# Investigating the Role of Knowledge-Based Supply Chains for Supply Chain Resilience by Graph Theory Matrix Approach


## Abstract

Nowadays, providing information flow at every phase of a knowledge-based supply chain with technologies has become a vital issue due to rapid population growth, globalisation, and increases in demand in the supply chain. Knowledge-based supply chains have a critical role in increasing resilience in supply chain processes with emerging technologies. Thus, it is necessary to determine the critical factors that increase SC resilience. Therefore, this study aims to determine SC resilience improvement factors in knowledge-based supply chains and investigate the importance level of determining factors using the Graph Theory Matrix Approach. The results suggest that the most important supply chain resilience improvement factor is Adaptive Capacity (F3), followed by Product Prioritization (F9) and Flexibility (F1), respectively. This study is expected to benefit managers and policymakers as it provides a better understanding of critical SC resilience improvement factors that play a role in knowledge-based supply chains. In order to increase resilience in the supply chain, system thinking and solutions should be encouraged by businesses to increase collaboration with stakeholders. Businesses and governments should provide collaborative long-term solutions for the uncertain environment to ensure a sustainable and resilient environment.



***Keywords:*** Knowledge-Based, Resilience, Supply Chain, Graph Theory Matrix Approach


***Abbreviation:*** Supply Chain - SC

## 1. Introduction

In order to deal with the limited resources in the globalising world, it is necessary to produce products with the lowest cost and highest efficiency (Yi et al., 2022). Providing product diversity has led enterprises to desire to reach global markets due to their shortened product life rather than their local region, the concept of superiority due to the labour force, technology and raw material factors (Rahman et al., 2022). The important thing in supply chain management (SCM) is to be successful not only in the competition between companies (Scholten et al., 2020) but also in the competition between the supply chain (SC) of the companies (Hofer et al., 2022).

Nowadays, the multi-stakeholder nature of SCs causes SCs processes to become more vulnerable (Gebhardt et al., 2022). Providing accurate and concurrent information flow in multi-stakeholder and multi-supplier SCs facilitates the follow-up of SCs (Sahebi et al., 2022). For this reason, knowledge-based SCs come to the fore, especially in order to provide resilience in the face of sudden disruptions in SCs (Yu & Sheng, 2021). Furthermore, knowledge-based SCs ensure that information sharing succeeds most effectively with the help of emergent technologies in SC processes (Singh et al., 2022). Hence, knowledge-based SCs play an important role in the resilience of SCs, but important factors must be considered to increase resilience in SC processes combined with emergent technologies (Alfarsi et al., 2019; Mathivathanan et al., 2021). A limited number of studies establish the relationship between SC resilience and knowledge-based SC (Ali et al., 2023; Singh et al., 2022; Orlando et al., 2022; Rosiello & Maleki, 2021). Moreover, revealing the importance level of critical factors about knowledge-based SCs is needed. Therefore, as a novelty, considering the literature review as a research gap, it is one of the newly studied topics in the literature.

Therefore, a research question is addressed in this study;

***RQ:*** What is the importance level of each SC resilience improvement factor in knowledge-based SCs?

To address the research question, firstly, a detailed literature review is conducted in order to be aware of the importance of the subject and to identify the factors that are important for the development of resilience in knowledge-based SCs by using the Graph Theory Matrix Approach.

To sum up, as a motivation for this study, although resiliency in the SC has become the most important topic of recent times, it is one of the most important elements to maintain and improve this resilience. Especially in knowledge-based SCs, their resiliency must constantly improve by keeping up with the latest. In addition to SC resilience studies, this study is crucial to determine SC resilience improvement factors in knowledge-based SCs by using Graph Theory. Thus, the novelty of this study is to provide a new perspective to improve resilience in knowledge-based SCs by determining the importance level of resilience improvement factors. Moreover, in the theoretical sense, SC resilience should adopt the system theory and provide a holistic perspective to the process. This study presents a theoretical infrastructure based on the system approach in the SC resilience process.

The following sections are organised as follows; Section 2 covers the role of knowledge-based SCs for SC resilience and determining SC resilience improvement factors in knowledge-based SCs. Then, section 3 explains the methodology, which is Graph Theory, and Section 4 highlights the implementation and results of the study. After that, Section 5 consists of discussions, implications, and conclusions.

## 2. Literature Review about the Role of Knowledge-Based SCs for SC Resilience

A supply chain (SC) is a network of stakeholders collaborating to create value for the end consumer. This includes all activities associated with creating and delivering a product or service (Boruchowitch & Firtz, 2022). Supply chain management (SCM) is a critical competency in today's global market. It enables companies to evaluate new products, identify new market opportunities and make strategic business decisions quickly and accurately in coordination with their SC partners (Sarkar et al., 2022). In the global economy, effectively managing the supply chain has become increasingly important for companies to remain competitive (Gloet & Samson, 2022).

Supply chains are extremely complex, particularly when it comes to global supply chains that involve a large number of suppliers and customers (Gong et al., 2022). Ensuring chain integrity is crucial as any problem caused by one of the stakeholders can have a ripple effect throughout the chain, compromising the quality of the product and putting the entire supply chain at risk (Irfan et al., 2022). Knowledge-based supply chains have become increasingly important in today's rapidly changing environment. This means it is essential to adopt emerging technologies in supply chain processes and integrate information technologies and supply chain processes, especially in the face of sudden disruptions (Badhotiya et al., 2022). The resilience of supply chains is threatened when there is a lack of preparation in operations. Taking immediate measures in operations and finding new solutions depends on evaluating and monitoring the supply chain provided by knowledge-based supply chains (Orlando et al., 2022).

Knowledge-based SCs are SC structures that focus on data, knowledge and human skills, in which advanced technologies can be adapted to the SC (Singh et al., 2022). Targeting more innovative applications in knowledge-based SCs provides error-free SCM from production to consumer with advanced technologies (Schoenherr, 2022). Information systems are used in knowledge-based SCs, and these information technologies are network systems defined as the use of internet-based communication devices, computing platforms, and protocols for the identification, calculation, transmission and storage of data (Sartori et al., 2022). Although these information systems are vital in the SC processes, in order to provide resilience in the face of sudden events in the SCs (Marcucci et al., 2022), the dynamic structure of the SCs should be aware of, and research should be carried out to make sense of the information (Amiri & Roshani et al., 2022). Making sense of information and analysing data in SCs provide a knowledge-based approach in SCs. In summary, knowledge-based SCs are crucial in ensuring resilience in global, dynamic and multi-stakeholder SCs (Yin et al., 2022).

