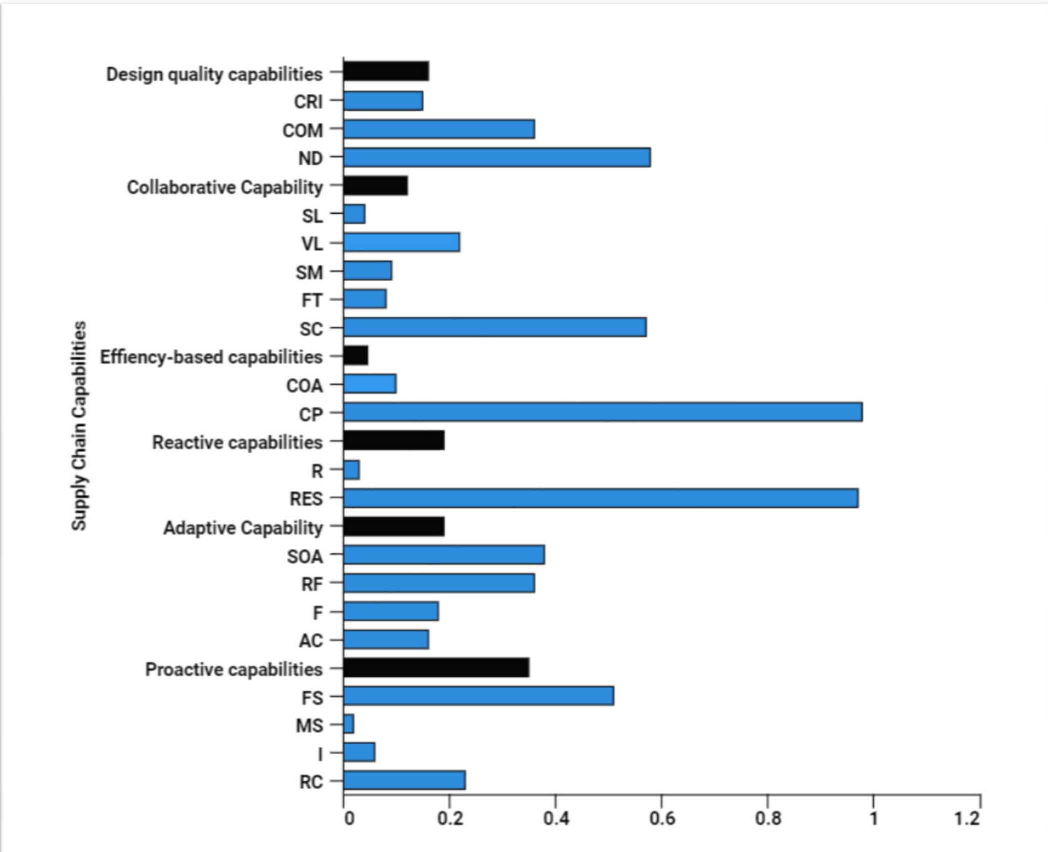

Figure 4. Ranking of the main capabilities and sub-capabilities.

5. Conclusions and Future Research

Supply chain resilience is a critical area of concern for businesses in today's dynamic and uncertain environment. To maintain competitiveness, businesses need to upgrade their operational performance regarding capabilities that are essential for effective supply chain management. In this study, the main supply chain resilience capabilities were prioritized using the FAHP method in the context of the COVID-19 pandemic, where two distinct capabilities were distinguished, namely, proactive and reactive supply chain resilience capabilities. Such capabilities help companies to determine their responses to market uncertainty, where a quick response to the market results in a better operational performance, which, in the future, will enhance the firm's operational and financial performance. An empirical study was conducted to examine the variables that significantly affect the way in which SCRE performance is measured, with the aim that companies in the food sector in some developing countries, such as Jordan, will be better equipped to foresee and address disruptions. Our results have several practical implications. Firstly, the suggested model can facilitate practitioners and managers in working toward a more robust supply chain resilience framework based on real situations when reacting to emergencies, such as the COVID-19 pandemic. Additionally, the findings could be used by managers when selecting their partners. Company decision-making centers should create proactive strategies to foresee the effects of supply chain disruption crises. Regarding the limitations of this study, a relatively small number of capabilities were analyzed, and the recruitment of experts was limited to Jordanian food sector companies. Furthermore, other methods may be required, in addition to FAHP, to ensure a more comprehensive approach. In the future, researchers could focus on developing new capabilities related to advanced technologies in order to improve resilience. Furthermore, exploratory empirical studies could be expanded to include international supply chain companies. Future research should concentrate on developing more integrated approaches that combine other decision-making methods, such as simulation and optimization, to improve decision making and ensure supply chain resilience.

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