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Research article

Managing supply chain resilience assessment model-relevant factors and activities using an FCM-FBWM approach

Zeinab Barmour [a,**], Sadra Ahmadi [b,*], Sajjad Shokouhyar [c]

[a] *Faculty of Management and Accounting, Shahid Beheshti University, Tehran, Iran*
[b] *Cyberspace Research Institute, Shahid Beheshti University, Tehran, Iran*
[c] *Dep. of Operations and Supply Chain Management, Australian Institute of Business, Adelaide, Australia*

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ABSTRACT

Supply chain resilience is essential for companies to survive in today's competitive market, as they face environmental and unforeseeable challenges in their supply chain. This paper aims to model and manage the factors and activities that influence supply chain resilience and how they relate to each other. This will help us devise plans for enhancing the resilience of a supply chain. By taking into account the factors and activities and their interrelationships, organizations can use their limited resources more efficiently to improve their supply chain resilience. We use a management matrix to rank the factors based on how they affect and contribute to the supply chain resilience. We conduct an empirical study in a pharmaceutical company to demonstrate the proposed management approach and provide improvement scenarios based on the ranking of the factors. The results show that the most important factors are "the cooperation and trust between supply chain members", "Visibility & Agility", and "Leadership Support and Commitment". The ranking of the factors may vary in different companies. Therefore, other companies can apply the method described in this paper and perform different improvement scenarios according to the ranking of the factors to effectively allocate their limited management efforts.

1. Introduction

The concept of resilience is currently attracting considerable attention [1,2], and many scholars are seeking to investigate resilience and its impacts on the systems of supply chains as an extensive field of study [3–5]. The capability of quick and effective recovery of prior or certain performance levels following unpredictable disruptive events has been known as *resilience* [6–8]. This concept represents both the power and flexibility utilized in almost all areas of research [9].

Yet, considerable changes have currently occurred in supply chains because of the growing trend of globalization and the increasing rate of innovation. The increase in the contribution of global supply chains can be related to the increase in interconnections of the suppliers and manufacturers, resulting in more dependence on supply chains, along with their more complexities [10–14]. Accordingly, supply chains act more effectively across stable business contexts, while also showing considerable vulnerability to risks and disruptive events.

The main motivation for studying supply chain resilience, which is the ability of a supply chain to withstand and recover from

* Corresponding author.
** Corresponding author.
E-mail addresses: zbarmour@yahoo.com (Z. Barmour), sa_ahmadi@sbu.ac.ir (S. Ahmadi).

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various disruptions is that the supply chains are complex and unpredictable because of the following reasons [15].

- High demand variability: This means that customer demand can change rapidly and unexpectedly, making it difficult for supply chain planners to forecast and match supply and demand [16–18].
- Short product life: This means that products have a limited time span in the market before they become obsolete or replaced by new products, requiring faster and more frequent innovation and production cycles [16–18].
- Diversity of consumer expectations and demands: This means that customers have different and sometimes conflicting preferences and requirements for products and services, such as quality, price, delivery time, customization, etc [16–18].

These challenges create a more unstable and unpredictable situation for supply chains, which need to adapt to such changes and cope with potential disruptions. Disruptions can be caused by various factors, such as natural disasters, pandemics, cyberattacks, political conflicts, etc. Disruptions can have adverse consequences for supply chains, such as reduced performance, increased costs, lost revenues, damaged reputation, etc. Therefore, it is inevitable to address the design of the supply chain to make it more effective and resilient against disruptive events. This means that supply chain design should consider not only efficiency and optimization, but also flexibility and robustness, to enable supply chains to respond and recover from disruptions, as well as to learn and improve from them [16–18].

Significant attention has been recently drawn to the resilience of supply chains to deal with this issue. According to Fiksel [19], resilience is one of the significant capabilities that is complementary to the conventional procedures of risk management in different companies. Based on Melnyk et al. [20], resilience is at the center of recent supply chain management thoughts. Even though several researchers have presented definitions of this concept, no one has provided a comprehensive definition that leads to a clear understanding of supply chain resilience. Some regard resilience as a reactive capability which can be used after disruptions, while some consider it in the form of more proactive efforts for preparing in the case of facing a disruption. As stated by Melnyk et al. [20], the confusion around this concept is not surprising considering such divergences. At the moment, we refer to the definition [7] has provided, widely cited in the research on the resilience of supply chains: the resilience of supply chains represents the adaptive capabilities of supply chains for preparing against unpredictable incidents, reacting against disruptions, and recovering from such events by retaining the ongoing process of operations at the desirable level of connectedness and control over structure and function [7]. Investigating the main of this research domain we summarize the main gaps in what follows.

- Most of the studies lack a suitable approach to model the causal relationships between the effective factors of resilience in the supply chain, and previous studies use a structural model that is not suitable for expressing human opinions and judgments.
- Previous studies do not provide an approach to develop and improve the evaluation model, while the proposed approach allows supply chain decision makers to provide a plan to improve factors affecting supply chain resilience.
- The studies mainly deal with the general state of research in the field of supply chain resilience, so no study provides a detailed view of the factors affecting supply chain resilience and the improvement of these factors.

To fill the mentioned research gap, this research seeks to answer the following questions.

- What factors influence the concept of supply chain resilience?
- How the influential factors are interrelated?
- How the factors could be prioritized based on their interrelationships and their contribution to the state of companies' supply chain resilience?
- How to provide a set of improvement scenarios based on influential factors priorities and analyze their result?

Thus, the present paper has attempted to use the Fuzzy Best- Worst Method (FBWM) with the Fuzzy Cognitive Maps (FCMs) with the aim of identifying influential factors on the enhancement of the SCRs approach. To obtain the objectives of the paper, a soft computing method has been suggested according to Fuzzy Cognitive Maps (FCMs) beneficial capabilities for effective assessment of supply chain resilience and identification of improvement factors with the highest influence on the overall resilience of supply chains. It is possible for the organizations to figure out any impacts of changing other interrelationships on the performance of every parameter through the FCM method. The weight of every parameter's contribution to the overall status of resilience across organizations can be determined using relative and absolute judgments [21]. Relative judgements compare every activity or factor with all other activities, determining the relative significance of every activity or factor [22]. Such as analysis leads to the creation of the assessment model, after which the decision-making trial and evaluation laboratory (DEMATEL) method is used to prioritize factors, and the limited organizational resources are effectively allocated by forming a management matrix. DEMATEL performs effectively by collecting group knowledge, analyzing the interrelationships of the system factors, and illustrating the cause-and-effect associations using a diagram [23,24]. Moreover, this technique is not dependent on large-scale information and can promptly identify the most influencing factors [25]. According to this prioritization, several improvement scenarios can be carried out to identify the most effective plan for the improvement of the overall resilience status across a company.

The decision-makers of supply chains are enabled to initially determine the related activities for the resilience of supply chains using the suggested approach, and then perform modeling of the causal associations of the 23 identified activities along with their contribution weights to the overall factors. Ultimately, decision-makers of supply chains can adopt the proposed approach in the development of an efficient factor improvement plan and prioritization of the activities with the highest influence on the overall factors. Besides, factors requiring improvement by the management are also identified to promote organizational resilience performance. Therefore, the present paper has distinguished the factors for the SCR, emphasizing these attributes to result in the SCR robustness.

The remaining of the paper has the following organization: A brief review of literature on the supply chain resilience (SCRs) and social media is provided after introduction. The third section provides a description of the FCM-FBWM methods. Section 4 is allocated to the results and main findings related to the data analysis. Then, the subsequent section discusses the conclusions, suggestions, and limitations of the study, along with potential directions for further studies.

2. Research background

2.1. Supply chain resilience

Supply chains are networks of connected and interrelated organizational contexts that work in a mutual and cooperative manner with the aim of controlling, managing, and improving the material and information flow from the supplier to the end user [26]. Each activity within supply chains faces the inherent risk of the adverse effects of undesirable or unforeseen events on the performance. Therefore, risks and uncertainties and events that lead to interruptions and disturbances in the flow of the supply chain should be taken into account, even if these events happen in a distant place, because they can cause disruptions on a large scale in the supply chain of which the firm is a member or the supply chain's environment [7,27–29]. According to Ponomarov and Holcomb [7], resilience reflects the adaptive capabilities of the supply chains for the preparation against unforeseen events, responding to disruptive incidents, and recovery from them through continuously operating for a certain level of connectedness and control over structure and function. Different critical elements regarding supply chain disruptions are considered such as: responding or restoring to the same or better condition and retaining (or maintaining) the same control over structure and function [27,30,31]. It is also claimed that disruptions are spread due to the dependence of supply chain layers on each other in maintaining the duration of operations [7].

Investigating supply chain resilience to reduce risks has been very effective in the last decade and has now become an important research topic that has attracted the attention of researchers [32–35]. Supply chain resilience indicates the organization's supply chain readiness to deal with unwanted disruptions in order to solve chain problems and normalize conditions [36–40].

Several researchers have defined the concept of "resilience" as the organizational ability to solve supply chain disruptions and normalize conditions or adjust quickly in the face of adverse or destructive events [41,42]. Fiksel [43] defines supply chain resilience as an organization's ability to provide an effective response to supply chain disruptions, along with growth through effective recovery. He believes that disruptions in the supply chain can be solved using a supply chain risk management approach. However, traditional risk management and assessment tools are unable to deal with unforeseen events. Currently, resilience is considered as the heart of supply chain management strategies. While, failure to design a resilient supply chain in order to respond to the vulnerabilities of the chain leads to irreparable damages when faced with a crisis. SCR has filled this gap as it takes the concept of supply chain risk management to a newer level [44].

In addition, it should be noted that SCR is not only the organization's ability to improve when faced with a crisis, but also the organization's ability to adapt in the face of new chain conditions [45–47]. Thus, three main dimensions of a resilient supply chain can be introduced as follows (Reference): (1) supply chain readiness, which indicates their readiness to face disruptive events. (2) supply chain agility, which indicates the speed of dealing with supply chain disruptions, and (3) the last one is the ability of the supply chain to solve problems in the face of disruptive events in the shortest possible time and return. By using these three dimensions, companies can deal with supply chain disruptions more effectively and return to normal conditions [48,49]. Therefore, supply chain flexibility helps organizations to react better and faster to disruptive and challenging events and return to normal conditions, as well as avoid significant financial and operational losses caused by supply chain disruptions [50–52].

