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Fuzzy cognitive mapping for investigating resilience in Iranol company: An analytical perspective

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Abstract This study investigates the factors influencing organizational resilience within Iranol company, a major player in Iran's oil and gas industry. Using a systematic literature review, fuzzy Delphi, and Fuzzy Cognitive Mapping (FCM), the research identifies and prioritizes key resilience indicators. Data were collected from 13 senior experts through pairwise comparison questionnaires, and analysed with FCM Expert software to capture causal interdependencies among factors. The findings reveal that human-centric drivers including HR empowerment, employee participation, organizational readiness, team learning, and training hold the highest centrality in fostering resilience, whereas structural elements such as flexible culture and agile structures play more supportive roles. These results highlight the importance of empowering employees and cultivating a collaborative, learning-oriented environment to strengthen organizational resilience. The study contributes to resilience research by applying FCM to the oil and gas sector, demonstrating its value for modelling complex, feedback-rich systems. Practical recommendations are provided for managers seeking to enhance resilience in volatile environments, while limitations and future research directions are discussed.

Keyword: Organizational Resilience, Oil and Gas Industry, Fuzzy Cognitive Mapping, Iranol.

1 Introduction

In recent decades, the increasing dynamism of the environment and rapid shifts in market preferences have made resilience a central concept in economic and organizational research [1]. Derived from the Latin term *resilire*, meaning "to bounce back," resilience refers to the capacity to recover from sudden disturbances [2, 3]. This concept has gained considerable attraction in organizational studies, especially as organizations face an array of complex disruptions from internal challenges to external crises such as natural disasters, socio-political instability, and global pandemics [4].

Organizational resilience is now regarded as a desirable characteristic, allowing firms to adapt, respond rapidly, recover from adversity, and even improve operations post-crisis [5, 6,

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7]. Several definitions of the concept have been proposed in the literature. For example, Munoz et al. [8] defined resilience as the ability to bounce back from performance downturns, while Martin-Rojas et al. [9] highlighted the proactive nature of resilient firms in anticipating and adapting to disruptions. Duchek et al. [10] conceptualized it as a dynamic capability to anticipate threats, respond effectively, and adapt to changing conditions. Su and Junge [11] and Garrido-Moreno et al. [3] reinforced this by viewing resilience as a continuous process of learning and improvement through disruption.

As embedded in the above definitions, resilience has been investigated from various perspectives. Some researchers have examined its outcomes, such as improved performance, sustained competitive advantage, and crisis management [11, 12]. Others have focused on the internal enablers of resilience, such as leadership, culture, human capital, knowledge management, and digital resources [2, 13]. Studies have also emphasized the importance of social capital, environmental pressures, IT deployment, and corporate social responsibility in building resilient organizations [14]. Karman et al. [15] categorized resilience determinants into four major capabilities: resilience capacity [16], flexibility [17], cooperation [18], and resource efficiency [19]. While these studies have greatly contributed to understanding resilience, several limitations remain. First, many rely heavily on conceptual frameworks or linear statistical models, which are often inadequate in capturing the complex, nonlinear, and interdependent relationships among resilience indicators [3, 13]. Additionally, few studies have examined resilience using advanced modelling tools capable of addressing dynamic feedback, expert knowledge, and systemic interactions.

In this study, oil and gas industry is considered as the case study. It's among the most disruption-prone sectors worldwide, exposed to market volatility, environmental risks, geopolitical tensions, and technological transformations. As a leading producer of lubricants and base oils, Iranol operates within the downstream segment of the oil and gas industry, making it directly influenced by the sector's volatility, oil price fluctuations, economic sanctions, global market dynamics, geopolitical uncertainty, regulatory pressures, and evolving customer expectations. In such a context, resilience is not just a favourable trait but a strategic necessity for ensuring continuity, adaptability, and long-term success [20]. For companies like Iranol, organizational resilience is not only a strategic advantage but a prerequisite for survival. Despite its critical importance, resilience research in this sector has largely relied on conceptual models or linear statistical techniques, which fail to capture the feedback loops and interdependencies that characterize real-world disruptions.

Despite significant advances in the resilience field of study, substantial gaps remain. First, due to the complex and dynamic nature of resilience, a comprehensive understanding of its components, based on a solid theoretical framework is lacking. Further, most empirical studies on the topic are based on conceptual and statistical studies, which have limited capacity to examine cause-effect relationships [3, 13], so there are few in-depth evaluations of organizational resilience dimensions, which limits the scope of the research. This study provides an in-depth analysis to evaluate the Iranol's resilience components using the Fuzzy Cognitive Mapping (FCM) approach. Compared to traditional linear models, FCM has the ability of analysis feedback structures, nonlinearity, handle qualitative factors, taking into account both direct and indirect relationships among them, and model systems where explicit knowledge is limited but expert (implicit) knowledge is available. Additionally, its adaptability and ability to handle complex data make it a preferred choice in many advanced applications, especially energy sector [13]. By applying FCM, this study addresses this gap and provides a structured, systems-oriented perspective on resilience determinants.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on organizational resilience, with particular emphasis on the oil and gas sector. Section 3 outlines the research methodology, including the fuzzy Delphi process and the FCM modelling approach. Section 4 presents the results of the analysis and discusses their theoretical and managerial implications. Finally, Section 5 concludes the study by summarizing key findings, highlighting contributions, outlining limitations, and proposing directions for future research.

