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Evaluating resilience in food supply chains during COVID-19

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ABSTRACT

The COVID-19 outbreak has revealed weaknesses in the supply chains (SCs) and how easily it can be influenced by these disruptions. Food supply chains (FSCs) is one of the most affected SCs, and it needs to be more resilient against SC disruptions because their vulnerable structure such as having perishable products. Therefore, this article aims to uncover the need for resilience in FSCs during the COVID-19 outbreak. For this purpose, the enablers of resilience on FSCs are determined after a detailed examination of the current literature. Then, the graph theory matrix approach has been used to reveal the relationships between these enablers and investigate importance of enablers of resilience in FSCs during COVID-19 outbreak. It is significant to determine preference of enablers and rank of importance to take actions effectively. Depending on the results, the rank orders of the enablers are classified as readiness, collaboration with stakeholders, IT alignment, risk aware, responsiveness, flexibility, appearance and sustainability, respectively. Suggested implications can be provided benefits for policymakers and managers in FSCs.

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Food supply chain; COVID-19 outbreak; resilience; enablers; graph theory matrix approach

Abbreviations

FSCs	food supply chains
SCs	supply chains

1. Introduction

Supply chains (SCs) are an operation network that is easily affected by disruptions emerging around the world (Asian and Nie 2014; Rajesh 2018; Majumdar, Shaw, and Sinha 2020). The sustainability of companies must manage their SCs well, be resilient to disruptions (Adobor 2019) and have the flexibility to adapt to suddenly changing conditions (Khan et al. 2020; Nandi et al. 2020).

Recently, the whole world has been fighting the epidemic, COVID-19 (Majumdar, Shaw, and Sinha 2020; Queiroz et al. 2020). The most important thing for people in this epidemic process is to keep their immunity high (Khan and Yu 2020; Mofijur et al. 2021; Tian et al. 2020). Similarly, companies must be resilient to keep their immune systems high and to be protected from the effects of COVID-19 (Belhadi et al. 2021). The ability of companies to be resilient depends primarily on their ability to react to disruptions and to be agile (Ivanov 2020). In this context, digitalisation affects companies' being open to innovations (Li et al. 2020), being greener (Li et al. 2021) being flexible against disruptions, being sustainable (Yang et al. 2019) and their speed of converting SC

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operations according to the new situations (de Camargo Fiorini and Jabbour 2017). As a real example, according to OECD (2020) reports, FSCs are collapsed in terms of SC from farm production to consumer stages especially in Australia, Mexico, United Kingdom, Germany, Canada i.e. for example, in the United States, food supply chain (FSC) has many problems, and revenues of companies and performance of operations of SCs are decreased (OECD 2020).

FSCs needs to be more resilient among other SCs against SC disruptions because their vulnerable structure such as having perishable products (Van Voorn, Hengeveld, and Verhagen 2020). The use of digital technologies in FSCs is always extremely important (Quayson, Bai, and Osei 2020). However, in times of disruption, digital technologies should be adopted more to prevent problems in FSCs (traceability, control, response time, etc) (Thilmany et al. 2020).

To the best of our knowledge, this is the first study determining enablers of resilience of FSCs during COVID-19 pandemic. Therefore, this study is important to investigate the importance of enablers of resilience in FSCs during COVID-19 by using graph theory matrix approach. In addition, the fact that this study is conducted in FSC differs from previous studies. Therefore, the following research questions are specified:

- **RQ1:** What are the enablers of resilience of FSCs?
- **RQ2:** What is the importance of enablers of resilience in FSCs during COVID-19?

In this study, the following research objectives are aimed in this study:

- To determine the enablers of resilience of FSCs
- To investigate relations between these enablers
- To rank the importance of enablers on resilience in FSCs during COVID-19 with graph theory matrix approach

To find answers to research questions, it is aimed to determine the enablers of reliance of FSCs, to find relations between these enablers and to analyse importance of enablers of resilience in FSCs during COVID 19 graph theory matrix approach method. With this study, enablers of resilience of FSCs are determined. By determining enablers and finding relations between them and also analysing the effects of COVID-19 on resilience in FSCs with graph theory matrix approach method, it is aimed to show that FSCs needs to be resilient.

The remainder of the article is structured as follows. Section 2 highlights the being resilient of FSCs during SCs disruptions such as COVID-19, need for analysing FSCs' resilience and the literature review about FSCs' resilience. Section 3 highlights the determining enablers of resilience of FSCs. Section 4 includes the graph theory matrix approach. Section 5 covers implementation and results. Section 6 exhibits the discussions and managerial and policymaker implications. Finally, Section 7 concludes this study by discussions, limitations and future works about the study. In the following section, the FSC resilience is explained in detail.