Resilience in the supply chain can be defined in two parts, proactive and reactive. If there is resilience in the supply chain before facing the crisis, the supply chain has a proactive resilience. The main components of a proactive supply chain resilience are "collaboration", "visibility", "velocity", "flexibility", "redundancy", "robustness", "alertness" and the "culture of risk management" [28,53–58]. In the case of disruptive events, supply chain resilience represents its reactive aspect, which includes "responsiveness" and "recovery". Although supply chain resilience is sometimes regarded as the capability of recovery alone as presented by Brandon-Jones et al. [59], some consider it as a combination of responsiveness and recovery [60]. When supply chain disruptions are frequently observed, organizations must take steps to manage supply chain resilience risk. Therefore, organizations seek to build supply chain flexibility to respond to volatile business environments [49].

A resilient supply chain can recover much better in the face of challenges [42]. Yet, resilience, rather than retrievability, requires a certain level of flexibility, along with the ability to adapt to contextual influences [61]. Thus, Hamel and Valikangas [45] believe that the resilience is one of preconditions of the sustainable economic development and companies competitive advantages. It is also a critical element for the development of strategic plans with the required sustainability and capability to produce better results compared to competitors with lower levels of resilience [46].

To sum up, it can be summarized that previous studies have briefly introduced the factors affecting the resilience of the supply chain and analyzed them in the form of deterministic or probabilistic models. While companies need to priorities of affecting factor for allocating their limited management efforts to improve their situation. In addition, most studies have considered factors as independent factors; while in this context, factors are interrelated and any improvement in one of them can affects the others. Thus, these interrelationships should also be considered in any improvement plan scenario.

2.2. Proposed factors

Existing studies have presented numerous attributes. Every factor contains a series of interrelated activities and has to be carried out to achieve factors for SCR. The factors are displayed as the ten criteria and twenty-three activities in Table 1.

Supply chain reengineering(F1): The design of supply chains primarily focuses on optimizing the costs and satisfying the customers. Considering the inherent risks of supply chains, incorporation of SCRM into supply chain design is even more important [62]. Thus, there is a requirement to redesign the conventional supply chains for the integration of resilience into their design. Ponomarov and Holcomb [7] as well as Scholten et al. [63] have stressed the necessity to reengineer supply chains and consider resilience incorporation.

Cooperation and trust between supply chain members(F2): Supply chains have spread worldwide, affecting their risk of disruption. Accordingly, the vulnerability of supply chains is a network-level phenomenon requiring consideration. Accordingly, risk management across supply chains need examination from the network point of view [64]. Proper examination of risk management in supply chains with considerable interconnectedness will not be possible unless there are high levels of collaboration, cooperation, and partnership among different entities. Pettit et al. [65] described collaboration as the capability of effective working with other entities for mutual advantages. Based on Faisal et al. [66], cooperation and collaboration are facilitated by trust both within the organizations and across partners in the supply chains. According to Sinha et al. [67], absence of trust is among the main factors which increase the risks for supply chains. Ponomarov [68] examined the mutual trust behaviors of buyer-supplier resilience and concluded that higher levels of mutual trust behaviors may lead to higher levels of relational resilience in buyer–supplier associations. Based on the results, longer orientation of the relationships leads to stronger relationships among mutual trust behaviors.

Information sharing as driver of resiliency(F3): Several researchers have argued for taking into account sharing information as a distinct resilience driver [69,70]. Information sharing was examined by Datta et al. [69] together with flexibility, monitoring, and decentralized structure as four SCR drivers.

Visibility & Agility(F4): Based on the first perspective, visibility is a driver of agility. Datta et al. [69] utilized agent-based modeling of complicated production/distribution systems for resilience improvement. According to reports, incorporation of the true sensors at various parts of the supply chains and their regular monitoring can be considered as the main components of agility, enhancing resilience. Based on Wieland and Wallenburg [71], visibility allows managers to become aware of the changes and is therefore a precondition for reaction. According to their hypothesis and verification, agility and resilience are improved by communication and cooperation as the visibility of functions and operations enhances. Agility can be described as the capability of the supply chains to provide a rapid response to changes through adaptation of their primary stable configuration [71]. According to Bakshi and Kleindorfer [72], agility stresses the fast reconfiguration of the systems when unexpected changes occur.

SCRM culture(F5): Based on Christopher and Peck [73], companies must welcome a culture for SCRM to establish a resilient context. Based on Sheffi [74], the culture of the organization is the main difference of successful and unsuccessful reaction against disruptions.

Speed of flexibility(F6): Speed is a concept inherent to agility [71,75]. Hence, velocity has been developed to incorporate speed (and subsequently time) into agility; velocity has been among the significant building blocks of agility [63]. As stated by Christopher and Peck [64], velocity represents distance during time. Velocity in a risk incident identifies the loss happening per unit of time [54]. It has

Table 1
Resilience.

Factors	References	Activity	Activity title
F1: Supply chain reengineering	[62,63]	*A1*	• Supply chain understanding (Flexibility vs. Redundancy)
		A2	• Using supply base strategies (suppliers' risk awareness)
		A3	• Designing principles for SCR
F2: Cooperation and trust between supply chain members	[64–68]	*A4*	• Management of risk
		A5	• Creating cooperative contracts among partners
		A6	• Trust facilitates cooperation and collaboration
F3: Information sharing as driver of resiliency	[69,70]	*A7*	• Internal and external knowledge sharing
		A8	• Monitoring, and decentralized structure
F4: Visibility & Agility	[69,71,72]	*A9*	• used modeling of complex production/distribution systems
		A10	• Quickly redesign supply chains
F5: SCRM culture	[73,74]	*A11*	• Creating a culture and change management
		A12	• Creating a risk management culture
F6: Speed of flexibility	[63,64,71,75]	*A13*	• Using streamlined processes
		A14	• Eliminating nonvalue- added time
		A15	• Reduction in bound lead times
F7: Leadership Support and Commitment	[62,64]	*A16*	• Investigate the contribution of leaders and top managers
		A17	• Review strategic decisions
F8: Innovation	[76–78]	*A18*	• Creating a flexibility
		A19	• Analyzing values, beliefs, and behavior patterns
F9: Supply chain community	[64,79]	*A20*	• Collaborative working and risk reduction
		A21	• Information sharing both pre and post disruption
F10: Sharing knowledge and risk	[54]	*A22*	• Mitigate disruptions
		A23	• Connectivity of supply chains and information-sharing resources

close associations with flexibility and adaptability, in which there are concerns about the speed of flexible adaptations [80].

Leadership Support *and Commitment(F7)*: Leaders and top managers play a significant role in changing the organizational culture. According to Christopher and Peck [64], nothing will be possible without the leadership support and commitment during the process of changing organizational culture. According to Wilding [62], leaders should review the policies and practices of the companies for the establishment of a risk management culture.

Innovation(F8): Innovation has been among the main elements for organizational long-term survival and development, contributing crucially to the organizational adaptation and response against changes in the context [77]. There is no innovation in a vacuum; there

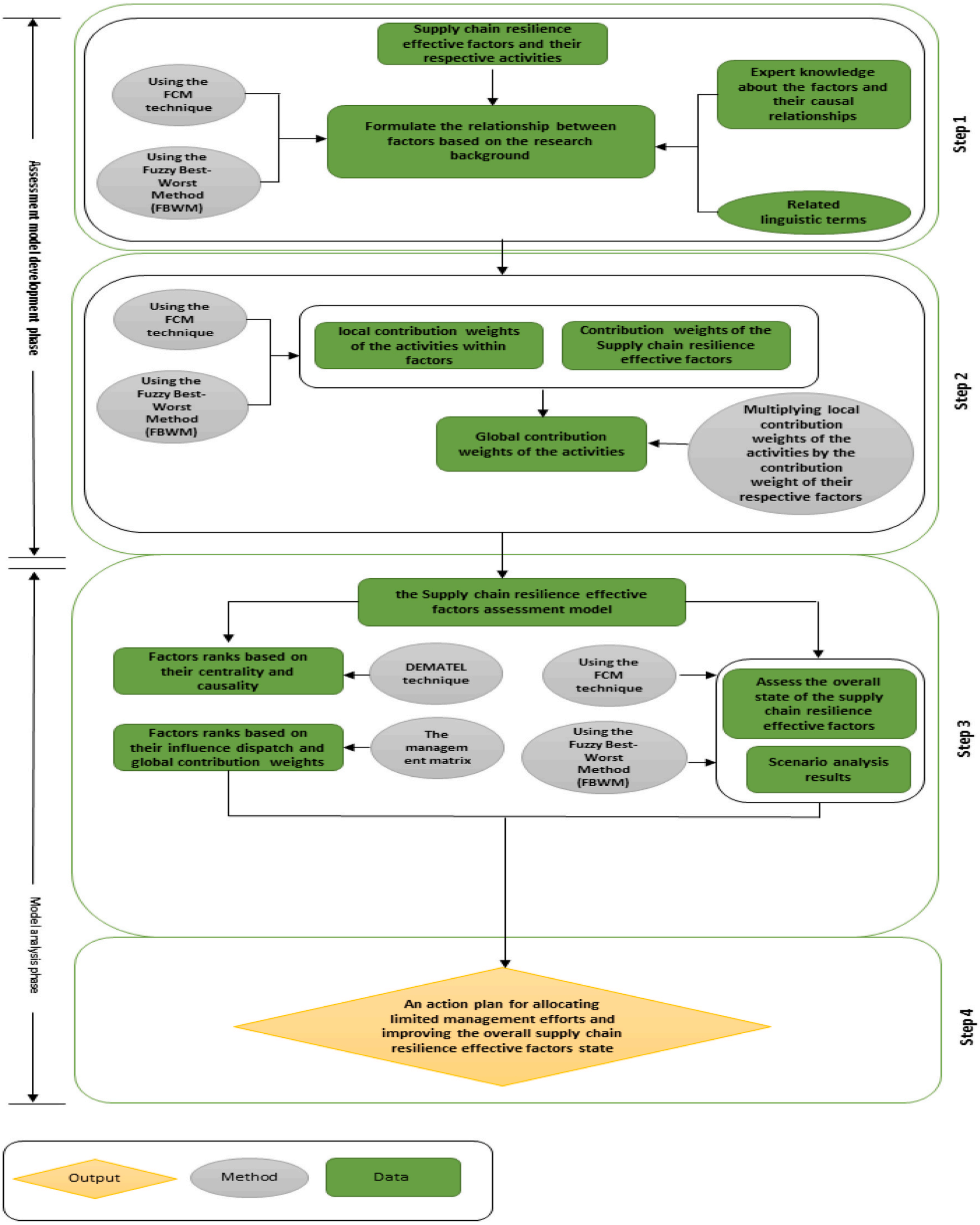

Fig. 1. Key phases and steps in the approach.

is a need for shared beliefs and an insight into innovations across the organizations to enable innovation institutionalization within the organizational context [76]. Based on Golgeci and Ponomarov [78], it is possible to view resilience as an important aspect of organizational survival, and innovativeness as a main enabler of resilience.

