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

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ABSTRACT

The COVID-19 pandemic has significantly affected the supply chains (SCs) of many industries, including the oil and gas (O&G) industry. This study aims to identify and analyze the drivers that affect the resilience level of the O&G SC under the COVID-19 pandemic. The analysis helps to understand the driving intensity of one driver over those of others as well as drivers with the highest driving power to achieve resilience. Through an extensive literature review and an overview of experts' opinions, the study identified fourteen supply chain resilience (SCR) drivers of the O&G industry. These drivers were analyzed using the integrated fuzzy interpretive structural modeling (ISM) and decision-making trial and evaluation laboratory (DEMATEL) approaches. The analysis shows that the major drivers of SCR are government support and security. These two drivers help to achieve other drivers of SCR, such as collaboration and information sharing, which, in turn, influence innovation, trust, and visibility among SC partners. Two more drivers, robustness and agility, are also essential drivers of SCR. However, rather than influencing other drivers for their achievement, robustness and agility are influenced by others. The results show that collaboration has the highest overall driving intensity and agility has the highest intensity of being influenced by other drivers.

1. Introduction

The oil and gas (O&G) industry is one of the major industries in terms of dollar value and employs hundreds and thousands of people worldwide [1]. Despite a substantial burst in the O&G industry with a slowdown in production and a decrease in revenue [2], the industry is still the major contributor to the GDPs of many countries and plays a major role in the generation of significant employment opportunities. As the world economy heads toward renewables, O&G will still play an important role in energy systems [3].

The O&G industry can be categorized into three major sections. The upstream section consists of the exploration and production of hydrocarbon fields by bringing crude oil and natural gas from underground to the surface. The midstream section consists of processes such as setting up gas plants, producing liquefied natural gas, and transporting crude oil and gas from upstream to refineries. The downstream section is concerned with processes such as the refinement, marketing, and distribution of crude oil and related products. As a large number of service and technology companies assist the operation of these three sections [4], a high level of cooperation among O&G supply chain (SC) partners and an integration of their capabilities are needed [5]. Sudden disruption to any link within the chain will have adverse effects on the entire chain. Therefore, the O&G SC needs to be resilient to adapt to the changes orchestrated by market dynamics.

Supply chain resilience (SCR) is defined as the ability of the SC to manage its activities as normally as possible during any form of disruption. Resilience in the SC contributes to improving customer service, market share, and profitability. It is therefore critical for the firm to understand and ensure SCR to mitigate obstacles caused by unforeseen disasters and maintain business growth. This is especially true during the COVID-19 pandemic, where more than 80% of global organizations are severely affected by the crisis [6]. The pandemic has affected every facet of human existence and all types of industries, including O&G. One recent example of the effect of the pandemic on an O&G SC was seen in the UK, with severe disruption to the chain to the extent that the government had to take drastic measures to relieve the impact of such a disruption.

With the advent of uncertainty caused by COVID-19, the need for structural change within the O&G supply network cannot be ignored despite investment costs. Such structural changes compensate for building required resilience and contribute to quickly increasing competitive advantage. Organizational managers need

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to identify appropriate strategies, prioritize them, and implement them with the goal to minimize risk and financial impact caused by disruptions in the network [7]. Several strategies such as reshoring, diversification, increasing inventory level, introducing additional supply sources, flexibility, agility, etc. can be deployed to strengthen the SC and maintain resiliency [8]. According to Centobelli et al. [9], the successful blending of the right strategies can help boost SCR. As well, investment in technologies is needed to make the O&G SC more intelligent and autonomous. Combining strategy and technology allows the supply network to sense and adapt faster to disruptions and changes.

1.1. Problem description

The O&G industry is critical in energy supply and maintenance, which is an essential element for all forms of productivity [10]. Some of the challenges faced by the industry due to the COVID-19 pandemic are disruptions in the production process caused by the shortage of human resources, the supply and delivery of necessary materials, components, various essential tools and technologies, etc. [11]. The ripple effect of the pandemic could continue to affect all SCs, including that of the O&G industry. To overcome uncertainty created by the pandemic, a company must have a proper strategy and initiate future mitigation plans to improve resilience in their SC. However, before adopting any strategy, it should identify the corresponding drivers that affect resilience as well as determine the relationships among the drivers and the influence of one driver over the others. This helps industries prioritize drivers and select strategies specific to the drivers to eliminate or minimize disruptions in the SC [10,12]. This is especially important in the current pandemic situation when global SC networks suffer from abnormalities such that nobody can predict with certainty how long the pandemic and its effect will last [7,13]. This study, therefore, tries to determine the most significant SCR drivers, understand their inter-relationships and the prioritization of drivers during the COVID-19 pandemic in the O&G industry.

1.2. Research contribution

Substantial research has been carried out in the past on SCR [8,9,14–16]. However, only a few attempts have been made to identify and analyze the drivers of SCR, with most of them considering generic disruptions or abnormalities in the SC, such as natural disasters, strikes, and accidents [17–20]. Moreover, no studies have contributed to the identification and analysis of SCR drivers in the O&G industry. As this industry is significant to the world economy, it must be able to withstand sudden severe disruptions caused by an unexpected disaster, such as the COVID-19 pandemic. Therefore, in this research, an attempt has been made to understand, identify, and prioritize the major drivers that can promote the resilience of the O&G SC during the pandemic. Based on this specific goal, this research has identified two major questions, and the authors believe that answering these questions would be a novel contribution toward the area of SCR, more specifically to the O&G industry. The two research questions, along with their sub-questions, are as follows:

- *RQ1*: What are the drivers of SCR?
  - *RQ1(a)*: What significant drivers affect resilience in the O&G SC under the COVID-19 pandemic?
  - *RQ1(b)*: How do these drivers affect SCR?
- *RQ2*: How does one analyze the identified drivers?
  - *RQ2(a)*: What relationship exists among the drivers of SCR?
    RQ2(b): What is the intensity of the relationship?

