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Managing disruptions and risks amidst COVID-19 outbreaks: role of blockchain technology in developing resilient food supply chains

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Abstract

This study attempts to present a contribution of Blockchain Technology (BC-T) in managing disruptions, and risk caused by the COVID-19 outbreaks and extending profound support in developing resilient Food Supply Chains (FSCs). The effects of the pandemic can be witnessed on global supply chains in their demand & supply side disruptions and in the changing patterns of consumer buying in the food industry. The assessment of the disruptive factors is required to explore the present issues and promising resilient strategies to impart robustness to the FSCs for mitigating disruptions in the future. An integrated approach of Fuzzy Analytic Hierarchy Process (FAHP) and Weighted Assessment Sum Product Assessment (WASPAS) is employed to assess the factors related to sourcing, lean, workforce, and flexibility, as well as evaluation of the BC-T enabled FSCs resilient strategies that mitigate the effect of disruption during the pandemic. The findings exhibit that 'Sourcing related' is the most affecting disruptive factor causing distress in the FSCs and 'flexibility resilient strategy' is the most relevant resilient strategy for BC-T enabled FSCs. The BC-T acts as a catalyst in enhancing the flexibility, traceability, and shorter supply chain network structure that may help the FSCs to mitigate risk and disruption in the pandemic situation. The BC-T helps the FSCs to control the demand and supply shocks, and supports the organization with real-time monitoring and sharing information. This study provides insights to the decision-makers, managers, and other stakeholders to take significant decisions during an emergency.

Keywords Blockchain Technology (BC-T) · Disruption · Food Supply chains (FSCs) · Resilient strategies · FAHP · WASPAS

1 Introduction

During the crisis, the resiliency of the Food Supply Chains (FSCs) has become significant and needs consideration of the decision-makers to adapt and adjust urgently to manage disruptions and risk caused in the demand and supply side streams (Hosseini et al. 2019). The SC have faced unprecedented challenges because of disruptions during Coronavirus outbreaks (de Sousa Jabbour et al. 2020). People all around had dealt with changing lifestyles from self-isolation to stockout situations. The pandemic has instigated panic buying of essentials and triggered the consumer's buying behavior (Barrett 2020). And due to the severe virus spread all across the world, consumers feel safe and minimum risk in buying through online shopping. Several scholars have categorised Supply Chain (SC) risk into operational and disruption risks (Xu 2020). The risks in the context to the general disturbance in SC operations such as demand fluctuations are categorized as operational risks whereas the

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events related to low frequency and high impacts are known to be disruption risks (Fahimnia et al. 2018; Ivanov et al. 2018; Hosseini et al. 2019). One more category has been added to the risks that is epidemic outbreaks which has the characteristics of high uncertainty and ripple effects (Ivanov and Dolgui 2020). The epidemic's effect has highlighted several threats to firm's viability during the last decade (Ivanov and Dolgui 2020; Karmaker et al. 2021).

The supply side of FSCs concentrated towards contactless deliveries using real time ordering, just-in-time order fulfilment strategies. The pandemic has shown the significance of short supply chains and production at local level (Cappelli and Cini 2020). The core strategy of the FSCs in this pandemic time is more reliant on digital technologies, real time information sharing, collaboration, viable supplier networks, configurations, omni-channels platforms, and hybrid business models (Moktadir et al. 2019). The industry 4.0 technologies provide new opportunities to the supply chains to enhance their transparency and flexibility but it also needs to understand issues related adoption and implementation to optimize the profitability and efficiency in the SCs (Lohmer et al. 2020)

Several industries have been affected by the pandemic, FSCs is one of the most affected industry as it serves the essential needs of humans and also one of the fastest growing industries across the world. The Indian food industry contributes more than 40% of India's consumer packaged goods (CPG) industry (Chowdhury et al. 2020). As the global FSCs are disturbed, the intermediaries; producers, suppliers, logistics chains, buyers, and customers are supposed to be dealt directly without any middlemen (Filimonau and Naumova 2020).

The need of the hour is to adopt a structural change in the 'new normal' era where high disruption will have to be handled through digital technology called Blockchain Technology (BC-T) that can perform even without intermediaries (Lakhani and Iansiti 2017). This BC-T is commonly called as a disruptive technology that obliterates processes and can bring radical changes in business models (Leible et al. 2019). The BC-T can contribute to achieve flexibility, stability, traceability, resiliency, minimizing risk, sustainability, and reducing cost (Hughes et al. 2019; Behnke and Janssen 2020). The ledgers used in the BC-T enabled systems is replicated and maintained by a number of identical hosts (Iansiti and Lakhani 2017). Once information is stored in one record, all the replicated copies are updated near real-time and are immutable. The updated records are verifiable thus eradicating the need for the middlemen verification and develops trust among the partners (Kshetri 2018). This adds to enhance efficiency and reduction in the cost by removing redundancy. BC-T has addressed Supply Chain (SC) pain points across several industries, logistics, and counterfeit product identifications (Treiblmaier 2019).

Although research on BC-T has gained attention in the last decade, there is less focus on the factors enhancing the effects of disruption, and risks on FSCs and also the possible solutions to become resilient in the post pandemic era (Dolgui and Ivanov 2021). This study aims at developing a holistic model for FSCs during the pandemic situation to enhance the organizational traceability, flexibility and resilience whereas previous research was limited to BC-T applications and measuring its effects. Thus, the research objectives of the study are as follows -

- To assess the factors affecting FSCs in the disruptive environment during the pandemic.
- To measure the contribution of BC-T in managing disruption, risk in FSC during the pandemic situation
- To develop a holistic decision model for the FSCs considering disruption, risk, and efficient resilient strategy.

The current study attempts to develop a holistic model for FSCs using an integrated approach through Multi-criteria decision-making methods (MCDM) - Fuzzy Analytic Hierarchy Process (FAHP) and Weighted Assessment Sum Product Assessment (WASPAS). The decision-making in the pandemic time is extremely complex and thus integrated methods are appropriate to be utilized for assessing key issues in BC-T enabled FSCs. The effects of the disruption risks are measured through FAHP, based on the experts' judgment and evaluation of the resilient strategies through WASPAS method.

The organization of paper is in 6 sections. Section 2 reviews literature on disruptions, risk and factors affecting FSCs. Section 3 imparts the research methodology undertaken followed by a proposed framework in section 4. Section 5 discusses the findings, research and managerial implications. Section 6 summarizes he study and suggest directions for future studies.