Supply chain community(F9): Based on Christopher and Peck [64], creating a supply chain community in which information is exchanged among the supply chain members is required as the main priority for collaboration and risk reduction. According to Mandal [79], collaboration can only take place in the case that each member obtains related information in an efficient and effective way.

Sharing knowledge and risk(F10): According to Jüttner and Maklan [54], sharing risks and knowledge within the supply chains can improve SCR through the improvement of supply network visibility.

3. Method

This section discusses the FCM-FBWM method and the analytical procedures employed in the proposed approach.

Before implementing the resilience programs across the organizations, planning is necessary to determine the activities associated with resilience. As the model suggested here is a conceptual framework and the factors and activities included in the comprehensive SCR model show various levels of impact in one another, there should be a more comprehensive approach to figuring out the different aspects of SCR and the decision-making about it in all companies. The article presents a fuzzy approach with the use of FCM, pairwise comparisons, and DEMATEL for better employment of the suggested conceptual model and enabling managers for better planning and implementing the SCR. The study was carried out in a pharmaceutical company, concentrating on the following four issues.

1) Identifying the causal associations of the factors: Different factors associated with resilience in the supply chains have interrelationships, as the output of one factor can be the input to another one.
2) Identifying the significance of every factor: The degree of every factor's significance in SCR in comparison with other factors is another dimension of the suggested method. Hence, the factors underwent pairwise comparisons.
3) Factor categorization and prioritization: Given the significance of every factor, the causal associations of the factors and the severity, multiplicity, and complexity of the associations, factors' prioritization seems to be challenging. Thus, the method suggested here categorizes factors based on their significance and the degree of their impact on others.
4) Assessing the status of activities: Every resilience factor and activity at every point of time possesses a maturity level. An indicator is proposed for the evaluation of the status of every factor and the overall status of resilience in supply chains across the companies.

The causal associations of the influencing factors are determined and modelled using the FCM method. The technique aimed to model the causal associations and feedback loops among the components of the complicated systems [81]. There are several advantages for the FCM method concerning the analysis of the complicated problems as such problems can be modelled conveniently, while the ability of displaying various causal associations of the concepts is enhanced and the required capability and flexibility in the system analysis and problem solving is ensured [82]. There are nonsymmetric or non-monotonic associations, because of which the triangular fuzzy numbers are utilized to determine the weights of relationships.

Comparative judgements with higher reliability compared to the absolute judgements [83] were utilized to evaluate the significance of activities and factors in SCR. Besides, the DEMATEL technique was employed to classify and prioritize the resilience factors to effectively allocate the restricted organizational resources. DEMATEL has been among the multi-criteria decision-making instruments on the bases of the graph theory [84] allowing the identification of the direction of the associations of factors. The factors having greater significance for the whole system and those without such an importance can be identified with the use of the DEMATEL method [24].

3.1. *A supply chain resilience assessment approach*

Fig. 1 illustrates the used approach for the supply chain resilience effective factors. Two phases are incorporated in the approach: (1) the assessment model development and (2) the model analysis. According to Fig. 1, phases (1) and (2) include two and three steps, respectively. An assessment model is developed by the company in the first phase, using the expert interviews. Then, the assessment of the present status of SCR initially takes place, and an action plan is developed to improve the overall status.

3.2. *FCM-FBWM*

3.2.1. *Formulation of factors' causal interrelationships*

According to Section 2, the main factors of SCR should be defined by the companies, followed by the identification of the activities associated with every factor for the application of the improvement plans. Several discussion sessions with experts, consisting of sector managers and other main stakeholders called the decision-makers can be conducted to identify the factors. The associations of the factors can be determined using the FCM model, in which the nodes and arcs show the factors and their causal associations, correspondingly. Every FCM model possesses a connection matrix whose cells indicate the positive or negative associations of factors and their weights. Cells with zero value indicate no associations of the two corresponding factors (Froelich et al., 2012). The experts can determine the causal associations of the factors by responding the following question:

Which of the factors B, C, D, etc., changes because of a change in factor A?

The weight of every causal is determined using an if-then rule [81] as presented below:

If the value of Fi factor changes by a (small, very small, medium, large or very large) amount, the Fj factor will change by a (small, very small, medium, large or very large) amount.

An overall of 13 linguistic terms have been utilized to identify the *factor Fi* impact the other *Fj factor*s (Table 2).

All experts create the associations of the *factor*s from their own perspective, eventually leading to the final matrix of connections as the result of the opinions of experts by obtaining the average of the expert opinions concerning every causal association.

A matrix of relationships usually demonstrates the fuzzy weights of these interrelationships. The augmented FCM, which was advances by Salmeron [85] was used to achieve agreement among experts concerning the ultimate FCM model. Hence, the experts create their own matrices of relationships that incorporate the distinctively characterized fuzzy weights. Afterwards, Eq. (1) is used to develop the final matrix.

$$\overline{w}_{A_i,A_j}^{Aug} = \frac{\Sigma_{k=1}^{m} \overline{w}_{A_i,A_j}^{k}}{m} \tag{1}$$

Where $\overline{w}_{A_i,A_j}^{Aug}$ represents the augmented fuzzy weight of the causal associations of activity A_i and A_j. m refers to the number of experts. k indicates the expert number k and $\overline{w}_{A_i,A_j}^{k}$ shows the fuzzy weight that expert number k allocates to the causal associations of activity A_i and A_j.

Equal weights are assigned by the approach to every expert's judgement, making it possible to maintain the diversity of the mental models of experts on the one hand and consider the associations on which the experts have agreement on the other hand. Thus, the approach plays an important role in the final model's reliability and ensuring that is will not be influenced by the possible imprecisions found in the individual experts' judgements [86].

3.2.2. Determining the contribution weights of the SCR factors and activities

To determine the contribution of each factor in the state of supply chain resilience, the two groups of absolute and comparative judgment could be used. In the comparative judgment, each factor is compared against the other to define its contribution weight [87]. In the absolute judgement technique, each factor is weighted without any comparison with other factors. In cases which there is no scale for weighting the decision criteria, the comparative judgement result is more reliable [88]. To conduct a comparative judgment while there are several decision-making criteria, a multi-criteria decision-making (MCDM) technique is usually applied by the decision makers [89–91]. MCDM techniques are computational methods that incorporate several criteria and order of preference in evaluating and selecting the best option among many alternatives based on the desired outcome (Reference) [92].

Since there is no scale to measure the contribution weight of resilience-related activities in the overall resilience of supply chains, an MCDM technique is chosen to determine the contribution weight of activities in the SCR state. In this research the Fuzzy Best-Worst Method (FBWM) technique is used as a MCDM technique because it's two major benefits compare to other technique: (1) lower number of comparisons and (2) higher consistency of the results. The BWM technique introduced by Rezaei [93] and preferred in this research because performing a significant number of comparisons needs a lot of time, while increasing the complication of the assessments and decreasing the reliability of the judgments [85]. Meantime, the judgments of experts on the comparative significance of factors consist of a specific degree of inaccuracy and uncertainty. Hence, Fuzzy BWM (FBWM) has been used in the approach suggested by us and shows higher consistency and reliability compared to the original BWM.

Experts are just allowed by the FBWM to carry out pairwise comparisons between the most (Best) and the least (Worst) important activity and other activities and also among other activities. These comparisons can be referred to as the reference versus the secondary comparisons that are not needed. The overall number of comparisons carried out will be $2n-3$, in which n indicates the number of activities under comparison [94]. The following question should be answered by the experts to identify the comparative significance of every activity than the other one:

"How much significance does the activity A_i have than activity A_j?"

Table 2
Linguistic terms utilized to assess casual associations of the factors.

Linguistic terms	Triangular fuzzy numbers
AP: Absolutely positive	(0.9,1,1)
EP: Extremely positive	(0.7,0.9,1)
STP: Strongly positive	(0.5,0.7,0.9)
MP: Moderately positive	(0.3,0.5,0.7)
WP: Weakly positive	(0.1,0.3,0.5)
SLP: Slightly positive	(0,0.1,0.3)
Z: Zero	(-0.1,0,0.1)
SLN: Slightly negative	(-0.3,-0.1,0)
WN: Weakly negative	(-0.5,-0.3,-0.1)
MN: Moderately negative	(-0.7,-0.5,-0.3)
STN: Strongly negative	(-0.9,-0.7,-0.5)
EN: Extremely negative	(-1,-0.9,-0.7)
AN: Absolutely negative	(-1,-1,-0.9)

The linguistic terms shown in Table 3 and their relative triangular fuzzy numbers show this corresponding significance. The five linguistic terms in FBWM can be distinguished better than the typical 1–9 scale in BWM, facilitating the achievement of higher accuracy in the experts' comparative judgments [95].

The present study has primarily measured main influential factors of SCR against one another and obtained their contribution weights. Then, the activities in every influential factor have undergone comparisons with one another, resulting in the local contribution weights of activities. It is then possible to calculate the global contribution weights of activities.

The FBWM approach is exactly described below to identify the local contribution weights of activities [95]. The contribution weights of effective factors can be determined by performing the same approach.

1) Providing a definition of the most (Best) and the least (Worst) important activity for resilience; Experts perform this process based on their knowledge of implementing resilience across supply chains and the perceived significance of resilience-related activities.
2) Execution of the fuzzy reference comparisons concerning the best activity; The linguistic terms shown in Table 3 are considered in making these pairwise reference comparisons, and the following Eq. (2) indicates the results in the fuzzy Best-to- others vector:

$$\widetilde{p}_B = (\widetilde{p}_{B1}, \widetilde{p}_{B2}, \cdots, \widetilde{p}_{Bn}) \tag{2}$$

Where $\widetilde{P}_B$ is the fuzzy Best-to-Others vector. $\widetilde{P}_{Bj}$ refers to the fuzzy relative importance of the Best activity A_B over activity A_j , $j = 1,2, \cdots, n$. n being the number of compared activities and $\widetilde{P}_{BB} = (1,1,1)$.

3) Executing the fuzzy reference comparisons regarding the Worst activity; These pairwise comparisons are also made based on the linguistic terms in Table 3 and result in the fuzzy Others-to-Worst vector presented in Eq. (3):

$$\widetilde{p}_W = (\widetilde{p}_{1W}, \widetilde{p}_{2W}, \cdots, \widetilde{p}_{nW}) \tag{3}$$

Where $\widetilde{p}_W$ represents the fuzzy Others-to-Worst vector. $\widetilde{p}_{jW}$, indicates the fuzzy respective significance of the activity A_j compared to the Worst activity A_W, $j = 1,2, \cdots, n$. n indicating the number of activities undergoing comparisons and $\widetilde{p}_{WW} = (1,1,1)$.