2 Literature review

As a company's capability to respond effectively to environmental disruptions, organizational resilience is a multifaceted concept, including broad and pervasive levels in addition to interlaced and influencing characteristics [12]. Numerous Studies have demonstrated the importance of organizational resilience in anticipation, acceptance, and transformation of enterprises in response to adverse external environmental influences [21].

In the O&G sector, resilience holds particular importance due to the high stakes associated with potential accidents and disruptions, which can lead to significant human, environmental, and economic consequences. The industry, divided into upstream, midstream, and downstream operations, plays a vital role in the global economy, contributing substantially to GDP and employment [22]. However, its complex supply chain is inherently vulnerable to disruptions, such as market volatility, cyberattacks, and natural disasters, which can cascade throughout the entire ecosystem [18]. Organizational resilience in this context requires not only effective risk management but also the integration of human factors and proactive strategies that emphasize adaptability and positive outcomes [23].

Despite growing research on organizational resilience, there remains a gap in understanding and prioritizing resilience drivers specific to the O&G sector, particularly in the context of unprecedented challenges like the COVID-19 pandemic or geopolitical tensions [24]. Moreover, resilience research within the O&G sector highlights the importance of fostering collaboration among supply chain partners and leveraging innovative solutions to mitigate disruptions. The COVID-19 pandemic revealed critical gaps in the resilience of O&G supply chains, prompting calls for more robust mechanisms to maintain operational continuity and competitive advantage [22]. By addressing these gaps and identifying key resilience drivers specific to the O&G industry, organizations can better prepare for future disruptions while maintaining their pivotal role in global energy systems, even as the world transitions toward renewable energy [25].

Numerous studies have been conducted in the literature to investigate organizational resilience from different perspectives. For instance, in pandemic condition, Homayounfar et al. [1] developed a thematic analysis and system dynamics approach to enhance startups' resilience during the COVID-19 pandemic. They categorized resilience factors and developed a system dynamics model based upon them to find the best scenario for enhancing resiliency. Rodrígues and de Noronha [6] conducted a study to find a way to overcome COVID-19 crisis, by unicorn startups. Their findings indicate that while the pandemic negatively affected unicorn businesses, innovations in digital business models had a positive impact on them. Chowdhury et al. [26], conducted a systematic review to examine the role of technology in implementing resilience strategies in supply chains and manage and mitigate the adverse impacts of the COVID-19 pandemic. Krammer [27], in a survey of over 11,000 companies from 28 countries before and after the COVID-19 pandemic, showed that innovative companies, especially startups, demonstrated greater adaptability to the pandemic compared to non-innovative firms. Kim et al. [28] explored organizational resilience as a theoretical framework to navigate pandemic-related challenges using a multi-level analysis grounded theory.

Investigating the relationships between resilience and other variables, Trieu et al. [29] examined how information technology capabilities and organizational ambidexterity facilitate SMEs' organizational resilience and performance. Their research also highlighted the role of government support in strengthening resilience and offers insights for SMEs on resource allocation and leveraging government aid for sustainable development. Conz et al. [30] studied the role of owners/ managers in fostering resilience among family businesses and employed phenomenological methods to understand their contributions to the resilience. He et al. [31] developed a theoretical relationship between digital transformation and organizational resilience, and the consequences of organizational resilience on organizations and employees during turbulent times. Do et al. [32] explored how resource-based management initiatives (RBMI) stimulate organizational resilience and its subsequent innovation. Their findings highlighted organizational learning as a salient mediator underlying the RBMI-resilience/innovation relationship. Georgescu et al. [33] investigated the role of strategic human resource management (SHRM) practices and organizational culture in enhancing organizational resilience. Their findings highlighted both the direct and indirect impacts of SHRM practices on organizational resilience.

In the context of technology, Sharma et al. [34] examined the influence of Industry 4.0, smart supply chains, agility, and resilience on sustainable business performance using a natural resource-based perspective. Their findings highlighted Industry 4.0's critical role in fostering smart and sustainable supply chains. Additionally, a partial link was observed between Industry 4.0 and supply chain agility via smart supply chain practices. de Sousa Jabbour et al. [35] investigated the link between adopting circular economy business models and organizational resilience, revealing the mediating roles of Industry 4.0 technologies and customer integration. The findings confirmed that circular economy models bolster resilience.