By considering the literature review, the term which is “knowledge-based SC” is a subject that has been discussed in the past but remains limited in terms of detailed analysis and practical implementation (Bates & Slack, 1998; Piramuithu, 2005; Kayis & Karningsih, 2012; Blome et al., 2014). However, according to Singh et al. (2022), although these studies have addressed the basic concept, as mentioned before, SC structures have differentiated and knowledge-based requirements have reached a different level. Recently, Pal (2023), one of the most recent studies, discussed that knowledge-based systems should be used for SC resilience. Moreover, Eslami et al. (2023) advocate the creation of knowledge-sharing among SC stakeholders. For this reason, stating that a knowledge-based approach should be adopted, and conducted research on dyadic knowledge-sharing approaches in supply chains. Moreover, Juan and Li (2023) focused on SC resilience during COVID-19 in the context of knowledge-based theory. First, however, they studied the financial performance of firms with SC.

Moreover, there are limited studies, such as Sunmola et al. (2023), especially about SC resilience improvement. They stated that SC resilience improvement is in line with the visibility of SCs. Furthermore, Bukhari & Zafar (2023) focused on the relationship between SC disruptions and resilience factors such as panic buying behaviour, misinformation etc. In addition, there are many risk studies about SC resilience (Al-Ayed & Al-Tit, 2023; Imbiri et al., 2023). However, as seen in these studies, although SC resilience, knowledge-based and risk issues have been studied, it has not been found in the literature which factors are affected by SC resilience in terms of knowledge-based.

In summary, although many factors are considered for SC resiliency in knowledge-based SCs, there are factors that need to be considered to maintain and develop this resiliency. By integrating all these factors with advanced technologies, information-based SCs with the most efficiency can be obtained. This study answers the questions of what SC resilience improvement factors are, how important for the knowledge-based SC literature, and which factors should be prioritised to improve as a result of this order of importance. In this context, it provides a perspective on the subject from a sectoral perspective in the next academic studies and in practice. Therefore, in the following section, these factors are determined.

### 2.1 Determining SC Resilience Improvement Factors in Knowledge-Based SCs

As mentioned above, knowledge-based SCs consist of processes in which the necessary conditions are met to ensure resilience. Factors such as technological infrastructure, risk analyses, employee knowledge etc., are met (Narassima et al., 2022). However, when knowledge-based SCs are combined with the global SC structure, it becomes difficult to improve the resilience of SCs (Foroozesh et al., 2022). For this reason, it is extremely important to determine the factors that are important for the development of SC resilience. As a result of the literature review, 9 factors are determined for SC resilience improvement. These factors are shown in Table 1.

**Table 1.** SC Resilience Improvement Factors

| **SC Resilience Improvement Factors** | **References** |
| --- | --- |
| Flexibility ($F_1$) | Kamalahmadi et al., 2022; Hsu et al., 2022 |
| Multi-sourcing ($F_2$) | Mangla et al, 2019; Narassima et al., 2022; Kumar et al., 2022 |
| Adaptive Capacity ($F_3$) | Ozdemir et al., 2022; Lopes et al., 2022 |
| Stakeholder's Collaboration ($F_4$) | Aigbogun et al., 2022; Pimenta et al., 2022 |
| Network Diversification ($F_5$) | Lopes et al., 2022; Foroozesh et al., 2022 |
| Nearshoring ($F_6$) | Jorge & Wendt, 2022; Maharjan & Kato, 2022 |
| Data Awareness & Technological Adaptation ($F_7$) | Orlando et al., 2022; Ozdemir et al., 2022 |
| Agility ($F_8$) | Hsu et al., 2022; Pimenta et al., 2022 |
| Product Prioritisation ($F_9$) | Prataviera et al., 2022; Moosavi et al., 2022 |

These factors can be briefly explained as follows.

**Flexibility ($F_1$):** A company's ability to handle unexpected SC disruptions with its current capabilities is defined as flexibility in SCs (Kamalahmadi et al., 2022). SC flexibility is the ability to respond to and recover from problems with minimal disruption to operations and customer timeframes, enabling SCs to increase resilience in the face of sudden disruptions (Hsu et al., 2022).

**Multi-sourcing ($F_2$):** In the face of unexpected events that occur in the SC, sticking to a single source location causes the processes to stop (Narassima et al., 2022). For this reason, the number of suppliers and sources of raw materials can be increased by adopting a multi-source approach in SCs, and risk distribution can be made against sudden disruptions that may occur by distributing different business processes to different suppliers (Kumar et al., 2022), and this ensures the improvement of resilience in SCs (Mangla et al., 2019).

**Adaptive Capacity ($F_3$):** Capacity and stock planning are extremely important to ensure resilience in SC processes (Lopes et al., 2022). Having a safety stock in the face of sudden situations that may occur in the SCs and being able to be flexible in capacity planning ensures that the SC processes can continue while dealing with problems in the background (Ozdemir et al., 2022).

**Stakeholder's Collaboration ($F_4$):** Since global SCs have a multi-stakeholder structure, cooperation between stakeholders is extremely important for the continuity of processes (Aigbogun et al., 2022). Collaboration between all stakeholders should be possible to monitor and analyse the situations that threaten the durability of the SCs and solve the problems quickly (Pimenta et al., 2022).

**Network Diversification ($F_5$):** One of the important factors for increasing resilience in SCs is network diversification. Especially with the globalisation of SCs and the complexity of operations today, distributing the supply network instead of focusing on one place in the supply processes comes to the fore (Lopes et al., 2022). Although this situation is seen as a cost, it is now considered a business cost for the development of SC resilience (Foroozesh et al., 2022).

**Nearshoring ($F_6$):** Nearshoring in SC processes generally refers to making region choices where inventory control can be done better and the finished product can be delivered to the consumer more easily without being tied to a single geographical region in the finished product process (Jorge & Wendt, 2022). When SCs depend on a single region for raw materials or other issues, they cannot maintain their resilience in the face of sudden disruptions (Maharjan & Kato, 2022). Therefore, in SC processes, SC resilience is improved by geographical region distribution with nearshoring.

**Data Awareness & Technological Adaptation ($F_7$):** To ensure resilience in SCs, it is necessary to follow technological developments and have a technological infrastructure (Orlando et al., 2022). However, the improvement of resilience in SCs depends on being aware of useful data that may arise in SC processes and providing technology adaptation to data (Ozdemir et al., 2022).

**Agility ($F_8$):** Agility means restructuring the system quickly against predictable changes. In the understanding of the SC, businesses that act with less agility in the event of any change in customer demands or in the face of sudden disruptions in the SC expose their suppliers to operational risk (Hsu et al., 2022). Therefore, agility is an important concept for the improvement of SC resilience (Pimenta et al., 2022).