4) Acquiring the fuzzy pairwise comparison matrix, which just integrates the reference comparison value and can be shown through Eq. (4).

$$\begin{array}{cccc} A_1 & A_2 & \ldots & A_n \end{array} \quad \widetilde{P} = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_3 \end{array} \begin{bmatrix} \widetilde{P}_{11} & \widetilde{P}_{12} & \cdots & \widetilde{P}_{1n} \\ \widetilde{P}_{21} & \widetilde{P}_{22} & \cdots & \widetilde{p}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{P}_{n1} & \widetilde{P}_{n2} & \cdots & \widetilde{P}_{nn} \end{bmatrix} \tag{4}$$

Where $\widetilde{P}_{ij}$ represents the fuzzy respective significance of activity Ai compared to activity A_j , $i,j = 1,2, \cdots, n$. n showing the number of activities undergoing comparison and $\widetilde{P}_{ij} = (1,1,1)$ for $i = j$.

5) Calculation of the optimal fuzzy significance weights of activities; Minimization of the maximum difference of the extracted weights and their respective pairwise comparison values is the main objective. Hence, minimization of the $\left|\frac{\widetilde{W}_B}{\widetilde{W}_i} - \widetilde{P}_{Bj}\right|$ and $\left|\frac{\widetilde{W}_j}{\widetilde{W}_w} - \widetilde{P}_{jW}\right|$ with $\widetilde{W}_B$, $\widetilde{W}_j$ and $\widetilde{W}_w$ correspondingly indicating the fuzzy weights of Best activity A_B, activity A_j and Worst activity A_W will lead to the optimum fuzzy weight for every activity A_j. The constrained optimization problem below is subsequently specified using Eq. (5) for the extraction of the optimum fuzzy significance weights of activities.

Table 3
Linguistic terms utilized to assess the activities' contribution weights.

Linguistic terms	Triangular fuzzy numbers
Equally important (EI)	(1,1,1)
Weakly important (WI)	(2/3,1,3/2)
Fairly important (FI)	(3/2,2,5/2)
Very important (VI)	(5/2,3,7/2)
Absolutely important (AI)	(7/2,4,9/2)

$$\min \xi \ s.t. \begin{cases} \left| \frac{\widetilde{W}_B}{\widetilde{W}_j} - \widetilde{P}_{Bj} \right| \leq \xi \\ \left| \frac{\widetilde{W}_j}{\widetilde{W}_w} - \widetilde{P}_{jw} \right| \leq \xi \\ \sum_{j=1}^{n} R(\widetilde{W}_j) = 1 \\ l_j^w \leq m_j^w \leq u_j^w \\ l_j^w \geq 0 \\ j = 1, 2, \ldots, n \end{cases} \tag{5}$$

Where $\widetilde{W}_B = (l_B^w, m_B^w, u_B^w), \widetilde{W}_j = \left(l_j^W, m_j^W, u_j^W\right)$, $\widetilde{W}_W = \left(l_W^W, m_W^W, u_W^W\right)$, $\widetilde{P}_{Bj} = (l_{Bj}, m_{Bj}, u_{Bj})$, $\widetilde{P}_{jW} = (l_{jW}, m_{jW}, u_{jW})$ and $\boldsymbol{\xi} = \max j \left\{ \left| \frac{\overline{W}_B}{\overline{W}_j} - \overline{P}_{Bj} \right|, \left| \frac{\overline{W}_j}{\overline{W}_W} - \overline{P}_{jW} \right| \right\}$.

6) Determining the defuzzified significance weights of activities; It is possible to defuzzify the fuzzy significance weights of activities using the Graded Mean Integration Representation (GMIR) according to the following Eq. (6):

$$R(\widetilde{W}_i) = \frac{l_i + 4m_i + u_i}{6} \tag{6}$$

Where l_i, m_i and u_i indicate the lower bound, peak, and upper bound of every fuzzy weight $\widetilde{W}_i$, correspondingly.

7) Calculation of the Consistency Ratio (CR) of pairwise comparisons; Consistency ratio represents the reliability of fuzzy pairwise comparisons. It is necessary to hold $\widetilde{P}_{Bj} \times \widetilde{P}_{jW} = \widetilde{P}_{BW}$ for all values of j for a completely consistent pairwise comparison, in which $\widetilde{P}_{BW}$ represents the fuzzy relative significance of the best activity A_B over the Worst activity A_W. The consistency ration of a pairwise comparison can be estimated using Eq. (7), and its close values to zero indicate higher reliability of the comparison data.

$$CR = \frac{\xi^*}{CI} \tag{7}$$

In which, $\boldsymbol{\xi}^*$ represents $\boldsymbol{\xi}$ optimal value obtained by the solution to the optimization problem, and CI shows the Consistency Index (CI) considering $\boldsymbol{\xi}$ maximum level, determined based on Table 4.

After identifying the local contribution weights of activities and SCR effective factors, it is possible to calculate the global contribution weights of activities using Eq. (8).

$$GW_{A_i} = \frac{LW_{A_i} \times LW_{F_K}}{\left(\prod_{i=1}^{NK} LW_{A_i}\right)^{\frac{1}{N_k}}} \tag{8}$$

Where GW_{A_i} and LW_{A_i} show the global and local contribution weights of activity A_i, respectively. k and N_k indicate the number of functional areas and activities within functional area k, whereas LW_{F_K} represents the local contribution weight of the functional area k.

When the causal associations of activities and their contribution weights to the overall resilience of supply chains are determined, improvement of the SCR assessment model will be possible.

3.2.3. Assessment of the status of SCR activities

Six linguistic terms have been utilized for the evaluation of SCR status in the domain of every activity (Table 5). The value of each activity and the local weights have been then used to calculate the value of every factor.

3.2.4. Assessment of the overall status of supply chain resilience

Following the assessment of the status of factors, it is possible to assess the scope of supply chain resilience presence across the organization as a whole with the use of the FCM model, in which these values change iteratively following the assignment of the nodes

Table 4
(CI) in fuzzy BWM.

Linguistic term for $\widetilde{P}_{BW}$	EI	WI	FI	VI	AI
CI	3.00	3.80	5.29	6.69	8.04

Table 5
Status of decision factor.

Linguistic term	Triangular fuzzy number
No decision (ND)	(0,0,0.2)
Very weak decided (VWD)	(0,0.2,0.4)
Weak decided (WD)	(0.2,0.4,0.6)
Moderate decided (MD)	(0.4,0.6,0.8)
Strong decided (SD)	(0.6,0.8,1)
Very strong decided (VSD)	(0.8,1,1)

and identification of the numerical values to each to obtain a status of equilibrium. Eq. (9) below indicates the calculation of the new value of every factor in the iteration t:

$$\widetilde{V}_{F_i}^{(t)} = \widetilde{V}_{F_i}^{(t=0)} + f\left(\sum\nolimits_{j=1}^{n} \widetilde{V}_{F_j}^{(t=1)} \times \widetilde{w}_{F_j,F_i}\right) \tag{9}$$

In which, $\widetilde{V}_{F_i}^{(t)}$ and $\widetilde{V}_{F_j}^{(t=1)}$ represent the factor's fuzzy values (F_i) in iterations in iteration t and $t-1$, respectively, $\widetilde{w}_{F_j,F_i}$ correlates with the fuzzy weight between two factors, and f reflects a threshold function converting the multiplication results to a number in the interval [0, 1]. There are various types for f function, among which the logistic function represented in Eq. (10) is the commonest:

$$f(x) = \frac{e^{c\widetilde{x}} - e^{-c\widetilde{x}}}{e^{c\widetilde{x}} + e^{-c\widetilde{x}}}\ \widetilde{X} = \sum\nolimits_{j=1}^{n} \widetilde{V}_{F_j}^{(t=1)} \times \widetilde{w}_{F_j,F_i} \tag{10}$$

In which, c > 0 represents the function slope with a constant value. Multiplication of the ultimate value of every factor by its global contribution weights takes place through Eq. (11), the results of which indicate the overall status of supply chain resilience across the organization.

$$\widetilde{FR} = \frac{\sum\limits_{i=1}^{n} \widetilde{V}_{F_i \times} Gw_{F_i}}{\sum\limits_{i=1}^{n} Gw_{F_i}} \tag{11}$$

In which, $\widetilde{V}_{F_i}$ is the final value of factor i derived from FCM step-by-step estimation. Gw_{F_i} represents the contribution weight of the factors resulting from the comparisons among them. Eq. (12) below is employed for defuzzification of the fuzzy value (l, m, n) of $\widetilde{FR}$ to a crisp value"

$$M(\widetilde{FR}) = \frac{L + 2m + u}{4} \tag{12}$$

3.2.5. Assessment model analysis

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique is employed for the categorization of the activities according to their centrality and causality. DEMATEL has considerable popularity employed to model associations of criteria and map the associations into as diagraph categorizing factors into cause as well as effect groups [96]. It is also possible to divide the diagraph into four segments to rank activities and consequently facilitate the improvement plan development [97].

The DEMATEL method employed in this step takes into account the connection matrix $[w_{ij}]_{n\times n}$ obtained from Step 5.1. The prioritizing steps below are followed in the **DEMATEL** method (Malekzadeh et al., 2016):

1. The following equations (13) and (14) shows the calculation of the normalized final connection matrix $[X_{ij}]_{n\times n}$:

$$[w_{ij}]_{n\times n}\ and\ 0 \le x_{ij} \le 1\ X = s \times W \tag{13}$$

$$s = \frac{1}{\max\limits_{1\le i\le n} \sum_{j}^{n} w_{ij}}\ i,j = 1,2,\ldots,n \tag{14}$$

2. The following Eq. (15) calculates Matrix T, which indicates the direct and indirect associations of activities.

$$T = (I - X)^{-1} \tag{15}$$

In which, I represents the $n \times n$ identity matrix.

3. It is possible to extract two "R" and "J" values from the T matrix. The column called "R" and the row known as "J" indicate the rows and the column sums, respectively. The extent to which other activities are influenced by the activity i is determined using Ri" (row sums), while the extent to which the activity i is influenced by other activities is determined using the "ji " (column sums).
4. Calculation of $(R_i + J_i)$ and $(R_i - J_i)$ values. The index $(R_i + J_i)$ shows the strength of impacts given and received and the degree of every factor's interaction in the FCM network. The index $(R_i - J_i)$ indicates the impact dispatching in comparison with receiving for every factor so that positive values of $(R_i - J_i)$ for a factor reflect a cause variable, and negative values represent an effect variable. It is possible to classify the factors into four zones (Fig. 2) as shown in the following with the use of the two values provided by the DEMATEL method:

- Factors having high $(R_i + J_i)$ and $(R_i - J_i)$ values indicate considerable significance in the FCM network, as no changes or improvements in the status of one of them significantly lead to changes or improvement of the status of other factors.
- Factors with high impact $(R_i - J_i)$ but low interaction $(R_i + J_i)$ need particular consideration because of their high level of impact on other factors.
- Factors with less impacts $(R_i - J_i)$ but high interactions $(R_i + J_i)$ should be only regularly considered because of their overall interaction with the other factors.
- Factors with less impacts $(R_i - J_i)$ and less interactions $(R_i + J_i)$ should be categorized as those requiring less consideration because of being only influenced by other factors without any special interactions with them in the model.