2. Food supply chain resilience

The COVID-19 outbreak has made a huge impact worldwide unprecedentedly (Amjath-Babu et al. 2020; Loayza and Pennings 2020). Its impact on food systems was instantly felt everywhere due to the restrictions placed on the movement of people and material (Ekren et al. 2021). While these restrictions were affecting food production, the outbreak initially caused a disruption to reach physical and economic access to the markets and to food (Heck et al. 2020). Because international and domestic SCs have been impeded by movement restrictions, the import of agri-food systems such as fertilizers, agro-chemicals, machinery, and seeds are prevented (Amjath-Babu et al. 2020). In addition to that, consumer's demand for staple foods has increased and meeting this increasing demand has been a challenge for the FSCs. These interruptions of the flow of goods have caused

serious disruptions on the FSCs and induced shortages of food supplies. Therefore, the COVID-19 outbreak indicates the weaknesses and vulnerability of the FSCs and how quickly it can be disrupted (Béné 2020) and revealed a need for improving the SC resilience research and practices (Ivanov and Dolgui 2020). In this context, the FSCs which has a fragile structure must be more resilient to reduce the impacts of the COVID-19. In addition, crises such as the COVID-19 pandemic and others tend to affect technical and system changes that encourage innovation and ideally create resistance against future shocks on an ongoing basis (Heck et al. 2020). For this purpose, innovative digital technologies can be used to reduce the effects of the COVID-19 (Jabbour et al. 2020; Quayson, Bai, and Osei 2020) and boost food systems to be more resilient. The resilience feature allows SCs to survive from the negative effects of unknown disruptions and adapt to unclear future events (Golan, Jernegan, and Linkov 2020). To adapt the SCs to COVID-19 and make it more resilient over the long term, there is an opportunity for these SCs to infer from the responses to climate change and natural disasters (Cvitanovic et al. 2016; Farrell et al. 2020).

2.1. Need for evaluation of FSC resilience

The adoption of more resilient food systems has become a requirement for the FSCs (Lal 2020); however, to build a more resilient food system, the area of current disruptions, effects and range of responses that are triggered by the COVID-19 must be comprehended (Love et al. 2021) for the current literature in detail. Therefore, it is aimed to expand the existing literature on FSCs resilience and uncover the need for resilience to absorb the effects of the COVID-19 pandemic. For instance, Béné (2020) explored the necessary changes and their actors to build resilience in local food systems due to the disruption caused by the COVID-19 pandemic. This study connects the resilience of food systems against sudden disruptions to food safety with a different perspective. Zhu and Krikke (2020) presented a system dynamic modelling for the recovery of the cheese SC for three scenarios (producer, a logistics service provider, and retailer) due to the implications of the outbreak. Moreover, the COVID-19 pandemic has caused many social and economic crises that exposed the fragility of the food system, as this fragile system was challenged in terms of stockpiling during this period. Power et al. (2020) studied in the field of food insecurity, food systems and disruptions caused by COVID-19 in the UK and provided recommendations for food security policies and emergency food provisions for retailers. This study approaches the effects of COVID19 from a government perspective. The Resilience360 Special Report (2020) addressed the impacts of the COVID-19 pandemic to the food and beverage SCs and reflected the vulnerabilities of the industry which have been revealed as a result of the outbreak. In this context, the report provided several recommendations related to the longevity of food and beverage products such as climate-controlled storage, transport and the adoption of preservative technologies.

The Agri-food SCs is among the most affected sectors from the COVID-19 pandemic crisis. They have experienced many disruptions due to the restrictions of material and people movement. Farmers could not find sufficient workers to work due to curfews and travel restrictions. Even where farmers found sufficient qualified and adequate numbers of workers, there was a slowdown in the progress of the work due to social distancing measures (Amjath-Babu et al. 2020). In this context, Amjath-Babu et al. (2020) suggested that well-designed and comprehensive monitoring systems can be used as an effective response against food system disruptions in agricultural SCs from farm field to consumer in this COVID-19 crisis. Because the study is based on monitoring process of food systems, some factors that increase resilience in food systems are eliminated. Lal (2020) also suggested home gardening and urban agriculture strengthen the local food production which has faced many disruptions and problems during the COVID-19 outbreak. In this study, it was emphasised that resilience should be increased by reducing food waste and providing stronger food production. Hobbs (2021) analysed the challenges of FSCs and SCs flexibility that faced disruptions during the COVID-19 outbreak in Canada. They also presented policy and industry strategies to strengthen FSCs' resilience for the food and agriculture sector. Mussell, Bilyea, and Hedley

(2020) summarised the set of risks that the COVID-19 poses to the agri-FSC in Canada Thus, several implications and prospective directions have been presented for building resilience and vulnerability in the agri-FSC system which requires serious policies and emergency planning.

Aquaculture (seafood SC) and livestock activities of the FSCs were also affected by this process in terms of stocking, feeding and other activities, which led to a decrease in production and prevented marketing of products on time (Amjath-Babu et al. 2020). In this context, Love et al. (2021) focused on building resilience as an action cycle to emerging COVID-19 outbreak's disruptions, effects and range of responses to the seafood sector of the FSCs.

In addition to that logistical constraints such as interruptions in international shipping and domestic transport and partial closures have started to be an issue during this period (Amjath-Babu et al. 2020) and drew attention to the distribution systems of food systems during the outbreak. In this sense, Singh et al. (2020) developed a simulation model for the network of the public distribution system to be more resilient and responsive FSCs. The reason underneath for focusing on the distribution network is because of the ever-changing scenarios with the increase of infected cases and recovery rates which caused a serious disruption in the FSCs due to the COVID-19 outbreak. Chenarides, Manfredo, and Richards (2020) addressed the underlying cause of market failure underlying the lack of flexibility in the agricultural SC. In this context, they presented a conceptual model to demonstrate the value of maintaining flexible supply and distribution systems and compared with the experimental model of the fresh produce industry as an example.