**Product Prioritisation ($F_9$):** Sudden situations that may be encountered in the SC processes may necessitate product selection. SC resilience can be improved by prioritising products to prevent damage to the entire SC resilience (Prataviera et al., 2022). For this reason, SC resilience can be improved by analysing which product will work best in the face of sudden situations and what constitutes the backbone of the SC (Moosavi et al., 2022).

## 3. Methodology: Graph Theory Matrix Approach

This study aims to evaluate resilience improvement factors in knowledge-based SCs such as the automotive industry.  Resilience in the automotive industry is one of the important sectors that should provide flexibility in speed and diversity in production processes. It is important to respond to customer needs more quickly and adapt quickly to flexible production methods when there are sudden changes in consumer demands. Besides, knowledge-based supply chains in the automotive industry enable the prediction and management of possible disruptions and risks that may occur in the supply chain. In addition, information-based supply chains provide benefits such as monitoring and evaluating the performance of suppliers, increasing cooperation and coordination within the supply chain, reducing costs and accelerating the product supply process. Knowledge-based supply chains enable real-time data collection, analysis and sharing with the technologies used in production and supply processes. In this way, better cooperation and coordination between all actors in the SC is ensured, and any disruption or risk in the SC is quickly detected and prevented. As a result, knowledge-based supply chains play an important role in increasing SC resilience in the automotive industry and provide benefits such as speeding up production processes, reducing costs and increasing customer satisfaction, which is critical, especially for the automotive sector. Thus, Graph Theory Matrix Approach is used to provide deep insights into SC resilience improvement factors and their relationships.

After elaborating on SC resilience improvement factors in the automotive industry, the stages of the algorithm are elaborated in the methodology section.

Graph theory is considered a framework of graphs (Ray, 2013). Visualisation of the interrelations of identified factors and the presenting graph is significant for increasing the understandability of the entire system (Singh & Kumar, 2019). Thus, this methodology is beneficial for indicating the relations between factors in order to create a solution for complex problems (Deo, 2017). Developing an effective decision-making environment is crucial for analysing and clarifying multiple interrelated factors (Wagner & Neshat, 2010; Gupta & Singh, 2020). This approach provides better insight to analyse and comprehend the system as a whole by identifying the system and sub-system. It helps in selecting the most suitable choice among various alternatives to the problem. SC resilience depends on the number of sub-variables and determining relationships between these key variables while the quantification of resilience in the SC is critical to creating long-term strategic decisions. Thus, with the graph theory matrix approach, SC resilience can be quantified by investigating the role of knowledge-based supply chains. Considering the literature review, previous studies didn't reflect the interdependencies between factors and didn't present requirements to adjust the factors for the changing conditions (Kaur et al., 2006). Thus, the approach provides flexibility to embrace new factors to deal with changing situations (Agarwal et al., 2022).
This methodology consists of three stages. First, a digraph provides a visual representation of factors and their interrelations. Digraph representation is significant in presenting the system visually. Converting matrix representation needs to provide calculations of the proposed diagram. Finally, the permanent function value is used to evaluate and rank the factors.

The first stage of this methodology begins by developing a digraph by indicating a set of ordered finite oriented edges or arcs (Kim et al., 2015; Yıldırım et al., 2021). Based on the digraph, Matrix representation is beneficial for reducing the complexity of the digraph representation by indicating factors, relationships and the relative importance of these factors. The matrix is shown in Equation 1.

$$M=\begin{bmatrix} A_{1,1} & \cdots & a_{1,10} \\ \vdots & \ddots & \vdots \\ a_{10,1} & \cdots & a_{10,10} \end{bmatrix} \quad (1)$$

According to matrix representation, Aij variables (i = j) characterise the relative importance of factor i over factor j, aij variables signify the relative importance of factor i over j, that is a value between 0 and 1 is assigned for the relative importance using scales considering Table 2 (Baykasoğlu, 2014).

**Table 2.** Relative importance of the improvement factors

| **Classification** | **rij** | **rji = 1-rij** |
|---|---|---|
| Equally important | 0.5 | 0.5 |
| One factor is slightly more important than other | 0.6 | 0.4 |
| One factor is more important | 0.7 | 0.3 |
| One factor is very important | 0.8 | 0.2 |
| One factor is exceptionally important | 0.9 | 0.1 |
| One factor is the most important | 1 | 0 |

This method used a permanent function which is one step further than the determinant function, which does not include the negative sign. The permanent function is the sum of the weights of cycle covers of the mentioned digraph. Each vertex *i* in the digraph represents a single successor $\sigma$ (i) in the cycle-cover. $\sigma$ indicates permutation on $\{1, 2\ldots\ n\ \}$ and $n$ shows the number of vertices in the digraph. Any permutation of $\sigma$ on $\{1, 2\ldots\ n\ \}$ resembles a cycle cover in which there is an arc from vertex *i* to vertex $\sigma$ (i) (Minc 1984; Rabbani et al., 2019). The final stages include creating the permanent function of a matrix. The permanent function is calculated by Equation 2.

$$Perm\ (A) = \sum_{\sigma} \prod_{i=1}^{n} \sigma \text{i}, \sigma(\text{i}) \quad (2)$$

For the data-gathering stage, nine experts from the automotive industry were approached. These included an information technology manager, a manufacturing engineer, a materials development engineer, an SC engineer, a purchasing engineer, a risk analyst, a production planning engineer, a research and development engineer, and an operations engineer. These selected experts were chosen because they had more than five years of experience in this field and many studies and projects that they have carried out in this context. The determined factors were also supported by the previous studies presented in the literature section.  Table 4 shows the details of the expert. Each participant was asked to compare and make an assessment of SC resilience improvement factors in knowledge-based SCs relative to each other. This was done in person through short interviews, by phone or by email. Each participant filled out the matrix M presented in equation 2 the resilience index value is calculated using the permanent function of the matrix. Each participant is assigned a value between 0 and 1 for evaluating the relative importance using scales considering Table 2.

**Table 3.** Information about experts

| **Experts** | **Position** | ***Years of Experience*** |
|---|---|---|
| 1 | Information Technology Manager | 6 |
| 2 | Manufacturing Engineer | 9 |
| 3 | Materials Development Engineer | 7 |
| 4 | SC Engineer | 6 |
| 5 | Purchasing Engineer | 7 |
| 6 | Risk Analyst | 5 |
| 7 | Production Planning Engineer | 6 |
| 8 | Research and Development Engineer | 5 |
| 9 | Operations Engineer | 8 |

## 4. Implementation and Results

Graph Theory and the Matrix Approach are used to provide an assessment of the SC resilience improvement factors and find the preference order of these factors. SC resilience improvement factors are indicated in Table 3.