In addition to the grouping technique mentioned here, another technique can be also employed to classify activities considering a different dimension. Another management matrix can be drawn as show in Fig. 3, utilizing two criteria of the geometric mean of the impact (direct and indirect) of every activity on the others (vertical axis), and the mean of contribution weight of every activity (already illustrated as GW_{F_i} on the overall success (horizontal axis) (Yeh et al., 2013).

Decision-makers can figure out the scope of the impact of changes in every activity on the success status of other activities using the vertical measures. However, the impact of these changes on the supply chain resilience overall status will be shown by the horizontal measures.

Those factors in the high attention zone (I) require special consideration when improving the overall status of supply chain resilience, since they affect other factors as well as the overall success. Appropriate resource allocation to these factors seems logical. Also, decision-makers need to supervise the success status of these factors constantly.

Characterization of factors in zone (II) is based on their significant impact in the network model and the low contribution levels. Given the impacts in the mode, the success status of the factors needs to be specially considered by the decision-makers to ensure appropriate resource allocation to them. Decision-makers can think of more resource allocation to these factors for their long-term plans.

The success status of the factors belonging to the regular attention zone (IV) should be regularly and periodically checked by decision-makers. Besides, decision-makers are recommended to consider the factors falling in the low attention zone (III) to a lesser extent and just after sufficient consideration has been allocated to other factors.

4. Result and discussion

The step-by-step practical directions on the suggested FCM-pairwise comparison procedure associated with the SCRs to an Iranian pharmaceutical company are provided in this section. Seven experts provided the input information for the present study.

4.1. Formulation of the causal associations of factors

The suggested FCM method in Section 3.2.1 is initially used for the formulation of the factors' interrelationships. Experts provided definitions of the directions of the relationships according to their perceptions of resilience and supply chain management. They also assessed the presence and weights of the factors' interrelationships through several workshops and meetings.

Table 6 indicates the final communication matrix among the factors.

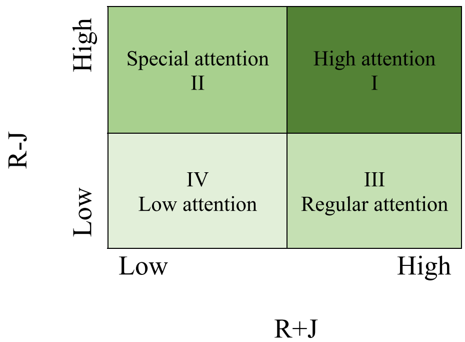

Fig. 2. Four management zones considered in factor analysis.

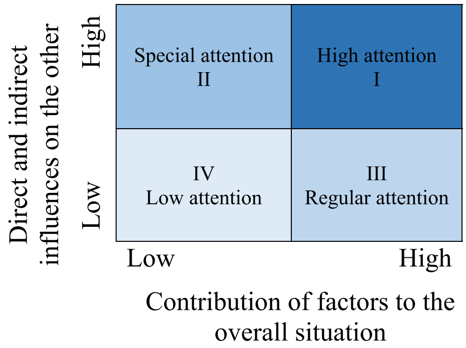

Fig. 3. Four management zones considered in factor analysis.

Table 6
The final communication matrix among the factors. $\left(\overline{W}^{Aug}_{A_i,A_j}\right)$.

F	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.3,0.5,0.7	0	0.1,0.3,0.5	0	0.5,0.7,1.0	0	0	0	0
F2	0	0	0.5,0.7,1.0	0.3,0.5,0.7	0.3,0.5,0.7	0.5,0.7.1.0	0	0	0.5,0.7,1.0	0
F3	0	0	0	0	0	0	0	0	0.3,0.5,0.7	0.5,0.7,1.0
F4	0	0.3,0.5,0.7	0	0	0	0.5,0.7,1.0	0	0	0	0
F5	0.3,0.5,0.7	0.5,0.7,1.0	0	0	0	0	0	0	0	0
F6	0.0,0.1,0.3	0.5,0.7,1.0	0	0.5,0.7,1.0	0	0	0	0	0	0.1,0.3,0.5
F7	0	0	0	0	0.5,0.7,1.0	0	0	0.3,0.5,0.7	0	0
F8	0	0	0	0	0.5,0.7,1.0	0	0	0	0	0.1,0.3,0.5
F9	0	0.5,0.7,1.0	0.3,0.5,0.7	0	0	0	0	0	0	0
F10	0	0	0.5,0.7,1.0	0.3,0.5,0.7	0	0.3,0.5,0.7	0	0	0	0

Fig. 4 provides a graphical representation of the mentioned connections. The graph presents the factors using circles and interrelationships of the factors by arrows. The impact direction is shown by the direction of arrows.

4.2. Assessment of the contribution of activities or factors to the overall success

The FBWM approach was utilized and the reference pairwise comparisons were executed for the calculation of the factors' contribution and the activities belonging to them to the overall resilience of the supply chain. Fig. 5 indicates the results obtained from pairwise comparisons and their relative Consistency Ratios (CR) while also representing the local and global contribution weights. As Rezaei [93] has stressed, all Consistency Ratios have significantly lower values compared to the threshold (0.1), indicating appropriate consistencies.

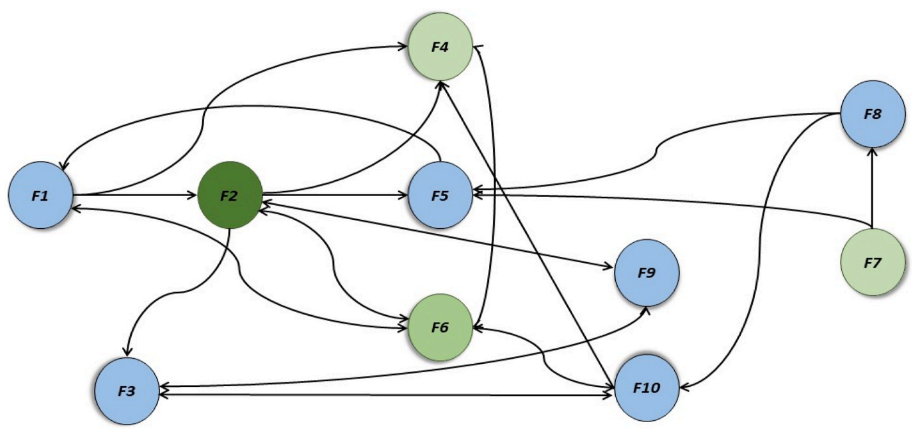

Fig. 4. The causal associations of the influencing factors.

Pairwise comparisons in F1

	A1	A2	A3	L,m,u			w	CR
A1	EI	AI	VI	0.632	0.632	0.632	0.632	
A2			FI	0.239	0.2	0.173	0.203	0.0941
A3			EI	0.189	0.165	0.145	0.166	

Pairwise comparisons in F2

	A4	A5	A6	L,m,u			w	CR
A4	EI			0.169	0.2	0.247	0.210	
A5	FI			0.202	0.247	0.294	0.247	0.0548
A6	FI/VI	VI	EI	0.514	0.552	0.552	0.542	

Pairwise comparisons in F3

	A7	A8	L,m,u			W	CR
A7	EI	VI/FI	0.8418	0.705	0.645	0.718	0.6310
A8		EI	0.282	0.282	0.309	0.288	

Pairwise comparisons in F4

	A9	A10	L,m,u			W	CR
A9	EI		0.618	0.705	0.845	0.718	0.1508
A10	VI/FI	EI	0.282	0.282	0.309	0.288	

Pairwise comparisons in F5

	A11	A12	L,m,u			W	CR
A11	EI	AI/VI	0.696	0.793	0.793	0.768	0.1663
A12		EI	0.198	0.227	0.232	0.221	

Pairwise comparisons in F6

	A13	A14	A15	L,m,u			w	CR
A13		WI		0.223	0.338	0.305	0.251	
A14		EI		0.190	0.196	0.240	0.205	0.0563
A15	FI	VI	EI	0.538	0.538	0.617	0.557	

Pairwise comparisons between ten factors

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	GW
F1										VI	0.080
F2	VI	EI	FI	WI	FI	VI	FI	VI	FI	VI/AI	0.210
F3										FI	0.108
F4										AI	0.155
F5										FI	0.111
F6										VI	0.079
F7										VI	0.128
F8										FI	0.053
F9										WI	0.062
F10										EI	0.039

Pairwise comparisons in F7

	A16	A17	L,m,u			W	CR
A16	EI	FI	0.654	0.645	0.759	0.673	0.0802
A17		EI	0.327	0.327	0.384	0.341	

Pairwise comparisons in F9

	A20	A21	L,m,u			W	CR
A20	FI		0.282	0.282	0.309	0.288	0.0820
A21	VI/EI	EI	0.618	0.705	0.845	0.718	

Pairwise comparisons in F8

	A18	A19	L,m,u			W	CR
A18	EI	FI/VI	0.618	0.705	0.845	0.718	0.0809
A19		EI	0.282	0.282	0.309	0.288	

Pairwise comparisons in F10

	A22	A23	L,m,u			W	CR
A22	EI		0.282	0.282	0.309	0.228	0.1268
A23	FI/VI	EI	0.618	0.705	0.845	0.718	

Fig. 5. Pairwise comparison results.

4.3. Evaluation of the activities' success status and the overall status of supply chain resilience

Six linguistic terms (Table 6) were used to assess the present status of every activity, followed by the injection of the results into the assessment model and the calculation of the factor values. The FCM inference (Eq. (8)) was used to calculate the impacts of attributes on one another, followed by the multiplication of the final values of factors by the factors' global contribution weights (GW_{F_k}) to identify supply chain resilience overall status in the pharmaceutical company.

Table 7 indicates both the fuzzy and conclusive final values of implementation status of supply chain resilience in the pharmaceutical company.

Fig. 6 indicates the final value equal to 0.594, which is very close to "Moderately decided." Thus, supply chain resilience seems to be comparatively accepted within the company.

4.4. The analysis assessment model

4.4.1. Planning and management of factors

The study has some practical insights for decision-makers in obtaining higher efficiency in the development of improvement plans. According to section 5.5, activities can be categorized into two matrices and according to four criteria: GW_A, R_i, $(R_i - J_i)$ and $(R_i + J_i)$, enabling decision-makers to choose improvement activities with the greatest desirability of the results. DEMATEL analysis results are presented in Table 8.