In the O&G context, Rahi et al. [36] developed a scale to measure organizational resilience in the O&G industry, identifying ten indicators and 40 items. The findings offer stakeholders a robust framework to assess organizational strengths and weaknesses. Ekram et al. [37] identified key logistics indicators causing disruptions in the O&G industry and proposed strategies to enhance resilience Egyptian O&G supply chain. It highlights flexibility, redundancy, visibility, and collaboration as critical factors for mitigating disruptions. Ghasemi Hamedan et al. [20] employed a two-level Adaptive Neuro-Fuzzy Inference System (ANFIS) method, for measuring the organizational resilience in O&G industry. Pokhriyal et al. [38] proposed a resilience roadmap to help the O&G industry adapt and thrive in turbulent times. They highlighted strategies such as automation, digitalization, and optimization to reduce risks and improve profitability. Mazaheri et al. [39] employed linear Bayesian models and weighted least squares (WLS) to determine that both systematic (6) and unsystematic (10) supply chain risks significantly impact the Economic Resilience Index in Iran's oil-related industries. Based on a review of literature, some of the new resilience studies are summarized in Table 1.

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Table 1 Recent studies on organizational resilience

Author	Contribution	Application Area	Tools/Techniques Used
Mazaheri et al. [39]	Identified and quantified specific systematic and unsystematic supply chain risks	Oil-related industries	linear Bayesian-Weighted Least Squares
Dubey et al. [40]	Identified resources, capabilities, and factors like trust and cooperation as predictors of SCR	Manufacturing firms	Regression analysis
Hosseini et al. [41]	Reviewed papers on SCR and identified five conceptual drivers	Generic SC	Systematic literature review
Emenike and Falcone [42]	Reviewed SCR literature related to the energy sector, including O&G	Energy sector	Systematic literature review
Bevilacqua et al. [43]	Developed a method for analysing the domino effect, unveiling hidden paths influencing SCR	Fashion industry	Fuzzy cognitive maps
Bahrami Seyfabad [44]	Developed a fuzzy network DEA model to assess resilience disparities between overall supply chains and their individual hierarchical levels	Petrochemical industry	Data Envelopment Analysis
Bravo and Hernandez [45]	Measured organizational resilience based on financial and operational metrics	O&G companies	Empirical study
Ali et al. [46]	Provided a broader view of SCR reactive strategies in dealing with COVID-19 disruptions.	Food industry	Conceptual study
Pokhriyal et al. [38]	Developed a roadmap to assess, analyse and mitigate the risks in pandemic	O&G industry	Conceptual study
Trieu et al. [29]	Investigated how IT capabilities and organizational ambidexterity facilitate SMEs' resilience and performance	SMEs	Structural equation modelling (SEM)-PLS
Kim et al. [28]	Proposed grounded theory model of resilience	Multi-industry	Grounded Theory
de Sousa Jabbour et al. [35]	Develop the link between circular economy and resilience by the mediating effects of Industry 4.0 technologies and customer integration	Manufacturing firms	SEM-AMOS
Georgescu et al. [33]	Investigated the effect of strategic human resource management practices and organizational culture on organizational resilience	Public institutions	Structural equation modelling
Rahi et al. [36]	Proposed a scale to measure organizational resilience in O&G industry	O&G industry	Conceptual study
Ekram et al. [37]	Highlighted the logistics perspective in the Egyptian O&G supply chain	O&G supply chain	Mix method
Sharma et al. [34]	Established the role of digitalization for attaining sustainable business value, by mediating role of SC agility, resilience and smartness	UK supply chains	SEM-AMOS and ANN
Ghasemi Hamedan et al., [20]	Employed a two-level ANFIS method, for measuring the organizational resilience	O&G industry	Delphi- ANFIS
Bento et al. [47]	maped and synthesized the conceptualizations, research methods, and central topics within the body of organizational resilience literature	O&G industry	Review
Homayounfar et al. [1]	Developed an approach to enhance startups' resilience during the COVID-19 pandemic	Startups	Thematic analysis-system dynamics

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While resilience studies have extensively explored theoretical frameworks and general applications, there is a notable gap in leveraging advanced analytical tools to investigate resilience within specific industrial contexts, such as O&G companies. This study applied FCM, because its unique ability to capture the complexity, uncertainty, and interdependencies inherent in organizational resilience. Unlike traditional statistical methods, which often assume linear and independent relationships among variables, FCM enables the modelling of nonlinear, feedback-rich systems where factors influence each other simultaneously. This is particularly relevant for resilience in the oil and gas sector, where disruptions are multidimensional and interconnected. Furthermore, FCM integrates both qualitative expert knowledge and quantitative analysis, making it especially suitable when empirical data are scarce or incomplete, but expert judgment is abundant. Compared to purely conceptual frameworks, FCM provides a visual and computational model that not only identifies key resilience indicators but also quantifies their causal influence, thereby supporting more informed managerial decision-making.