The remaining portion of the paper is structured as follows. To answer the first research question (RQ1), the literature is extensively reviewed to identify the drivers and understand their relationship with SCR. Thereafter, through a questionnaire survey with the expert, the significant drivers of O&G SCR were identified (see Section 2). Section 3 is dedicated to the analysis of the identified drivers using an integrated fuzzy ISM–DEMATEL method to answer the second research question (RQ2). The ISM methodology helps determine the contextual relationships among the identified drivers. On the other hand, the DEMATEL technique computes the intensity of the relationship. The integration of these two techniques is preferred over other techniques given their ability to convert the inheritance, interdependence, and intensity of the identified drivers into a useful and logical conclusion. Section 4 discusses the study results and presents the validation of the results obtained through statistical analysis. Finally, the paper concludes with future research directions in Section 5. This section also highlights the novelty and limitations of this research work.

2. Literature review

A global supply network is a complex ecosystem consisting of multilayer, multidimensional facets that facilitate on-time delivery, just-in-time manufacturing, and a lean production system [21]. It becomes even more complex and vulnerable during various threats such as natural disasters, cyberattacks, trade wars, pandemic situations, accidents, etc. The existence of such threats can put the organization's supply network at risk. In such situations, it is crucial to consider resilience in SC operations [22]. Advances in various smart technologies can help improve SCR and contribute toward adaptation and anticipation capabilities [23]. Moreover, they can offer expected flexibility in day-to-day sourcing, visibility in manufacturing, and order fulfillment [15].

Since the end of 2019, humankind has suffered unprecedented challenges caused by the emergence of COVID-19. According to one report [24], the COVID-19 pandemic is responsible for the most critical threat to global supply networks than natural disasters, trade sanctions, and cyberattacks. The report also stated that around 60% of the surveyed companies revealed that COVID-19 had directly affected their operations. Companies were shut down, and many people lost their jobs and, unfortunately, their lives. There was a significant disruption to the SCs of virtually all types of companies. As such, the firm needs to focus on the strategy that will improve resilience in their SC [13].

Table 1 shows the list of some recently published papers in the area of SCR, arranged according to the publication year. As shown in the table, many studies have been conducted to understand SCR, measure its level, and determine its impact on SC performance. A few papers have attempted to identify the drivers of SCR and analyze the relationships among the drivers using modeling tools [18,25,26]. Moreover, many papers have focused on generic SCs rather than SCs related to specific industries. It can be argued that the drivers of SCR or their importance may be different for different industries. Nevertheless, no effort has yet been made to identify, analyze, and prioritize SCR drivers under the COVID-19 pandemic and related to the O&G industry. This research aims to fill this gap in the area of SCR.

Table 1
Recent literature in the area of SCR.

#no	Author	Contribution	Focused area	Tools/ techniques used
1	Soni et al. [18]	Identified ten significant enablers of SCR and developed a model to measure the level of SCR.	Generic SC	ISM
2	Scholten and Schilder [27]	Identified that collaborative activities such as information-sharing, communication, mutually created knowledge, and joint relationship efforts among the SC partner increases SCR via increased visibility, velocity, and flexibility.	Food processing industry	Empirical study
3	Gunasekaran et al. [8]	Introduced the relationship between complexities and proactive management practices in SCR. Further, the paper proposed a global sourcing resilience framework.	Generic SC	Conceptual paper
4	Jain et al. [25]	Identified thirteen enablers of SCR and analyzed the identified enablers using the structural equation modeling (SEM) approach.	Generic SC	ISM and SEM
5	Namdar et al. [28]	Developed an optimization model to investigate sourcing strategies for achieving SCR under disruption.	Generic SC	Mathematical modeling
6	Altay et al. [29]	Investigated the effects of agility and resilience on SC performance.	Generic SC	SEM
7	Macdonald et al. [30]	Developed a framework aimed at building better theories in SCR.	Generic SC	Simulation model
8	Kumar and Anbanandam, [26]	Identified fifteen drivers of SCR and developed a model to measure organizational SCR.	Manufacturing industry	Integrated delphi and fuzzy logic
9	Rajesh, [19]	Identified five strategies and twenty-three attributes for SCR. Further, the paper proposed a fuzzy model to measure the resilience level of a company.	Electronics manufacturing	Fuzzy logic
10	Hossain et al. [31]	Developed a probabilistic model to assess the resilience level of the O&G SC.	Oil and gas	Bayesian network
11	Dubey et al. [20]	Identified resources, capabilities, behavioral uncertainty, trust, commitment, and cooperation as the predictors of SCR.	Generic SC	SEM
12	Hosseini et al. [32]	Reviewed papers on SCR and identified five conceptual drivers of SCR.	Generic SC	Systematic literature review
13	Emenike and Falcone [10]	Reviewed papers on SCR related to the energy sector, including the O&G industry.	Energy sector	Systematic literature review
14	Bevilacqua et al. [12]	Developed a method for enhancing the analysis of the domino effect, by unveiling causal and hidden paths among factors influencing SCR.	Fashion industry	Fuzzy cognitive maps
15	Ivanov and Das [13]	Modeled ripple effect of COVID pandemic in global SCs considering the velocity of pandemic propagation, the duration of production, distribution, and market disruption.	Generic SC	Simulation model
16	Bravo and Hernandez [33]	Measured organizational resilience based on financial and operational metrics.	Oil and gas	Empirical study
17	Ali et al. [7]	Provided a broader view of SCR reactive strategies in dealing with the disruption caused by COVID-19.	Food industry	Conceptual study

2.1. O&G SCR drivers under COVID-19

To identify the drivers responsible for a resilient SC in the O&G industry, an extensive literature survey was conducted, with a focus on collecting recently published papers in journals that fall under quartile Q1 or Q2, and have good impact factors. Around 90% of the papers collected were published in 2010 and later. Several keywords such as "supply chain resilient", "drivers of resilient", "supply chain risk", "risk management in supply chain", "resilient enabler", "supply chain disruption", and "security in supply chain" were used as primary phrases in the initial round of the literature survey. Secondary phrases such as "COVID-19", "pandemic", "oil & gas industry", "petroleum industry", and "energy" were used in the next round. Search strings were generated using the combination of primary and secondary phrases to limit the search space. During the literature survey, various databases such as Science Direct, Scopus, Emerald, Springer, Google Scholar, and ISI Web of Science were used. From the literature review, altogether, twenty drivers of SCR were identified.