Digital technologies can be used as a gamechanger to reverse the COVID-19 outbreak's impacts on the FSCs and can assist the management of the flow of the food systems. Therefore, Quayson, Bai, and Osei (2020) emphasised digital technologies and digital inclusion to overcome the disruptions and implications caused by the COVID-19. Furthermore, the cases from the developed and developing countries have been studied to design a transition to digital transformation for the post-COVID-19 period for smallholder farmers in FSCs. Thilmany et al. (2020) proposed a technical assistance agenda for local and regional FSCs to respond to ever-changing market demands and policy challenges, update business plans against COVID-19 disruptions.

Based on the literature review, it is essential to determine the enablers of resilience of FSCs to show the effects of COVID-19 on SCs resilience. This study is also important for ranking enablers of FSCs resilient during the COVID-19 pandemic as an innovation of the study.

3. Determining enablers of resilience of food supply chains

Based on detailed literature review, ten enablers of resilience in FSCs validated with ten industry experts and five academics experts. These academic experts are professors in various universities from SC management, information technology, food engineering and industrial engineering. Moreover, these academic experts have various indexing studies about resilience, FSC, investigating impacts of COVID-19 on FSC and assessing criteria to resilience in FSC. In addition, the industrial experts consist of ten SC experts in food sector. These experts, which have more than ten years' experience in this sector, are selected in various well-known food companies. Furthermore, these experts are involved in different projects about FSCs and resiliency such as 'prevention of losses

Table 1. Examples of projects and studies of selected experts.

Project areas of industry experts	Study areas of academic experts
• "Prevention of Losses in The Food Supply Chain"	• Resilience
• "Increasing the Resilience of Food Supply Chains"	• Food Supply Chain
• "The Effects of Cooperation in Food Supply Chains on Resilience"	• Investigating Impacts Of COVID-19 On Food Supply Chain
• "Problems in Food Supply Chains During The COVID-19 and Developing Solution Proposals"	• Assessing Criteria to Resilience in Food Supply Chain

in the FSC', 'increasing the resilience of FSCs', 'the effects of cooperation in FSCs on resilience', 'problems in FSCs during the COVID-19 and developing solution proposals' as summarised in Table 1.

Moreover, this expert group is a group selected according to their expertise in terms of the subject studied. Creating another group outside of this group may lead to a lack of information. At the same time, since the group that reflects the population about this area the best in terms of their background, the consequences of the change in the number of experts are great.

Based on interviews with these experts, totally ten enablers are determined. After validation stage, these enablers are evaluated by experts to specify their interactions with each enabler. These enablers are risk aware, responsiveness, IT alignment, sustainability, appearance, collaboration with stakeholders, readiness and flexibility as shown in Table 2.

Enablers of resilience in FSCs are identified as follows:

- *Risk Aware (N_1):* All of those facilitating the resilience of FSCs actually rely on risk management (Leat and Revoredo-Giha 2013). Effective risk management in FSCs, awareness of emerging risks and making quick decisions about these risks will help increase resilience in FSCs (Dani and Deep 2010). To create risk awareness, risk management should be considered within the company (Stone and Rahimifard 2018).
- *Responsiveness (N_2):* Another enabler that helps increase the resilience of FSCs is 'responsiveness' (Stone and Rahimifard 2018). The ability to respond quickly to sudden disruptions in FSCs or changing conditions, consumer demands, helps to increase the resilience of the FSCs in connection with the readiness (Fattahi, Govindan, and Keyvanshokooh 2017; Chiffoleau et al. 2020).
- *IT Alignment (N_3):* IT alignment and information sharing have a direct impact on the operational performance of SCs (Ding et al. 2014). IT alignment encompasses IT similarity, compatibility and connectivity between SC partners (Gružauskas and Vilkas 2017; Parashar, Sood, and Agrawal 2020). Moreover, IT alignment is extremely important, especially in terms of ensuring efficiency in the information management of SCs, and this makes SCs resilient to risks (Parashar, Sood, and Agrawal 2020).
- *Sustainability (N_4):* Sustainability is one of the important enablers for the competitive advantage and resilience of FSCs (Soni, Jain, and Kumar 2014). The sustainability of FSCs depends on companies' operations taking environmental, social and economic policies into account and managing the associated risks (Faisal 2010). Sustainable FSCs combine with other features such as flexibility and appearance, resulting in a structure more resilient to sudden disruptions such as pandemics (Stone and Rahimifard 2018).
- *Appearance (N_5):* It covers important processes for companies such as FSCs, inventory, transportation and distribution (Soni, Jain, and Kumar 2014). Therefore, the appearance of FSCs is extremely important in terms of getting information about their processes and intervening in possible

Table 2. Enablers of resilience of FSCs.

Abbreviation	Enablers	Author(s)
N1	Risk aware	Dani and Deep (2010); Leat and Revoredo-Giha (2013)
N2	Responsiveness	Fattahi, Govindan, and Keyvanshokooh (2017); Chiffoleau et al. (2020)
N3	IT alignment	Ding et al. (2014); Gružauskas and Vilkas (2017); Parashar, Sood, and Agrawal (2020)
N4	Sustainability	Faisal (2010); Soni, Jain, and Kumar (2014); Stone and Rahimifard (2018)
N5	Appearance	Soni, Jain, and Kumar (2014); Ivanov et al. (2017); Singh, Soni, and Badhotiya (2019)
N6	Collaboration with stakeholders	Scholten and Schilder (2015); Liu et al. (2017); Parashar, Sood, and Agrawal (2020)
N7	Readiness	Manning and Soon (2016); Liu et al. (2017); Belhadi et al. (2021)
N8	Flexibility	Lam and Bai (2016); Smith et al. (2016); Gružauskas and Vilkas (2017)

risks (Ivanov et al. 2017). While the appearance of FSCs reduces risks, it increases the resilience of FSCs in sudden events (Singh, Soni, and Badhotiya 2019).