2 Literature review

The Systematic Literature Review (SLR) is employed using two databases – The Web of Science (WoS) and Scopus databases. The search term ('Disruption' OR 'Risk' OR 'Resilience') AND ('Food Supply chain's) AND ('Blockchain' OR 'Blockchain technology') had been used with the term 2015-2020. This study has used the systematic literature adapted from Garza-Reyes (2015) and Nadeem et al. 2017. The databases were considered major sources of information to establish the understanding of BC-T application and FSCs scenario in last 5 years. The major criteria for selection were to explore the BC-T adoption and FSCs requirements for developing a holistic model for handling disruption. The study has only included those articles that have been published with direct focus and within the context of BC-T and FSCs. The search retrieved 545 papers. After eradicating the duplicates, 292 articles are shown. The abstracts were thoroughly read to identify the relation to the research objectives. Finally, 44 papers were found to be appropriate and in the context to the objectives.

The flowchart of the SLR is shown in Fig. 1.

2.1 Disruptions and risk amidst COVID-19 outbreak in food supply chains

The disruptions are rising extensively and extending throughout the entire SC network since the corona outbreaks outbursts across the world. The perishable characteristics of the FSCs make it more complex than the other SCs (Ali and Nakade 2017). Since, last few years FSCs are facing challenges of price volatility, issues in food wastage, food security (Von Braun 2018; El Bilali 2019; El Bilali et al. 2019; Qi et al. 2018), and governance (Gokarn and Kuthambalayan 2017). The complexity of global SCs, low stock levels, fewer redundancies, and wide varieties of products are required to achieve operational efficiency. The operational efficiencies increase the exposure to uncertainties related to risks and disruptions (Chopra and Sodhi 2014). The redundancies and wide range of products together develop resilience in FSCs.

The corona outbreaks have profoundly disturbed the FSCs at each and every level. At least 265 million were at risk of going hungry during the lockdown. Due to the excessive demand of food products, there was an increase in panic buying among the individuals and by traders also. The disruption was more severe for perishable products (Coluccia et al. 2021).

During COVID-19 pandemic, approximately 110 million people were living in acute food insecurity (UN 2020). The developing countries had bigger challenges where people were facing acute hunger. People lost their job, employment and income and disruptive SCs and led towards double crisis food insecurity in developing countries. India's food insecurity was very poor even before the lockdown; India ranked 102 in Global Hunger Index. India's per capita GDP in purchasing-power-parity (PPP) terms being almost double of each of the neighboring countries such as Bangladesh, Nepal and Pakistan (World Bank 2020).

The disruptions exist at several levels such as sourcing, flexibility, lead-time, and workforce safety concerns. The lack of workforce, transportation, and logistics has reduced the level of production that consequently leading towards a decrease in operational efficiency. There has been a question raised on the survivability of the SCs. To develop resilient SCs, firms have adopted lean and JIT practices that decrease in the inventory levels and help the firm to reduce their cost and manage disruptions. There has been a change in the SC configurations such as shifting towards SC networks to deal with the disruptions (Ivanov and Dolgui 2020). The COVID-19 effect on the SCs is severe and due to the change in the consumption pattern inventory buffering is gaining hikes.

2.2 Blockchain-enabled food supply chains amidst COVID-19

The food chain initiates with farmers using farm supplies such as seeds, fertilizers, and machinery etc. The farmers transport the food through logistics providers directly or indirectly through storage or marketing. The farmer is limited to the processor and does not extend to the customer or even the distributor. There is a lack of traceability & transparency in this traditional SC (Garnett et al. 2020; de Sousa Jabbour et al. 2018). In the Industry 4.0 era, digitization has enhanced the performance level of the firms and technologies like additive manufacturing, Internet of Things (IoT), and BC-T has strengthened the processes of the FSCs (Kamilaris et al. 2019; Wong et al. 2020). BC-T is a decentralized platform that allows peer to peer direct transactions, eradicates the third party and validates information. It has been observed that BC-T improves traceability and revolutionize the digitized contemporary FSCs (Kouhizadeh and Sarkis 2018).

In BC-T, a list of transactions is recorded into a ledger over a given period and created 'block'. Each transaction is kept into a block and each block is connected to the other blocks before and after it. These blocks are 'chained' together though hashing function (Wang 2019). These chained blocks are immutable. The uniqueness of the BC-T is its ability to create a self-correcting system without any third party. Instead, the enforcement is executed through a consensus algorithm (Min 2019). The Blockchains (BCs) may be in two categories: public and permissioned BCs. The main benefits of the BC-T are disintermediation, transparency, security, and automation (Tönnissen and Teuteberg 2020).

BC-T enabled FSCs offers transparency to the partners which is essential to improve the traceability and authenticity of the food products (Leng et al., 2018). During the pandemic, real-time tracking was very much required

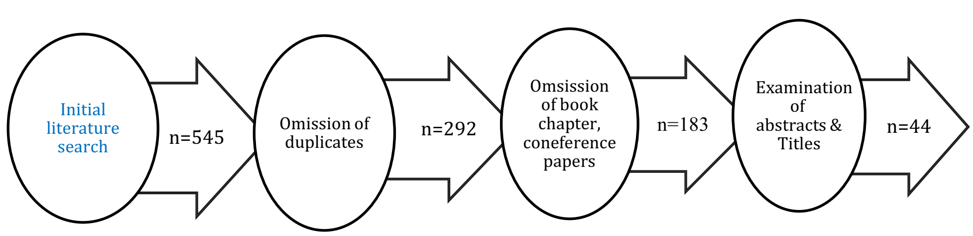

Fig. 1 A systematic literature review

to know the source and tracking of products (Kim and Laskowski 2018). During the pandemic the collaboration among the partners is very crucial and thus transparency of BC helps in developing trust among the SC sellers, buyers and manufacturers, and third party. The BC is also useful in enhancing the efficiency of the organization by taking preventive measures, reducing waste, operational cost, and better inventory management (Kharif 2016; Klimczuk-Kochańska 2018).

2.3 Blockchain technology and resilient food supply chains

FSCs need collaboration and information sharing to enhance their resilience (Ambulkar et al. 2015; Bottani et al. 2019, 2020). BC-T may act as an intermediary for inter-relationships among the SC actors (Crosby et al. 2016). During the pandemic time, FSCs may receive information faster with BC-T implementation. BC-T can connect to Industry 4.0 technologies and may help in optimization processes (Saberi et al. 2019).