To determine the drivers that have affected the SCR of the O&G industry during the COVID-19 pandemic, a questionnaire was prepared based on the twenty identified drivers, and a survey was conducted. As shown in Appendix A.1, in the survey, the participants were requested to select an appropriate score on a scale for the driver based on the effect that the driver has on SCR during the COVID-19 pandemic. Altogether, 114 questionnaires were distributed to people working in O&G companies. However, only 89 responses were received, and out of these responses, 18 were removed as they were deemed incomplete. Table A.2 shows the participants' demographic information. All three sections of the O&G industry participated in the questionnaire survey. The percentage distribution in the table is shown in round figure form.

To consolidate the final SCR drivers, the cutoff point of two in the questionnaire survey scale was fixed in consultation with six experts, including three academicians with wider experience in teaching and research in SC management. These experts also took part in the questionnaire survey, where it was found that six drivers received an average scale of less than or equal to the cutoff point. These drivers (resource mobility, additive manufacturing, velocity, SC redesign, sustainability, training, and skill development) were removed from the initial list of drivers. The final drivers, their relationships with SCR, and references are shown in Table 2.

3. Methodology

There are many multi-criteria decision making (MCDM) methods, and AHP is one of the most popular methods. It is mainly used to identify the weight of the alternate criteria and then rank them. Other popular methods are TOPSIS and GRA, which are used to rank the alternatives based on multiple criteria. Traditionally, TOPSIS and GRA use equal weight for all the criteria. Therefore, many papers have integrated these methods with AHP to allocate different weights for different criteria in the decision process [21,57]. Though ISM and DEMATEL are also MCDM methods, they are used to understand the interactions among the identified factors and cluster them into certain groups. Moreover, ISM helps understand the "what" and "how" in theory building, and DEMATEL analyzes both direct and indirect effects to establish the cause-and-effect relationships among the factors, which cannot be done via the AHP, TOPSIS, and GRA methods. Nevertheless, they both have limitations. While DEMATEL can segregate drivers into the cause and effect categories, it cannot provide a hierarchical structure. On the other hand, while ISM can provide a hierarchical structure showing the driving and dependent factors, it cannot calculate the intensity of the relationships among the drivers. Therefore, this research proposes an integrated fuzzy ISM–DEMATEL method to analyze the identified drivers of SCR. Integrating these two methods will help overcome the limitations that persist in their individual forms [58,59]. These methods also require fewer experts than other modeling tools, such as SEM [60].

Fig. 1 shows the methodological steps followed in this research. As discussed in Section 2, the drivers of SCR are identified through an intensive literature survey and finalized in consultation with experts. Thereafter, an ISM methodology is implemented to identify the contextual relationships among the drivers. The intensity of these relationships is computed using the fuzzy DEMATEL method, and the drivers are then classified into various clusters based on the fuzzy MICMAC analysis. As both the ISM and DEMATEL methods are expert-based decision-supported tools, the experts' knowledge and experiences were solicited. The same experts who helped in the confirmation of the final drivers took part in these procedural steps. Here, fuzzy logic is introduced with the ISM-DEMATEL method to deal with the vagueness and uncertainty in the experts' judgment during the decision-making process. As reflected by Table 1, this will be an initial attempt to use an integrated approach under a fuzzy environment to analyze the drivers of SCR.

3.1. ISM methodology

ISM is an illustrious modeling tool to decode poorly articulated mental maps into a clear structural model [61]. This tool supports transforming a complicated taxonomy into a manageable subsystem and finding the relationships among the drivers [62]. The steps involved in the use of the ISM methodology are discussed below.

Step 1: *Structural Self-Interaction Matrix* (SSIM)

Once the drivers of SCR in the O&G industry during the COVID-19 pandemic are identified, a structural self-interaction matrix (SSIM) is developed to define contextual relationships among 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 exists between drivers i and j.

To define the appropriate relationships among the drivers, experts were invited for the brainstorming sessions. The results from these sessions are presented in Table 3.

Step 2 Reachability Matrix (RM)

An initial reachability matrix (IRM), which is an $n \times n$ matrix with ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, n$), is produced based on the outcomes from Table 3 by substituting the alphabet variables with binary values (1 and 0) using the following rules:

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

The IRM is shown in Table B.1 in Appendix B. As shown in the IRM, if $i = j$ (i.e., the diagonal elements of the matrix), then the binary variable will be 1. Once the IRM is developed, the internal consistency among the relationships will be confirmed 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 4 shows the final RM after using the concept of transitivity. 1* in the table represents a change in the relationship in IRM among the drivers because of transitivity.

Step 3: Level Partition

In this step, based on the final RM, the reachability, antecedent, and intersection sets for each driver are derived. The reachability set consists of a driver (i) and all other drivers (j) influenced by it. On the other hand, the antecedent set consists of a driver (i) and the other drivers (j) that influence it. 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 any other drivers above their level achieve resilience. 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 C, and the final result is shown in Table 5.

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 Fig. 2. Such a graph is known as an ISM digraph. The relationships among the drivers in the graph are indicated by an arrow directed from i to j. Note that the ISM digraph in Fig. 2 shows the levels of the drivers based on ISM and the intensity of the relationship among the drivers as calculated based on the integrated fuzzy ISM–DEMATEL method. The next section will discuss the calculations of such intensities.

