Analysis of supply chain resilience drivers in oil and gas industries during the COVID-19 pandemic using an integrated approach

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Analysis of Supply Chain resilience drivers during COVID-19 using integrated Fuzzy ISM-DEMATEL approach

Abstract

The paper aims to identify and analyze the drivers of supply chain resilience (SCR) under severe supply chain (SC) disruption such as COVID-19 Pandemic. The analysis helps to understand each of the driver with the highest driving power and driving intensity over others to achieve resilience in SC. Through extensive literature review and experts' discussions, this study identified fourteen SCR drivers. These drivers were analyzed using a hybrid Fuzzy ISM-DEMATEL approach. The integration of ISM and DEMATEL approaches is preferred over other techniques by considering their abilities to convert the inheritance, interdependence and intensity of the identified drivers into a useful and logical conclusion. The analysis from Fuzzy ISM-DEMATEL shows that the major drivers of SCR are "Government Support" and "Security". These two drivers help to improve another two drivers such as "Collaboration" and "Information sharing", which further drive other drivers such as "Innovation", "Trust" and "Visibility" within the SC partners. In addition, two more drivers such as "Robustness" and "Agility" are also seen as essential drivers of SCR. However, rather than driving the other drivers, these drivers are also driven by themselves. Furthermore, the result shows that the drivers "Collaboration" and "Agility" have the highest overall driving intensity and the highest intensity of being driven by other drivers respectively.

Keywords Supply chain resilience, Resilience drivers, COVID-19, ISM-DEMATEL, Fuzzy logic

1. Introduction

Global supply networks are a complex ecosystem consisting of multi-layer, multi-dimensional facets that facilitate on-time delivery, just-in-time manufacturing and lean production system (Piya *et al.,* 2021). It becomes even more complex and vulnerable during various threats such as natural disasters, cyber-attacks, trade war, pandemic situations, accidents, etc. The existence of such threats can make the organizations supply network at risk. In such situations, it is crucial to consider resilience in SC operations (Christopher and Peck, 2004; Azadegan and Jayaram, 2018). Advances in various smart technologies can help to improve SCR and contribute toward adaptation and anticipation capabilities (Clauson *et al*., 2018). Moreover, they can offer expected flexibility in day-to-day sourcing, visibility in manufacturing and order fulfillment (Pettit *et al*., 2019).

SCR is considered as an ability of the SC to manage its activities as normal as possible during any forms of disruptions. This resilience in SC contributes to improving customer service, market share and profitability (Piya et al., 2020). It is, therefore, critical for the firm to understand and ensure resiliency of SC in order to mitigate obstacles that occurred due to unforeseen disasters and maintain the business growth. This is especially true in today's COVID-19 pandemic, where more than 80% of global organizations are severely affected by the crisis (Supply chain, 2020).

With the advent of COVID-19, the needs for structural change within the supply network cannot be ignored despite investment cost. Such structural changes in the supply network compensate for building required resilience and contribute to increasing competitive advantage more quickly. Organizational managers need to identify, prioritize and implement an action plan with the goal to minimizing risk and financial impact as occurred due to disruption in the supply network (Ali *et al*., 2021). The formulated actions can be in the form of getting up-to-date visibility, analyzing collected data to measure risk and impact, developing a short-term remedial plan, mobilizing task force to manage the crisis, developing a future plan on key impact in SC, etc.

Several strategies such as reshoring, diversification, increasing inventory level, introduce additional supply sources, sustainability, agility, etc., can be deployed to strengthen SC and maintain resiliency (Gunasekaran *et al*., 2015). However, each of the strategies has its own advantages and disadvantages. The successful blending of the right strategy can promote boosting of SCR (Centobelli *et al*., 2020). Together with strategy, there needs investment in technologies to make SC more intelligent and autonomous. Investments in certain strategy and technologies are critical for building long-term resilience through enabling higher transparency or visibility in SC. Combining strategy and technology allows the supply network to sense and adapt faster to disruptions and changes.

1.1 Problem statement

The COVID-19 pandemic was responsible for the most critical threat to global supply networks than natural disasters, trade sanctions and cyberattacks (Supply Chain Resilience Report, 2020). The report also stated that around 60% of the surveyed companies revealed that COVID-19 had directly affected their SC. Consequently, 96% of companies are reorganizing their SC to bring resiliency. Accordingly to Capgemini Research Institute (2020), “The pandemic has forced organizations to priorities SCR, with two-thirds stating that their SC strategy needs to change significantly to adapt to the new normal”. In such consequence, it is essential for the firm to focus on the strategy that will improve resilience in their SC (Ivanov and Das, 2020). There is growing concern that in order to stay competitive during COVID-19 by reacting and adapting quickly to potential risks and disruptions, SC needs to be more agile and flexible (Supply chain, 2020).

This study specially focused on the supply chain resiliency in oil and gas industry during COVID-19. This industrial sector is critical with respect to energy supply and maintenance, which is an essential element for all forms of productivity (Emenike and Falcone, 2020). Along with other business sector, oil and gas industry is also facing several challenges during COVID-19 pandemic. Some of the challenges can be stated as disruptions in production process due to shortage of human resources, supply and delivery of necessary parts/components, various essential tools and technologies, etc. (Bento et al., 2021). These forms of uncertainties come generally due to disruptions to the transportation network (Bravo and Hernández, 2021). In this current situation, it is also seeming that the ripple effect of the COVID-19 pandemic might continue for a longer time to come across all supply chains including oil and gas industry. In order to overcome with such a significant uncertainty due to the novel COVID-19 pandemic, there needs to initiate future mitigation plans and proper modeling for supply chain resilience. This study therefore, tried to find out the required drivers, responsible for supply chain disruptions during COVID-19 and suggested how these drivers can be used as a decision-making process in oil and gas industry to maintain SCR in general.

1.2 Research contribution

Before adopting any strategy to monitor and manage SCR, it is necessary to identify the corresponding drivers that drive SC towards resilience. Identification of the drivers makes it easy to choose a proper strategical plan to eliminate or minimize the disruptions in SC during COVID-19 (Bevilacqua *et al*., 2020; Emenike and Falcone, 2020). Some research has been carried out in the past to understand the drivers and measure SCR (Spiegler *et al*., 2012; Soni *et al*., 2014; Hosseini *et al*. 2019). However, apart from understanding the drivers, it is essential to know the relationship between the drivers and the influence of one driver over others for driving SC towards resilience. Understanding the influence helps the firms to prioritize the drivers and to select strategy specific to the drivers for improving SCR.

In general, substantial research has been done so far towards the identification and prioritization process of the drivers responsible for SCR (Christopher and Peck, 2004; Azadegan and Jayaram, 2018; Sujan et al., 2020). All such drivers were identified considering mainly generic disruptions or abnormalities in supply chain such as natural disasters, trade war, strikes, accident, etc. However, till-to-date, it is not seen any substantial amount of research conducted, which are based on identifying the drivers responsible for supply chain disruption considering ongoing COVID-19 pandemic situation (Ivanov and Das, 2020; Ali *et al*., 2021). Therefore, in this research, an attempt has been taken to understand, identify and prioritize the major drivers that can promote SC resiliency under the COVID-19 pandemic. Based on such specific goals, this research study identified three research questions. It is believed that by answering these three questions would be a novel contribution towards the supply chain resiliency under this pandemic situation. Three research questions can be stated as follows:

- *RQ1*: What are the drivers of SCR during the COVID-19 pandemic?
- *RQ2*: What relationship exists between the drivers to drive SC towards resilience?
- *RQ2*: What is the intensity of the relationship?

The remaining portion of the paper is structured as follows: Section 2 identifies the SCR drivers based on the extensive literature review and expert's discussion. Section 3 presents the novel

Fuzzy ISM-DEMATEL method proposed to analyze the identified drivers and understand the intensity of the relationship. Section 4 discusses the results drawn from the study. Finally, the paper concludes with future research directions in Section 5.