SC agility is the strategic approach to accept change with the corresponding organization's actions promptly. It is determined by visibility and velocity. In BC-T based enabled systems agility can be enhanced by adding new partners, information sharing, and resources that mitigate risks in the disruptive environment (Cole et al. 2019). Food products can be tracked, and traced with the help of real-time information throughout the system that enhances the SC resilience (Tendall et al. 2015; Stone and Rahimifard (2018). Velocity is linked to flexibility, as the pace of adaptation towards disruption is a key issue. BC-T can particularly influence the pace to discover from disruptions. Agility is highly influenced by collaboration, integration, and communication through BC-T (Ivanov and Rozhkov 2019). The relationship between disruption and risks during pandemic and adoption of resilient FSCs facilitated by BC-T is exhibited in Fig. 2.

2.4 Research gaps

The BC-T contribution is multidisciplinary, such as tourism (Kwok and Koh 2019; Sigala 2020); consumer to consumer business model (Sigala 2017); distribution channels and trade (Önder and Treiblmaier 2018; Treiblmaier 2019); Smart hospitality (Buhalis and Leung 2018); sustainability (Gretzel et al. 2015); strategic management (Kewell and Ward 2017); Healthcare (Sharma and Joshi 2021; Filimonau and Naumova 2020); SCs (Helo and Hao 2019; Chang et al. 2020; Laskowski and Kim 2016). The resilience in SC strategies has been elaborated with high flexibility and agility (Christopher and Peck 2004; Francisco and Swanson 2018). The significance of redundancy and flexibility in resilience is measured (Sheffi and Rice 2005).

The risk in SCs has also been discussed and proposed flexible strategies for mitigating risk, but still there is a need of an integrated approach for sustainable practices to manage risk (Tang and Musa 2011; Choi 2020; Joshi et al. 2020). Monroe at al. (2014) discussed the SC vulnerabilities and disruptions to understand the possible risk and developing risk mitigation strategies. Sustainability issues need to be addressed for developing resilient SCs (Amui et al. 2017). The resilience among FSCs is also evaluated (Zhao et al. 2017; Gholami-Zanjani et al. 2021).

The resilient strategies have been discussed using several MCDM methods. Risk mitigation strategies have been analyzed using DEA and non- parametric statistical methods (Talluri et al. 2013). Despite the short span of time since the COVID-19 outbursts, there are research studies that focused on healthcare, consumer's decision-making, GSCs, and FSCs (Petetin 2020). Though the BC-T contribution, disruption in FSCs, and resilience among SCs have been discussed by the researchers in past but till date, no study has been conducted to evaluate the disruption and risk related factors affecting FSCs under COVID-19 environment. Also, how BC-T can enhance the resilience in FSCs is still unexplored. This study bridges this gap by assessing the factors affecting FSCs and also the BC-T contribution in developing resilience.

3 Research methods

Fuzzy AHP (FAHP) and WASPAS methods are employed in the current study. With the help of the systematic literature review, the factors (main four criteria and fourteen sub-criteria) are assessed using. These factors are evaluated on the extent of effects raised by the pandemic disruption in the environment. The BC-T enabled resilience strategies that may enhance the efficiency and survivability of FSCs. A total of twelve alternatives are evaluated using WASPAS method. The following sections elaborates the methods undertaken in the study.

3.1 Fuzzy analytic hierarchy process (FAHP)

It is a complex task for the decision-makers to decide on the multifaceted problem, as a number of uncertainties arise during the analysis of the problem. In a complex situation, MCDM methods are significant for assessment and choosing the best alternative. The FAHP is an effective assessment method that is used to collect the responses from the experts (Wang et al. 2019a, b, 2020).

In this study, FAHP examines the factors affecting FSCs in the disruptive environment. The pairwise comparisons are made using Triangular Fuzzy Numbers (TFNs), employed to evaluate and obtaining the weights. Fuzzy set theory is a general form of the crisp values, and fuzzy set numbers only