The decision-makers can provide two plots according to Figs. 7 and 8 using these four criteria. As shown in Fig. 7, activities are categorized into four management zones considering two criteria: $(R_i - J_i)$ and $(R_i + J_i)$. As indicated in Fig. 8, activities are categorized using the criterion GW_A, and the overall impacts of activities on others (R_i).

Fig. 7 can be analyzed considering the four segments in Fig. 8, according to which the factor of Speed of flexibility (F6) had a significant impact on others but insignificant contribution weight to the supply chain resilience, which means it should be specially considered by managers. One factor, called cooperation and trust between supply chain members (F2) is accommodated by the considerable attention segment in Fig. 8, according to which this factor showed a comparatively considerable centrality and causality among other factors, hence, constituting the first priority to allocate resources. Several factors in Fig. 8 show a high level of GW, with lower than average direct and indirect impacts. The improvement of these factors requires regular management efforts, including Visibility & Agility (F4), Leadership Support and Commitment (F7).

4.4.2. Scenario analysis of the improvement plan

The decision-makers need to identify the best improvement plan following the evaluation of the current organizational success status to enhance the total success status of the organizational supply chain resilience. According to what was previously mentioned, the key benefit of considering the causal associations in the development of the assessment model is evaluating the overall organizational status with significant precision after various improvement scenarios are conducted. The following set of improvement

Table 7
The overall supply chain resilience status in the pharmaceutical company.

Factors	*Activity*	*A state*			*WA state*			*F state*		
F1: Supply chain reengineering	A1 Supply chain understanding (Flexibility vs. Redundancy)	0.60	0.80	1.00	0.37	0.50	0.63	0.47	0.67	0.80
	A2 Use supply base strategies (suppliers' risk awareness)	0.20	0.40	0.60	0.04	0.08	0.12			
	A3 Design principles for resilience of supply chains	0.40	0.60	0.80	0.06	0.09	0.13			
F2: Cooperation and trust between supply chain members	A4 Management of risk	0.60	0.80	1.00	0.12	0.16	0.21	0.42	0.62	0.83
	A5 Creating cooperative contracts among partners	0.40	0.60	0.80	0.09	0.14	0.19			
	A6 Trust facilitates cooperation and collaboration	0.40	0.60	0.80	0.21	0.32	0.43			
F3: Information sharing as driver of resiliency	A7 Internal and external knowledge sharing	0.60	0.80	1.00	0.43	0.57	0.71	0.60	0.80	0.99
	A8 Monitoring, and decentralized structure	0.60	0.80	1.00	0.17	0.23	0.28			
F4: Visibility & Agility	A9 used modeling of complex production/distribution systems	0.40	0.60	0.80	0.28	0.43	0.57	0.39	0.60	0.80
	A10 Quickly redesign supply chains	0.40	0.60	0.80	0.11	0.17	0.23			
F5: SCRM culture	A11 Creating a culture and change management	0.00	0.00	0.20	0.00	0.00	0.15	0.04	0.08	0.28
	A12 Creating a risk management culture	0.20	0.40	0.60	0.04	0.08	0.13			
F6: Speed of flexibility	A13 Using streamlined processes	0.60	0.80	1.00	0.15	0.20	0.25	0.45	0.65	0.85
	A14 Eliminating nonvalue- added time	0.40	0.60	0.80	0.08	0.12	0.16			
	A15 Reduction in bound lead times	0.40	0.60	0.80	0.22	0.33	0.44			
F7: Leadership Support and Commitment	A16 Investigate the contribution of leaders and top managers	0.40	0.60	0.80	0.26	0.40	0.53	0.32	0.53	0.73
	A17 Review strategic decisions	0.20	0.40	0.60	0.06	0.13	0.20			
F8: Innovation	A18 Creating a flexibility	0.40	0.60	0.80	0.28	0.43	0.57	0.33	0.54	0.74
	A19 Analyzing values, beliefs, and behavioral patterns	0.20	0.40	0.60	0.05	0.11	0.17			
F9: Supply chain community	A20 Collaborative working and risk reduction	0.60	0.80	1.00	0.17	0.23	0.28	0.60	0.80	0.99
	A21 Information sharing both pre and post disruptions	0.60	0.80	1.00	0.43	0.57	0.71			
F10: Sharing knowledge and risk	A22 Mitigate disruptions	0.40	0.60	0.80	0.11	0.17	0.23	0.54	0.74	0.94
	A23 Connectivity of supply chains and information-sharing resources	0.60	0.80	1.00	0.43	0.57	0.71			

FR			deFR
0.4026	0.5944	0.7970	0.5971

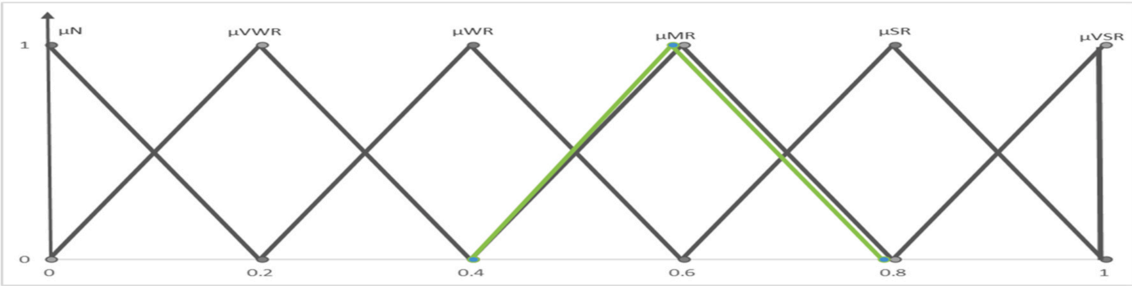

Fig. 6. Situation assessment results.

Table 8
DEMATEL analysis results.

F	R	J	$(R_i - J_i)$	$(R_i + J_i)$	GW
F1	1.2373	0.4339	0.8034	1.6712	0.0800
F2	2.0692	2.2735	−0.2043	4.3427	0.2100
F3	0.7962	1.5356	−0.7394	2.3318	0.1080
F4	1.0441	1.6439	−0.5998	2.6880	0.1550
F5	1.0532	1.0082	0.0450	2.0614	0.1110
F6	1.4559	1.9890	−0.5331	3.4449	0.0790
F7	0.7317	0	0.7317	0.7317	0.1280
F8	0.6690	0.1575	0.5115	0.8265	0.0530
F9	0.9837	1.1468	−0.1631	2.1305	0.0620
F10	1.1188	0.9708	0.1480	2.0896	0.0390

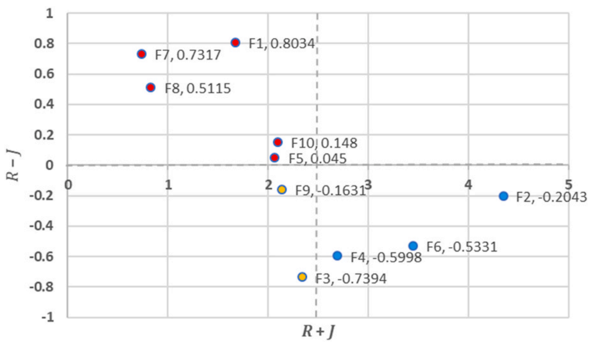

Fig. 7. Classifying factors according to $(R_i - J_i)$, $(R_i + J_i)$.

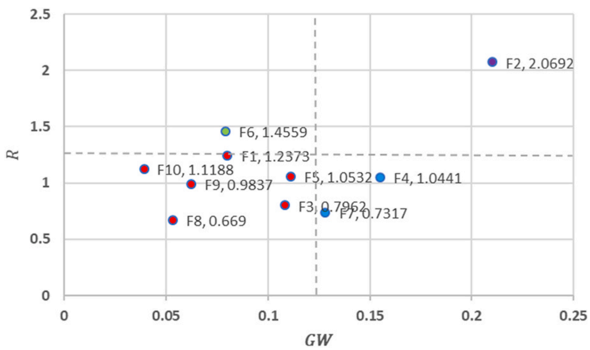

Fig. 8. Classifying factors according to their contribution weight and impact on the other activities.

scenarios will be developed.

1) Application of one level up improvement in a single activity and evaluation of its impacts on the overall organizational success. The activity with the highest impact in the model will be determined by the results obtained from this improvement scenario.
2) Application of one level up improvement in total activities associated with a factor and measurement of its effects on the overall organizational status. The factor with the highest impact in the model will be determined by the results obtained from this improvement scenario.

Table 9
The results of the 23 improvement scenarios.

Factors	*Activity*	*A state*			*Improvement scenario*	*F state*			*rank*	*deF*
F1: Supply chain reengineering	A1 Supply chain understanding (Flexibility vs. Redundancy)	0.60	0.80	1.00	0.8000	0.60	0.80	0.88	**6**	**0.7700**
	A2 Use supply base strategies (suppliers' risk awareness)	0.20	0.40	0.60	0.4000	0.51	0.71	0.92	**11**	**0.7125**
	A3 Design principles for resilience of supply chains	0.40	0.60	0.80	0.6000	0.54	0.75	0.95	**8**	**0.7475**
F2: Cooperation and trust between supply chain members	A4 Management of risk	0.60	0.80	1.00	0.8000	0.46	0.67	0.83	**16**	**0.6575**
	A5 Creating cooperative contracts among partners	0.40	0.60	0.80	0.6000	0.47	0.67	0.88	**14**	**0.6725**
	A6 Trust facilitates cooperation and collaboration	0.40	0.60	0.80	0.6000	0.53	0.73	0.94	**10**	**0.7325**
F3: Information sharing as driver of resiliency	A7 Internal and external knowledge sharing	0.60	0.80	1.00	0.8000	0.74	0.94	0.99	**1**	**0.9025**
	A8 Monitoring, and decentralized structure	0.60	0.80	1.00	0.8000	0.66	0.85	0.99	**3**	**0.8375**
F4: Visibility & Agility	A9 used modeling of complex production/distribution systems	0.40	0.60	0.80	0.6000	0.54	0.74	0.94	**9**	**0.7400**
	A10 Quickly redesign supply chains	0.40	0.60	0.80	0.6000	0.45	0.66	0.85	**17**	**0.6550**
F5: SCRM culture	A11 Creating a culture and change management	0.00	0.00	0.20	0.2000	0.04	0.23	0.43	**20**	**0.2325**
	A12 Creating a risk management culture	0.20	0.40	0.60	0.4000	0.08	0.13	0.32	**21**	**0.1650**
F6: Speed of flexibility	A13 Using streamlined processes	0.60	0.80	1.00	0.8000	0.50	0.70	0.85	**13**	**0.6875**
	A14 Eliminating nonvalue-added time	0.40	0.60	0.80	0.6000	0.49	0.69	0.89	**12**	**0.6900**
	A15 Reduction in bound lead times	0.40	0.60	0.80	0.6000	0.56	0.76	0.96	**7**	**0.7600**
F7: Leadership Support and Commitment	A16 Investigate the contribution of leaders and top managers	0.40	0.60	0.80	0.6000	0.46	0.66	0.87	**15**	**0.6625**
	A17 Review strategic decisions	0.20	0.40	0.60	0.4000	0.39	0.60	0.80	**19**	**0.5975**
F8: Innovation	A18 Creating a flexibility	0.40	0.60	0.80	0.6000	0.45	0.68	0.74	**18**	**0.6375**
	A19 Analyzing values, beliefs, and behavioral patterns	0.20	0.40	0.60	0.4000	0.39	0.60	0.80	**19**	**0.5975**
F9: Supply chain community	A20 Collaborative working and risk reduction	0.60	0.80	1.00	0.8000	0.66	0.85	0.99	**4**	**0.8225**
	A21 Information sharing both pre and post disruptions	0.60	0.80	1.00	0.8000	0.74	0.94	0.99	**1**	**0.9025**
F10: Sharing knowledge and risk	A22 Mitigate disruptions	0.40	0.60	0.80	0.6000	0.60	0.80	0.99	**5**	**0.7975**
	A23 Connectivity of supply chains and information-sharing resources	0.60	0.80	1.00	0.8000	0.68	0.88	0.94	**2**	**0.8450**