2. Supply Chain Resilience Drivers

To identify the drivers responsible for resilient SC, an extensive literature survey was conducted. Several keywords such as “supply chain resilient”, “drivers of resilient”, “supply chain risk”, “resilient enabler”, supply chain disruption”, “security in supply chain”, “COVID-19” etc., were used. During the literature survey, various available databases such as Science Direct, Scopus, Emerald, Springer, Google Scholar, and ISI Web of Science were used. The drivers identified from the literature review were consolidated and experts were solicited for confirmation. In discussion with the experts, it is made clear that the research is about identifying the SCR drivers specific to the ongoing pandemic. The consolidated drivers, after consultation with the experts, their relationship with SCR and references were as shown in Table 1. As shown in the table, altogether fourteen drivers of SCR were identified.

Table 1: SCR drivers under pandemic situation

3. Methodology

This research proposes an integrated Fuzzy ISM-DEMATEL approach to analyze the drivers of SCR. As discussed in the literature review section, the drivers of SCR are identified through an intensive literature survey and finalized in consultation with the experts. Thereafter, an ISM methodology is implemented to identify the contextual relationships between the drivers. The intensity of the relationships between the drivers is computed using the fuzzy DEMATEL method and the drivers are then classified into various cluster based on the fuzzy MICMAC analysis. As both the ISM and DEMATEL methods are expert-based decision support tools, expert’s knowledge and experiences were solicited. Six experts took part in these procedural steps; two of them were academicians who have wider experiences in both teaching and research in the area of SC management. The others were chosen from industries with experience of more than 10 years working in production, procurement and SC departments. Figure 1 shows the methodological steps as followed in this research.

Figure 1: Display of methodological steps to study the drivers of SCR

3.1 ISM Methodology

Interpretive Structural Modelling (ISM) is an illustrious modelling tool to decode poorly articulated mental maps into a clear structural model (Majumdar *et al*., 2021). This tool supports transforming complicated taxonomy into a manageable sub-system and finding the relationships among the drivers (Piya *et al*., 2019). To provide a methodical and directional framework for a complex system ISM uses expert's knowledge and experience, thereby allowing the concerned authority to understand the drivers involved and perceive a realistic picture of the situation for decision-making. One major advantage of ISM is that it requires fewer experts than other modelling tools such as Structural Equation Modelling (Yadav and Barve, 2015). Moreover, the outcome of ISM gives a clear structural view for an unstructured problem showing directed links between the drivers through ISM digraph. To characterize the relationships between elements affecting the system, it has been progressively used by various researchers in different areas (Piya *et al*., 2020). The steps involved in the use of ISM methodology is as discussed below.

Step 1: *Structural self-interaction matrix* (SSIM)

Once the drivers of SCR are identified, a structural self-interaction matrix (SSIM) is developed to define a contextual relationship between the drivers using the following symbols:

V: driver *i* will complement driver *j* to achieve resilience

A: driver *j* will complement driver *i* to achieve resilience

X: drivers *i* and *j* will complement each other to achieve resilience

O: no relationship between drivers *i* and *j*

To define the appropriate relationships between the drivers, six experts, as discussed in Section 3, were invited for the brainstorming sessions. The results from the multiple brainstorming sessions are presented in Table 2 in the form of SSIM.

Table 2: Structural self-interaction matrix for the identified drivers

Step 2: Reachability matrix (RM)

Initial reachability matrix (IRM), which is $n*n$ matrix with (i=1, 2, …, n; j=1, 2, …., n) is produced based on the outcomes from Table 2 by substituting the alphabets with binary values 1's and 0's using the following rules:

- *V* for driver (i, j), then the binary value in IRM for (i, j) becomes 1, and (j, i) becomes 0.
- *A* for driver (i, j), then the binary value in IRM for (i, j) becomes 0, and (j, i) becomes 1.
- *X* for driver (i, j), then the binary value in IRM for both (i, j) and (j, i) becomes 1.
- *O* for driver (i, j), then the binary value in IRM for both (i, j) and (j, i) becomes 0.

IRM is shown in Table A in Appendix A. As shown in IRM, if $i = j$ i.e., diagonal element of the matrix, then the binary variable will be 1. Once the IRM is developed, the internal consistency between the relationships is confirmed by using the concept of transitivity, which states that if A is related to B and B is related to C, then A must be related to C. Table 3 shows the final RM after using the concept of transitivity. 1* in Table 3 represents a change in the relationship in IRM between the drivers due to transitivity.

Table 3: Final reachability matrix

Step 3: Level partition

In this step, based on the final RM, reachability set, antecedent set and intersection set for each driver is derived. The reachability set consists of a driver (i) itself and all other drivers (j) influenced or driven by the former. On the other hand, the antecedent set consists of a driver (i) itself and the other drivers (j), which influence or drive the former. The common drivers of these two sets help in obtaining the interaction set. The drivers with identical reachability and intersection sets in the first iteration will be clustered as level I and these drivers fall under the top-level in the hierarchy. The drivers at this level will not help to drive any other drivers above its level. Once the top-level drivers are identified, they are eliminated from the remaining sets. Further, the process is iterated to find the drivers in the next levels. The iteration is continued until the last driver remains in the sets. The result of each iteration is shown in Appendix B and the final result is shown in Table 4.

Table 4: Levels of drivers of supply chain resilience

Step 4: Develop ISM Digraph

Based on the result from step 3 and after eliminating indirect links, the drivers are then organized graphically in levels as shown in Figure 2. Such graph is known as ISM diagraph. The relationships between the drivers in the graph are indicated by an arrow directed from *i* to *j*.

Figure 2: ISM Diagraph with the intensity of relationship between the drivers

The ISM diagraph developed based on the traditional ISM shows the levels of drivers and relationship of one driver over other using arrow directed from *i* to *j* in the graph. It means that the traditional ISM method can tell whether there is a relationship or not by using binary variables (0 or 1). However, it does not show the degree or intensity of the relationship that exists between driver *i* and driver *j*. To overcome this limitation of ISM, it has been integrated with Decision Making Trial and Evaluation Laboratory (DEMATEL) method in different fields (Chauhan *et al*., 2018; Wang *et al*., 2018; Yadav *et al*., 2020). Therefore, an integrated ISM and DEMATEL approach has been applied in this study to obtain better results. Note that the ISM diagraph in Figure 2 shows the levels of drivers based on the traditional ISM and the intensity of the relationship between the drivers as calculated based on the integrated Fuzzy ISM-DEMATEL method. The next section will discuss the calculations of such intensities.

3.2 Fuzzy DEMATEL

DEMATEL can be used to identify the intensity of the relationship between one driver over others. To use DEMATEL, it is necessary to develop an intensity matrix between the drivers, which is obtained based on the expert's opinion. Here we propose integrating fuzzy logic with DEMATEL method to deal with the vagueness and uncertainty in human judgement during the decision making process. The following steps are followed to calculate the Fuzzy DEMATEL method.

Step 1: Construct Binary direct relationship matrix (BDRM)

BDRM is constructed by converting all 1 in the diagonal elements of IRM (Appendix C) to 0.

Table 5: Linguistic variable, notation and corresponding Fuzzy set

Step 2: Construct linguistic direct reachability matrix (LDRM)

When there is a relationship between the drivers represented by BDRM, the relationship is replaced with an appropriate linguistics variable. The linguistic variable and its fuzzy scale used are as shown in Table 5. Here, the shape and the range characterize the fuzzy numbers. The triangular fuzzy membership function is considered for the shape as it is simple to use, intuitively easy to infer and calculate by the decision makers compared to others shapes (Shamsuzzoha *et al*., 2021). The graphical representation of the membership function is shown in Figure 3.

Figure 3: Triangular member function

Three experts took part in the process of assigning linguistic variables. These experts were also involved in defining the contextual relationships and helped to develop Table 2. To avoid the influence of point of view of one expert over the other, the experts' opinions were solicited individually. The LDRM obtained from these experts is shown in Table 6.