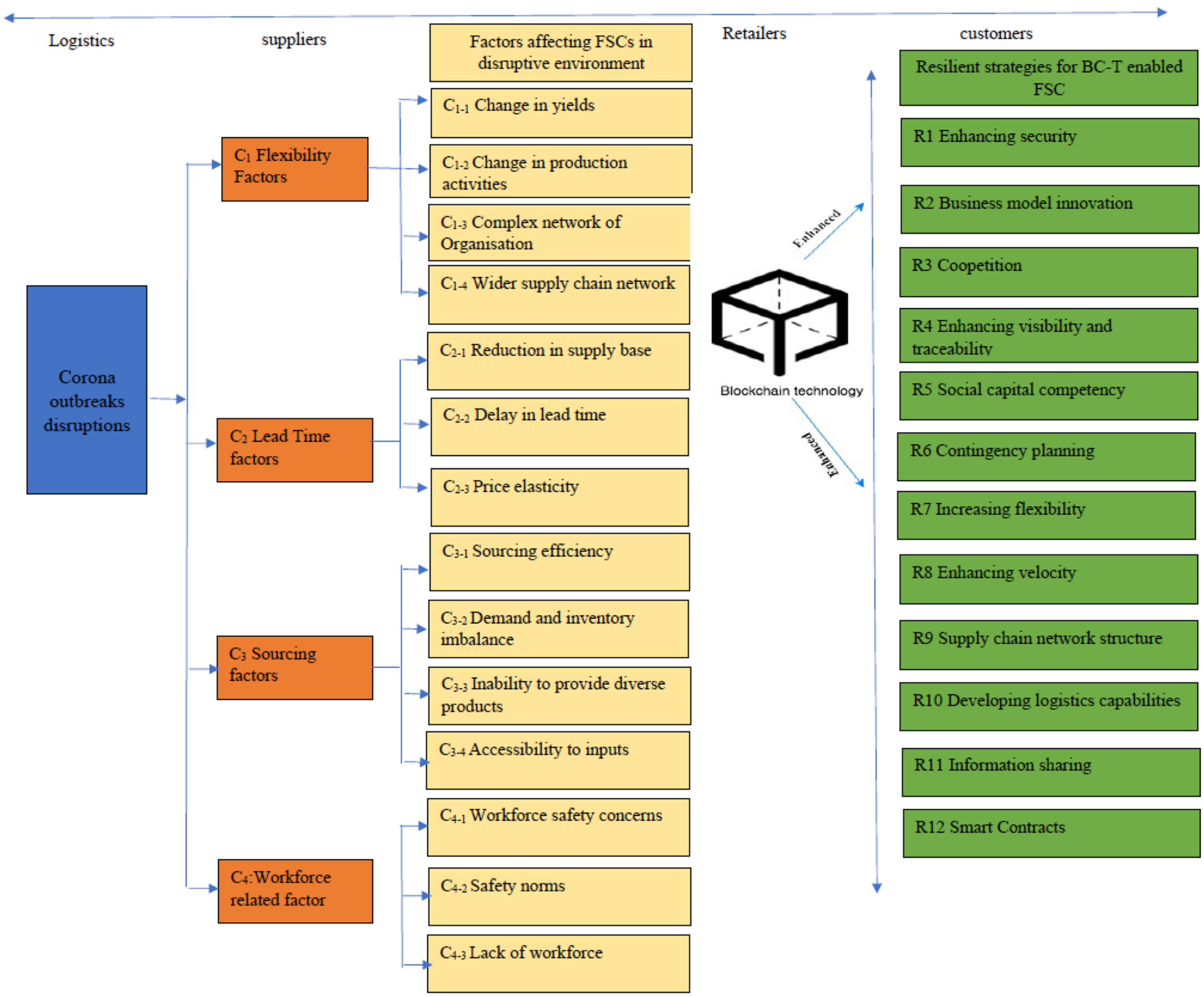

Fig. 2 Disruption, blockchain technology and resilient food supply chains amidst COVID-19

consider the values range from 0 and 1, where 0 signifies the non-membership function and 1 denotes full membership function. The TFNs are very helpful in fuzzy situations. The TFNs scale used for the current problem is exhibited in Table 1.

The steps of FAHP are as follows:

3.1.1 Establishing pairwise comparisons

The responses from the experts are collected using linguistic scale; the pairwise comparisons for criteria and sub-criteria are developed. Each expert is asked to respond for each criterion and sub-criteria.

$$A^{\sim 1} = \begin{bmatrix} 1 & a^{\sim 1}12 & \dots & a^{\sim 1}1n \\ a^{\sim 1}21 & 1 & & a^{\sim 1}2n \\ \vdots & & \vdots & \vdots \\ a^{\sim 1}n1 & a^{\sim 1}n2 & \dots & 1 \end{bmatrix}, \dots A^{\sim k} = \begin{bmatrix} 1 & a^{\sim k}12 & \dots & a^{\sim k}1n \\ a^{\sim k}21 & 1 & & a^{\sim k}2n \\ \vdots & & \vdots & \vdots \\ a^{\sim k}n1 & a^{\sim k}n2 & \dots & 1 \end{bmatrix} \quad (1)$$

From Eq. 1, the pairwise matrix is formed where k represents the experts who are requested to assess the factors.

Each element a_{ij}^{-K} of the pairwise comparison matrix A^{-K} represents the fuzzy number corresponding to the linguistics scale.

Table 1 Linguistic variable and TFNs (Kaganski et al. 2018)

No.	Linguistic variable	TFNs
1	Equally significant (ES)	(1,1,1)
2	Equally to average significant (EAS)	(1,2,3)
3	Averagely significant (AS)	(2,3,4)
4	Averagely to strongly significant (ASS)	(3,4,5)
5	Strongly significant (SS)	(4,5,6)
6	Strongly to very strongly significant (SSS)	(5,6,7)
7	Very strongly significant (VSS)	(6,7,8)
8	Very strongly to extremely significant (VES)	(7,8,9)
9	Extremely significant (EXS)	(9,9,9)

3.1.2 Developing aggregated fuzzy pairwise comparison matrix

$$A^{\sim 1} = \begin{bmatrix} \frac{a^{\sim 1}{}_{21} \oplus \ldots^{1} \oplus a^{\sim k}{}_{21}}{k} & \frac{\frac{a^{\sim 1}{}_{12} \oplus \ldots \oplus a^{\sim k}{}_{12}}{k}}{1} & \cdots & \frac{\frac{a^{\sim 1}{}_{1n} \oplus \ldots \oplus a^{\sim k}{}_{1n}}{k}}{\frac{a^{\sim 1}{}_{2n} \oplus \ldots \oplus a^{\sim k}{}_{2n}}{k}} \\ \vdots & & & \vdots \\ \frac{a^{\sim 1}{}_{n1} \oplus \ldots \oplus a^{\sim k}{}_{n1}}{k} & \frac{a^{\sim k}{}_{n2} \oplus \ldots \oplus a^{\sim k}{}_{n2}}{k} & & 1 \end{bmatrix} \quad (2)$$

The aggregated fuzzy pairwise matrix is developed as shown in Eq. 1.

3.1.3 Defuzzifying the pairwise comparison values and checking consistency ratio

Defuzzifying the values by graded mean integration approach checks the consistency of the fuzzy aggregated pairwise comparison matrix. The results need to be re-evaluated, in case the result is not consistent.

3.1.4 Computation of weights

The fuzzy geometric mean is calculated according to Eq. 2. The fuzzy geometric mean of the first parameter of the TFNs in each row is calculated as follows:

$$\begin{aligned} ai1 &= [1Xai12X...Xai1n]^{\frac{1}{n}} \\ ai2 &= [ai12X1X...Xai2n]^{\frac{1}{n}} \\ aii &= [ain1Xain2...X1]^{\frac{1}{n}} \end{aligned} \quad (3)$$

The geometric mean of second and third parameters of TFNs of each row is calculated similarly using Eq. 2.

3.1.5 Computation of fuzzy weights

The fuzzy criteria weights are calculated as Eq. 4

$$\tilde{W} = \begin{matrix} \tilde{W}_1 \\ \tilde{W}_2 \\ \vdots \\ \tilde{W}_n \end{matrix} = \begin{matrix} \left(\frac{a_{l1}}{a_{us}}, \frac{\tilde{a}_{m1}}{a_{ms}}, \frac{a_{u1}}{a_{ls}} \right) \\ \left(\frac{a_{l2}}{a_{us}}, \frac{a_{m2}}{a_{ms}}, \frac{a_{u2}}{a_{ls}} \right) \\ \vdots \\ \left(\frac{a_{ln}}{a_{us}}, \frac{a_{mn}}{a_{ms}}, \frac{a_{un}}{a_{ls}} \right) \end{matrix} \quad (4)$$

The fuzzy weights are obtained and are undertaken for alternative evaluation using WASPAS method in section 3.2.