FR			deFR
0.4026	0.5944	0.7970	0.5971

3) Application of one level up improvement in all 10 factors through application of one improvement in one of the activities belonging to it with the highest impact on the overall organizational status**.**

When the above improvement scenarios are conducted and their impacts on the overall status of supply chain resilience are assessed, there will be more likelihood to determine the improvement plan with the highest efficiency.

Improvement of all activities one level up takes place in the first set of scenarios, according to which when there are weak decisions (WD) on an activity's current success status, it is improved to a moderate decision (MD) by the decision-makers.

The effects of proposed 23 improvement scenarios on the overall status of the pharmaceutical company are shown in Table 9.

The results of every improvement scenario are shown in the column (overall status defuzzified value) in Tables 9 and it is possible to

Table 10
Improvement scenarios within each factor.

Factors	*Activity*	*A state*			*Improvement Factors*	*F state*	*DeF*
F1: Supply chain reengineering	A1 Supply chain understanding (Flexibility vs. Redundancy)	0.60	0.80	1.00	0.8000	**0.67**	**0.8450**
	A2 Use supply base strategies (suppliers' risk awareness)	0.20	0.40	0.60	0.4000		
	A3 Design principles for resilience of supply chains	0.40	0.60	0.80	0.6000		
F2: Cooperation and trust between supply chain members	A4 Management of risk	0.60	0.80	1.00	0.8000	**0.62**	**0.8175**
	A5 Creating cooperative contracts among partners	0.40	0.60	0.80	0.6000		
	A6 Trust facilitates cooperation and collaboration	0.40	0.60	0.80	0.6000		
F3: Information sharing as driver of resiliency	A7 Internal and external knowledge sharing	0.60	0.80	1.00	0.8000	**0.80**	**0.9425**
	A8 Monitoring, and decentralized structure	0.60	0.80	1.00	0.8000		
F4: Visibility & Agility	A9 used modeling of complex production/distribution systems	0.40	0.60	0.80	0.6000	**0.60**	**0.7975**
	A10 Quickly redesign supply chains	0.40	0.60	0.80	0.6000		
F5: SCRM culture	A11 Creating a culture and change management	0.00	0.00	0.20	0.2000	**0.08**	**0.2775**
	A12 Creating a risk management culture	0.20	0.40	0.60	0.4000		
F6: Speed of flexibility	A13 Using streamlined processes	0.60	0.80	1.00	0.8000	**0.65**	**0.8375**
	A14 Eliminating nonvalue-added time	0.40	0.60	0.80	0.6000		
	A15 Reduction in bound lead times	0.40	0.60	0.80	0.6000		
F7: Leadership Support and Commitment	A16 Investigate the contribution of leaders and top managers	0.40	0.60	0.80	0.6000	**0.53**	**0.7325**
	A17 Review strategic decisions	0.20	0.40	0.60	0.4000		
F8: Innovation	A18 Creating a flexibility	0.40	0.60	0.80	0.6000	**0.54**	**0.7050**
	A19 Analyzing values, beliefs, and behavioral patterns	0.20	0.40	0.60	0.4000		
F9: Supply chain community	A20 Collaborative working and risk reduction	0.60	0.80	1.00	0.8000	**0.80**	**0.9425**
	A21 Information sharing both pre and post disruptions	0.60	0.80	1.00	0.8000		
F10: Sharing knowledge and risk	A22 Mitigate disruptions	0.40	0.60	0.80	0.6000	**0.74**	**0.9025**
	A23 Connectivity of supply chains and information-sharing resources	0.60	0.80	1.00	0.8000		

FR			deFR
0.4026	0.5944	0.7970	0.5971

FR-SA2			deFR-SA2
0.5907	0.7983	0.9244	0.7779

determine ranks in the last column through these values of activities. Accordingly, the highest levels of supply chain resilience status were obtained by one level improvement in A23, A7, and A21, leading to values of 0.902 and 0.845, correspondingly. Therefore, one of these activities needs improvement to achieve the improvement of only one of the activities in the pharmaceutical industries.

Table 11
Scenarios of improvement for all 10 factors and the topmost considered 10 influencing activities.

Factors	*Rank*	*activity*	*A state*			*Improvement scenario1*	*Improvement scenario2*	*F state1*			*F state2*		
F1: Supply chain reengineering	**6**	A1 Supply chain understanding (Flexibility vs. Redundancy)	0.60	0.80	1.00	**0.8000**	**0.8000**	0.60	0.80	0.88	0.63	0.84	0.91
	11	A2 Use supply base strategies (suppliers' risk awareness)	0.20	0.40	0.60	**No change**	**No change**						
	8	A3 Design principles for resilience of supply chains	0.40	0.60	0.80	**No change**	**0.6000**						
F2: Cooperation and trust between supply chain members	**16**	A4 Management of risk	0.60	0.80	1.00	**No change**	**No change**	0.53	0.73	0.94	0.42	0.62	0.83
	14	A5 Creating cooperative contracts among partners	0.40	0.60	0.80	**No change**	**No change**						
	10	A6 Trust facilitates cooperation and collaboration	0.40	0.60	0.80	**0.6000**	**No change**						
F3: Information sharing as driver of resiliency	**1**	A7 Internal and external knowledge sharing	0.60	0.80	1.00	**0.8000**	**0.8000**	0.74	0.94	0.99	0.80	0.99	0.99
	3	A8 Monitoring, and decentralized structure	0.60	0.80	1.00	**No change**	**0.8000**						
F4: Visibility & Agility	**9**	A9 used modeling of complex production/distribution systems	0.40	0.60	0.80	**0.6000**	**0.6000**	0.54	0.74	0.94	0.54	0.74	0.94
	17	A10 Quickly redesign supply chains	0.40	0.60	0.80	**No change**	**No change**						
F5: SCRM culture	**20**	A11 Creating a culture and change management	0.00	0.00	0.20	**0.2000**	**No change**	0.04	0.23	0.43	0.04	0.08	0.28
	21	A12 Creating a risk management culture	0.20	0.40	0.60	**No change**	**No change**						
F6: Speed of flexibility	**13**	A13 Using streamlined processes	0.60	0.80	1.00	**No change**	**No change**	0.56	0.76	0.96	0.56	0.76	0.96
	12	A14 Eliminating nonvalue-added time	0.40	0.60	0.80	**No change**	**No change**						
	7	A15 Reduction in bound lead times	0.40	0.60	0.80	**0.6000**	**0.6000**						
F7: Leadership Support and Commitment	**15**	A16 Investigate the contribution of leaders and top managers	0.40	0.60	0.80	**0.6000**	**No change**	0.46	0.66	0.87	0.32	0.53	0.73
	19	A17 Review strategic decisions	0.20	0.40	0.60	**No change**	**No change**						
F8: Innovation	**18**	A18 Creating a flexibility	0.40	0.60	0.80	**0.6000**	**No change**	0.48	0.68	0.74	0.33	0.54	0.74
	19	A19 Analyzing values, beliefs, and behavioral patterns	0.20	0.40	0.60	**No change**	**No change**						
F9: Supply chain community	**4**	A20 Collaborative working and risk reduction	0.60	0.80	1.00	**No change**	**0.8000**	0.74	0.94	0.99	0.80	0.99	0.99
	1	A21 Information sharing both pre and post disruptions	0.60	0.80	1.00	**0.8000**	**0.8000**						
F10: Sharing knowledge and risk	**5**	A22 Mitigate disruptions	0.40	0.60	0.80	**No change**	**0.6000**	0.68	0.88	0.94	0.74	0.94	0.99
	2	A23 connectivity of supply chains and information-sharing resources	0.60	0.80	1.00	**0.8000**	**0.8000**						

FR			deFR
0.4026	0.5944	0.7970	0.5971

FR-SA3			deFR-SA3
0.5216	0.7273	0.8911	0.7168

FR-SA3			deFR-SA3
0.4882	0.6775	0.8380	0.6703

Nevertheless, there are other limitations such as time, budget, and the likelihood of obtaining an improvement in every activity, which require consideration.

the second set of scenarios investigates the factors with the greatest improvement priority, taking their efficiency in the model into account. Overall, 10 scenarios were carried out for every single factor. As shown by the results of Table 10, every scenario implemented one level improvement for all activities that belonged to every factor. Column 3 of the table describes every scenario. As an instance, activities A1, A2, and A3 received one level improvement in the first scenario, leading to the defussified value of 0.845. Hence, the pharmaceutical industries can use this analysis to determine the factors which have the greatest improvement priority.

The combined strategy is taken into account as shown in the following through the third set of scenarios.

1) Improvement a single activity in every factor with the highest rank of impacts; and
2) Improvement of 10 activities with the highest rank of impacts.

The influencing ranks of the 23 mentioned activities are shown in the last column of Table 11, according to which, nearly similar results are obtained in two scenarios, and the company can select one of them. Yet, the first scenario leads to the improvement of all the 10 factors. However, by considering the first scenario, all the 10 factors are somehow improved, and the status of pharmaceutical company had improvements from all influencing dimensions and all associated departments in the company were involved in this improvement. management and application of this improvement plan could be more convenient compared to the second scenario, because simultaneous improvement of multiple activities that belong to one factor is necessary in the second scenario. The pharmaceutical industries may lack the required resources for the improvement of all activities. The selection of the scenario needs analyzing management and other resources required for improvement carefully.