Table 2
SCR drivers in O&G industry under COVID pandemic.

#no	Driver	Relationship with SCR	References
F1	Robustness	Robustness helps SC cushion sudden disturbance and perform its function. A robust SC resists shock by retaining its stability if any changes occur.	[3], [32], [34]
F2	Visibility	Visibility in the SC provides valuable insight for firms to coordinate and align their competencies. This helps minimize disruptive impact and improves resilience.	[18], [32], [35]
F3	Information sharing	Timely and accurate information sharing helps mitigate risk and improves SCR capability. The complex nature of work with a large volume of data interchange coupled with a highly collaborative work process between various SC partners in O&G SC demands the need for robust and special infrastructure for sharing information efficiently.	[18], [32], [36]
F4	Knowledge and risk management culture	Knowledge and risk management culture help SC act promptly to any disruptive event. This will be a valuable building block for creating a resilient SC in the O&G industry.	[3], [15], [19], [26], [37], [38]
F5	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 authorities, and using technologies such as Blockchain, IoT, AI, etc. Without an appropriate amount of security, SC cannot be resilient. Multiple service and technology companies assist this operation in the O&G industry.	[3], [39], [40]
F6	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.	[18], [41]
F7	Redundancy	Having redundant capacity improves the ability of SC to adapt to sudden disruption through the use of excess capacity either in production, transportation, or inventory.	[3], [26], [42]
F8	Agility	An agile SC leads to increased velocity to quickly adapt to unexpected changes in the demand or supply. Research has shown that market orientation and SC orientation are the antecedents of agility in the O&G SC.	[1], [18], [19], [26]
F9	Collaboration and co-opetition	Collaboration with SC partners has been considered as one of the significant elements that hold the chain together in a crisis. In O&G industries, significant collaborative effort is needed, especially at the upstream level, where multiple parties will be involved in the exploration of an oil field, drilling of oil rigs, and transporting crude oil to the refinery. In co-opetition, companies collaborate and compete at the same time for a win-win situation.	[32], [43], [44], [45]
F10	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.	[19], [46], [47]
F11	Government support	Financial support from the government through offering incentives, tax cuts, loans, logistic supports in the form of flexible rules and regulations plays an important role during abnormal/pandemic situations like COVID-19. Multiple government incentive programs and financial packages would assist the organization to recover financial losses caused by COVID-19.	[3], [7], [48]
F12	Application of technologies such as automation, robotics, and Logistics 4.0.	Application of automation and robotics in the operation increases SC autonomy, ensures protection and boosts productivity. Furthermore, Logistics 4.0 supports full automation without the intervention of humans and provides extended flexibility, connectivity, real-time information sharing, cost reduction, and shorter lead-time in the supply network. Advanced and state-of-the-art technology is needed especially at the upstream level of O&G SC, which involves tasks like exploration, drilling, and extraction of oil.	[40], [49], [50]
F13	Digitization and virtualization of SC	Promoting and adopting a digitalization strategy supports SC resiliency. It generates and uses a vast amount of data enablers, which improves visibility and makes SC more trustworthy and sustainable. In the current pandemic situation, the research has shown that the winners are those companies who were able to expand digital and online capacities.	[51], [52], [53]
F14	Supply chain innovation culture	Exploration of innovation culture within the supply networks enables them more resilient against disruptions. The nature of work practiced in O&G industries for the production and development of O&G involves extremely sophisticated, hazardous, as well as, capital and labor-intensive processes. Therefore, the Company culture should support learning, experimentation, and innovation with the focus on continuous improvement through regular monitoring of the environment to identify necessary changes.	[54], [55], [56]