Table 6: Experts linguistic assessment for the contextual relationship

Step 3: Construct an Average Influence Matrix (AIM)

To construct an AIM, at first, the LDRM is defuzzified for each expert's opinion using Best Non Fuzzy performance (BNP) method (Equation 1) as proposed by Bhosale and Kant (2016). In the equation, k represents an expert. The BNP_{ijk} values of three experts are then aggregated by using the geometric mean method (Equation 2) as discussed in Arunachalam *et al*., (2020). In Equation 2, K represents the total participating experts. The resulted AIM is shown in Table 7.

$$BNP_{ijk} = \frac{(u-l)+(m-l)}{3} + l \quad (1)$$

$$B = [b_{ij}]_{n*n} = \sqrt[K]{\prod_{k=1}^{K} BNP_{ijk}} \quad (2)$$

Table 7: Average influence matrix

Step 4: Normalize AIM

The AIM is then normalized by using Equation (3). For normalization, b_{ij} value in the matrix is divided by the maximum value of the summation of b_{ij} among entire rows in the AIM matrix. The normalized AIM matrix is shown in Table 8.

$$X = [x_{ij}]_{n*n} = \frac{B}{\max_{1 \le i \le n} \sum_{j=1}^{n} b_{ij}} \quad (3)$$

Table 8: Normalized Average Influence Matrix

Step 5: Develop Total Influence Matrix (TIM)

The total influence matrix is then constructed by using the relation as shown in Equation (4). In the Equation, I is an identity matrix. The TIM is shown in Table 9.

$$T = [t_{ij}]_{n*n} = X[I - X]^{-1} \quad (4)$$

Table 9: Total Influence Matrix

Step 6: Identify the relationship map

The relationship map is then identified by calculating the sum of the rows (R) and columns (C) of the TIM as shown in Equations (5) and (6), respectively.

$$R = [r_i]_{n*1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n*1} \quad (5)$$

$$C = [c_i]_{1*n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1*n} \quad (6)$$

Step 7: Identify causal relationship

The casual relationships between the drivers were identified by calculating the sum and the difference of R & C i.e., (R+C) and (R-C), respectively. The (R+C) value denotes the strength of the driver. On the other hand, (R-C) represents the net effect of the driver on the system. If the value of (R-C) is positive, then it represents that the driver has a net influence on other drivers and such driver is classified into cause group. However, if (R-C) is negative, then it means that other drivers influence the driver in the system. Such driver is classified into effect group.

3.3 Fuzzy MICMAC Analysis

MICMAC analysis is the last step and an important outcome of ISM methodology. MICMAC analysis helps to group the drivers into four different clusters, rather than only two clusters as in DEMATEL. For the analysis, we integrated fuzzy logic with traditional MICMAC analysis to cushion the effect of vagueness in human judgement. To use Fuzzy MICMAC analysis, the AIM developed in section 3.2 is used as an input. Once the AIM is developed, the following steps are followed:

Step 1: Construct fuzzy MICMAC Stabilized matrix

The AIM is stabilized to obtain a fuzzy MICMAC stabilized matrix by using the concept of fuzzy multiplication (Mishra *et al*., 2017). It means that the matrix is multiplied until the values of driving and dependence powers are stabilized. Following rules of Fuzzy Matrix multiplication as highlighted in Equation 7 is used to stabilize the matrix.

$Z = A, B = \max k\ [(\min (a_{ik}, b_{kj})]$ where $A = [a_{ik}]$ and $B = [b_{kj}]$ (7)

In Equation 7, Z is Fuzzy MICMAC stabilized matrix, A is binary direct relation matrix (BDRM) and B is average influence matrix (AIM). The stabilized matrix is shown in Table 10.

Table 10: Fuzzy stabilized matrix

Step 2: Construct Fuzzy MICMAC plot

The MICMAC analysis helps to cluster the drivers into four different quadrants. To segregate the drivers into these clusters, the row and column values in the Fuzzy MICMAC Stabilized matrix are summed up and depending upon the values the drivers are plotted against the Fuzzy MICMAC graph as shown in Figure 4.

Figure 4: Fuzzy MICMAC analysis of SCR drivers under pandemic

First quadrant: Drivers that fall under this quadrant have less driving power and less dependency. Therefore, this quadrant is known as an autonomous quadrant.

Second quadrant: Drivers that fall under this quadrant are known as dependent drivers. Such drivers will have low driving power but high dependency.

Third quadrant: Drivers with high driving power and high dependency falls under this quadrant. Any action on the drivers, which fall under this quadrant, will have knock-on effects on others. Therefore, this quadrant is also known as linkage.

Fourth quadrant: This quadrant consists of the drivers with strong driving power but weak dependency. All these drivers drive other drivers to accomplish resilience in SC.

4. Results and Discussions

4.1 ISM Result

From Figure 2, drivers such as 'Robustness and Agility' have the highest levels, i.e. level I, which means that these drivers have the highest level of dependency. These drivers are very important to achieve resilience and are highly dependent on other drivers above its level. On the other hand, drivers such as 'Government support' and 'security' lie at the lowest level in the diagraph, i.e. level V, which means that these drivers have the highest driving power to drive SC towards resiliency under a pandemic situation such as CoVID 19. These two drivers drive all other drivers of supply chain resilience. This result is in line with the OECD report (2020), which highlighted the importance of government support and high-level institutional arrangements put in place by the government to help private and government sector institutions become agile and improve resilience. As shown in Figure 2, apart from these two drivers, other drivers such as information sharing, trust and knowledge, and risk management culture are very important to survive and be resilient in difficult situations. These drivers fall under level 4 and are the major drivers of SCR. The remaining drivers such as trust, visibility, innovation, redundancy, application of technology and digitization lie in between the top and bottom levels in the ISM diagraph.

From the ISM diagraph, it can be seen that some drivers have two-way interactions. For example, drivers at level IV and V have two-way interactions. It means that these drivers affect or drive to each other for their accomplishments. On the other hand, there are drivers, especially at different levels with one-way interaction or drive. For example, government support helps drive collaborations between SC entities. However, the opposite is not true. Even though some drivers fall under the same level, they do not interact with each other. For example, driver "Innovation" does not interact with other drivers, which lie at the same level.

Furthermore, as an example of one link in a chain from lower to higher level, the following can be interpreted from the ISM diagraph:

- Government support (F11) helps to drive collaboration (F9) among SC partners. Due to the CoVID-19 pandemic, many companies across and within the borders are collaborating with each other, especially in pharmaceutical industries to develop therapeutics, vaccines and medical equipment to fight against CoVID-19. Such collaboration requires significant government support financially and in the form of regulation and policy implementation (Aigbogun *et al*., 2018).
- Collaboration (F9) between SC partners affects SC visibility (F2). Effective collaboration and on-time information sharing among SC partners are very important to improve the level of visibility within SC (Soni *et al*., 2014).
- SC visibility (F2) helps to drive SC flexibility (F10). Improved visibility through coordination and appropriate information sharing among SC partners helps to utilize/ share available resources, thereby improves SC flexibility.
- Finally, SC Flexibility (F10) helps improve the level of SC agility (F8). Research has shown that flexibility and agility are directly proportional to each other (Prater *et al*., 2001).

4.2 Results from Fuzzy DEMATEL analysis

As discussed in Section 3.2, Fuzzy DEMATEL is used to understand the intensity of the relationships between the identified supply chain resilient drivers. The result of Fuzzy DEMATEL is as shown in Table 9 and reflected in Figure 2 in the ISM diagraph. Based on Table 9, it is seen that five drivers such as Robustness (F1), Visibility (F2), Trust (F6), Agility (F8) and Flexibility (F10) fall under the effect group. On the other hand, drivers such as Information sharing (F3), Security (F5), Collaboration (F9), Government support (F11), Application of Technology (F12), SC innovation (F14) fall under the cause group. Even though drivers F4, F7, F13 fall under the cause group, their R-C values are closer to zero. It signifies that the driver net influence on other drivers and other drivers combine influences on it is the same.

Table 9 also shows the direct and indirect intensity of the relationship between the drivers. For example, the influence of driver F12 on driver F13 is very high as compared to the influence of driver F13 on driver F12 (i.e., 0.14 vs 0.05). In case of drivers F7 and F10, their influences on each other are similar (i.e., 0.12). From Table 9, it is also obvious that the influence of one driver over others in some cases is very minimal. Therefore, to show the significant influence, a threshold value (β), as discussed by Gardas *et al*., (2019), is identified by taking the average of all the drivers in the total influence matrix. The intensity of the relationship greater than this threshold value (0.04) is considered significant and such relationships between the drivers are shown in Figure 5 by the Intensity relationship map.