5. Findings and implications

This study aims to provide a resilient supply chain model that ranks and prioritizes the factors affecting its resilience. Unlike previous studies that used deterministic or probabilistic models, this study uses the FCM - FBWM technique to evaluate and assign different weights to the factors based on the FBWM method, which results in different ranking of factors. This method also avoids wasting time and money to improve factors that depend on other factors. This study adopts a wide and comprehensive view of the problem, which covers the gap of previous research that lacked a partial and comprehensive view. It can be said that this study covers the gap of previous research and helps managers to provide effective strategies to improve the business performance of their companies and organizations. This is claimed to be a comprehensive and novel approach that can cover the gap of previous research that lacked a partial and comprehensive view of the problem.

In this paper, to reject the inherent subjectiveness and imprecision involved in the evaluation process, the authors use the concept of fuzzy logic in this approach for developing the assessment model and analyzing the model for allocating the management efforts in the most efficient way to improve the resilience in supply chain deployment level. The proposed approach allows supply chain decision makers to (1) identify the relevant factors for resilience in supply chain, (2) model the causal relationships among the identified factors, (3) assess the factors " contribution weights to the overall improvement, and (4) develop an effective improvement plan by prioritizing those factors with the most impact on the overall improvement. Fuzzy cognitive maps (FCMs) are employed to model the causal relationships between the factors, and the fuzzy best worst method (FBWM) is adopted to establish the contribution weights of the factors to the resilience in supply chains overall improvement.

Considering the priority set for each attribute, a decision model is shown in (Fig. 9), which enables organizations and companies to make better decisions regarding resilience in the supply chain. The diagram shown in (Fig. 9) shows resilience strategies in the supply chain at the time of challenges and possible disruptions proposed to companies based on the prioritization of features (Fig. 8) and three other semi-qualitative factors such as uncertainty, lack of coordination, and financial challenges.

Uncertainty: The main source of supply chain uncertainty is the demand forecasting. The demand forecasting is influenced by several factors such as competition, prices, current conditions, technological development and the general level of customer commitment. Another factor of uncertainty in the supply chain is the delivery times, which depend on factors such as the breakdown ratio of machines in the linear production process, traffic congestion that interferes with transportation, and material quality problems that may cause production delays.

Lack of coordination: These types of problems happen when a department of the company does not have a good relationship with other departments. When the message is incomprehensible to the business partners and when the company's departments are not aware of some issues, or they become aware of what is needed or what should happen too late. Among others, we can mention the effect of leather whip and deceptive reserve.

Financial challenge: It is a kind of challenge that the organization does not have enough money to face its financial consequences. If the organization uses loans and credits, it must be able to repay them on time, otherwise it will face financial challenges. Four decision categories in this model are as follow:

In general, considering the three aforementioned challenges and the priority resilience features determined in the previous analysis, various scenarios for supply chain challenges could be presented. We classified the scenarios in the following three categories.

5.1. *Category 1: Scenarios related to significant attention features*

According to the diagram in Fig. 8, if the company is facing financial challenges, lack of coordination and uncertainty, by increasing

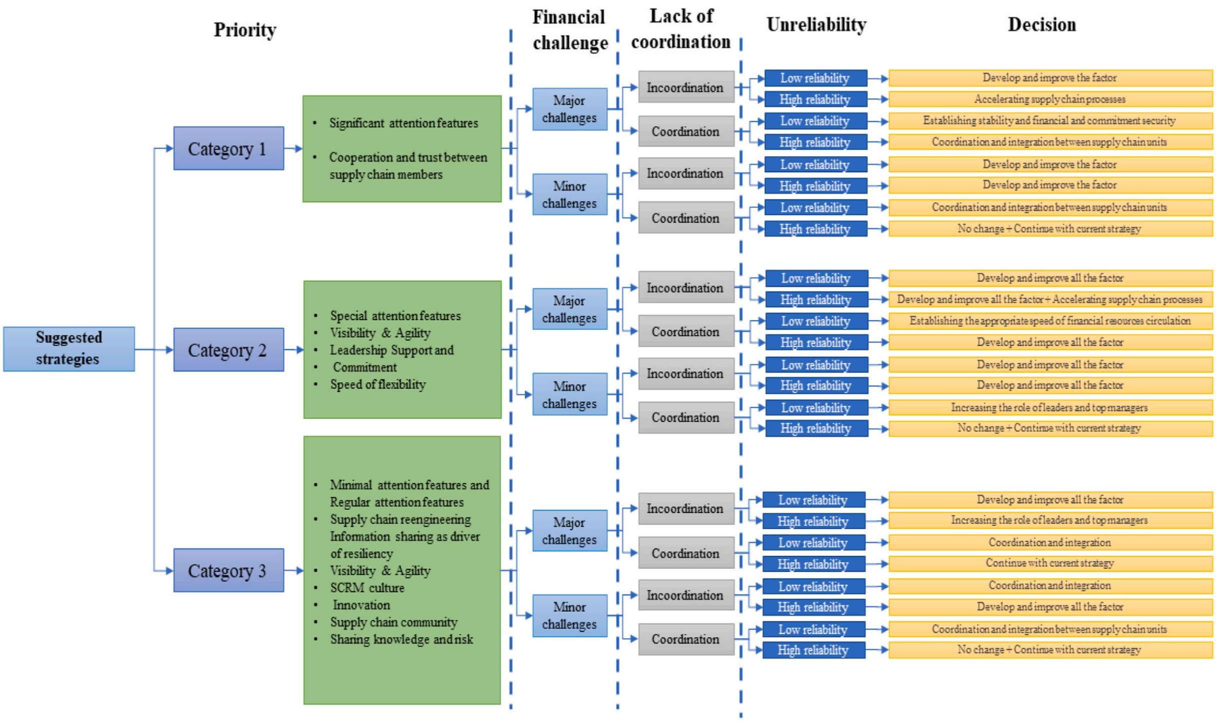

Fig. 9. Suggested feature strategies.

cooperation and trust between the members of the supply chain as one of the most important factors of resilience in the supply chain, reducing the challenges mentioned and organization preparation helps when events occur. High levels of this factor can reduce risk and coordinate decisions and coordinate incentives to respond to challenges and disturbances at system levels. On the other hand, if there are financial problems of companies, it will create stability and confidence for the actors of the chain. provide the ground to encourage the entry of activists and funds into it. If the stated challenges do not exist or are at a low level, companies can continue with the current strategy unchanged.

5.2. Category 2: Scenarios related to special attention features

If the effective factor in supply chain resilience has priority 2 and is faced with financial challenges, lack of coordination and uncertainty, companies should increase speed and flexibility according to the goals of the organization and the role of senior managers and leaders. Speed is closely related to flexibility. And it is compatible and instead of emphasizing the effectiveness of accountability and improving the supply chain, it improves efficiency in companies. In the absence of the mentioned challenges, it is better for the company to continue with the previous solutions.

5.3. Category 3: Scenarios related to minimal and regular attention features

If the desired factors have a low priority, regardless of whether the stated challenges exist or not and it is at a low level, the desired factors should be increased at this level. Organizations should adopt CRM culture more and more to create a resilient structure. In order to change and improve the organizational culture, the role and support of managers and leaders, it is vital to review the company's success with policies and methods and to create coordination and integration between all units of the supply chain. Finally, innovation and other factors are the main elements for the long-term survival and growth of a company and play an important role in how companies adapt to the environment.

Considering the mentioned scenarios of Fig. 9, companies could understand their current resilience status and provide a plan for improving/changing influential features.

6. Conclusions

SCR has received increasing attention in recent years; Our goal through this work is to clarify the applicability of improving the study of supply chain resilience components and provide a path for broadening the scope of resilience analysis. However, before implementing the Supply chain Resilience program, a company needs to recognize the influencing activities to implement, utilize a model for the assessment of the existing Supply chain Resilience status and design an improvement plan according to it. The current study has identified the influencing factors, suggested a structured FCM- Fuzzy multi criteria decision making approach to the management of Supply chain Resilience activities and implemented it on a company to clarify the issue. There are several new conceptual and methodological contributions made by the proposed approach because of addressing the main issues in employing Supply chain Resilience in companies. The main three developments are listed below.

1) A set of valid as well as reliable factors or activities were identified by the study, making it possible to model the causal associations of the influencing factors over the process of assessing supply chain resilience;
2) Handling comparative judgements will be possible with the aim of determining the contribution of every single activity to the total status of the organizational resilience; and
3) Researchers will have the opportunity to evaluate the effects of improving one or several activities or factors on other ones as well as the total resilience status of the supply chains by taking the causal associations into account.

The result of present study shows that the two factors of "the importance of collaboration" and "trust among the members of supply chains" are the most important factors in achieving high level of resilience in the company.

An overview of the pattern can be founded that most of the factors are intertwined with each other and any change in the situation of one factor will affect the others and the total SC resilience situation.

Taking these causal associations into account will enable the decision-makers in the analysis of different improvement scenarios. To illustrate various stages of the presented approach, an empirical study was conducted in a pharmaceutical company and the assessment, analysis, and improvement scenarios are described in this paper.

7. Further research and limitations

To address the generalizability issues of the research, future studies should focus on different countries or industrial sectors that may have different contexts and challenges for supply chain resilience. Moreover, future research should explore newer and more effective approaches for assessing the activity levels of supply chain resilience, such as using historical data and automatic methods for constructing fuzzy cognitive maps, which could increase the effectiveness of the model and reduce the reliance on expert knowledge.

The research aims to identify the factors affecting the resilience of the supply chain, which is the ability of a supply chain to cope with disruptions and uncertainties. However, the research has some limitations that need to be addressed. First, the research is based on a questionnaire survey that may not capture the complexity and diversity of supply chain resilience across different contexts and cultures. Second, the research only considers the opinions of supply chain professors, who may not have the practical experience or the technical knowledge of the real-world challenges and solutions for supply chain resilience. Third, the research does not validate the model or the factors with empirical data or case studies from high-risk situations. Therefore, future research should expand the scope and the depth of the study by involving more experts and stakeholders, conducting comparative analysis across different regions and industries, and testing the model and the factors with quantitative and qualitative methods.

Data availability statement

The data that support the findings of this study are available from the first author, Zeinab Barmour, upon reasonable request.

CRediT authorship contribution statement

Zeinab Barmour: Writing – original draft, Visualization, Methodology, Investigation. **Sadra Ahmadi:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Sajjad Shokouhyar:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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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