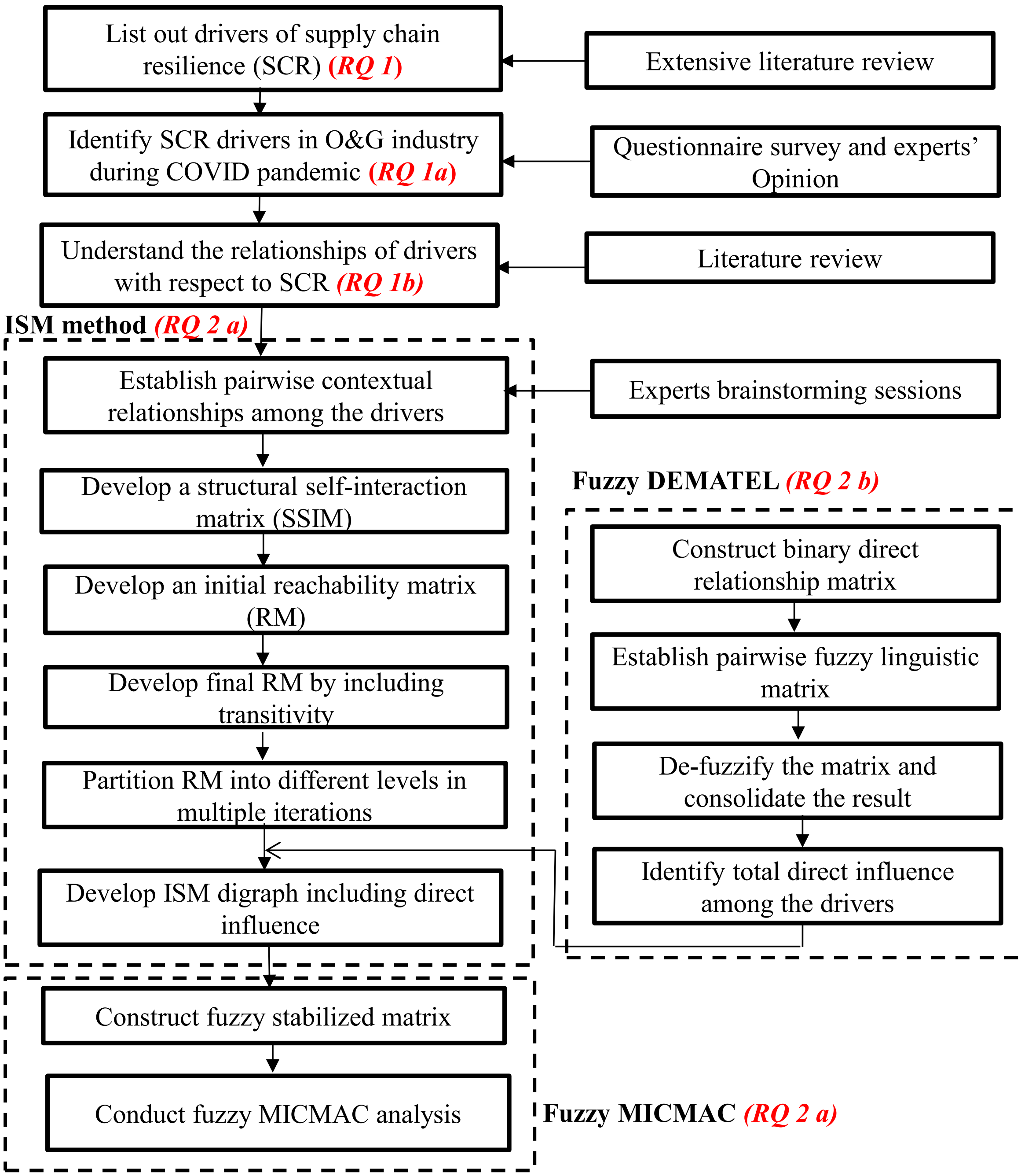

Fig. 1. Methodological steps followed to study the drivers of SCR.

Table 3
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 4
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 5
Levels of drivers of SCR.

Driver *i*	Reachability set	Antecedent set	Intersection set	Level
F1	1	1, 2, 3, 4, 7, 9, 10, 11, 12, 14	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, 14	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

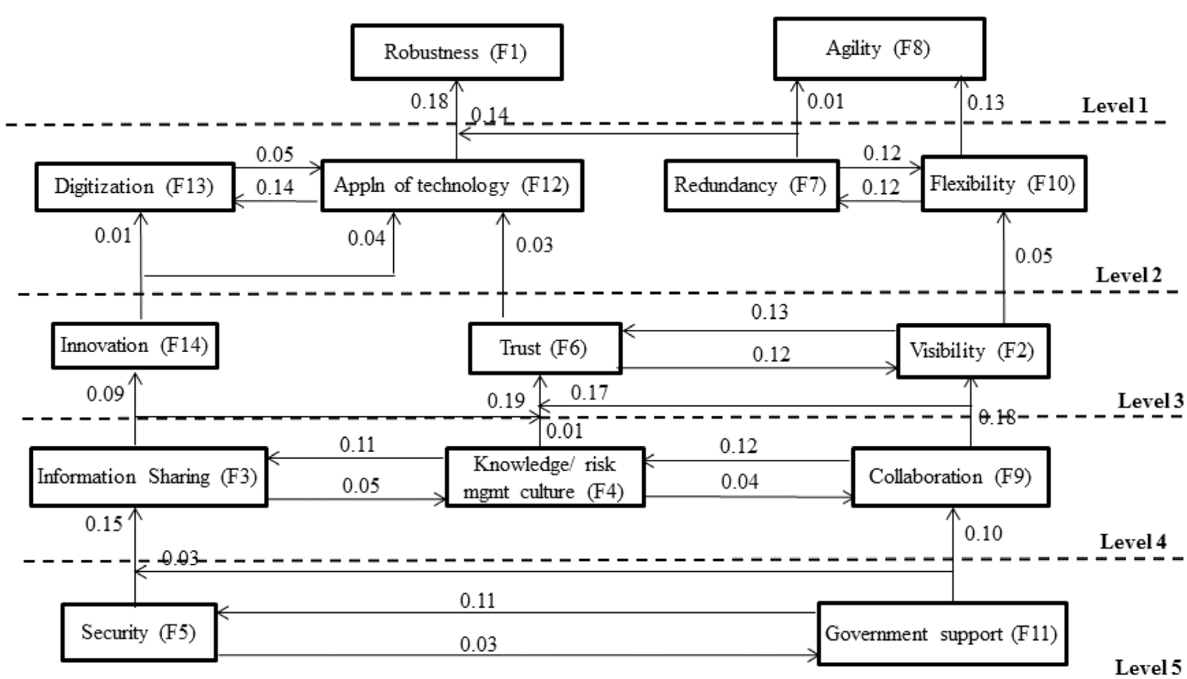

Fig. 2. ISM digraph with the intensity of the relationship among the drivers.

Table 6
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)

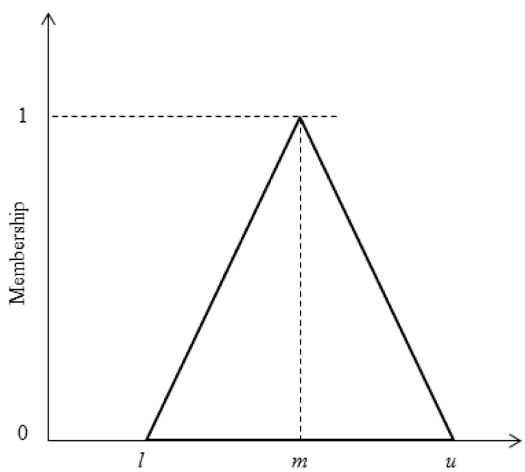

Fig. 3. Triangular member function.

3.2. Fuzzy DEMATEL

To use fuzzy DEMATEL, it is necessary to develop an intensity matrix among the drivers. The following steps are taken for this purpose.