Figure 5: Intensity relationship map of significant relationships

4.3 Results from Fuzzy MICMAC analysis

From the Fuzzy MICMAC analysis and Figure 4, the study reveals the following:
First quadrant: Only one driver i.e., Digitization and visualization (F13) falls under this quadrant. However, this driver lies very close to being in the second quadrant.
Second quadrant: Five drivers such as F6 (Trust), F2 (Visibility), F7 (Redundancy), F8 (Agility), F1 (Robustness) falls under this quadrant and they lie at the highest and middle levels in the ISM diagraph. The drivers that lie under the fourth quadrant significantly affect these drivers.
Third quadrant: Two drivers i.e., Information sharing (F3) and Application of Technologies (F12) falls under this quadrant. Driver F10 i.e., Flexibility is inconclusive in the sense that it lies between second and third quadrants.
Fourth quadrant: Five drivers such as Knowledge and risk management culture (F4), Security (F5), Collaboration and cooperation (F9), Government support (F11) and Supply chain Innovation (F14) falls under this category and most of them lie at the lowest level in the ISM diagraph. All these drivers drive other drivers to accomplish the resilience in SC.

5. Conclusions and future research directions

CoVID-19 pandemic has disrupted the SC significantly on a global scale. Most common disruptions can be identified as government-mandated lockdowns, planned closure of factories and strict restrictions on travel to restrict the spread of the virus, etc., which has never been seen in the last many years. According to Zhu *et al.* (2020), around 94% of fortune 1000 companies have experienced CoVID-19 driven SC disruptions. Managing and being resilient to such disruption is crucial for the survival of companies. Government and policymakers within or outside the companies are coming up with different policies and strategies to improve the resilience and cushion the impact of CoVID-19 on global SC. However, to improve resilience, at first it is necessary to identify the drivers that affect the level of resilience and understand how these drivers interact with each other. This helps the policymakers to devise strategies with the objective to improve the resilience of SC significantly.

Based on the intensive literature review and discussion with both academicians and industrial experts, this research identifies fourteen drivers of SC resilience. These drivers were then analyzed using Fuzzy ISM-DEMATEL modelling technique. ISM helps explore the contextual relationship between the identified drivers and segregates them into different levels based on whether the driver drives to other drivers to achieve resilience or others drive the driver. As traditional ISM methodology does not show the intensity of contextual relationships between the drivers, a fuzzy DEMATEL technique is integrated with ISM. Such integration not only helps to understand the intensity of relationships between the drivers but also helps to know the net influence of the driver over others thus making it possible to cluster the drivers into cause or effect constructs. The results show that the most important drivers of SCR are Government regulations and Security. Apart from these two drivers, other drivers such as information sharing, effective collaboration with SC partners and knowledge & risk management culture of an organization are very important drivers. Policymakers should devise policy or strategy to improve the functioning of these drivers, as these drivers will propel other drivers to achieve resilient SC. Even though SC agility and robustness in SC are very important drivers to achieve SCR, these drivers do not drive other drivers. Rather, other SCR drivers drive them.

In future research, a mathematical model can be developed to measure the resilient level of SC based on the identified drivers in this study. Such model can also be used to identify the driver, which is significantly affecting the level of SCR so that the SC can focus on the strategy to improve the functioning of such driver. Moreover, incorporating a strategy to improve the functioning of one driver may trigger another driver, or it may decrease the level of resilience created by other drivers. Therefore, another interesting avenue of research may be to understand the knock-on effect of one driver over others so that companies can focus on improving the drivers that will have less or no knock-on effects on other drivers of resilience.

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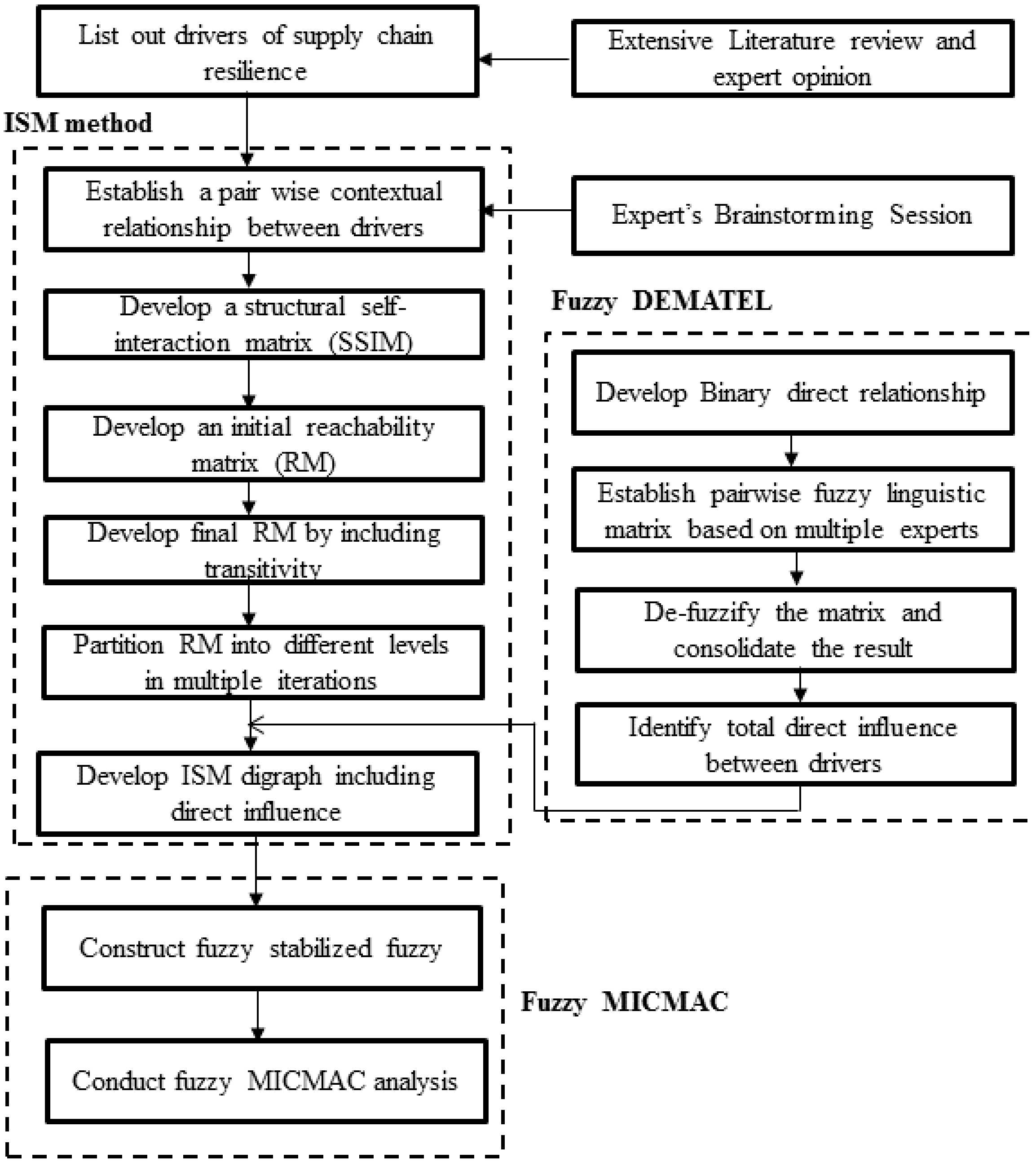