3.2 Weighted assessment sum product assessment (WASPAS)

WASPAS includes two different models a) Weighted Sum Model (WSM) and b) Weighted Product Model (WPM). This method is the most suitable method for evaluating the alternatives (Mardani et al. 2017). A decision matrix is developed where n is the number of alternatives, *m* represents the evaluation criteria and X_{ij} represents the performance of i^{th} alternative with respect to j^{th} criterion. The following steps are undertaken for evaluating the alternatives (Table 7).

3.2.1 The category of criteria is defined

a) If beneficial criteria,

$$\tilde{x}_{ij} = \frac{x_{ij}}{maxx_{ij}} \quad (5)$$

b) *If non-beneficial criteria*

$$\tilde{x}_{ij} = \frac{\min x_{ij}}{x_{ij}} \quad (6)$$

3.2.2 Computation of total relative importance of i^{th} alternative of WSM

$$Q_i^{(1)} = \sum_{i=1}^{m} \tilde{x}_{ij} w_j \quad (7)$$

3.2.3 Computation of total relative importance of i^{th} alternative of WPM

$$Q_i^{(2)} = \sum_{i=1}^{m} (\tilde{x}_{ij}) w_j \quad (8)$$

$$Q_i = 0.5Q^{(1)} + 0.5Q^{(2)} = 0.5 \sum_{j=1}^{n} \tilde{x}_{ij} w_{j+} 0.5 \sum_{j=1}^{n} \left(\tilde{x}_{ij} \right)^{w_j} \quad (9)$$

3.2.4 Final weights calculation

$$Q_i = Q_i^{(1)} + (1-)Q_i^{(2)} = \sum_{j=1}^{n} x_{ij} w_j + (1-) \sum_{j=1}^{n} \left(\tilde{x}_{ij} \right)^{wj} \quad (10)$$

3.3 Selection of experts and data collection

The current study has undertaken 12 professionals from the FSCs in India. These experts are aware about the effects of disruptions, issues, and difficulties faced by the FSCs. The experts are selected on the basis of their experience in food industry. These professionals are also competent to foresee the future of the food industry in the long run and in post pandemic situation. The panel of experts consists of small and long SCs to understand the different perspectives of the food industry in the current scenario. The panel also included IT professionals who have practiced BC-T implementation in the firms for developing more resilient SCs in the last few years. The panel consists of 2 professionals in the area of packed food, 2 purchase managers for supermarkets, 1 SC consultant in the food industry, 2 are risks and crisis management consultants, 2 IT experts, 2 corporate strategists and 1 academician in the area of agri-food SC. These experts are asked to respond on the questionnaire on the linguistic scale for performing the pairwise comparison of the factors and the resilient strategies (Appendix-A, Tables 9, 10, and 11). The data collection has been done through telephonic communication during April-May, 2020.

4 Proposed research framework

It consists of a sequential procedure for FAHP and WASPAS method implementation. It is presented in Fig. 3.

The three phases of the research study are: a) Defining the problem b) Application of FAHP to calculate weights of factors affecting FSCs c) Application of WASPAS for evaluation of BC-T enabled resilient SCs FSCs.

4.1 Defining the problem

There are number of factors that are disrupting the FSCs during the pandemic. With the BC-T inclusion, the resilient FSCs can be developed. The study aims to select the most appropriate resilient strategy that a FSC should adopt to mitigate the effect of disruption. The experts are undertaken from the area of SCs, digital technologies, and FSCs. These experts are the key decision-makers in the FSC industry.

During COVID-19, the disruption affecting FSCs through factors such as sourcing related factors, lead time related factors etc. The goal of the decision-making problem is to evaluate the most preferred resilient strategy of BC-T enabled FSCs during the pandemic is at the first level. From the systematic literature review, 14 factors are identified and categorized into four main criteria. At the second level, four main criteria are sourcing related factors, lead-time related factors, flexible system and, workforce related factors. Each criterion has sub-criteria. The linguistic scales are also selected to receive feedback from the experts. The linguistic Table formed is exhibited in Table 2. Similarly, the linguistic scales for the sub-criteria are established based of the response from experts.

4.2 Application of FAHP to calculate weights of factors affecting FSCs

Each expert response is undertaken and aggregated value for the factors are obtained. The method is followed sequentially