- *Collaboration with stakeholders (N_6):* Collaboration in a FSCs enables companies and stakeholders to work together and plan their FSCs operations correctly (Scholten and Schilder 2015; Liu et al. 2017). Moreover, collaboration in FSCs enables increased communication between partners, rapid solutions to potential risks, and real-time information exchange, while increasing the durability of FSCs (Parashar, Sood, and Agrawal 2020).
- *Readiness (N_7):* Readiness is recognised as the ability to keep up with constantly changing business conditions (Manning and Soon 2016). FSCs of every company and companies are at risk, especially in rapidly changing demands or operations especially in during disruption times such as pandemics (Belhadi et al. 2021). Being able to react quickly at times similar to these increases the sustainability and resilience of the FSCs of companies (Liu et al. 2017).
- *Flexibility (N_8):* Flexibility is the ability of FSCs to change their operations and processes to deal with sudden events quickly (Gružauskas and Vilkas 2017). Flexibility includes the speed at which the FSCs can cope with sudden disruptions and return to its original state (Lam and Bai 2016; Smith et al. 2016). In this way, the flexibility of FSCs helps to reduce risks and increase their resilience (Gružauskas and Vilkas 2017).

One of the most important points of the study, how these enablers are selected, is based on the literature and expert opinions. After listing the most important 10 of the enablers of resilience in FSCs during COVID-19 outbreak based on the literature, 8 items that need to be addressed are formed as a result of interviews with experts on the subject. Therefore, as a result of the interviews and literature review, it is seen that these 8 enablers should be addressed in order for the analyses to be clear and understandable. Although the number of enablers can be changed according to the company or sector structure to be applied, the aim of this study is to analyse among the most important enablers of resilience in FSCs during COVID-19 outbreak.

4. Methodology

This study focuses on graph theory matrix approach to determine the enablers of resilience of FSCs during COVID-19 pandemic. The proposed methodology begins by identifying enablers of resilience of FSCs and then considers the interrelations between these enablers of resilience in the FSCs. Stages of algorithm is discussed in the following part.

Graph theory is based on study of graphs (Kim, Chen, and Linderman 2015). Drawing of a graph is a representation that aims to visualise interrelations of identified factors within systems and it provides model as a graphically. Graph theory has many advantages. Graph theory is useful to analyse and understand the entire system by determining the relations between factors. Besides, graph theory and matrix representation is used to solve complex problems (Geetha and Sekar 2016). Besides, graph theory matrix approach can be used also to solve multi-criteria decision-making. This approach is mainly aimed to model and create effective decision-making environment with multiple and interrelated factors. First, a digraph is developed to visually represent the problem addressed, indicators and interrelations of them are examined (Soni, Jain, and Kumar 2014). Digraph representation is beneficial to provide analysis of the system visually. Matrix representation is developed to analyse the digraph of the model. Permanent function is developed for analysing the system.

The graph theory matrix approach involves three stages which are representing digraph, developing matrix, and calculating permanent function value (Geetha and Sekar 2016). First, digraph is expressed as a set of finite oriented edges or arcs that are ordered pairs of vertices with a finite set of objects called vertices (Kim, Chen, and Linderman 2015). Digraph shows the factors and interrelations of them using nodes and edges. Rao and Gandhi (2002) suggested that while a node i has a relative importance on other node j, an arrow is drawn from node i to j (dij), if node j has

a relative importance on i, then a directed edge is drawn from node j to i (dji). Therefore, while direction of edge is from i to j, the factor x has relative importance than y and is indicated by dxy; direction of edge is from j to i, it indicated that y has relative importance than x and is shown by dyx (Rao 2007; Mangla et al. 2019).

After creating diagraph, the matrix representation is developed to reduce complexity of diagraph. It shows a one-to-one relationship between factors and relative importance of them (Wagner and Neshat 2010). The main factors are indicated in the diagonal elements which called as a Ri and the relative importance between each factor are shown in the non-diagonal elements which called aij (Rabbani, Yazdanparast, and Mobini 2019). The matrix of the digraph is presented in Equation (1).

$$\mathrm{A} = \begin{bmatrix} R1 & \cdots & a1m \\ \vdots & \ddots & \vdots \\ am1 & \cdots & Rm \end{bmatrix} \tag{1}$$

Baykasoglu (2014) suggested that relative importance between factors ri, j can be assigned a value between 0 and 1 using scales as indicated in Table 3. In Table 3 rji = 1−rij; however, it is not necessary rij and rji are interrelated (Baykasoglu 2014). Proposed scale is used in this study.

The third stages of this method are to develop the permanent function of a matrix. It is a function that involves combinatorial computing (Soni, Jain, and Kumar 2014). Permanent function is calculated by Equation (2). The permanent function of matrix is indicated in Equation (2).

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

The flowchart of methodology is presented in Figure 1.

5. Implementation of the study

This study proposes graph theory and matrix approach to evaluate and the enablers of resilience index of FSCs during COVID-19 pandemic and preference order or rank of enablers. The eight enablers of resilience in FSCs are used in this article. Table 4 shows these proposed enablers in this study.

To collect data based on pairwise comparisons, eight experts from the industry work different departments of food company, and they have different years of experience. The details of expert based on their positions and year of experience are shown in Table 5. The competencies of the experts in the study were determined according to their fields of expertise. While selecting the experts, attention was paid to the fact that they had a certain year of experience in the field and that they were working on the subject in question in terms of their positions.