Figure 1: Display of methodological steps to study the drivers of SCR

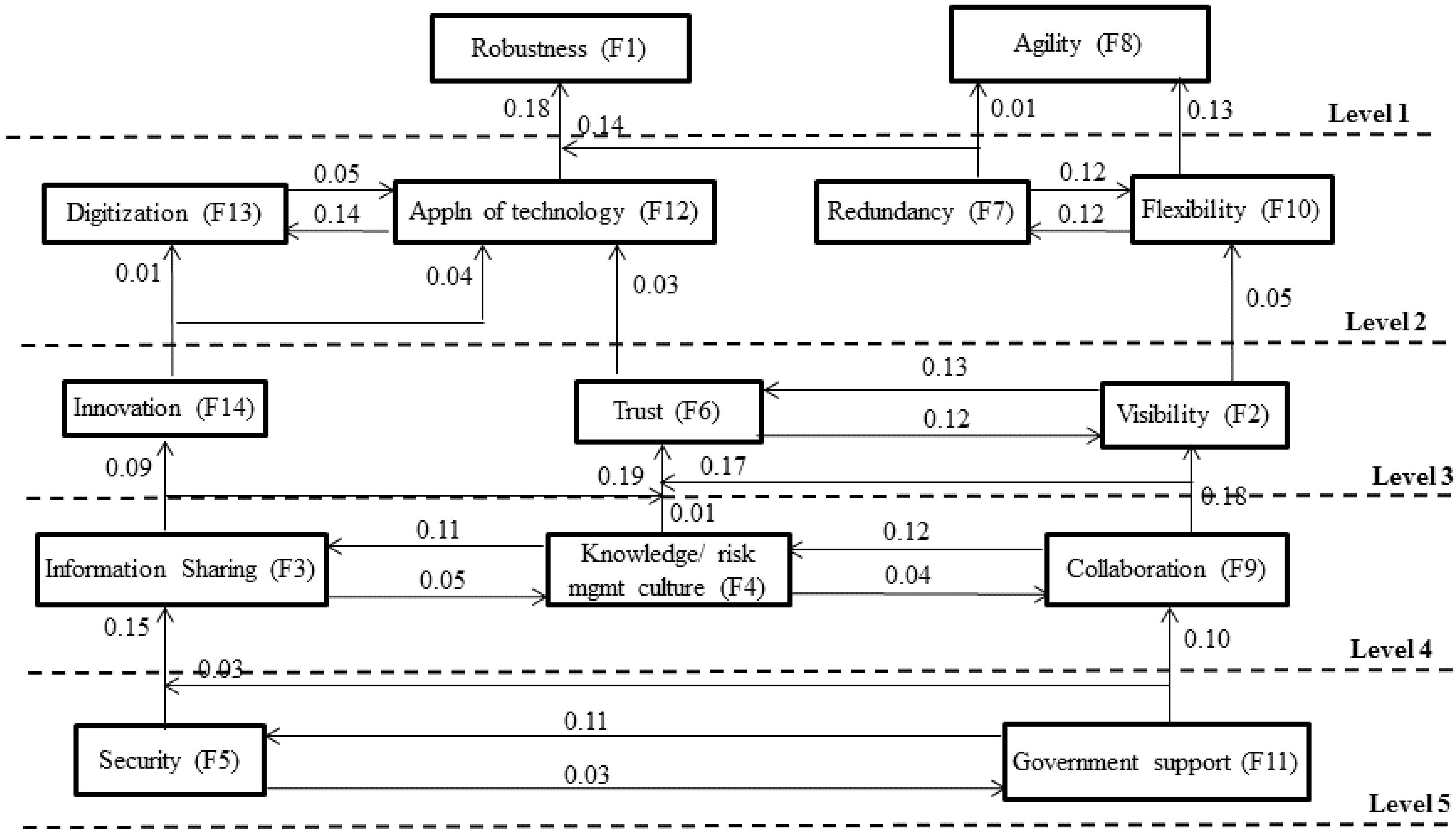

Figure 2: ISM Diagraph with the intensity of relationship between the drivers

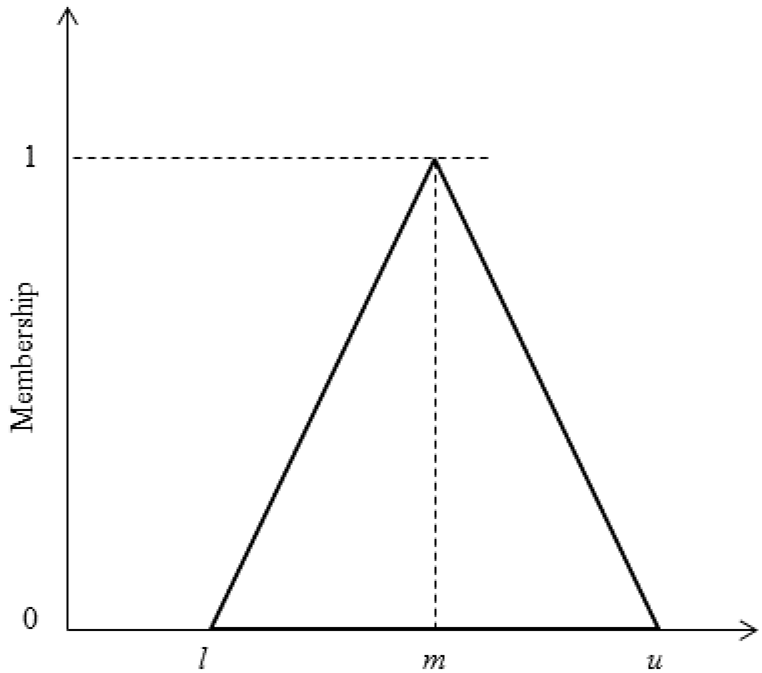

Figure 3: Triangular member function

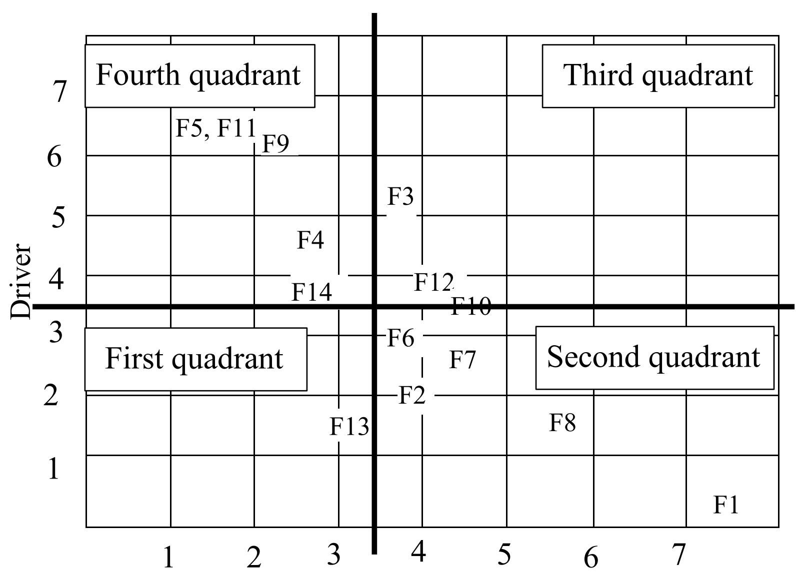

Figure 4: Fuzzy MICMAC analysis of SCR drivers under pandemic

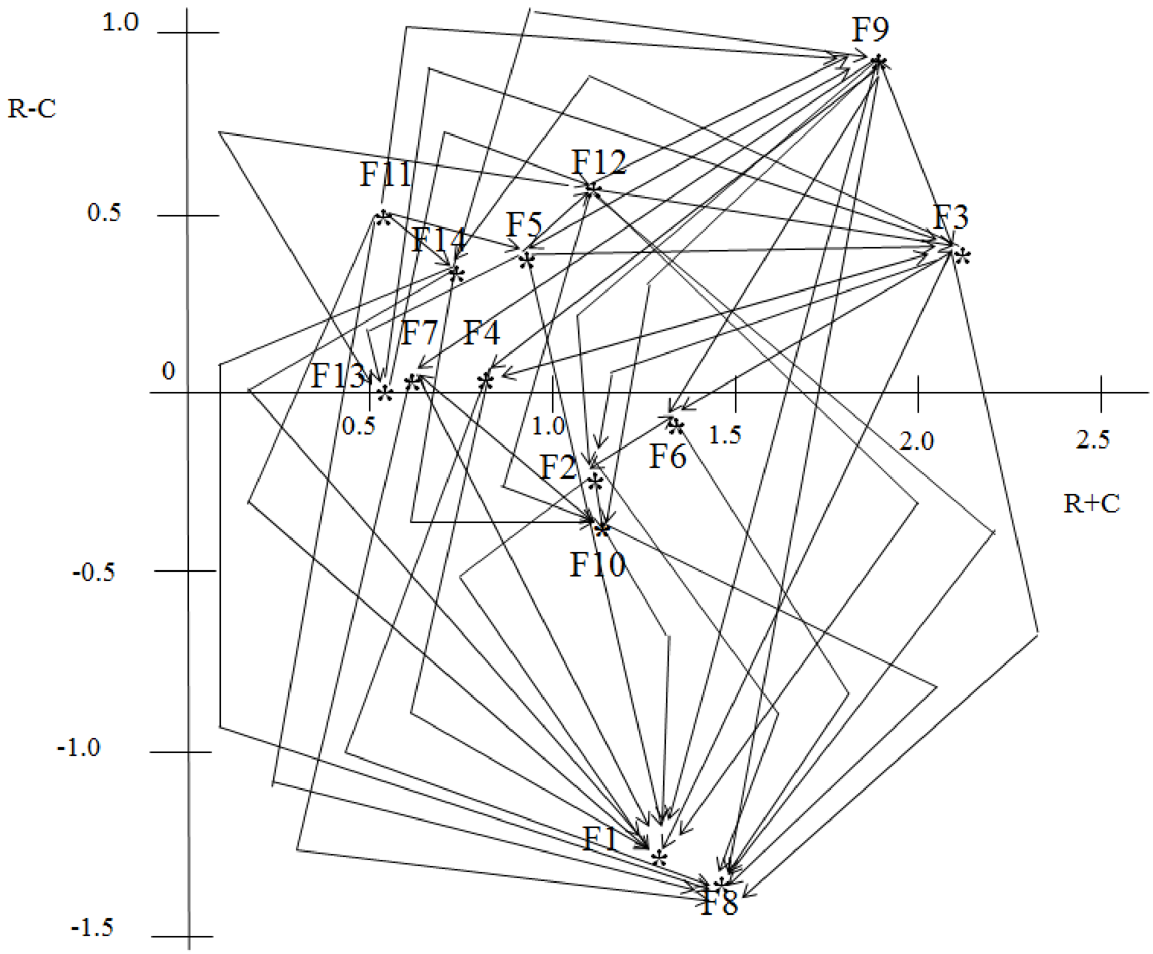

Figure 5: Intensity relationship map of significant relationships

Table 1: SCR drivers under pandemic situation

#no	Driver	Relationship with SCR	References
1	Robustness	Robustness helps SC cushion sudden disturbance and perform its function. A robust SC resists shocks by retaining its stability if any changes occur.	Wallace and Choi, 2011; Ali *et al*., 2017; Hosseini *et al*., 2019
2	Visibility	Visibility in the SC provides valuable insight for firms to coordinate and align their competencies. This helps minimize disruptive impact and improves resilience.	Stecke and Kumar, 2009; Soni *et al*., 2014; Hosseini *et al*., 2019
3	Information sharing	Timely and accurate information sharing helps mitigate risk and improves the SCR capability. Studies found that by exchanging and sharing of information between SC entities before and after any disruption can improve the SCR.	Faisal 2010; Soni *et al*., 2014; Hosseini *et al*., 2019
4	Knowledge and risk management culture	Knowledge and risk management culture helps SC act promptly to any disruptive event. This will be a valuable building block for creating a resilient SC.	Pettit *et al*., 2019; Ali *et al*., 2017; Kwak *et al*., 2018; Kumar and Anbanandam, 2019; Rajesh, 2019; Zanon *et al*., 2021
5	Security	Security against litigation, tampering, counterfeiting, freight transportation etc is very important for the proper functioning of SC. Moreover, cyber security is now a significant challenge. Security can be improved by creating synergies between SC partners, support from concerned authority and by using technologies such as Blockchain, IoT, AI, etc. Without appropriate amount of security, SC cannot be resilient.	Stevenson and Busby, 2015; Ali *et al*., 2017; Ivanov *et al*., 2018
6	Trust	Trust fosters cooperation and collaboration within and across the SC partners. It helps reduce functional conflict, enhance integration and decision-making capabilities under the conditions of uncertainty.	Sahay, 2003; Soni *et al*., 2014
7	Redundancy	Having redundant capacity improves the ability of SC adapting to sudden disruption through the use of excess capacity either in production, transportation or inventory.	Rice and Caniato, 2003; Ali *et al*., 2017; Kumar and Anbanandam, 2019

8	Agility	Agility is the ability of an organization to respond to unpredictable and rapidly changing business environment. An agile SC leads to increased velocity to quickly adapt to unexpected changes in demand or supply.	Soni *et al*., 2014; Rajesh, 2019; Kumar and Anbanandam, 2019 Piya *et al*., 2020.
9	Collaboration and co-opetition	Collaboration with SC partners has been considered as one of the significant element that holds the chain together in crisis. In co-opetition, companies collaborate and compete at the same time for a win-win situation.	Richey and Autry, 2009; Bakshi and Kleindorfer, 2009; Wieland and Wallenburg, 2013; Hosseini *et al*., 2019