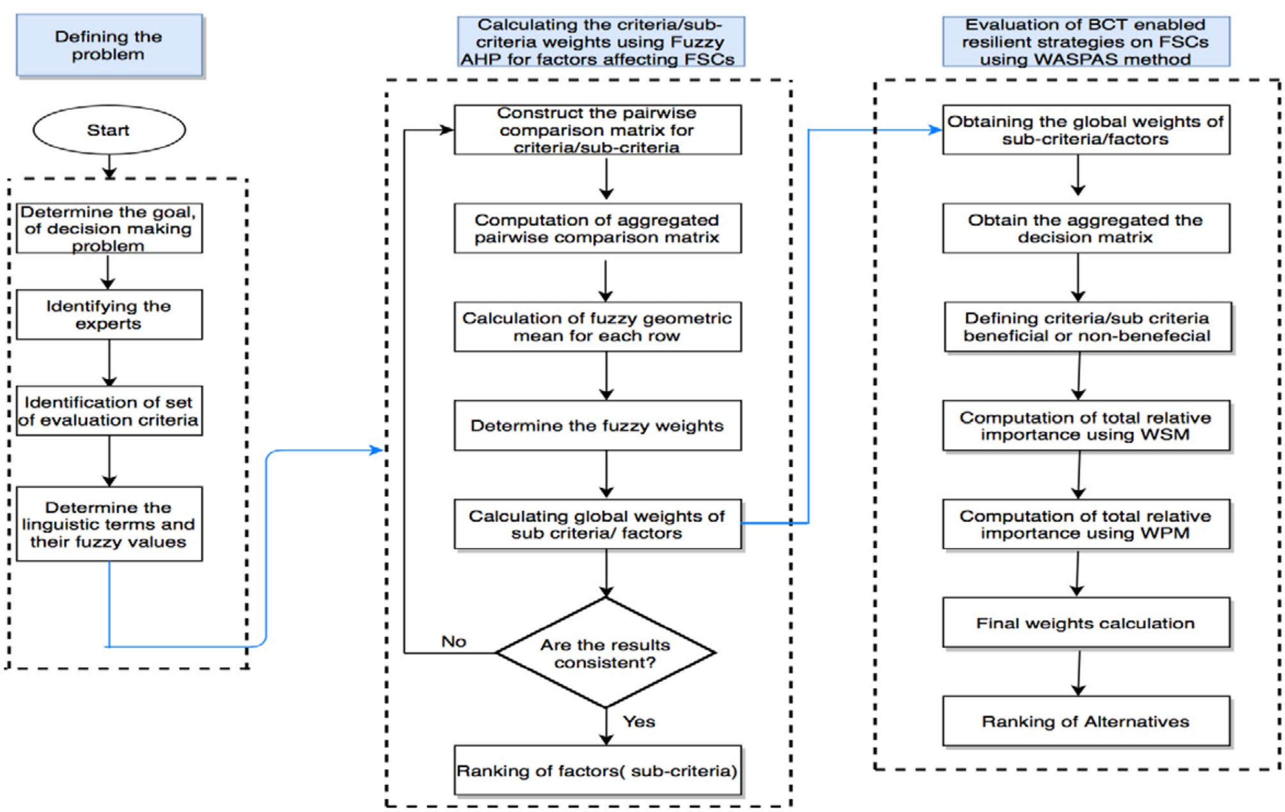

Fig. 3 Proposed research framework

Table 2 Linguistic scale values for main criteria

	C_1				C_2				C_3				C_4			
	E1	E2	...	E12	E1	E2	...	E12	E1	E2	....	E12	E1	E2	...	E12
C_1	ES	ES	...	ES	VES	SS	...	VSS	ASS	ASS	...	SSS	ES	AS	...	ES
C_2	AS	AS	...	EAS	ES	ES	...	ES	SS	SS	...	ASS	AS	ES	...	ASS
C_3	VSS	SS	...	VSS	SS	SS	...	SSS	ES	ES	...	ES	ASS	ASS	...	SSS
C_4	EAS	SS	...	AS	AS	ASS	...	ASS	AS	SS	...	AS	ES	ES	...	ES

in subsection 3. By using Eq. 1 aggregated fuzzy pairwise matrix is obtained, presented in Table 3.

4.2.1 Calculation of geometric mean fuzzy values for criteria

From Eqs. 1, 2, the fuzzy weights for the main criteria are calculated. Using Eq. 3, the average weight and normalized weight criterion are obtained. For the main criteria and sub criteria, average weight (Mi) and normalized weight (Ni) are obtained (Table 4).

The average weight (Mi) and normalized weight (Ni) for the sub-criteria are obtained using the similar steps.

4.2.2 Calculation of global weights and ranking

The global weights were computed based on the weights of criteria and sub-criteria. The ranking is performed on the obtained global weights. The global weights of the main criteria and the sub-criteria are shown in Table 5.

4.3 Application of WASPAS for evaluating the resilient strategies of BC-T enabled FSCs

The response from the experts has been taken on the scale 1-9, where 9 represent the highest priority and 1 represents the least priority. The resilient strategies (R_1-R_{12}) are rated by the experts based on the highly prioritized to mitigate risk and manage disruption during the pandemic time. The beneficial criterion is decided by the experts for all the alternatives (R1- R12).

4.3.1 Developing decision matrix

With the help of equations, Eqs. 5, 6, the beneficial criteria are defined for evaluating the alternatives. Each alternative is evaluated by the experts and decision matrix is formed.

4.3.2 Total relative importance (WSM and WPM)

Using Eqs. 7, 8 the calculations for WSM and WPM are performed. From both the models WSM and WPM, the final weights of the resilient strategies are obtained.

4.3.3 Ranking of alternatives

Using Eq. 10, the final values for the alternatives (resilient strategies) are obtained. The final weights (Q_i) of the resilient strategies are shown in Table 6. The ranking is also performed to identify the highest prioritized resilient strategy to be adopted through BC-T inclusion during the pandemic time.

5 Findings and discussions

The FAHP results from Table 5 signify that sourcing related (C_3) is the most affecting factor in the disruptive environment during the pandemic. Sourcing related factors (C_3) has obtained the maximum weight (0.3084) followed by the flexibility factors with a weightage of (0.2457). During the crisis, SCs in the food industry is facing challenges in sourcing factors due to the border restrictions worldwide, and lack of transportation. The stringent regulations, increasing cost of transportation, and less availability of shipping crews are enhancing the difficulties for the FSCs. The severity of the sourcing factors affecting FSCs is based on alternative suppliers, reliance on JIT, and inventory stock of food supplies (Pinner et al. 2020). The inability to provide a wide range of products (C_3-3) has obtained highest global weight (0.1043) and ranked as the most crucial factor affecting the FSCs in the current crisis.

The results also revealed that the suppliers are unable to offer a wide range of the food supplies and the resources for the production during this pandemic due to the

Table 3 Aggregated fuzzy pairwise matrix for main criteria

	C_1	C_2	C_3	C_4
C_1	(1.000, 1.000,1.000)	(2.500,3.500,4.500)	(4.910,5.910,6.910)	(2.000, 3.800, 4.000)
C_2	(2.160, 3.080,4.000)	(1.000,1.000,1.000)	(2.750,3.750,4.660)	(1.750, 3.500,4.410)
C_3	(4.830,5.830, 6.830)	(4.160,5.160,6.160)	(1.000,1.000,1.000)	(4.250, 5.250,6.250)
C_4	(2.580,3.580,6.580)	(2.660,3.660,4.580)	(2.660,3.660,4.660)	(1.000,1.000,1.000)

Table 4 Averaged weight criterion (Mi) and normalized weight criterion (Ni)

CRI	Mi	Ni
C_1	0.259287771	0.245736556
C_2	0.227821177	0.215914508
C_3	0.325442444	0.308433773
C_4	0.242593903	0.229915163

transportation, logistics, and wide network of the supplier base (Garnett et al. 2020).

The flexibility related factors are disrupting the global resources and affecting the wide network of suppliers. Though complex SCs are optimized to maximize the flow of resources but failure at one point in the network may propagate through the network and expose the FSCs to ripple effects (Dolgui et al. 2018). Failure in the complex SCs may cause a deadlock in the network. The FSCs are vertically and horizontally coordinated where some FSCs are depending on the wider organizational network. These FSCs are more prone to failures due to lack of input and other support functions. The upstream and downstream FSCs are facing demand and supply shocks and changing consumer purchase decisions. The other factors related to the workforce are also enhancing the deadlock situations.

The COVID-19 has revealed the preparedness or readiness of the GSCs and lack of contingency planning. The GSCs are complex and there is need to monitor and measure the practices of suppliers and buyers, but due to lack of digitization and transparency it is unable to obtain transparency, communication and information exchange (Marques 2019). Due to the lack of the collaboration among suppliers, FSC vulnerability has also increased. Because of increasing price elasticity and consumers' fear towards shopping is a major concern for the FSCs.