3 Research method

This study applied a systematic approach for analyzing the indicators of organizational resilience in Iranol company, in Iran. Iranol Company was selected as the case study due to its strategic position in Iran’s oil and petrochemical sector, where operational continuity and resilience are of paramount importance. As a leading manufacturer of lubricants and industrial oils, Iranol operates in a highly dynamic and risk-prone environment, facing challenges such as market volatility, supply chain disruptions, environmental regulations, and geopolitical tensions. These conditions make it a suitable and insightful case for studying organizational resilience. Moreover, the company's willingness to collaborate and provide access to experienced experts and internal data further supported its selection for this research. The required data for implementing the research methods, were collected from experts of central office of Iranol company in Tehran. Experts included senior managers, safety officers, and strategic planners with over 10 years of experience in the oil and energy sector. Table (2) presents the demographic and academic characteristics of the selected experts.

Table 2 Expert Profile Information

Field of Study	Gender	Work Experience	Age	Academic Rank
Executive Management	Male	20	47	Master's Degree
Electrical Engineering	Male	23	48	Master's Degree
Industrial Engineering	Male	16	43	Master's Degree
Public Administration	Male	12	36	Ph.D.
Electrical Engineering	Male	15	39	Bachelor's Degree
Industrial Management	Female	14	41	Ph.D. Candidate
Industrial Engineering	Male	18	42	Ph.D.
Entrepreneurship Management	Male	10	34	Master's Degree
Entrepreneurship	Male	14	44	Ph.D.
Artificial Intelligence	Male	12	32	Ph.D.

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Strategic Management	Female	25	51	Master's Degree
Chemistry Engineering	Female	27	50	Master's Degree
Material Engineering	Male	16	43	Ph.D.

Conducting the research, in the first stage, resilience indicators were extracted through the systematic review of the scientific papers. Relevant keywords including as "organizational resilience", "resilience factors", "resilience indicators", "resilience measurement", "resilience assessment" and "resilience dimensions" used to search databases such as Scopus and Web of Science, and commonly cited resilience indicators were identified, compared, and synthesized to form an initial list for expert validation. Accordingly, 54 resilience indicators were extracted from the stage 1.

In the second stage, fuzzy Delphi method was used to refine the indicators. Thirteen experts from the central office of Iranol Company (See Table 2) participated in three rounds of the fuzzy Delphi process. They evaluated indicators' importance using fuzzy scales from vert low (0 1 3) to vert high (7 9 10). It is noteworthy that experts were also asked to add any other important indicators not included in the initial list. After three rounds, 24 indicators with an average score above the 0.7 were selected as key indicators of organizational resilience.

In the third stage, FCM is used for analyzing the resilience indicators and developing improvement suggestions. The main resilience indicators were investigated based on the opinions of 13 experts to construct an adjacency matrix, reflecting the relationships between them. This involved analyzing the influence, sensitivity, and prioritization of each element using static analysis outputs. The geometric mean was used to aggregate expert opinions in this study. This method is particularly suitable for combining fuzzy numbers or ratings provided on a multiplicative or ratio scale. Unlike the arithmetic mean, the geometric mean reduces the influence of extreme values (outliers) and maintains the proportional relationships among data points. This makes it more reliable when dealing with subjective judgments, such as those obtained through expert surveys in fuzzy Delphi studies. Furthermore, the geometric mean preserves the consistency of the experts' opinions and is widely recommended in multi-criteria decision-making and fuzzy logic applications. Figure 1 illustrates the research framework in sequential steps.

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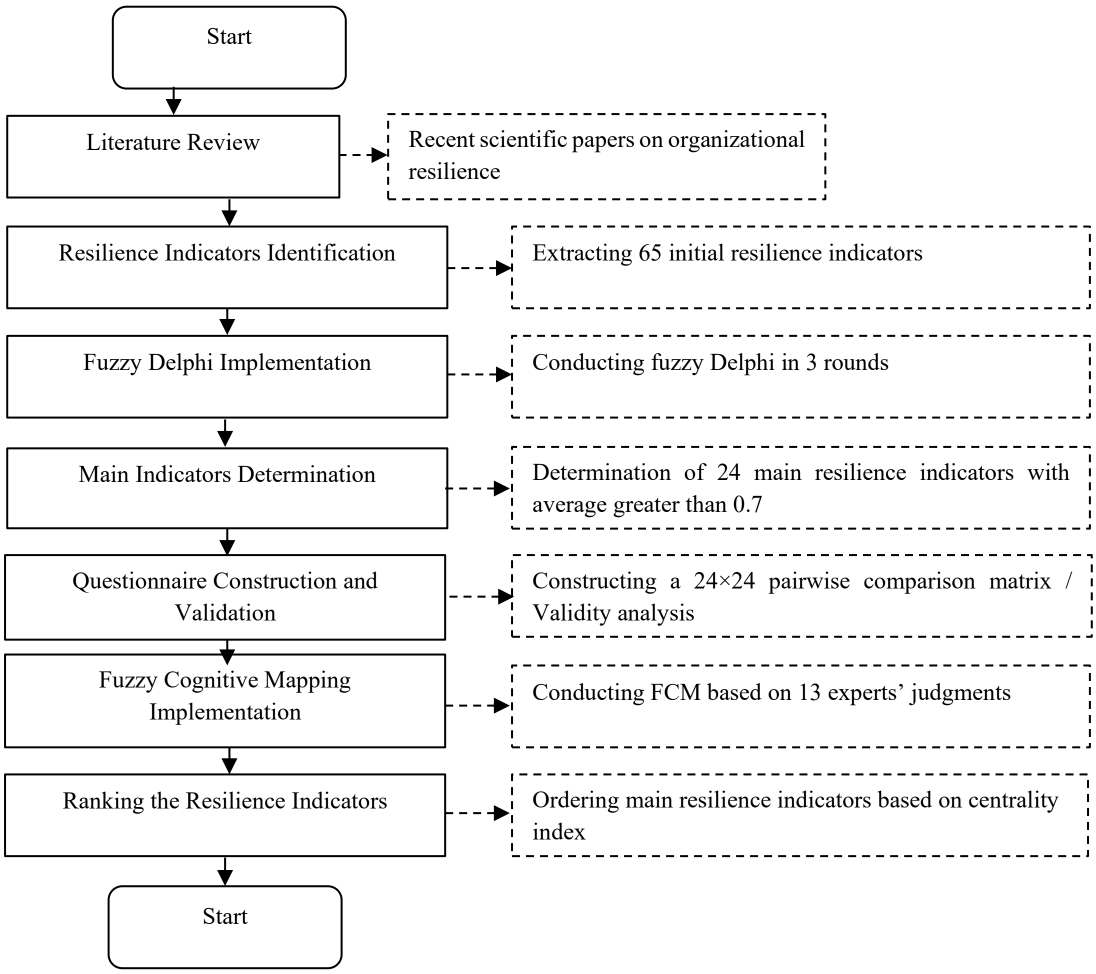