Considering enablers of resilience which is discussed in Table 3, the diagraph of the algorithm is presented. Figure 2 indicates the digraph of enablers of resilience of FSCs. The graph shows interrelations between enablers of resilience in FSCs. Risk awareness, responsiveness, IT alignment, sustainability, appearance, collaboration with stakeholders, readiness and flexibility are showed using

Table 3. Relative importance of factors.

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

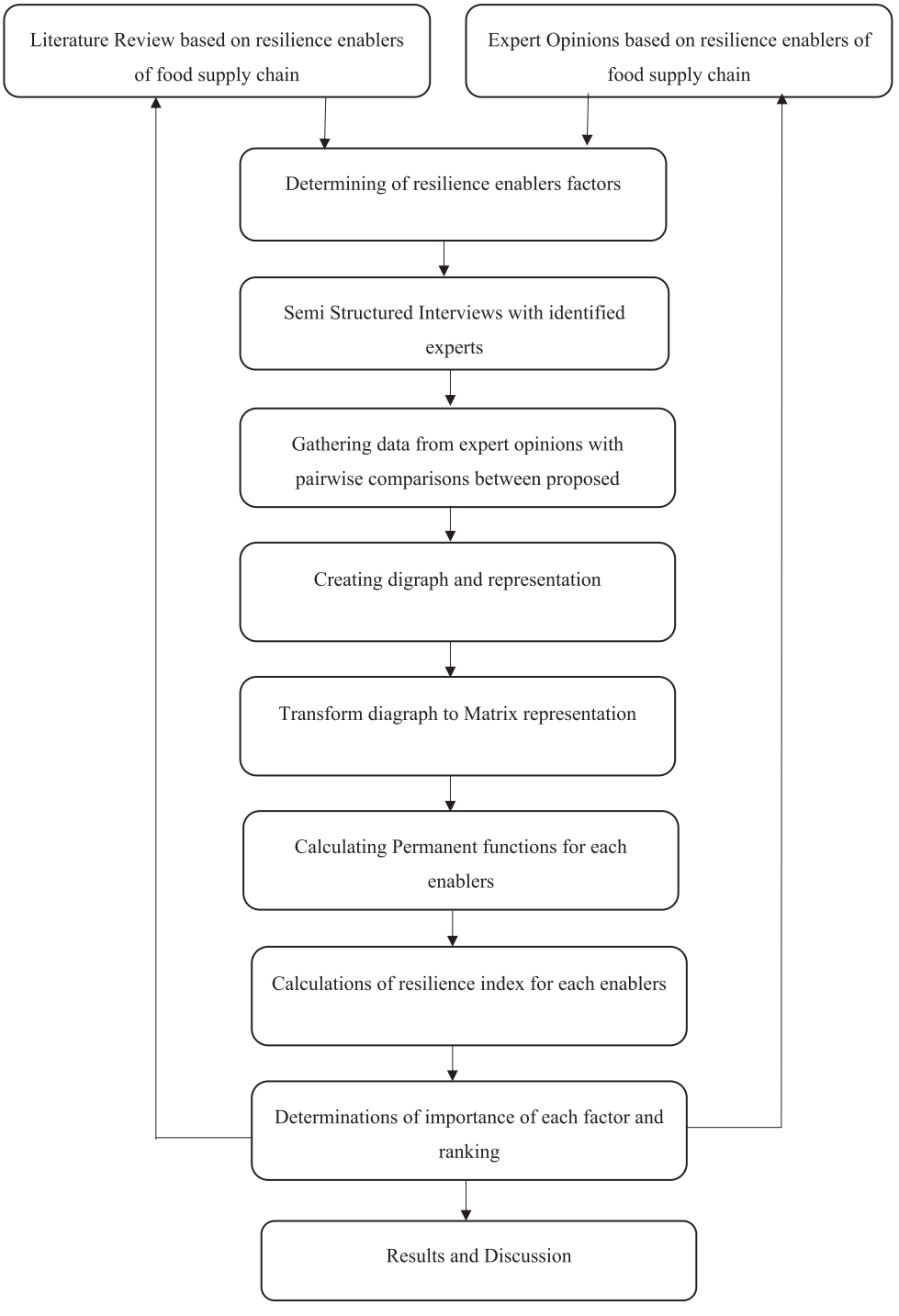

Figure 1. Flowchart of research methodology.

node, and the relative importance of enablers are indicated by arrows in Figure 2. Responsiveness has a relative importance on risk awareness, while sustainability has a relative importance on IT alignment. Collaboration with stakeholders has a relative importance on responsiveness and

Table 4. Enablers of resilience of FSCs.

Abbreviation	Enablers
N_1	Risk aware
N_2	Responsiveness
N_3	IT alignment
N_4	Sustainability
N_5	Appearance
N_6	Collaboration with stakeholders
N_7	Readiness
N_8	Flexibility

Table 5. Details of experts.