Table 5 Global weights and ranking

Main Criteria	Local weight	Sub-criteria	Local weights	Global weight	Ranking
C_1	0.2457	$C_{1\text{-}1}$	0.1867	0.0459	14
		$C_{1\text{-}2}$	0.1893	0.0465	13
		$C_{1\text{-}3}$	0.3627	0.0891	3
		$C_{1\text{-}4}$	0.2613	0.0642	8
C_2	0.2159	$C_{2\text{-}1}$	0.2575	0.0556	12
		$C_{2\text{-}2}$	0.3460	0.0747	6
		$C_{2\text{-}3}$	0.3964	0.0856	4
C3	0.3084	$C_{3\text{-}1}$	0.1915	0.0591	11
		$C_{3\text{-}2}$	0.1937	0.0597	10
		$C_{3\text{-}3}$	0.3381	0.1043	1
		$C_{3\text{-}4}$	0.2767	0.0853	5
C_4	0.2299	$C_{4\text{-}1}$	0.4179	0.0961	2
		$C_{4\text{-}2}$	0.2716	0.0624	9
		$C_{4\text{-}3}$	0.3105	0.0714	7

The WASPAS results for the resilient strategies of BC-T enabled FSCs are shown Table 6. From the Table 6, it is clear that improving flexibility (R7) is the most significant key resilient. This strategy has obtained a weight of 0.875. Flexibility of the SCs is their ability to absorb any change caused by the disruption. The main advantage of the flexibility is that it encompasses the redundancy and thus more number of suppliers for same products with different risk is essential (Sheffi 2015). For long run, organizations need to enhance flexibility to respond quickly to the disruptions. This strategy is essential to become resilient and preparing the FSCs for future disruptions.

The flexibility in BC-T enabled FSCs will be relying neither on the identity of the participants nor on whether the participant change over time making the network flexible network an independent from central authority (Kamilaris et al. 2019). Resilience refers to the redundance o_f the stored information that leads to robustness against malicious attacks as well as censorship it is the aforementioned characteristics of trust, shared availability, low friction due to the cut-out of trusted middle men, peer verification, underlying cryptography, immutability, decentralization, redundancy, versatility, and the potential for automation that all blockchains share (Casino et al. 2020).

Visibility is another resilience strategy in the FSCs (Purvis et al. 2016). The study has shown that visibility is the key resilient strategy and ranked second with a weightage of 0.0848. This finding is line with the previous study where visibility of the FSCs with the BC-T inclusion reduced the information audit cost, enhanced the information sharing that consequently increases transparency at the customer's side and diminished the volatility of demand (Choi et al. 2020). This is the advantage of BC-T that enhances the overall efficiency of the organization is enhanced. BC-T also supports the SCs in customers identification affected

Table 6 Ranking of Alternatives

Alternatives (Resilient strategies)	$Q_i^{(1)}$	$Q_i^{(2)}$	Q_i	Ranking
R1	0.206	0.169	0.375	12
R2	0.359	0.345	0.704	6
R3	0.346	0.323	0.669	7
R4	0.433	0.415	0.848	2
R5	0.226	0.219	0.445	11
R6	0.304	0.291	0.595	9
R7	0.439	0.436	0.875	1
R8	0.409	0.383	0.792	4
R9	0.412	0.405	0.818	3
R10	0.342	0.307	0.649	8
R11	0.400	0.355	0.754	5
R12	0.310	0.281	0.591	10

by the disruption. Thus, with enhanced visibility and real time information of the SCs supported by BC-T positively impacts the ripple effect that further helps the organization to remain effective and efficient during the crisis.

The third most significant strategy is the change in the SC network structure. This resilient strategy (R9) has obtained a weight of 0.0818. Due to the pandemic disruption, the complex GSCs are not able to manage their operations due to the wide network structure and thus, with the help of BC-T and other digital technologies the SC will become shorter and more efficient during any disruption. The shortening may boost the resilience in the FSCs. The velocity of the SCs is also significant.

In the disruptive environment, there is also a need of tracking and tracing the system for enhancing the efficiency of the operations (Saberi et al. 2019). Thus, BC-T can support the organization to enhance the velocity for making the FSCs more efficient. The disruption has not only affected the supplier networks but the consumer's purchase decision has also been changed. The shift has been visible in the buying patterns of the customers and thus new models need to be developed (Galanakis 2020). The pandemic has shown an opportunity for the FSCs to serve the consumers with online business models that may help them to be safe and secure while shopping.

It is clear that FSCs need to have innovative strategic plan to redesign the FSCs to become more resilient and sustainable in future. This pandemic has exposed the vulnerability of the SCs in terms of sourcing, labor, lack of preparedness etc. Hence, there is need for digital transformation, integrated decision-making by stakeholders, collaboration for developing more resilient FSCs Montecchi et al. (2019).

5.1 Theoretical implications

The main objective was to assess the factors affecting FSCs in the disruptive environment during the pandemic and measure the role of BC-T in managing disruption, risk in FSC during the pandemic situation. The current study contributes in many ways. First, the research has compiled all the relevant studies on BC-T and extracted the literature to identify the factor for managing the disruption in FSCs. The current study is the pioneer research type that has identified factors affecting FSCs in the disruptive environment during the COVID-19 pandemic using an integrated approach of FAHP and WASPAS in context to India. The study provided insights to the researchers and practitioners to manage the factors in developing BC-T enables FSCs. Finally, the developed framework may help the researchers to consider the factors and create some research models.

5.2 Managerial implications

There are many issues arisen due to the current crisis but the main problem is the high level of uncertainty and complexity. The FSCs need to be quick, digitalized, shorter, and collaborated efforts of all the stakeholders. Regardless of the size of their organizations, there is a need to enhance flexibility, visibility, traceability and shorter SCs. This study has wide-reaching implications for the FSCs as it has enhanced the understanding of factors and resilience strategies that is managing the disruptions in the environment. The decision-makers need to redesign their business models now as the digital platforms have taken a lead in the consumer's preference list.