**Table 4.** SC Resilience improvement index

| **SC Resilience Improvement Factors** |
|---|
| Flexibility ($F_1$) |
| Multi-sourcing ($F_2$) |
| Adaptive Capacity ($F_3$) |
| Stakeholder's Collaboration ($F_4$) |
| Network Diversification ($F_5$) |
| Nearshoring ($F_6$) |
| Data Awareness & Technological Adaptation ($F_7$) |
| Agility ($F_8$) |
| Product Prioritisation ($F_9$) |

The digraph of the algorithm is presented in Figure 1. This digraph indicates the relationships among the SC Resilience improvement factors. Flexibility (F1), Multi-sourcing (F2), Adaptive Capacity (F3), Stakeholder Collaboration (F4), Network Diversification (F5), Nearshoring (F6), Data Awareness & Technological Adaptation (F7), Agility (F8), Product Prioritisation (F9) are showed in the node. The arrows show the relative importance of factors. Without an arrow, a relationship between the two factors cannot be established.

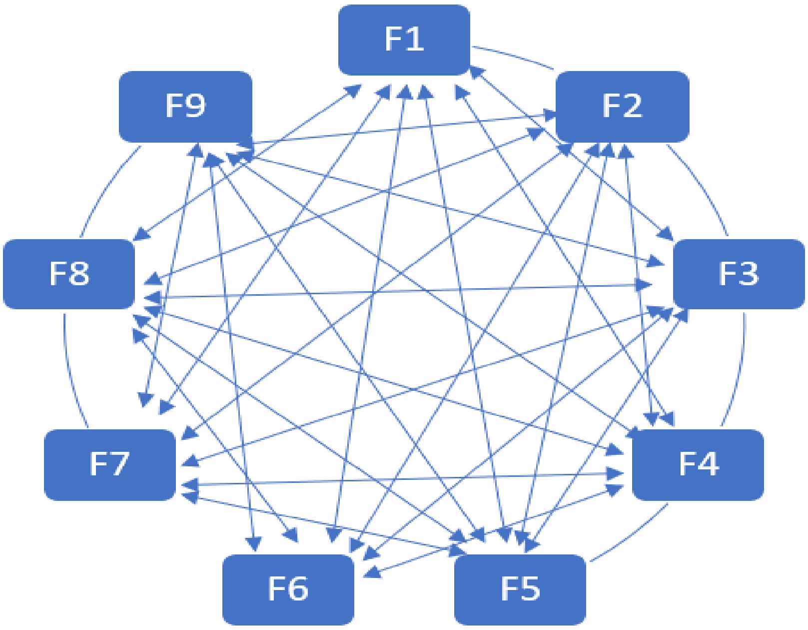


**Figure 1.** SC Resilience improvement factors digraph

Pairwise comparisons of the SC Resilience improvement index are presented in Table 5. Data were obtained from different experts to calculate the SC Resilience improvement index level, as indicated in Table 4. For the pairwise comparisons, the relative importance of factors is weighted using the scale shown in Table 2. If there is no relationship between the two factors, a value of 0 is assigned.

**Table 5.** Pairwise comparisons SC Resilience improvement index

| | ***F1*** | ***F2*** | ***F3*** | ***F4*** | ***F5*** | ***F6*** | ***F7*** | ***F8*** | ***F9*** |
|---|---|---|---|---|---|---|---|---|---|
| ***F1*** | 1 | 0.6 | 0.7 | 0.5 | 0.6 | 0.5 | 0.6 | 0.8 | 0 |
| ***F2*** | 0.4 | 1 | 0.5 | 0.8 | 0.9 | 0.6 | 0.6 | 0.5 | 0.8 |
| ***F3*** | 0.3 | 0.5 | 1 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.6 |
| ***F4*** | 0.5 | 0.2 | 0.5 | 1 | 0.5 | 0.7 | 0.8 | 0.5 | 0.7 |
| ***F5*** | 0.4 | 0.1 | 0.5 | 0.5 | 1 | 0 | 0.5 | 0.6 | 0.5 |
| ***F6*** | 0.5 | 0.4 | 0.4 | 0.3 | 1 | 1 | 0 | 0.8 | 0.7 |
| ***F7*** | 0.4 | 0.4 | 0.4 | 0.2 | 0.5 | 1 | 1 | 0.6 | 0.8 |
| ***F8*** | 0.2 | 0.5 | 0.3 | 0.5 | 0.4 | 0.2 | 0.4 | 1 | 0.9 |
| ***F9*** | 1 | 0.2 | 0.4 | 0.3 | 0.5 | 0.3 | 0.2 | 0.1 | 1 |

The permanent SC Resilience improvement index for each expert is included in Table 6.

**Table 6.** The permanent SC Resilience improvement index for each expert

| | ***F1*** | ***F2*** | ***F3*** | ***F4*** | ***F5*** | ***F6*** | ***F7*** | ***F8*** | ***F9*** |
|---|---|---|---|---|---|---|---|---|---|
| ***Expert1*** | 3 | 3 | 2 | 5 | 5 | 5 | 4 | 5 | 3 |
| ***Expert2*** | 3 | 3 | 3 | 4 | 5 | 4 | 5 | 4 | 3 |
| ***Expert3*** | 4 | 3 | 3 | 5 | 5 | 4 | 5 | 5 | 2 |
| ***Expert4*** | 4 | 5 | 2 | 3 | 4 | 5 | 4 | 3 | 3 |
| ***Expert5*** | 5 | 5 | 2 | 5 | 3 | 4 | 3 | 5 | 3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Expert6*** | 4 | 4 | 4 | 3 | 4 | 3 | 5 | 4 | 4 |
| ***Expert7*** | 5 | 4 | 3 | 3 | 3 | 3 | 4 | 5 | 3 |
| ***Expert8*** | 5 | 4 | 3 | 2 | 4 | 4 | 3 | 3 | 2 |
| ***Expert9*** | 4 | 4 | 4 | 4 | 4 | 5 | 2 | 3 | 4 |

By converting the digraph presented in Figure 1 to matrix representation, Table 5 and Table 6 are used. Diagonal values of the matrix show expert opinions for each SC Resilience improvement index. The average of each expert's pairwise comparisons values is used for the pairwise comparisons. Table 7 indicates the resilience improvement index of ''flexibility (F1)'' based on expert 1.