Fig. 1 Research framework

- **Fuzzy Cognitive Map (FCM)**

First introduced by Kosco in 1986, FCM is a powerful method to model and analyse complex systems with high levels of interaction between components. The reasoning process of fuzzy cognitive mapping is based on neuro-fuzzy system [24]. Actually, FCM consists of a set of neural processing entities called concepts (neurons) and the causal relations among them. The activation value of such neurons regularly takes values in the [0, 1] interval, so the stronger the activation value of a neuron, the greater its impact on the network. Also, connected weights are relevant in this scheme. The strength of the causal relation between two neurons Ci and Cj is quantified by a numerical weight $wij \in [-1, 1]$.

There are three types of causal relationships between neural units in an FCM, being detailed as follows [48, 49]:

- $wij > 0$ indicate a positive causality,
- $wij < 0$ indicate a negative causality,
- $wij = 0$ indicate no causality.

Equation (1) formalizes Kosko's activation rule, with A (0) as the initial value. A new activation vector is calculated at each step t and after a fixed number of iterations the FCM will be at one of the following states: (i) equilibrium point, (ii) limited cycle or (iii) chaotic behaviour. The FCM is said to have converged if it reaches a fixed-point attractor, otherwise the updating process terminates after a maximum number of iterations T is reached.

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$$A_i^{(t+1)} = f\left(\sum_{j=1, j\neq i}^{M} w_{ji} \times A_j^{(t)}\right) \quad (1)$$

Subsequently, the values Ait+1 and Ait, respectively, provide the value of the conceptual variable Ci at discrete times t+1 and t. In this case, Ajt will be the value of the concept Cj in the t-th iteration of the simulation.

In the equation (1), f (0) denotes a monotonically non-decreasing function to clamp the activation value of each concept to the allowed intervals [0, 1] or [-1, 1]. The functions most extensively used based on literature are depicted as Bivalent, Trivalent, Saturation, Hyperbolic and Sigmoid function.

Stylios and Groumpos [50] proposed a modified inference rule (Equation 2), where neurons also take into account its own past value. This rule is preferred when updating the activation value of independent neurons, i.e., neurons that are not influenced by any other neural processing entities.

$$A_i^{(t+1)} = f\left(\sum_{j=1, j\neq i}^{M} w_{ji} \times A_j^{(t)} + A_i^{(t)}\right) \quad (2)$$

After analysing the adjacency matrix, FCM is drawn. Subsequently, in the continuation of the modelling process, FCM implements the model and repeats the simulation based on the principles of the neural network method and using one of the common activation functions and continues the calculations until the system converges. As illustrated in Equation (3), convergence occurs when the difference between the next two output values equals to or less than epsilon (ε=0.001).

$$\left|A_i^{(t+1)} - A_i^{(t)}\right| \leq \varepsilon \quad (3)$$

The FCM network can be described using concepts such as input degree, output degree and centrality. The input degree (degree of influence) of the concept *i* is equal to the sum of the values of the column related to the variable *i* and the output degree (degree of to be influenced) is also equal to the sum of the values of the row related to variable *i* in the adjacency matrix. The centrality index is also obtained from the sum of the input and output degrees of that concept. Generally, using FCM, it is possible to evaluate the impact of concepts on each other, as well as the whole system. The steps of FCM modelling are as followings:

- *Step 1. Identification of the indicators related to the problem*
- *Step 2. Evaluation of causal relationships among related indicators by experts*
- *Step 3. Evaluation of the causal relationships' intensity among the indicators (concepts).* In this step, the experts were asked to determine the causal relationships' intensity using a linguistic scale. It should be noted that before determining the relevant intensities, a consensus on the direction (sign) of all system effects was reached by experts.
- *Step 4. Aggregation of the expert opinions.* After de-fuzzification of the individual fuzzy influence matrixes, the average of the experts' judgments, called "aggregated adjacency matrix" will be computed using equation (14)." The elements of the main diameter of matrix are considered equal to zero, which means that no measure leads to its formation.
- *Step 5. Developing the fuzzy cognitive map*. The analysis of the adjacency matrix from the fourth step, provides important information such as input degree, output degree, centrality index and density of fuzzy cognitive map to analyze the network structure.
- *Step 6. Implementation of the simulation process.* In order to check the dynamic state of the system and using relations (4) and (9), the values of the indicators are calculated during the simulation and the new values will repeatedly replace the previous values.
- *Step 7. Checking the termination conditions.* After the system convergence, it will be possible to present the final values of the concepts.

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4 Results and discussion

To apply the proposed model to the real-world context of Iranol company, a panel of experts from the Iranol company was engaged to evaluate the causal relationships among resilience indicators and the strengths of these connections. Although defining an exact number of expert participants can be challenging, it is generally recommended to involve a small group of experts, typically from 3 to 10 experienced individuals or more [51]. In this study, a group of 13 experts from Iranol Company participated in the evaluation process. The selection criteria for these experts included their theoretical knowledge, practical experience, willingness, and capacity to contribute meaningfully to the research. All discussions, analyses, and assessments regarding the identification and comparison of resilience indicators were conducted in collaboration with these experts, ensuring the findings were grounded in both theory and practice (See Table 3).

Table 3 Main indicators of organizational resilience

Concept	Component	Authors
Organizational Adaptability	Flexible and Agile Structure Flexible Culture Aligned Goals Leadership Style & Traits	[3], [8], [18], [28], [33], [34], [52]
Collaborative Factors	Team Learning Knowledge Management Effective Communication Employee Participation Trust Development	[3], [12], [18], [32], [47], [52], [52], [53]
Change Management	Individual/ Organizational Readiness Adaptability Capacity Continuous Environmental Monitoring Innovation & Creativity Creative Organizational Climate Diversity Management	[3], [6], [12], [18], [25], [29], [32], [47], [52]
HR Management	Employees Training Attention to Human Capital HR Recruitment HR Empowerment	[3], [12], [17], [19], [18], [32], [33], [47], [52], [53]
Production Management	Resource Management Relationship Management Process Improvement Cost Control Product Development	[2], [3], [12], [15], [17], [19], [29], [32], [33], [34], [47], [50], [52], [53]

After identifying the components of organizational resilience, they must be evaluated by the experts. For this purpose, a questionnaire was designed based on the indicators in Table 3; then, the 24 selected indicators were mentioned in the first row and column of the table, and the experts were asked to determine the intensity of causal relationships between the indicators based on the linguistic variables from extremely low (1) to extremely high (10). Since the judgments of the experts were ambiguous and uncertain, the linguistic variables in this study were converted to triangular fuzzy numbers. Next, the fuzzified matrixes of the experts' judgments were obtained and their average is calculated in form of the "aggregated adjacency matrix". Table 4 illustrates this matrix.

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In the modelling process, the structure of fuzzy cognitive map was analysed using the FCM Expert software. The output of the analysis, which is based on the principles of graph theory, was analysed and the results were presented as degree of input, degree of output and centrality index. These values are illustrated in Table (5) based on the descending order of the centrality index. It should be noted that the higher the centrality index score of an element is, the more importance role plays in the organizational resilience.

According to the results, HR Empowerment (F19) emerges as the most influential, with the highest Input value (7.73) and Centrality (14). This indicates that empowering human resources serves as a cornerstone for resilience, cascading its influence across the system. Empowered employees are likely to take initiative, drive innovation, and adapt to changes, which amplifies the organization’s capacity to withstand and recover from disruptions. Similarly, Team Learning (F5), with a high Input of 7.01 and Centrality of 11.89, underscores the importance of fostering collaborative knowledge-sharing environments. Learning at the team level enables organizations to respond dynamically to challenges and seize opportunities in uncertain environments.