Experts	Position	Years of experience
1	Supply chain manager in food company	10
2	Operations manager	8
3	Sustainability analysist	7
4	Food engineer	6
5	Total quality manager	10
6	Information technology manager	12
7	Risk analyst	15
8	Research and development engineer	9

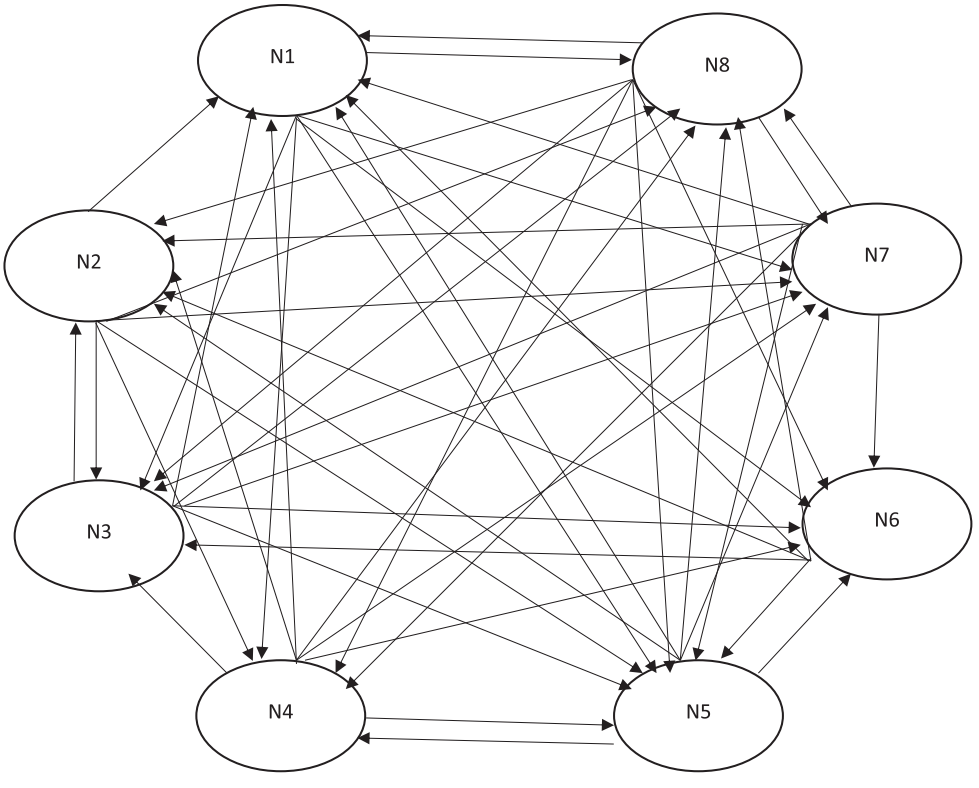

Figure 2. The resilience of enablers in FSCs diagraph.

readiness has a relative importance on collaboration with stakeholders. Other enablers have interrelations with each other as indicated Figure 2.

Table 6. The collected data using pairwise comparisons resilience level of enablers in FSCs.

Drivers	N1	N2	N3	N4	N5	N6	N7	N8
N1	1	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	1	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	1	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	1	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	1	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	1	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	1

The semistructured interviews from eight experts are used to collect the data for obtaining resilience levels of each enablers. Related data are gathered from experts and discussed in Table 4. Regarding pairwise comparisons among the factors for each enabler are weighted using 0–1 scale by experts. The collected data based on pairwise comparisons resilience level of enablers in FSCs are shown in Table 6 and each enabler factor weights are gathered from expert's opinion that is indicated in Table 7. Value of 0 is assigned to enablers which have no relationship. Relative importance of enablers is calculated by using Table 3.

Matrix representation is developed with eight enablers of resilience of FSCs using the values in Tables 6 and 7. Expert opinions for each enabler are indicated in the diagonal values of the matrix. Other values of matrix are obtained from average of each expert's pairwise comparisons values from expert opinions. Relationships between enablers of resilience in FSCs are developed using digraph in Figure 2. Developed values for calculating resilience index of 'Risk Aware' considering expert opinions in Table 8.

Developed matrix is calculated through Equation (1) for each enablers and permanent resilience levels are determined. To calculate resilience index and to find preference of enablers, matrix representations is developed for each enabler. Constructed matrix is solved via Equation (1) for each enablers and Resilience Permanent Index for each enabler. Permanent resilience indexes for each enabler are calculated by using in a similar way. Therefore, resilience index is considered as the permanent function of matrix which the enablers of resilience in FSCs especially COVID-19 period.

The graph theory matrix approach analysis is beneficial to obtain the preference order or rank of enablers (Mangla et al. 2019; Rabbani, Yazdanparast, and Mobini 2019). The rank and importance of resilience enablers in FSCs is indicated in Table 9.

The enabler's resilience index of FSCs is calculated using Equation (2), and these enablers rank by ascending order to evaluate the resilience index and prioritise them. Based on Table 9, the results show that it is the most important resilience enablers has been determined as readiness. After readiness, collaboration with stakeholders, IT alignment has been obtained second and third rank, respectively. Appearance is followed by risk awareness. Other enablers are responsiveness flexibility, appearance and sustainability, respectively.

Table 7. The permanent resilience levels for the resilience level from each expert.

	Drivers							
Experts	N1	N2	N3	N4	N5	N6	N7	N8
Expert 1	5	4	5	1	2	5	5	3
Expert 2	4	3	4	2	1	2	5	3
Expert 3	2	5	5	1	5	4	4	4
Expert 4	1	1	2	5	5	5	5	1
Expert 5	4	3	1	4	1	4	2	2
Expert 6	5	4	4	1	4	4	4	5
Expert 7	4	4	5	1	2	5	5	4
Expert 8	3	2	5	2	1	5	4	1

Table 8. Values for calculating resilience index of 'Risk Aware' considering expert opinions.