**Table 7.** Resilience Improvement Index of ''Flexibility (F1)'' based on the expert opinion

| | ***F1*** | ***F2*** | ***F3*** | ***F4*** | ***F5*** | ***F6*** | ***F7*** | ***F8*** | ***F9*** |
|---|---|---|---|---|---|---|---|---|---|
| ***F1*** | 0 | 0.6 | 0.7 | 0.5 | 0.6 | 0.5 | 0.6 | 0.8 | 0 |
| ***F2*** | 0.4 | 3 | 0.5 | 0.8 | 0.9 | 0.6 | 0.6 | 0.5 | 0.8 |
| ***F3*** | 0.3 | 0.5 | 2 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.6 |
| ***F4*** | 0.5 | 0.2 | 0.5 | 5 | 0.5 | 0.7 | 0.8 | 0.5 | 0.7 |
| ***F5*** | 0.4 | 0.1 | 0.5 | 0.5 | 5 | 0 | 0.5 | 0.6 | 0.5 |
| ***F6*** | 0.5 | 0.4 | 0.4 | 0.3 | 1 | 5 | 0 | 0.8 | 0.7 |
| ***F7*** | 0.4 | 0.4 | 0.4 | 0.2 | 0.5 | 1 | 4 | 0.6 | 0.8 |
| ***F8*** | 0.2 | 0.5 | 0.3 | 0.5 | 0.4 | 0.2 | 0.4 | 5 | 0.9 |
| ***F9*** | 1 | 0.2 | 0.4 | 0.3 | 0.5 | 0.3 | 0.2 | 0.1 | 3 |

In order to calculate SC Resilience Improvement Index, matrix representations are used for factors. Equation 1 is used by converting constructed matrix and then SC Resilience Improvement Index is found for each factor. Permanent resilience indexes for each factor are also found similarly. Therefore, the rank of the SC Resilience Improvement Index is indicated in Table 8.

**Table 8.** SC Resilience Improvement Index

| | ***Flexibility (F1)*** | ***Multi-sourcing (F2)*** | ***Adaptive Capacity (F3)*** | ***Stakeholder's Collaboration (F4)*** | ***Network Diversification (F5)*** | ***Nearshoring (F6)*** | ***Data Awareness & Technological Adaptation (F7)*** | ***Agility (F8)*** | ***Product Prioritisation (F9)*** |
|---|---|---|---|---|---|---|---|---|---|
| ***Average*** | 91473.80 | 83895.01 | 107129.14 | 87138.01 | 80583.70 | 79176.40 | 85479.11 | 79136.59 | 98649.79 |
| ***Rank*** | 3 | 6 | 1 | 4 | 7 | 8 | 5 | 9 | 2 |

SC Resilience Improvement Index is calculated with Equation 2 in order to assess the prioritisation of the resilience index. According to the results shown in Table 8, the most important SC Resilience Improvement factor is considered *Adaptive Capacity (F3). After Adaptive Capacity (F3), Product Prioritisation (F9) and Flexibility (F1)* are considered as the second and third rank, respectively. Then, *Stakeholder Collaboration (F4) and Data Awareness*

*& Technological Adaptation (F7)* are followed by *Multi-sourcing (F2)*. Other SC resilience improvement factors are *Network Diversification (F5), Nearshoring (F6)* and *Agility (F8)*, respectively.

As a final stage for the validation of the results, the proposed SC resilience improvement index and prioritisation of the resilience index are further validated based on semi-structured interviews with three academics and five industry experts who have researched and experienced in this field. The academic experts consist of university professors from SC management, operations management and information technology departments. The industrial experts include five SC experts from the automotive sector. The results are discussed in the next section.

## 5. Discussions and Implications

Knowledge-based SCs are SC structures in which information sharing and flow are ensured at every stage of the SC, and technology is used to achieve this. Supply chains that contain technology and information flow increase the resiliency of supply chains as they are more flexible and agile in the face of sudden disruptions (Shishodia et al., 2021). Various factors must be considered to maintain and enhance their resiliency to provide efficiency in knowledge-based supply chains. Integrating these factors into information-based supply chains can create a highly resilient and efficient supply chain process. Thus, the main contribution of this study is to provide a perspective on enhancing resilience in knowledge-based supply chains by identifying the significance of key factors that can improve their resilience.

When our results are discussed in relation to other studies, it can be seen that Adaptive Capacity (F3) is determined as the most important factor for SC resilience improvement in knowledge-based supply chains. It is also essential to increase resiliency in food SCs, especially in the distribution stage, during pandemics (Bruckner & Dasaro, 2022). Similar to our study, adaptive capacity is like managing stocks required by the supply chain, keeping safety stock in sudden situations, reducing or increasing etc. (Basset et al., 2022; Maharjan and Kato, 2022). Moreover, in line with the results of our study, according to Rezapour Niari et al. (2022), adaptive capacity and its management become the most important issue during pandemics to have resilient SC operations.

Moreover, Product Prioritisation (F9) is determined as the second important factor for SC resilience improvement in knowledge-based supply chains in our study. According to researchers (Pina et l., 2022; Lamy et al., 2022), similar to our study, product prioritisation is a critical factor in having resilient SCs. Moreover, Khan et al. (2022) stated that product prioritisation is important, especially in sudden situations such as pandemics, as it includes the analysis of which product is decided to be produced and delivered to the customer with priority.

A third important factor for SC resilience improvement in knowledge-based supply chains is Flexibility (F1). According to Lusiantoro & Pradiptyo (2022), flexibility is one of the most critical factors that affect SC resilience improvement. In our study, it is examined as a third important factor. Moreover, Kamalahmadi et al. (2022) stated that flexibility provides more SC resilience, especially in disruption times, similar to our study.

There are several implications that can be derived from the results of this study. Theoretical, managers, policy-makers and practical implications are presented, respectively. As supply chain structures have become increasingly complex, the demand for knowledge-based requirements is to be integrated into supply chain management practices. This need stems from the recognition that a complex understanding of the supply chain is essential to optimise its performance and ensure its long-term success. Besides, a resilient supply chain is built on strong relationships among various stakeholders and should be grounded in knowledge. By assessing the role of knowledge-based supply chain resilience factors, researchers can identify potential paths for research into the impact of social networks and knowledge flows on supply chain performance. Evaluation of the importance of knowledge-based supply chain resilience factors provides a deeper understanding of the complex interactions and relationships within supply chain consideration. By examining the importance of supply chain resilience factors, researchers can support the development of more robust supply chain management models. It is important to analyse and integrate a knowledge-based approach into supply chain management to achieve these purposes.

Especially in SC resilience issues, the system thinking approach is extremely important in order to keep it under full control in the process. The system thinking approach offers a holistic perspective of processes. Supply chain resilience can be viewed as an emergent property of the complex system arising from the interactions and interdependencies among the various components of the supply chain. Thus, each critical process for achieving supply chain resilience should be handled holistically, and therefore resilience should be increased theoretically with a system approach.