10	Flexibility	In a supply network, it is important to have the ability to adjust and rework in case of disruption. Increasing flexibility provides the ability to adapt to change quickly and readily in the case of disruption and to facilitate operational efficiencies in normal conditions.	Kamalahmadi and Parast, 2016; Machado *et al*., 2018; Rajesh, 2019
11	Government support	Financial support from the government through offering incentives, tax cuts, loans, logistic supports in the form of flexible rules and regulations plays important role during abnormal/pandemic situation like COVID-19. Multiple government incentive programs and financial packages would assist the organization to recover financial losses caused by COVID-19. Moreover, cooperation between public and private organizations promotes to minimize SC risks and potential business threats.	Ali *et al*., 2017, Singh *et al*., 2018; Ali *et al*. 2021.
12	Application of technologies such as automation, robotics and Logistics 4.0.	Application of automation and robotics in manufacturing, as well as, service industries increase SC autonomy, ensure protection, and boost productivity. Furthermore, Logistics 4.0 supports full automation without intervention of human and provides extended flexibility, connectivity, real-time information sharing, cost reduction and shorter lead-time, etc., in the supply network.	Strozzi *et al*., 2017; Ivanov *et al*., 2018; Ralston and Blackhurst, 2020
13	Digitization and virtualization of SC	Promoting and adopting digitalization strategy supports SC resiliency. It generates and uses vast amount of data enablers thus improves visibility and makes the SC more trustworthy and sustainable.	Vendrell-Herrero *et al*., 2017; Schniederjans *et al*., 2020.
14	Supply chain innovation culture	Exploration of innovation culture within the supply networks enables them more resilient against disruptions. The ability to redesign SC	Fiksel *et al*., 2015; Christopher and

		through innovation provides necessary support to cushion the effect of disruption.	Holweg, 2017; Treiblmaier, 2018

Table 2: Self-Structure Interaction Matrix for the identified drivers

Drivers (*i*/*j*)	*F14*	*F13*	*F12*	*F11*	*F10*	*F9*	*F8*	*F7*	*F6*	*F5*	*F4*	*F3*	*F2*	*F1*
F1	*A*	*O*	*A*	*A*	*A*	*A*	*O*	*A*	*O*	*O*	*A*	*A*	*A*	
F2	*O*	*O*	*O*	*O*	*V*	*A*	*V*	*O*	*X*	*O*	*O*	*A*		
F3	*X*	*A*	*A*	*O*	*O*	*X*	*V*	*O*	*X*	*A*	*X*			
F4	*O*	*O*	*O*	*O*	*O*	*X*	*V*	*O*	*A*	*O*				
F5	*O*	*V*	*V*	*X*	*O*	*X*	*O*	*O*	*O*					
F6	*O*	*O*	*V*	*O*	*O*	*A*	*V*	*O*						
F7	*O*	*O*	*O*	*O*	*X*	*A*	*V*							
F8	*A*	*O*	*O*	*A*	*A*	*A*								
F9	*A*	*O*	*A*	*A*	*V*									
F10	*A*	*O*	*A*	*O*										
F11	*V*	*O*	*O*											
F12	*A*	*X*												
F13	*O*													
F14														

Table 3: Final reachability matrix

Driver (*i*/*j*)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	0	1	0	1	0	1	0	0	0	0
F3	1	1	1	1	0	1	0	1	1	0	0	0	0	1
F4	1	1*	1	1	0	0	0	1	1	0	0	0	0	0
F5	0	0	1	0	1	0	0	0	1	0	1	1	1	0
F6	0	1	1	1	0	1	0	1	0	0	0	1	0	0
F7	1	0	0	0	0	0	1	1	0	1	0	0	0	0
F8	0	0	0	0	0	0	0	1	0	0	0	0	0	0
F9	1	1	1	1	1	1	1	1	1	1	0	0	1*	0
F10	1	0	0	0	0	0	1	1	0	1	0	0	0	0
F11	1	0	0	0	1	0	0	1	1	0	1	0	0	1
F12	1	0	1	0	0	0	1*	0	1	1	0	1	1	0
F13	0	0	1	0	0	0	0	0	0	0	0	1	1	0
F14	1	0	0	0	0	0	0	1	1	1	0	1	0	1