Expert 1	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	1	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	2	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	4	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	4	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	3
Expert 2	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	*5*	*0*	*0.8*	*0.7*	*0.9*	*0,4*	*0.4*	*0.2*
N2	*1*	*1*	*0.4*	*0.9*	*0.8*	*0*	*0.1*	*0.6*
N3	*0.2*	*0.6*	*2*	*0*	*0.5*	*0.4*	*0.8*	*0.9*
N4	*0.3*	*0.1*	*1*	*1*	*0.4*	*0.7*	*0.4*	*0.3*
N5	*0.1*	*0.2*	*0.5*	*0.6*	*4*	*0.1*	*0.8*	*0.4*
N6	*0,6*	*1*	*0.6*	*0.3*	*0.9*	*5*	*0*	*0.6*
N7	*0.6*	*0.9*	*0.2*	*0.6*	*0.2*	*1*	*4*	*0.9*
N8	*0.8*	*0.4*	*0.1*	*0.7*	*0.6*	*0.4*	*0.1*	*3*
Expert 3	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	5	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	1	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	4	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	4	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	3
Expert 4	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	5	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	2	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	4	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	4	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	3
Expert 5	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	5	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	2	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	1	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	4	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	3
Expert 6	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	*5*	*0*	*0.8*	*0.7*	*0.9*	*0,4*	*0.4*	*0.2*
N2	*1*	*4*	*0.4*	*0.9*	*0.8*	*0*	*0.1*	*0.6*
N3	*0.2*	*0.6*	*2*	*0*	*0.5*	*0.4*	*0.8*	*0.9*
N4	*0.3*	*0.1*	*1*	*1*	*0.4*	*0.7*	*0.4*	*0.3*
N5	*0.1*	*0.2*	*0.5*	*0.6*	*4*	*0.1*	*0.8*	*0.4*
N6	*0,6*	*1*	*0.6*	*0.3*	*0.9*	*1*	*0*	*0.6*
N7	*0.6*	*0.9*	*0.2*	*0.6*	*0.2*	*1*	*4*	*0.9*
N8	*0.8*	*0.4*	*0.1*	*0.7*	*0.6*	*0.4*	*0.1*	*3*
Expert 7	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	5	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	2	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	4	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	1	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	3
Expert 8	***N1***	***N2***	***N3***	***N4***	***N5***	***N6***	***N7***	***N8***
N1	5	0	0.8	0.7	0.9	0,4	0.4	0.2
N2	1	4	0.4	0.9	0.8	0	0.1	0.6
N3	0.2	0.6	2	0	0.5	0.4	0.8	0.9
N4	0.3	0.1	1	1	0.4	0.7	0.4	0.3
N5	0.1	0.2	0.5	0.6	4	0.1	0.8	0.4
N6	0,6	1	0.6	0.3	0.9	5	0	0.6
N7	0.6	0.9	0.2	0.6	0.2	1	4	0.9
N8	0.8	0.4	0.1	0.7	0.6	0.4	0.1	1

Table 9. Resilience index of enablers in FSCs.

Enablers	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Average resilience permanent index	Rank
Risk aware	11955.4	14138.4	22427.0	31981.1	14339.8	12152.1	14632.4	17559.1	17398,16	4
Responsiveness	9559.61	11462.2	8821.02	21532.4	11893.2	9904.77	9995.25	15086.2	12281,83	5
IT alignment	18885.1	22369.9	20177.5	36920.6	54275.6	23102.3	20949.3	19888.4	27071,09	3
Sustainability	2492.14	1905.05	2492.14	1210.26	1372.53	2492.14	2492.14	1896.73	2044,14	8
Appearance	3912.53	5213	2447.76	2350.98	5213	2644.66	4067.98	5213.	3882,86	7
Collaboration with stakeholders	43815.5	85943	54717.7	45446.3	53101.2	51610.6	45167.7	44171.5	52996,69	2
Readiness	44550.6	43736.3	54816.3	46203.4	89427.2	52965.1	46730.4	54203.	54079,04	1
Flexibility	5652.16	5539.46	5114.23	9852.33	7219.65	4190.93	4962.58	9852.33	6547,96	6

6. Discussions and implications

FSCs are sensitive to sudden adversities such as a pandemic (Amjath-Babu et al. 2020). These disruptions of FSCs are caused by the resilience level of FSCs. Therefore, it is essential to improve resilience of FSCs against disruptions (Golan, Jernegan, and Linkov 2020), and for this purpose, it is critical to determine criteria, which are related with resilience in FSCs and to understand them (Stone and Rahimifard 2018).

According to Stone and Rahimifard (2018), for SC resilience collaboration, flexibility, readiness and appearance factors are important, respectively. In this study, it is determined as the readiness, collaboration with stakeholders and IT alignment, respectively. Readiness is determined as the most important enabler of resilience in FSCs similar with Manning and Soon (2016). Furthermore, similar with this study, Carvalho, Azevedo and Cruz-Machado (2012) considered flexibility, responsiveness, appearance and collaboration in their study. Leat and Revoredo-Giha (2013) investigates the role of collaborations with stakeholders in enhancing FSC resilience. This study suggested that increasing collaboration with stakeholders in the SC causes assured quality by increasing security and thus factor is important for dealing with enhancing SC resilience. Besides, Kumar and Kumar Singh (2021) addressed that collaboration among stakeholders is vital to reduce pandemic risks. Effective coordination among stakeholders minimises the impact of SC disruptions and thus it is an important factor for increasing resilience in the SC. Moreover, Bode and Macdonald (2017) stated that firm's readiness level plays a key role to deal with disruptions in the SC, and Hobbs (2021) discussed FSC flexibility and resilience during COVID-19. While economies of scale offer economic efficiency advantages in normal times, automation and digitalisation became an important factor to respond quickly and to take rapid action in the disruption times. Thus, the infrastructure that can adapt to digitalisation is required for companies, and therefore readiness and IT alignment become more important factors in these periods than in normal times to increase the capacity of resilience.