Step 1: Construct Binary Direct Relationship Matrix (BDRM)
A binary direct relationship matrix (BDRM) is constructed by converting all 1s in the diagonal elements of IRM (Appendix D) to 0s.

Step 2: Construct Linguistic Direct Reachability Matrix (LDRM)
When there is a relationship among the drivers represented by the BDRM, the relationship is replaced with an appropriate linguistic variable. The linguistic variable and its fuzzy scale are shown in Table 6. 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, and intuitively easy to infer and calculate by the decision maker compared to other shapes [63]. The graphical representation of the membership function is shown in Fig. 3.

Three industrial experts took part in the process of assigning linguistic variables. To avoid the influence of one expert's point of view over that of another, the experts' opinions were solicited individually. The LDRM obtained from these experts is shown in Table 7.

Step 3: Construct Average Influence Matrix (AIM)
To construct an average influence matrix (AIM), first, the LDRM is defuzzified for each expert's opinion using the best non-*fuzzy* performance (BNP) method (Eq. (1)), as proposed by [64]. In the equation, k represents an expert. The BNP_{ijk} values of the three experts are then aggregated using the geometric mean method (Eq. (2)), as discussed in [65]. In Eq. (2), K represents the total participating experts. The resulted AIM is shown in Table 8.

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

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

Step 4: Normalize AIM
The AIM is then normalized using Eq. (3). For normalization, the 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 9.

$$X = \left[x_{ij}\right]_{n\times n} = \frac{B}{1 \le max_i \le n \sum_{j=1}^{n} b_{ij}} \quad (3)$$

Step 5: Develop Total Influence Matrix (TIM)
The total influence matrix (TIM) is then constructed using the relation as shown in Eq. (4). In the equation, I is an identity matrix. The TIM is shown in Table 10.

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

Step 6: Identify 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 Eqs. (5) and (6), respectively.

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

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

Step 7: Identify Causal Relationship
The casual relationships among the drivers were identified by calculating the sum and the difference of R and C, i.e., $(R + C)$ and $(R - C)$, respectively. The $(R + C)$ value denotes the strength of the driver, while $(R - C)$ represents the net effect of the driver on the system. If the value of $(R - C)$ is positive, then the driver has a net influence on other drivers, and such a driver is classified into the cause group. However, if $(R - C)$ is negative, then it means that other drivers influence the driver in the system. Such a driver is classified into the effect group.

3.3. Fuzzy MICMAC analysis

MICMAC analysis is the last step and an important outcome of the ISM methodology. The analysis helps group the drivers into four different clusters rather than only two clusters, as in DEMATEL. For fuzzy MICMAC analysis, the AIM developed in Section 3.2 is used as an input. Once the AIM is developed, the following steps are taken.

Step 1: Construct Fuzzy MICMAC Stabilized Matrix
The AIM is stabilized to obtain a fuzzy MICMAC stabilized matrix using the concept of fuzzy multiplication [66]. This means that the matrix is multiplied until the values of driving and dependence powers are stabilized. The rules of fuzzy matrix multiplication, as highlighted in Eq. (7), are followed to stabilize the matrix.

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

In Eq. (7), Z is the fuzzy MICMAC stabilized matrix, A is the BDRM, and B is the AIM. The stabilized matrix is shown in Table 11.

Table 7
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 8
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 9
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 10
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 11
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		

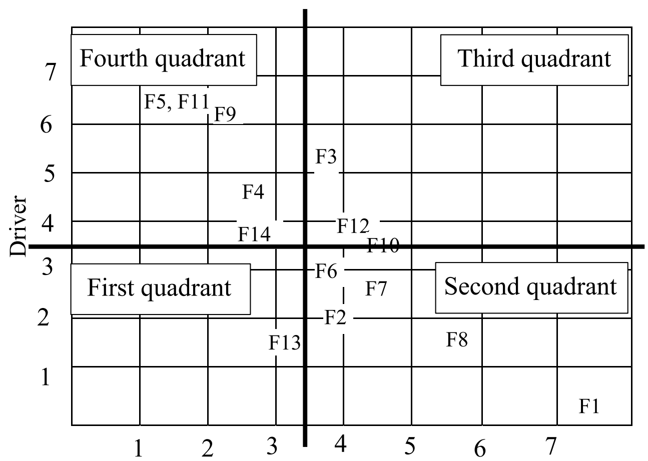

Fig. 4. Fuzzy MICMAC analysis of SCR drivers.

Step 2: Construct Fuzzy MICMAC Plot

The MICMAC analysis helps 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 Fig. 4.

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 fall under this quadrant. Any action on the drivers that 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. Drivers in this quadrant influences other drivers to accomplish SCR.

4. Results and discussions

4.1. ISM result

As shown in Fig. 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 crucial to achieve resilience and are highly dependent on other drivers above their level. On the other hand, drivers such as government support and security lie at the lowest level in the digraph, i.e., Level V, which means that these drivers have the highest driving power. These two drivers influence all other drivers to achieve SCR during the COVID-19 pandemic. This result is in line with that of the OECD report [67], which highlighted the importance of government support and high-level institutional arrangements put in place by the government to help private and government institutions become agile and improve resilience. As shown in Fig. 2, apart from these two drivers, other drivers such as information sharing, trust and knowledge, and risk management culture are crucial to survive and be resilient in difficult situations. These drivers fall under Level 4 and are the major drivers of SCR in the O&G industry. 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 digraph.

The ISM digraph shows that some drivers have two-way interactions. For example, drivers at Levels IV and V have two-way interactions. This means that these drivers affect one another for their accomplishments. On the other hand, there are drivers, especially at different levels, with one-way interactions or drive. For example, government support helps drive collaborations among SC entities, but the opposite is not true. While some drivers fall under the same level, they do not interact with one another. For example, the driver innovation does not interact with other drivers that lie at the same level.