Table 4 Aggregated adjacency matrix for resilience indicators

Indicators		F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}	F_{20}	F_{21}	F_{22}	F_{23}	F_{24}
Flexible and Agile Structure	F_1	-	2.11	0	4.18	0	0	3.45	3.02	0	6.97	4.59	4.16	0	0	0	0	0	0	0	0	4.53	0	0	0
Flexible Culture	F_2	3.27	-	4.66	3.23	0	0	7.1	5.99	0	4.17	5.18	0	3.26	0	0	0	0	0	2.96	0	3.1	0	0	0
Integrated Goals	F_3	0	0	-	0	0	0	0	0	0	4.1	3.14	0	0	0	4.24	0	0	0	0	5.27	0	0	0	0
Leadership Style & Features	F_4	0	2.65	5.55	-	0	0	0	4.62	5.9	0	0	0	4.22	4.41	6.26	7.13	3.33	0	3.78	0	5.99	0	4.43	0
Team Learning	F_5	0	3.1	2.49	0	-	7.55	5.25	6.13	4.23	0	3.15	0	6.19	3.53	3.19	6.88	0	4.12	6.1	0	0	0	0	0
Knowledge Management	F_6	0	0	0	0	8.23	-	3	0	0	4.15	3.77	0	5.22	3.13	0	6.89	0	0	7.17	0	0	3.64	0	2.95
Effective Communication	F_7	0	0	3.74	0	4.11	0	-	5.94	5.37	4.72	4.13	3.15	0	0	5.35	0	3.14	4.01	0	0	6.74	0	0	0
Employee Participation	F_8	0	0	5.19	0	3.33	4.51	0	-	4.68	5.15	0	0	0	0	0	3.1	0	0	4.29	0	3.51	0	0	0
Trust Development	F_9	0	0	3.87	4.19	0	0	7.19	6.15	-	0	0	0	0	0	0	2.84	0	0	0	0	6.17	4.76	0	0
Individual/ Organizational Readiness	F_{10}	0	4.12	0	0	0	0	0	4.88	0	-	7.65	0	0	0	3.03	0	0	6.11	3.06	4.14	0	0	0	0
Adaptability Capacity	F_{11}	4.19	3.55	0	0	5.39	3.33	0	4.44	0	6.58	-	5.66	0	0	5.84	0	0	0	0	0	5.48	6.05	0	0
Continuous Environment Monitoring	F_{12}	0	0	0	0	0	0	4.45	0	0	6.92	3.02	-	0	0	0	0	0	0	0	3.65	3.47	0	0	0
Innovation & Creativity	F_{13}	0	3.71	0	0	4.72	4.55	0	5.04	0	0	0	0	-	7.89	0	0	3.15	3.69	4.85	0	0	8.02	0	6.28
Creative Organizational Climate	F_{14}	0	2.89	0	3.96	5.64	5.06	0	6.9	0	0	0	0	8.55	-	0	2.85	4.11	0	5.25	0	0	6.44	0	4.77
Diversity Management	F_{15}	0	0	0	4.19	0	0	5.32	0	0	3.53	3.75	0	0	0	-	0	0	0	0	0	4.64	0	0	0
Employee Training	F_{16}	0	0	3.88	0	5.12	5.66	0	6.84	0	3.65	0	0	7.12	4.13	0	-	3.84	6	6.26	0	0	0	0	4.25
Attention to Human Capital	F_{17}	0	0	0	5.13	0	3.33	0	7.28	5.52	0	0	0	4.57	2.69	0	6.84	-	5.24	6.35	0	3.25	0	0	0
Proper Employee Selection	F_{18}	0	0	0	0	4.18	0	3.98	6.08	0	0	4.16	0	2.86	4.62	3.16	5.75	0	-	4.1	0	0	3.55	0	0
HR Empowerment	F_{19}	3.55	3.75	0	4.02	4.28	3.65	0	7.13	0	6.14	5.36	0	6.49	4.98	0	0	4.16	4.24	-	0	0	5.64	0	5.67
Resource Management	F_{20}	0	0	0	0	0	3.13	0	0	0	4.11	0	3.1	0	2.65	0	0	0	0	0	-	0	3.88	6.44	0
Relationship Management	F_{21}	0	0	3.35	0	0	0	3.84	0	0	4.23	0	4.12	0	0	3.99	0	3.45	4.76	0	7.13	-	3.64	5.19	0
Process Improvement	F_{22}	0	0	0	0	0	0	0	0	0	4.55	0	0	0	0	0	0	0	0	0	5.73	0	-	7.92	5.64
Cost Control	F_{23}	0	0	0	3.29	0	0	0	0	0	-4.44	0	0	0	0	0	-3.39	0	0	0	-3.76	0	-5.63	-	-6.02

Table 5 Ranking the resilience indicators

Indicators	Indicator	Input	Output	Centrality
HR Empowerment	F_{19}	7.76	6.28	14.04
Employee Participation	F_8	3.63	9.51	13.14
Individual/ Organizational Readiness	F_{10}	3.64	8.29	11.93
Team Learning	F_5	7.01	4.88	11.89
Employee Training	F_{16}	6.46	5.17	11.63
Innovation & Creativity	F_{13}	5.84	5.64	11.48
Adaptability Capacity	F_{11}	5.65	5.34	10.99
Creative Organizational Climate	F_{14}	6.38	4.29	10.67