System thinking and solutions should be promoted by businesses to increase collaboration among suppliers, employees, customers, and different stakeholders. Companies can boost their resilience by collaborating with various stakeholders. Moreover, businesses should ensure effective relationships and should investigate resources for their business that can be accessed from other organisations during uncertain times. Effective planning and management are also important to provide collaboration. Thus, collaborations between stakeholders can be considered a key concept to making supply chains more resilient.

Resilience is mainly based on providing different alternative ways and reacting rapidly to disruptive situations. Adaptive capacity is a significant resilience improvement factor to increase resilience in the supply chain. Thus, businesses should provide strategic adaptive strategies since these strategies are crucial to ensure resilience by improving knowledge of strategic actions. Besides, businesses should make an effective long-term strategic plan for their capacity to take advantage of opportunities or to provide a quick response. Adaptive capacity can be increased by supporting learning, and knowledge and developing flexible problem-solving. Thus, businesses should support effective planning capacity and innovation. Moreover, employees should be included in the process and motivated.

The second important resilience improvement factor has been found to be product prioritisation. Businesses should be aware of the organisation's priorities in order to deal with a crisis. Thus, product prioritising must be clearly defined by predicting minimum business operating requirements. Thus, investigations organisation's priorities would be following a crisis, clearly defined at the organisation level, and an understanding of the organisation's minimum operating requirements. Moreover, cost, quality and process regulations should also be revised in an integrated manner according to all product prioritisation processes.

The third important resilience improvement factor is flexibility. In order to increase adaptivity, businesses should design their processes to provide flexibility with the multi-time scale perspectives in the supply chain. To increase resilience in supply chains, businesses should develop multiple strategies. In order to create a sustainable business, organisations should develop measurement techniques and tools for flexibility, adaptation, and other components of resilience.

As policymakers' and practical implications, data awareness & technological adaptation are also significant for improving resilience since it provides enhanced explorations of the new capabilities and increased flexibility in the entire supply chain.  Infrastructure and technologies investments should support by the governments. Businesses and governments should provide long-term collaborative solutions for dealing with the uncertain environment to ensure a sustainable and resilient environment. Digital technologies and their applications should be adopted to increase readiness in order to adapt to rapidly chaining environments. By collaborating with institutes, the government should also encourage training, seminars and education to develop different resilience strategies to deal with unexpected situations.

## 6. Conclusions

Knowledge-based SCs come to the fore, especially in order to provide resilience in the face of sudden disruptions in SC. In other words, knowledge-based SCs ensure that information sharing is done most effectively with the help of emergent technologies in SC processes. It is extremely important to be aware of SC resilience improvement factors in knowledge-based SCs in order to keep up with the complex structure in these times when SCs are becoming more complex and globalised. Therefore, this study aims to determine these SC resilience improvement factors in knowledge-based SCs and to highlight the importance level of these factors.

As indicated in Table 8, the most critical SC Resilience Improvement factor is Adaptive Capacity (F3). Product Prioritisation (F9) and Flexibility (F1) have been followed by Adaptive Capacity (F3). Then, Stakeholder Collaboration (F4) Data Awareness & Technological Adaptation (F7) is followed by Multi-sourcing (F2). Other SC resilience improvement factors are Network Diversification (F5), Nearshoring (F6) and Agility (F8), respectively.

As a limitation of this study, although the knowledge-based SC needs to be adopted in operations, it has been difficult to find an expert on the subject because companies/organisations do not fully understand this concept and cannot reflect it in their processes. For further research, the factors discussed in the study may vary within the framework of rapid technological developments, sudden disruptions and the flexibility of SCs. Moreover, comparative analyses can be made according to the development levels of countries.

## References


Agarwal, N., Seth, N., & Agarwal, A. (2022). Evaluation of supply chain resilience index: a graph theory-based approach. Benchmarking: An International Journal, 29(3), 735-766.

Aigbogun, O., Xing, M., Fawehinmi, O., Ibeabuchi, C., Ehido, A., Ahmad, R., & Abdullahi, M. (2022). A supply chain resilience model for business continuity: The way forward for highly regulated industries. *Uncertain Supply Chain Management*, *10*(1), 1-12.

Al-Ayed, S., & Al-Tit, A. (2023). The effect of supply chain risk management on supply chain resilience: The intervening part of Internet-of-Things. *Uncertain Supply Chain Management*, *11*(1), 179-186.

Alfarsi, F., Lemke, F., & Yang, Y. (2019). The importance of supply chain resilience: an empirical investigation. Procedia Manufacturing, 39, 1525-1529.

Ali, A. A. A., Udin, Z. B. M., & Abualrejal, H. M. E. (2023). The Impact of Artificial Intelligence and Supply Chain Resilience on the Companies Supply Chains Performance: The Moderating Role of Supply Chain Dynamism. In International Conference on Information Systems and Intelligent Applications (pp. 17-28). Springer, Cham.

Amiri, S., & Roshani, G. (2022). Modeling the impact of Covid-19's stress and resilience on job burnout using Radial Basis Functions-Artificial Neural Network The case of knowledge-based companies. *Journal of Production and Operations Management*, *13*(2), 23-43.

Badhotiya, G. K., Soni, G., Jain, V., Joshi, R., & Mittal, S. (2022). Assessing supply chain resilience to the outbreak of COVID-19 in Indian manufacturing firms. *Operations Management Research*, 1-20.

Bassett, H. R., Sharan, S., Suri, S. K., Advani, S., & Giordano, C. (2022). A comparative study of small-scale fishery supply chains' vulnerability and resilience to COVID-19. *Maritime Studies*, 1-20.

Bates, H., & Slack, N. (1998). What happens when the supply chain manages you?: A knowledge-based response. *European Journal of Purchasing & Supply Management*, 4(1), 63-72.

Baykasoglu, A. (2014). A review and analysis of "graph theoretical-matrix permanent" approach to decision making with example applications. *Artificial Intelligence Review*, 42(4), 573-605.

Blome, C., Schoenherr, T., & Eckstein, D. (2014). The impact of knowledge transfer and complexity on supply chain flexibility: A knowledge-based view. *International Journal of Production Economics*, 147, 307-316.

Boruchowitch, M. F., & Fritz, M. M. (2022). Who in the firm can create sustainable value and for whom? A single case-study on sustainable procurement and supply chain stakeholders. *Journal of Cleaner Production*, 132619.