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

- Government support (F11) helps achieve collaboration (F9) among O&G SC partners. As a result of the COVID-19 pandemic, many companies across and within borders are collaborating with one another to fight against it. Such collaboration requires significant government support financially and in the form of regulation and policy implementation [68].
- Collaboration (F9) among SC partners affects SC visibility (F2). Effective collaboration and on-time information sharing among SC partners are critical to improve the level of visibility within the SC [18].
- SC visibility (F2) helps drive SC flexibility (F10). Improved visibility through coordination and appropriate information sharing among SC partners helps them utilize/share available resources, thereby improving 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 [69].

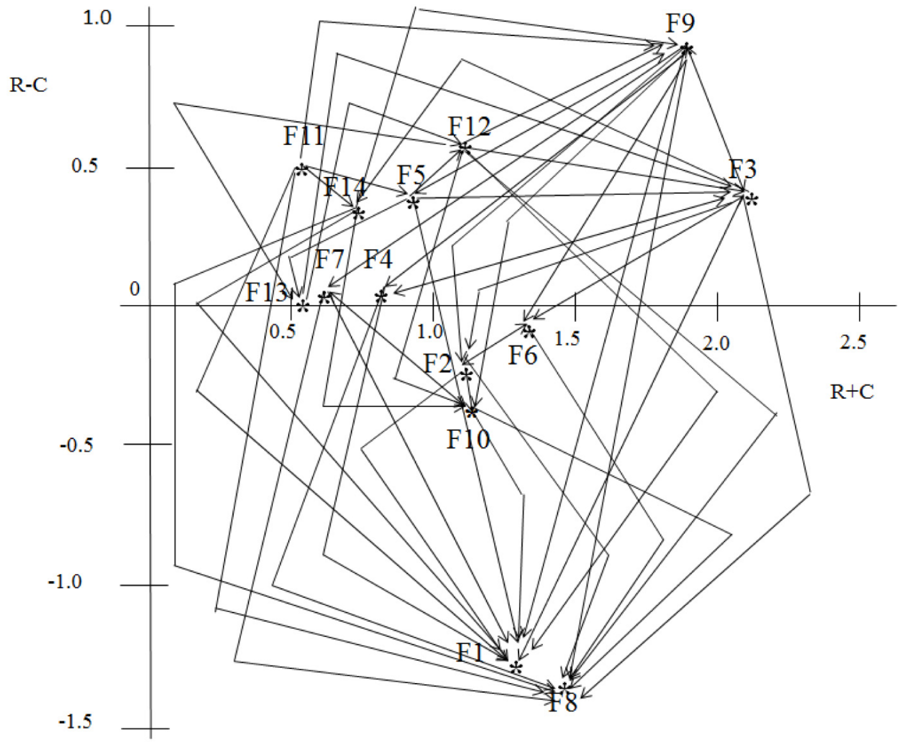

Fig. 5. Intensity relationship map of significant relationships.

4.2. Results from Fuzzy DEMATEL analysis

As discussed in Section 3.2, fuzzy DEMATEL is used to understand the intensity of the relationships among the identified SCR drivers of the O&G industry. The fuzzy DEMATEL results are shown in Table 10 and reflected in Fig. 2 in the ISM digraph. Table 10 shows that five drivers i.e., 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), and SC innovation (F14) fall under the cause group. Even though knowledge and risk management culture (F4), redundancy (F7), and digitization and virtualization (F13) drivers fall under the cause group, their (R − C) values are closer to zero. This signifies that the driver net influence on other drivers and the other drivers' combined influences on it are the same.

Table 10 also shows the direct and indirect intensity of the relationship among the drivers. For example, the influence of Driver F12 on Driver F13 is extremely high as compared to the influence of Driver F13 on Driver F12 (i.e., 0.14 vs 0.05). In the case of Drivers F7 and F10, their influences on each other are similar (i.e., 0.12). As shown in Table 10, the influence of one driver over others in some cases is extremely minimal. Therefore, to show the significant influence, a threshold value (β), as discussed by [70], is identified by taking the average influence of all the drivers in the TIM. The intensity of the relationship greater than this threshold value (0.04) is considered significant, and such relationships among the drivers are shown in Fig. 5 by the intensity relationship map.

4.3. Results from Fuzzy MICMAC analysis

As shown in the fuzzy MICMAC analysis and Fig. 4, the study reveals the following:

First Quadrant: Only driver digitization and visualization (F13) falls under this quadrant. However, this driver lies extremely close to the second quadrant.

Second Quadrant: Five drivers—F6 (trust), F2 (visibility), F7 (redundancy), F8 (agility), and F1 (robustness)—fall under this quadrant, and they lie at the highest and middle levels in the ISM digraph. 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) fall under this quadrant. Driver F10 (flexibility) is inconclusive as it lies between the second and third quadrants.

Fourth Quadrant: Five drivers—knowledge and risk management culture (F4), security (F5), collaboration and cooperation (F9), government support (F11), and SC innovation (F14)—fall under this category, and most of them lie at the lowest level in the ISM digraph. All these drivers influence other drivers to accomplish SCR.

4.4. Statistical validation

To understand the percentage of experts who favor the findings of this research, a statistical analysis was conducted based on the questionnaire presented in Appendix E. The questionnaire, together with the results of this study, was sent to the same experts whose opinions helped screen out fourteen out of twenty drivers collected from the extensive literature review. The data collected from the questionnaire was analyzed using the Mini-tab software. The analysis found no outlier data in the data set, and the histogram shows that the data follows normal distribution. The minimum, average, and maximum ratings collected from the questionnaire were (6.0, 8.7, 10.0), respectively, and the standard deviation in the data distribution was 1.126.