Based on the results of the study, as mentioned before, with graph theory matrix approach, the rank orders of enablers of resilience in FSCs are determined as readiness, collaboration with stakeholders, IT alignment, risk aware, responsiveness, flexibility, appearance and sustainability, respectively. Risk aware and responsiveness are determined as in the same order similar with flexibility and appearance.

According to the rank order, the most important enablers are especially readiness, collaboration with stakeholders and IT alignment. Therefore, there are many implications for managers and policymakers. To start with readiness, one of the most important issues required in the FSCs is readiness. To ensure readiness in major SCs, other stakeholders ensure that the work flow is updated, and action can be taken according to the given needs. As a real example, during COVID-19, major organisations, such as World Health Organization and The Inter-Agency Standing Committee, have reported that food companies that can organise the readiness have recovered from the negative impacts of the COVID-19 with minimum damage (The Inter-Agency Standing Committee 2020; World Health Organization 2020). In addition, increasing the resilience of FSCs is dependent on SC adoption of readiness. The ability to integrate readiness with digital technologies enables real information execution of SC operations and real-time monitoring of every stage. Therefore, technologies such as Blockchain, Internet of Things (IoT) and Data Science must be adopted to increase the readiness and direct permanence of FSCs.

Moreover, although it is important in every SC, it is very important to be able to provide collaboration with stakeholders, especially due to the vulnerable nature of FSCs. Collaboration with stakeholders should be strong to increase the resilience of FSCs against sudden deterioration. As a real case example, International Food Policy Research Institute reported that effective collaboration of stakeholders recovers food companies from negative impacts of COVID-19 (International Food Policy Research Institute 2021a). It is necessary to benefit from digital technologies to ensure

real-time information exchange between stakeholders and to take fast action against sudden deflections.

Furthermore, IT alignment in FSCs are critical enabler of resilience and directly affects operational performance of FSCs. When there is lack of sufficient infrastructure in FSCs based on digital technologies, operational performance disrupts. Therefore, to ensure IT alignment, an appropriate infrastructure must be provided, and this compatibility must be achieved with the help of digital technologies. Providing appropriate infrastructure with the help of digital technologies will increase the resilience of FSCs to deterioration by ensuring correct information sharing in FSCs. According to major organisations and companies, IT alignment becomes an essential issue for FSC during COVID-19. Moreover, as a real example, critical International Food Policy Research Institute and The United Nations Industrial Development Organization' reports state that adopting IT alignment in FSCs by companies provides being more resilient against to disruptions causes from COVID-19 in FSCs (International Food Policy Research Institute 2021b; The United Nations Industrial Development Organization 2020).

7. Conclusions

Emerging disruptions worldwide such as natural disasters, pandemics, and terrorism attacks, etc. have a huge impact on SCs. In particular, the COVID-19 outbreak has revealed the weaknesses in the SCs and how easily it can be influenced by these disruptions. In this context, FSCs is one of the most affected sectors due to pandemic. Flows of food supplies have been interrupted by the lockdowns and international and domestic restrictions which result in shortages in food supplies. The underlying reason why the FSCs are so damaged by these emerging disruptions is the FSC's inability to resist these disruptions and lack of flexibility to adapt to such suddenly evolving conditions. Therefore, there is a need for a more flexible and robust FSC that can absorb the shocks of these emerging threats. Much attention, research and practices are required to resilience in FSCs during the COVID-19 outbreak. The main purpose of this article is to uncover the need for resilience in FSC. Therefore, this article examines the interaction among the enablers of resilience on FSCs and the impacts of COVID-19 on SC resilience. Furthermore, this study also provides information importance of enablers FSCs' resilience which is affected by the COVID-19 outbreak. In this context, enabling digital technologies can be used as a facilitator in order to absorb the shocks of these disruptions, caused by the COVID-19 outbreak.

The current literature about the resilient food system and SCs is investigated in detail to determine the main enablers of the FSCs. As a result of this detailed literature review, the main enablers are classified as collaboration with stakeholders, appearance, sustainability, flexibility, risk aware, responsiveness, IT alignment and readiness. The graph theory matrix approach has been used to reveal the relationship among these enablers. This approach has been chosen because while it is evaluating the alternatives, it also considers and presents the interactions between any number of the qualitative and quantitative attributes in a visualised way. The results show that the rank orders of enablers of resilience in the FSCs are determined as readiness, collaboration with stakeholders, IT alignment, risk aware, responsiveness, flexibility, appearance and sustainability, respectively. Moreover, by considering real case examples as mentioned in Implication Section, it can be shown that these results are meaningful to have resilient FSCs during COVID-19.

The limitations of this study can be a limited number of enabler alternatives. Therefore, the number of enablers can be extended to obtain more detailed results for the future scope of this study. In addition, different approaches or hybrid methods can be conducted to rank the alternatives and compare the results and validate the robustness of the framework.

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