Bruckner, H., & Dasaro, S. (2022). Adaptive capacity in emergency food distribution: Pandemic pivots and possibilities for resilient communities in Colorado. *Journal of Agriculture, Food Systems, and Community Development*, *11*(3), 1-20.

Bukhari, S & Zafar, I. (2023). Impact of global supply chain disruption on global supply chain resilience during pandemic like COVID-19.*Journal of Future Sustainability*, 3(3), 133-142.

Deo, N. (2017). *Graph theory with applications to engineering and computer science*. Courier Dover Publications.

Eslami, M. H., Achtenhagen, L., Bertsch, C. T., & Lehmann, A. (2023). Knowledge-sharing across supply chain actors in adopting Industry 4.0 technologies: An exploratory case study within the automotive industry. *Technological Forecasting and Social Change*, 186, 122118.

Foroozesh, N., Karimi, B., & Mousavi, S. M. (2022). Green-resilient supply chain network design for perishable products considering route risk and horizontal collaboration under robust interval-valued type-2 fuzzy uncertainty: A case study in food industry. *Journal of Environmental Management*, *307*, 114470.

Gebhardt, M., Spieske, A., Kopyto, M., & Birkel, H. (2022). Increasing global supply chains' resilience after the COVID-19 pandemic: empirical results from a Delphi study. *Journal of Business Research*.

Gloet, M., & Samson, D. (2022). Knowledge and innovation management to support supply chain innovation and sustainability practices. *Information Systems Management*, *39*(1), 3-18.

Gong, H., Xiang, Y., Wu, J., Nkebiwe, P. M., Feng, G., Jiao, X., & Zhang, F. (2022). Using knowledge-based management for sustainable phosphorus use in China. *Science of the Total Environment*, *814*, 152739.

Gupta, A., & Singh, R. K. (2020). Developing a framework for evaluating sustainability index for logistics service providers: graph theory matrix approach. International Journal of Productivity and Performance Management.

Hazen, B., Confente, I., Pellathy, D., & Russo, I. (2022). From End-of-the-road to Critical Node: The Role of End-user "Consumers" in Shaping Circular Supply Chain Management. In Circular Economy Supply Chains: From Chains to Systems. Emerald Publishing Limited.

Hofer, C., Barker, J. M., D'Oria, L., & Johnson, J. L. (2022). Broadening our understanding of interfirm rivalry: A call for research on how supply networks shape competitive behavior and performance. *Journal of Supply Chain Management*, *58*(2), 8-25.

Hsu, C. H., Li, M. G., Zhang, T. Y., Chang, A. Y., Shangguan, S. Z., & Liu, W. L. (2022). Deploying Big Data Enablers to Strengthen Supply Chain Resilience to Mitigate Sustainable Risks Based on Integrated HOQ-MCDM Framework. *Mathematics*, *10*(8), 1233.

Imbiri, S., Rameezdeen, R., Chileshe, N., & Statsenko, L. (2023). Risk propagation and resilience in the agribusiness supply chain: a systematic literature review. *Journal of Agribusiness in Developing and Emerging Economies*, (ahead-of-print).

International Journal of Logistics Systems and Management, Vol. 2 No. 4, pp. 321-341.
Irfan, I., Sumbal, M. S. U. K., Khurshid, F., & Chan, F. T. (2022). Toward a resilient supply chain model: critical role of knowledge management and dynamic capabilities. *Industrial Management & Data Systems*, (ahead-of-print).
Jorge, J., & Wendt, C. (2022). Supply chain redesign: From building resiliency to positioning for growth. *Journal of Supply Chain Management, Logistics and Procurement*, *4*(3), 239-249.
Juan, S. J., & Li, E. Y. (2023). Financial performance of firms with supply chains during the COVID-19 pandemic: the roles of dynamic capability and supply chain resilience. *International Journal of Operations & Production Management*, (ahead-of-print).
Kamalahmadi, M., Shekarian, M., & Mellat Parast, M. (2022). The impact of flexibility and redundancy on improving supply chain resilience to disruptions. *International Journal of Production Research*, *60*(6), 1992-2020.
Kaur, A., Kanda, A. and Deshmukh, S.G. (2006), "A graph theoretic approach for SC coordination",
Kayis, B., & Karningsih, P. D. (2012). SCRIS: A knowledge-based system tool for assisting manufacturing sorganisations in identifying supply chain risks. *Journal of Manufacturing Technology Management.*
Khan, S. A. R., Piprani, A. Z., & Yu, Z. (2022). Supply chain analytics and post-pandemic performance: Mediating role of triple-A supply chain strategies. International Journal of Emerging Markets, (ahead-of-print).
Khan, S. A. R., Piprani, A. Z., & Yu, Z. (2022). Supply chain analytics and post-pandemic performance: Mediating role of triple-A supply chain strategies. International Journal of Emerging Markets, (ahead-of-print).
Kim, Y., Chen, Y. S., & Linderman, K. (2015). Supply network disruption and resilience: A network structural perspective. *Journal of Operations Management*, 33, 43-59.
Kumar, M., Raut, R. D., Sharma, M., Choubey, V. K., & Paul, S. K. (2022). Enablers for resilience and pandemic preparedness in food supply chain. *Operations Management Research*, 1-26.
Lamy, E., Viegas, C., Rocha, A., Lucas, M. R., Tavares, S., e Silva, F. C., ... & Anzman-Frasca, S. (2022). Changes in food behavior during the first lockdown of COVID-19 pandemic: A multi-country study about changes in eating habits, motivations, and food-related behaviors. *Food quality and preference*, *99*, 104559.
Lopes, J. M., Gomes, S., & Mané, L. (2022). Developing knowledge of supply chain resilience in less-developed countries in the pandemic age. *Logistics*, *6*(1), 3.
Lusiantoro, L., & Pradiptyo, R. (2022). Rebuilding disrupted supply chains: How can a self-organised social group facilitate supply chain resilience?. International Journal of Operations & Production Management, (ahead-of-print).
Maharjan, R., & Kato, H. (2022). Resilient supply chain network design: a systematic literature review. *Transport Reviews*, 1-23.
Mangla, S. K., Sharma, Y. K., Patil, P. P., Yadav, G., & Xu, J. (2019). Logistics and distribution challenges to managing operations for corporate sustainability: study on leading Indian diary organisations. *Journal of Cleaner Production*, 238, 117620.
Marcucci, G., Mazzuto, G., Bevilacqua, M., Ciarapica, F. E., & Urciuoli, L. (2022, January). Conceptual model for breaking ripple effect and cycles within supply chain resilience. In *Supply Chain Forum: An International Journal* (pp. 1-20). Taylor & Francis.
Mathivathanan, D., Mathiyazhagan, K., Rana, N. P., Khorana, S., & Dwivedi, Y. K. (2021). Barriers to the adoption of blockchain technology in business supply chains: a total interpretive structural modelling (TISM) approach. *International Journal of Production Research*, *59*(11), 3338-3359.
Minc H (1984) Permanents. vol 6. Cambridge University Press.
Moosavi, J., Fathollahi-Fard, A. M., & Dulebenets, M. A. (2022). Supply chain disruption during the COVID-19 pandemic: sRecognising potential disruption management strategies. *International Journal of Disaster Risk Reduction*, 102983.
Narassima, M. S., Anbuudayasankar, S. P., Mathiyazhagan, K., Ganesh, K., & Lee, T. R. (2022). Supply chain resilience: conceptual model building and validation. *International Journal of Logistics Research and Applications*, 1-33.