Further, a one-sample t-test was conducted to validate the results. At first, the test value was set at 9.5, which means that 95% of the opinions agree with the results of this research. However, the null hypothesis was rejected in this case. Next, the test value was set at 8.9. In this case, the null hypothesis was accepted at a 95% confidence interval (CI: 8.708 ± 0.2035). Therefore, it can be interpreted that 89% of the participants agree that the SCR drivers and their interrelationships identified in this research for O&G industries during the COVID-19 pandemic are valid.

5. Conclusions

The COVID-19 pandemic has disrupted the SC significantly on a global scale. The most common disruptions can be identified as government-mandated lockdowns, planned closures of factories, and restrictions on travel to minimize the spread of the virus. According to Zhu et al. [71], around 94% of Fortune 1000 companies have experienced COVID-19 driven SC disruptions. Government and policymakers within or outside the companies are coming up with different policies and strategies to improve resilience and cushion the impact of COVID-19 on the global SC. To improve resilience, it is necessary to first identify the drivers that affect the level of resilience and understand how these drivers interact with one another. This helps policymakers devise strategies with the objective to improve SCR significantly.

This study focuses on the identification, analysis, and prioritization of drivers related to SCR in the O&G industry under the COVID-19 pandemic. Based on an intensive literature review, a questionnaire survey with people from the O&G industry, and consultation with academicians and experts, the research identifies fourteen SCR drivers. These drivers were analyzed using the fuzzy ISM–DEMATEL modeling technique. The results from the analysis show that the most important drivers of SCR are government regulations and security, followed by information sharing, effective collaboration with SC partners, and knowledge and risk management culture of an organization. Policymakers should devise policies or strategies to improve the functioning of these drivers as these drivers will influence other drivers to achieve SCR. While agility and robustness are crucial drivers to achieve SCR in the O&G industry, these drivers do not influence other drivers; rather, other drivers of resilience influence them.

5.1. Research novelty

As the O&G industry has a significant impact on the global economy, it should be able to cushion the impact of disruptive events such as the COVID-19 pandemic. The following points summarize the novelty and contribution of this research work in the area of SCR:

- To the best of author's knowledge, this is the first study that attempts to identify the drivers of SCR during the COVID-19 pandemic.
- Moreover, no paper in the past has contributed to research on the identification and analysis of SCR drivers dedicated to the O&G industry.
- The study has implemented an integrated ISM-DEMATEL approach under a fuzzy environment to overcome the issue of vagueness in the experts' decision processes and improve the results.

5.2. Research limitations

- This research focuses on the O&G industry. Therefore, the identified drivers of SCR and the results of the analysis may not be applicable to other industries. However, any industry can use the methodological steps proposed in this research to identify and analyze drivers of SCR.
- The research has identified fourteen major SCR drivers of the O&G SC under the COVID-19 pandemic based on a literature review, a questionnaire survey, and experts' opinions. If a new driver is added to the lists in the future, then a complete analysis will be needed.
- The proposed integrated approach uses experts' subjective judgments, and the judgment of each expert may change with the situation or the availability of new information. This will impact the results obtained from this research.

5.3. Future research direction

In the future, a mathematical model can be developed to measure and compare the resilience levels of O&G companies based on the drivers identified in this study. Such a model can also be used to identify drivers that significantly affect the level of SCR of an industry so that the industry can focus on creating strategies to improve the functioning of such drivers. Moreover, incorporating a strategy to improve the functioning of one driver may trigger another driver or decrease the level of resilience created by other drivers. Another notable avenue of research may be to understand the knock-on effects of one driver on others so that companies can focus on improving drivers that have less or no knock-on effects on other drivers of resilience.

CRediT authorship contribution statement

Sujan Piya: The research was conceptualized, Designed and performed, Revision, Formatting and proofreading of the manuscript. **Ahm Shamsuzzoha:** Revision, Formatting and proofreading of the manuscript. **Mohammad Khadem:** Revision, Formatting and proofreading of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

A.1. Questionnaire

This survey is intended to identify the important drivers that affect **supply chain resilience during COVID-19 pandemic**. Below in the table you will find 20 drivers identified by the researchers based on the literature review. For each driver, five scales are provided. Please select any one scale that is most applicable to your esteemed company. We would like to assure that all the information provided will be dealt with confidentiality and remains anonymous in any technical report published based on the provided information.

Section 1: Background Informant of the Respondent

Name (Optional): Company Name:
Job Designation: Years of Experience:

Section 2: Supply Chain Resilience Driver

#no	Drivers	Scale (1: Negligible effect on SCR; 5: Significant effect on SCR)				
		1	2	3	4	5
1	Robustness					
2	Visibility					
3	Resource Mobility					
4	Information sharing					
5	Knowledge and risk management culture					
6	Security					
7	Trust					
8	Additive manufacturing					
9	Redundancy					
10	Agility					
11	Velocity					
12	Supply chain redesign					
13	Collaboration and co-opetition					
14	Flexibility					
15	Government support					
16	Sustainability					
17	Application of technologies such as automation, robotics and Logistics 4.0.					
18	Training and skill development					
19	Digitization and virtualization of SC					
20	Supply chain innovation culture					

Table A.2
Demography of the participant.

Level in O&G Industry	Percentage distribution
Upstream	27%
Mid-stream	42%
Downstream	31%
Position of Participant	
Production manager	20%
Purchasing manager	21%
Supply chain manager	32%
HR manager	17%
General manager	10%
Work Experience	
10–15	31%
15–20	52%
>20	17%

Appendix B

See Table B.1.

Table B.1
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 C

See Tables C.1–C.5.

Table C.1
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, 14	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, 14	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 C.2
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 C.3
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 C.4
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 C.5
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 D

See Table D.1.

Table D.1
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

Appendix E. Statistical validation

Please rate the extent to which supply chain resilience drivers and the intensity of the relationship among them identified in this research are valid in the oil & gas industry under the COVID-19 pandemic.

Rating Scale:

8–10 Strongly agree
6–8 Agree
4–6 Moderately agree
2–4 Agree to some extent
0–2 Do not agree

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