Table 4: Levels of drivers of Supply Chain Resilience

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F1	1	1, 2, 3, 4, 7, 9, 10, 11, 12,	1	I
F2	1, 2, 6, 8, 10	2, 3, 4, 6, 9	2, 6	III
F3	1, 2, 3, 4, 6, 8, 9, 14	3, 4, 5, 6, 9, 12, 13	3, 4, 6, 9	IV
F4	1, 2, 3, 4, 8, 9	2, 3, 4, 6, 9,	2, 3, 4, 9	IV
F5	3, 5, 9, 11, 12, 13	5, 9, 11	5, 9, 11	V
F6	2, 6, 8, 12	2, 3, 6, 9	2, 6	III
F7	1, 7, 8, 10	7, 9, 10, 12	7, 10	II
F8	8	2, 3, 4, 6, 7, 8, 9, 10, 11,	8	I
F9	1, 2, 3, 4, 6, 7, 8, 9, 10, 13	2, 3, 4, 6, 9, 11, 12, 14	2, 3, 4, 6, 9	IV
F10	1, 7, 8, 10	2, 7, 9, 10, 12, 14	7, 10	II
F11	1, 5, 8, 9, 11, 14	5, 11	5, 11	V
F12	1, 7, 10, 12, 13	5, 6, 12, 13, 14	12, 13	II
F13	12, 13	5, 9, 12, 13	12, 13	II
F14	1, 8, 10, 12, 14	3, 11, 14	14	III

Table 5: Linguistic variable, notation and corresponding Fuzzy set

Fuzzy Linguistic variable	Notation	Fuzzy set (l, m, h)
Very low	VL	(0, 1, 3)
Low	L	(1, 3, 5)
Medium	M	(3, 5, 7)
High	H	(5, 7, 9)
Very high	VH	(7, 9, 10)

Table 6: Experts linguistic assessment for the contextual relationship

Driver	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	M, M, H	0	0	0	0	H, H, VH	0	L, M, H	0	L, L, L	0	0	0	0
F3	H, H, M	VH, VH, VH	0	L, M, H	0	H, VH, VH	0	VH, VH, VH	VH, H, VH	0	0	0	0	M, M, M
F4	VH, M, VH	0	VL, L, M	0	0	0	0	H, H, H	VL, L, VL	0	0	0	0	0
F5	0	0	H, H, H	0	0	0	0	0	VL, VL, VL	0	VL, L, VL	M, M, H	L, M, H	0
F6	0	M, M, M	VH, H, VH	L, L, L	0	0	0	H, H, M	0	0	0	VL, VL, L	0	0
F7	H, H, H	0	0	0	0	0	0	M, M, L	0	H, H, H	0	0	0	0
F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	M, H,VH	VH,VH, H	M, H, H,	M, M, H	M, H, H	H, H, H	L, L, L	VH, VH, H	0	H, H, H	0	0	0	0
F10	H, H, H	0	0	0	0	0	H, H, H	H, VH, M	0	0	0	0	0	0
F11	L, L, L	0	0	0	M, M, H	0	0	L, L, L	M, M, M	0	0	0	0	L, M, VL
F12	H, VH, H	0	H, H, M	0	0	0	0	0	VL, L, L	M, H, VH	0	0	VH, VH, H	0
F13	0	0	M, M, M	0	0	0	0	0	0	0	0	L, L ,L	0	0
F14	M, H, H	0	VL, VL, VL	0	0	0	0	H, H, H	L, L ,VL	M, H, VH	0	L, VL, L	0	0

Table 7: Average influence matrix

Driver	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	5.59	0	0	0	0	7.52	0	4.72	0	3	0	0	0	0
F3	6.26	8.67	0	4.72	0	8.07	0	8.67	8.07	0	0	0	0	5
F4	7.22	0	2.71	0	0	0	0	7	1.74	0	0	0	0	0
F5	0	0	7	0	0	0	0	0	1.33	0	1.74	5.59	2.71	0
F6	0	5	8.07	1.33	0	0	0	6.26	0	0	0	1.74	0	0
F7	7	0	0	0	0	0	0	4.22	0	7	0	0	0	0
F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	6.72	8.07	6.26	5.59	6.26	7	3	8.07	0	7	0	0	0	0
F10	7	0	0	0	0	0	7	6.72	0	0	0	0	0	0
F11	3	0	0	0	5.59	0	0	3	5	0	0	0	0	2.71
F12	7.52	0	6.26	0	0	0	0	0	2.29	6.72	0	0	8.07	0
F13	0	0	5	0	0	0	0	0	0	0	0	3	0	0
F14	4.22	0	1.33	0	0	0	0	5	2.29	6.72	0	2.29	0	0

Table 8: Normalized Average Influence Matrix

Driver	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0.1	0	0	0	0	0.13	0	0.08	0	0.05	0	0	0	0
F3	0.11	0.15	0	0.08	0	0.14	0	0.15	0.14	0	0	0	0	0.09
F4	0.12	0	0.05	0	0	0	0	0.12	0.03	0	0	0	0	0
F5	0	0	0.12	0	0	0	0	0	0.02	0	0.03	0.1	0.05	0
F6	0	0.09	0.14	0.02	0	0	0	0.11	0	0	0	0.03	0	0
F7	0.12	0	0	0	0	0	0	0.07	0	0.12	0	0	0	0
F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	0.12	0.14	0.11	0.1	0.11	0.12	0.05	0.14	0	0.12	0	0	0	0
F10	0.12	0	0	0	0	0	0.12	0.12	0	0	0	0	0	0
F11	0.05	0	0	0	0.1	0	0	0.05	0.09	0	0	0	0	0.05
F12	0.13	0	0.11	0	0	0	0	0	0.04	0.12	0	0	0.14	0
F13	0	0	0.09	0	0	0	0	0	0	0	0	0.05	0	0
F14	0.07	0	0.02	0	0	0	0	0.09	0.04	0.12	0	0.04	0	0

Table 9: Total Influence Matrix

Driver	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	Rsum (R)	R-C	R+C	Group
F1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.37	1.37	Effect
F2	0.11	0.02	0.02	0.01	0.00	0.13	0.01	0.11	0.00	0.05	0.00	0.00	0.00	0.00	0.46	-0.17	1.10	Effect
F3	0.18	0.20	0.05	0.11	0.02	0.19	0.01	0.24	0.15	0.04	0.00	0.01	0.00	0.09	1.30	0.41	2.18	Cause
F4	0.14	0.01	0.05	0.01	0.00	0.01	0.00	0.14	0.04	0.01	0.00	0.00	0.00	0.00	0.43	0.09	0.76	Cause
F5	0.05	0.03	0.15	0.02	0.01	0.03	0.01	0.04	0.05	0.02	0.03	0.10	0.06	0.01	0.62	0.35	0.88	Cause
F6	0.04	0.12	0.15	0.04	0.00	0.04	0.00	0.16	0.02	0.01	0.00	0.03	0.00	0.01	0.64	-0.02	1.30	Effect
F7	0.14	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00	0.12	0.00	0.00	0.00	0.00	0.36	0.08	0.65	Cause
F8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.42	1.42	Effect
F9	0.20	0.18	0.16	0.12	0.11	0.17	0.07	0.24	0.03	0.15	0.00	0.02	0.01	0.01	1.46	0.94	1.98	Cause
F10	0.14	0.00	0.00	0.00	0.00	0.00	0.12	0.13	0.00	0.01	0.00	0.00	0.00	0.00	0.40	-0.31	1.11	Effect
F11	0.08	0.02	0.03	0.01	0.11	0.02	0.01	0.08	0.10	0.02	0.00	0.01	0.01	0.05	0.54	0.51	0.58	Cause
F12	0.18	0.03	0.13	0.02	0.01	0.03	0.02	0.05	0.06	0.13	0.00	0.01	0.14	0.01	0.82	0.53	1.10	Cause
F13	0.02	0.02	0.10	0.01	0.00	0.02	0.00	0.02	0.02	0.01	0.00	0.05	0.01	0.01	0.29	0.05	0.53	Cause
F14	0.11	0.01	0.04	0.01	0.01	0.01	0.02	0.12	0.05	0.13	0.00	0.04	0.01	0.00	0.54	0.33	0.75	Cause
Csum (C)	1.37	0.64	0.88	0.34	0.26	0.66	0.29	1.42	0.52	0.71	0.04	0.28	0.24	0.21				