Orlando, B., Tortora, D., Pezzi, A., & Bitbol-Saba, N. (2022). The disruption of the international supply chain: Firm resilience and knowledge preparedness to tackle the COVID-19 outbreak. *Journal of International Management*, *28*(1), 100876.
Ozdemir, D., Sharma, M., Dhir, A., & Daim, T. (2022). Supply chain resilience during COVID 19 pandemic. *Technology in Society*, 101847.
Pal, K. (2023). Supply Chain Resilience Management Using a Semantically-Enhanced Web Service Portal. In Handbook of Research on Promoting Logistics and Supply Chain Resilience Through Digital Transformation (pp. 264-285). IGI Global.
Pimenta, M. L., Cezarino, L. O., Piato, E. L., da Silva, C. H. P., Oliveira, B. G., & Liboni, L. B. (2022). Supply chain resilience in a Covid-19 scenario: Mapping capabilities in a systemic framework. *Sustainable Production and Consumption*, *29*, 649-656.
Pina, T., Lewis, M., Garrison, C., & Razatos, A. (2022). Using automation to manage donor engagement and fine-tune supply and demand during the first year of the COVID-19 pandemic. *Transfusion and Apheresis Science*, 103420.
Piramuthu, S. (2005). Knowledge-based framework for automated dynamic supply chain configuration. *European Journal of Operational Research*, 165(1), 219-230.
Prataviera, L. B., Creazza, A., Melacini, M., & Dallari, F. (2022). Heading for Tomorrow: Resilience Strategies for Post-COVID-19 Grocery Supply Chains. *Sustainability*, *14*(4), 1942.
Rabbani, M., Yazdanparast, R., & Mobini, M. (2019). An algorithm for performance evaluation of resilience engineering culture based on graph theory and matrix approach. International Journal of System Assurance Engineering and Management, 10, 228-241.
Rahman, T., Paul, S. K., Shukla, N., Agarwal, R., & Taghikhah, F. (2022). Supply chain resilience initiatives and strategies: A systematic review. *Computers & Industrial Engineering*, 108317.
Ray, S. S. (2013). *Graph theory with algorithms and its applications: in applied science and technology*. New Delhi: Springer.
Rezapour Niari, M., Eshghi, K., & Fatahi Valilai, O. (2022). Adaptive capacity management in cloud manufacturing hyper-network platform: Case of COVID-19 equipment production. *International Journal of Management Science and Engineering Management*, 1-20.
Rosiello, A., & Maleki, A. (2021). A dynamic multi-sector analysis of technological catch-up: The impact of technology cycle times, knowledge base complexity and variety. *Research Policy*, *50*(3), 104194.
Sahebi, I. G., Mosayebi, A., Masoomi, B., & Marandi, F. (2022). Modeling the enablers for blockchain technology adoption in renewable energy supply chain. *Technology in Society*, *68*, 101871.
Sarkar, P., Ismail, M. W. M., & Tkachev, T. (2022). Bridging the supply chain resilience research and practice gaps: pre and post COVID-19 perspectives. *Journal of Global Operations and Strategic Sourcing*.
Sartori, J. T. D., Frederico, G. F., & de Fátima Nunes Silva, H. (2022). sOrganisational knowledge management in the context of supply chain 4.0: A systematic literature review and conceptual model proposal. *Knowledge and Process Management*, *29*(2), 147-161.
Schoenherr, T. (2022). The knowledge-based view. In Handbook of Theories for Purchasing, Supply Chain and Management Research (pp. 118-139). Edward Elgar Publishing.
Scholten, K., Stevenson, M., & van Donk, D. P. (2020). Dealing with the unpredictable: supply chain resilience. International Journal of Operations & Production Management.
Sharma, M., Alkatheeri, H., Jabeen, F., & Sehrawat, R. (2022). Impact of COVID-19 pandemic on perishable food supply chain management: a contingent Resource-Based View (RBV) perspective. *The International Journal of Logistics Management*.
Shishodia, A., Sharma, R., Rajesh, R., & Munim, Z. H. (2021). Supply chain resilience: A review, conceptual framework and future research. The International Journal of Logistics Management, 1-25.
Singh, J., Pandey, K.K., Kumar, A. *et al.* Drivers, barriers and practices of net zero economy: An exploratory knowledge-based supply chain multi-stakeholder perspective framework. *Operations Management Research* (2022). https://doi.org/10.1007/s12063-022-00255-x
Singh, R. K., & Kumar, P. (2019). Measuring the flexibility index for a supply chain using graph theory matrix approach. *Journal of Global Operations and Strategic Sourcing*.

Sunmola, F., Burgess, P., Tan, A., Chanchaichujit, J., Balasubramania, S., & Mahmud, M. (2023). Prioritising Visibility Influencing Factors in Supply Chains for Resilience. *Procedia Computer Science*, *217*, 1589-1598.

Wagner, S. M., & Neshat, N. (2010). Assessing the vulnerability of supply chains using graph theory. *International Journal of Production Economics*, *126*(1), 121-129.

Yi, Z., Yu, M., & Cheung, K. L. (2022). Impacts of counterfeiting on a global supply chain. *Manufacturing & Service Operations Management*, *24*(1), 159-178.

Yıldırım, M., Okay, F. Y., & Özdemir, S. (2021). Big data analytics for default prediction using graph theory. Expert Systems with Applications, 176, 114840.

Yin, J., Ren, X., Liu, R., Tang, T., & Su, S. (2022). Quantitative analysis for resilience-based urban rail systems: A hybrid knowledge-based and data-driven approach. *Reliability Engineering & System Safety*, *219*, 108183.

Yu, D., & Sheng, L. (2021). Exploring the knowledge base and trajectories of knowledge dissemination in closed loop supply chain. *Journal of Cleaner Production*, *316*, 128231.