The sale of the products through e-commerce has gained momentum significantly in the last year able to satisfy the consumer needs. The digitization not only helps the organizations to sell but also provides an opportunity to manage the inventory more efficiently. The BC-T enabled FSCs may access real-time information that facilitates decision making. The changed environment where people are compelled to remain indoors, there has been a marked shift in the e-commerce transactions. The use of BC-T controls and enhances the traceability of the products and processes with optimized opera\1tions. The traceability has enabled the FSCs to track their product sourcing and transportation, helping the decision makers to reduce risk, uncertainty, and enhances the coordination among the SC partners. There is reduction in the unnecessary production & wastage of food that helps in achieving the sustainable outcomes for the organizations. In the current circumstances, the FSCs need to become flexible for adopting new modes of buying patterns.

The firms should focus on developing efficient and advanced risk identification measures. The current study shows that the suppliers are limited with food supplies and the resources for the production during this pandemic due to the transportation, logistics, and wide network of the supplier base. This justifies the need to develop BC-T enabled systems for developing resilient FSCs. The firms can develop SC risk management approach to enhance their efficiency and face high-frequency-low-impact events. The disruption during COVID highlighted the significance of collaboration and inter-collaboration resource sharing. This study demonstrates the need for the SCs and the focus area for the SC practitioners and decision-makers to focus on flexibility, visibility, volatility, network structure of SCs, and new business models for managing disruptions caused by the pandemic.

The BC-T has the potential to replace some workflows that are currently captured by ERP systems. For BC-T implementation in FSCs, an integration is required with

ERP systems. The main concern is the integration of user interface and integrating data structures that is generated and stored in blockchain. Moreover, standardisation becomes more important. When several members of a supply network decide to implement their own proprietary blockchain and promote their use along their own supply chain, it is conceivable that administrative complexity for upstream suppliers first drives costs before it even becomes unmanageable. Participatory governance mechanisms could facilitate the development and acceptance of a standard. Given the prospect of cost reductions and efficiency gains for all members of the supply network, the collective action initiative could be extended to a multi-stakeholder initiative in order to gain moral legitimacy. A successful implementation of blockchain technology clearly needs a collaboration of all supply network members alongside the provision of support services such as infrastructure and training. It must be ensured that the technology serves all stakeholder interests, including data portability to conventional databases, standardization and participatory governance.

5.3 Unique contribution of the research

The study has assessed the factors affecting the FSCs in the disruptive environment during COVID-19. This study is the first attempt to analyze the factors and resilient strategies for the BC-T enabled FSCs. The study has highlighted the insights for the food industry professionals, consultants, and strategists and government organizations to manage their FSCs to become more resilient and prepared for disruptions. The study has also used an integrated approach FAHP-WAPAS for examining these factors and strategies. -

6 Conclusion

The impact of the pandemic is witnessed across all the industries but the major impact is seen in the food industry. The severity of the effects is visible across all the companies, based on factors such as network structure, flexibility, agility, etc. FSCs suffer from uncertain dangerous disruptions leading towards huge financial losses. The perishability of product is to be considered while developing the network structure of the FSCs.

FSCs need to be supported through technology such as BC-T. The study aimed to explore the factors affecting FSCs in the disruptive environment during COVID-19 and the resilient strategy to mitigate the risk, uncertainty, and controlling disruptions. Accordingly, the robust and resilient FSCs have emerged as the most significant characteristic since last year.

The pandemic has exposed the unprepared state of FSCs and inefficiency to control disruption during the crisis. The FSCs are shifting towards shortening of their SCs, shifting towards local SCs, impending digital technologies, enhancing flexibility, traceability to manage the disruption, enhances their efficiency, and developing robust SCs for the future. This study has highlighted the benefits of resilience during the crisis. The shorter SCs with higher traceability of products and processes will develop stronger contingency plans for the future that may manage GSCs efficiently. The changing needs of consumers have also created an opportunity for innovation in business models.

The study has a few limitations. Firstly, the inability to have a face-to-face discussion with the experts as the data has been collected remotely. The technical faults and connection issues that caused the disturbance in the process interrupted the discussion. Secondly, the pairwise comparisons are based on expert judgments and hence the results may be biased. Thirdly, the study may be extended for empirical analysis of the events in real networks for testing the results of the study.

Appendix-A

Table 7 List of Factors affecting FSCs in disruptive environment

Main Criteria		Sub-criteria	
C_1	Flexibility related	$C_{1\text{-}1}$	Change in yields
		$C_{1\text{-}2}$	Change in production activities
		$C_{1\text{-}3}$	Complex network of organization
		$C_{1\text{-}4}$	Wider supply chain network
C_2	Lead time related	$C_{2\text{-}1}$	Reduction in supply base
		$C_{2\text{-}2}$	Delay in lead time
		$C_{2\text{-}3}$	Price elasticity
C_3	Sourcing related	$C_{3\text{-}1}$	Souring efficiency
		$C_{3\text{-}2}$	Demand and inventory imbalance
		$C_{3\text{-}3}$	Inability to provide range of resources/products
		$C_{3\text{-}4}$	Accessibility to inputs
C_4	Workforce related	$C_{4\text{-}1}$	Workforce safety concerns
		$C_{4\text{-}2}$	Safety norms
		$C_{4\text{-}3}$	Lack of workforce

Table 8 Resilient strategies for BC-T enabled FSCs

R1	Enhancing security
R2	Business model innovation
R3	Coo petition
R4	Enhancing visibility and Traceability
R5	Social capital competency
R6	Contingency planning
R7	Increasing flexibility
R8	Enhancing velocity
R9	Supply chain network structure
R10	Developing logistics capabilities
R11	Information sharing
R12	Smart contracts

Table 9 Criteria pairwise comparison for Fuzzy AHP calculation (Please provide response in the linguistic scale)

	C_1	C_2	C_3	C_4
C_1	ES			
C2		ES		
C3			ES	
C4				ES

Table 10 Sub-criteria pairwise comparison for Fuzzy AHP calculation

	$C_{1\text{-}1}$	$C_{1\text{-}2}$	$C_{1\text{-}3}$	$C_{1\text{-}4}$	....	$C_{4\text{-}3}$
$C_{1\text{-}1}$	ES					
$C_{1\text{-}2}$		ES				
$C_{1\text{-}3}$			ES			
$C_{1\text{-}4}$				ES		
...					....	
...						
$C_{4\text{-}4}$						ES

Table 11 Matrix for WASPAS calculation (Please rate on the scale of 1-9, R1-R9 are resilient strategies mentioned in Table 8)

Resilient Strategies	Max/Min	Max/Min	Max/Min	Max/Min
	$C_{1\text{-}1}$	$C_{1\text{-}2}$	-------	$C_{4\text{-}3}$
R1				
R2				
...				
...				
R12				

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