Table 10: Fuzzy stabilized matrix

Driver	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	Driver	Rank
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
F2	0.5	0	0	0	0	0.7	0	0.5	0	0.3	0	0	0	0	2	12
F3	0.7	0.867	0	0.5	0	0.867	0	0.867	0.867	0.3	0	0	0	0.5	5.468	4
F4	0.867	0	0.3	0	0	0.867	0.7	0.7	0.133	0	0.7	0.5	0	0	4.767	5
F5	0.867	0.867	0.7	0.7	0	0.133	0	0	0.133	0.7	0.133	0.5	0.867	0.867	6.467	2
F6	0	0.5	0.867	0.3	0	0	0	0.7	0	0	0	0.7	0	0	3.067	9
F7	0.7	0	0	0	0.133	0.133	0.7	0.5	0	0.7	0	0	0	0	2.866	10
F8	0	0	0	0	0	0	0.3	0	0	0	0	0	0.7	0.7	1.7	13
F9	0.7	0.867	0.133	0.5	0.7	0.7	0.3	0.867	0	0.7	0	0.7	0	0	6.167	3
F10	0.7	0	0	0	0	0	0.7	0.7	0	0	0	0.7	0.7	0	3.5	8
F11	0.867	0.867	0.867	0.867	0.5	0.5	0.7	0.3	0.5	0	0.5	0	0	0.3	6.768	1
F12	0.7	0	0.7	0	0	0	0.5	0	0.3	0.7	0	0	0.867	0	3.767	6
F13	0	0	0	0	0	0	0.5	0	0	0.7	0	0.5	0	0	1.7	11
F14	0.7	0	0.133	0	0	0	0	0.7	0.3	0.7	0	0.5	0	0.5	3.533	7
Depend	7.301	3.968	3.7	2.867	1.333	3.9	4.4	5.834	2.233	4.8	1.333	4.1	3.134	2.867		
Rank	1	6	8	10	12	7	4	2	11	3	12	5	9	10		

Appendix A:

Table A: Initial reachability matrix

Driver (*i*/*j*)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	1	1	0	0	0	1	0	1	0	1	0	0	0	0
F3	1	1	1	1	0	1	0	1	1	0	0	0	0	1
F4	1	0	1	1	0	0	0	1	1	0	0	0	0	0
F5	0	0	1	0	1	0	0	0	1	0	1	1	1	0
F6	0	1	1	1	0	1	0	1	0	0	0	1	0	0
F7	1	0	0	0	0	0	1	1	0	1	0	0	0	0
F8	0	0	0	0	0	0	0	1	0	0	0	0	0	0
F9	1	1	1	1	1	1	1	1	1	1	0	0	0	0
F10	1	0	0	0	0	0	1	1	0	1	0	0	0	0
F11	1	0	0	0	1	0	0	1	1	0	1	0	0	1
F12	1	0	1	0	0	0	0	0	1	1	0	1	1	0
F13	0	0	1	0	0	0	0	0	0	0	0	1	1	0
F14	1	0	0	0	0	0	0	1	1	1	0	1	0	1

Appendix B

Table **B1**: First iteration for Level partitioning

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F1	1	1, 2, 3, 4, 7, 9, 10, 11, 12,	1	I
F2	1, 2, 6, 8, 10	2, 3, 4, 6, 9	2, 6	
F3	1, 2, 3, 4, 6, 8, 9, 14	3, 4, 5, 6, 9, 12, 13	3, 4, 6, 9	
F4	1, 2, 3, 4, 8, 9	2, 3, 4, 6, 9,	2, 3, 4, 9	
F5	3, 5, 9, 11, 12, 13	5, 9, 11	5, 9, 11	
F6	2, 6, 8, 12	2, 3, 6, 9	2, 6	
F7	1, 7, 8, 10	7, 9, 10, 12	7, 10	
F8	8	2, 3, 4, 6, 7, 8, 9, 10, 11,	8	I
F9	1, 2, 3, 4, 6, 7, 8, 9, 10, 13	2, 3, 4, 6, 9, 11, 12, 14	2, 3, 4, 6, 9	
F10	1, 7, 8, 10	2, 7, 9, 10, 12, 14	7, 10	
F11	1, 5, 8, 9, 11, 14	5, 11	5, 11	
F12	1, 7, 10, 12, 13	5, 6, 12, 13, 14	12, 13	
F13	12, 13	5, 9, 12, 13	12, 13	
F14	1, 8, 10, 12, 14	3, 11, 14	14	

Table **B2**: Second iteration for Level partitioning

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F2	2, 6, 10	2, 3, 4, 6, 9	2, 6	
F3	2, 3, 4, 6, 9, 14	3, 4, 5, 6, 9, 12, 13	3, 4, 6, 9	
F4	2, 3, 4, 9	2, 3, 4, 6, 9,	2, 3, 4, 9	
F5	3, 5, 9, 11, 12, 13	5, 9, 11	5, 9, 11	
F6	2, 6, 12	2, 3, 6, 9	2, 6	
F7	7, 10	7, 9, 10, 12	7, 10	II
F9	2, 3, 4, 6, 7, 9, 10, 13	2, 3, 4, 6, 9, 11, 12, 14	2, 3, 4, 6, 9	
F10	7, 10	2, 7, 9, 10, 12, 14	7, 10	II
F11	5, 9, 11, 14	5, 11	5, 11	
F12	7, 10, 12, 13	5, 6, 12, 13, 14	12, 13	II
F13	12, 13	5, 9, 12, 13	12, 13	II
F14	10, 12, 14	3, 11, 14	14	

Table **B3**: Third iteration for Level partitioning

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F2	2, 6	2, 3, 4, 6, 9	2, 6	III
F3	2, 3, 4, 6, 9, 14	3, 4, 5, 6, 9	3, 4, 6, 9	
F4	2, 3, 4, 9	2, 3, 4, 6, 9,	2, 3, 4, 9	
F5	3, 5, 9, 11,	5, 9, 11	5, 9, 11	
F6	2, 6	2, 3, 6, 9	2, 6	III
F9	2, 3, 4, 6, 9	2, 3, 4, 6, 9, 11, 14	2, 3, 4, 6, 9	
F11	5, 9, 11, 14	5, 11	5, 11	
F14	14	3, 11, 14	14	III

Table **B4**: Fourth iteration for Level partitioning

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F3	3, 4, 9	3, 4, 5, 9, 12, 13	3, 4, 9	IV
F4	3, 4, 9	3, 4, 9,	3, 4, 9	IV
F5	3, 5, 9, 11,	5, 9, 11	5, 9, 11	
F9	3, 4, 9	3, 4, 9, 11, 12	3, 4, 9	IV
F11	5, 9, 11	5, 11	5, 11	

Table **B5**: Fifth iteration for Level partitioning

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F5	5, 11,	5, 11	5, 11	V
F11	5, 11	5, 11	5, 11	V

Appendix C:

Table C: Binary direct relation matrix

Driver (*i*/*j*)	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	1	0	0	0	0	1	0	1	0	1	0	0	0	0
F3	1	1	0	1	0	1	0	1	1	0	0	0	0	1
F4	1	0	1	0	0	0	0	1	1	0	0	0	0	0
F5	0	0	1	0	0	0	0	0	1	0	1	1	1	0
F6	0	1	1	1	0	0	0	1	0	0	0	1	0	0
F7	1	0	0	0	0	0	0	1	0	1	0	0	0	0
F8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F9	1	1	1	1	1	1	1	1	0	1	0	0	0	0
F10	1	0	0	0	0	0	1	1	0	0	0	0	0	0
F11	1	0	0	0	1	0	0	1	1	0	0	0	0	1
F12	1	0	1	0	0	0	0	0	1	1	0	0	1	0
F13	0	0	1	0	0	0	0	0	0	0	0	1	0	0
F14	1	0	0	0	0	0	0	1	1	1	0	1	0	0