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Indicators	Indicator	Input	Output	Centrality
Effective Communication	F_{21}	4.77	5.62	10.39
Relationship Management	F_7	5.56	4.8	10.36
Leadership Style & Features	F_4	6.53	3.35	9.88
Knowledge Management	F_6	5.46	4.16	9.62
Proper Employee Selection	F_{18}	4.75	4.27	9.02
Process Improvement	F_{22}	2.65	5.8	8.45
Attention to Human Capital	F_{17}	5.69	2.73	8.42
Flexible Culture	F_2	4.72	2.74	7.46
Trust Development	F_9	3.87	2.85	6.72
Diversity Management	F_{15}	2.31	3.87	6.18
Resource Management	F_{20}	2.5	3.61	6.11
Cost Control	F_{23}	2.93	3.09	6.02
Integrated Goals	F_3	1.8	3.41	5.21
Product Development Capability	F_{24}	1.17	4.01	5.18
Flexible and Agile Structure	F_1	3.61	1.14	4.75
Continuous Environment Monitoring	F_{12}	2.34	2.18	4.52

Employee Training (F16) also plays a critical role, with an Input of 6.45 and Centrality of 11.64, reflecting the significance of skill development in enhancing organizational readiness and adaptability. Effective Leadership Style & Features (F4), with an Input of 6.53 and Centrality of 9.89, further supports this dynamic by setting a strategic vision and motivating employees to align with organizational goals during crises. Together, these indicators highlight the criticality of investing in human-centric initiatives to drive resilience. On the other hand, Employee Participation (F8) has the highest Output value (9.51), suggesting that it is highly influenced by other indicators in the system. This implies that while participation is critical for resilience, it depends heavily on enablers such as empowerment, training, and effective communication. Similarly, Individual/ Organizational Readiness (F10), with an Output of 8.31, signifies its dependence on foundational indicators like leadership, adaptability, and team dynamics. Indicators like Relationship Management (F21) and Effective Communication (F7) also show substantial Output values, indicating their reliance on systemic integration and trust-building mechanisms.

The Centrality metric provides a holistic perspective on the indicators' overall importance. Innovation & Creativity (F13), with a Centrality of 11.46, highlights the role of fostering innovative solutions to enhance resilience. Adaptability Capacity (F11), with a Centrality of 11, reflects the organization's ability to navigate uncertainty and maintain operational continuity. Indicators such as Creative Organizational Climate (F14) and Knowledge Management (F6) are also significant, emphasizing the interplay between a conducive work environment and strategic resource utilization. In contrast, indicators like Flexible and Agile Structure (F1) and Continuous Environment Monitoring (F12) show lower Centrality values (4.75 and 4.53, respectively), indicating limited influence on the overall resilience framework. These findings suggest that while such indicators are relevant, their impact is secondary compared to high-centrality drivers like empowerment and team dynamics. Next, the FCM graphic structure of the resilience indicators is presented in Figure (2). In this fuzzy cognitive mapping, the number of 24 resilience indicators are connected by 204 arcs that express the causal relationships between the related resilience indicators. The transfer function is considered "Sigmoid", the activation rule is "Kosko's activation rule with self-memory", and the epsilon index (Convergence) is equal to 0.001.

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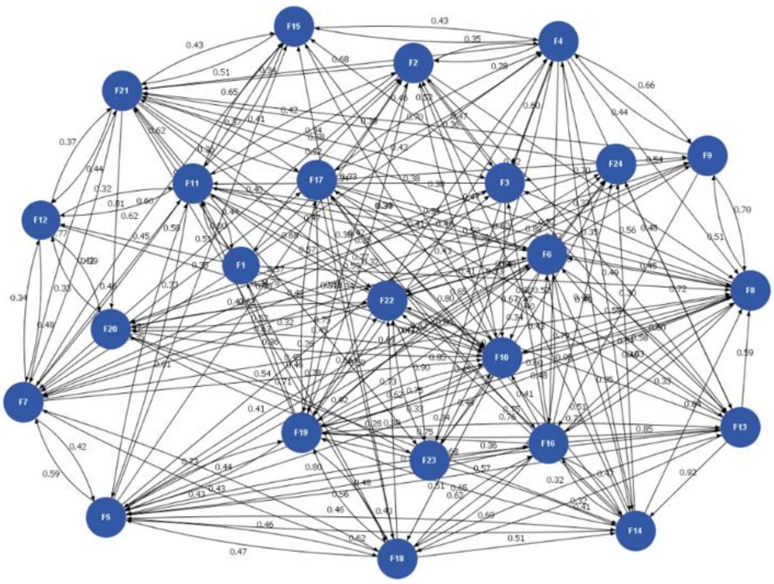

Fig. 2 Graphical structure of the resilience indicators

In order to visually understand the FCM in Figure (2), after eliminating the causal relationships with weights less than |±0.6|, the corresponding FCM was again presented in Figure (3); So, only the most important causal relationships are displayed and a more accurate understanding of FCM is obtained for the viewer.

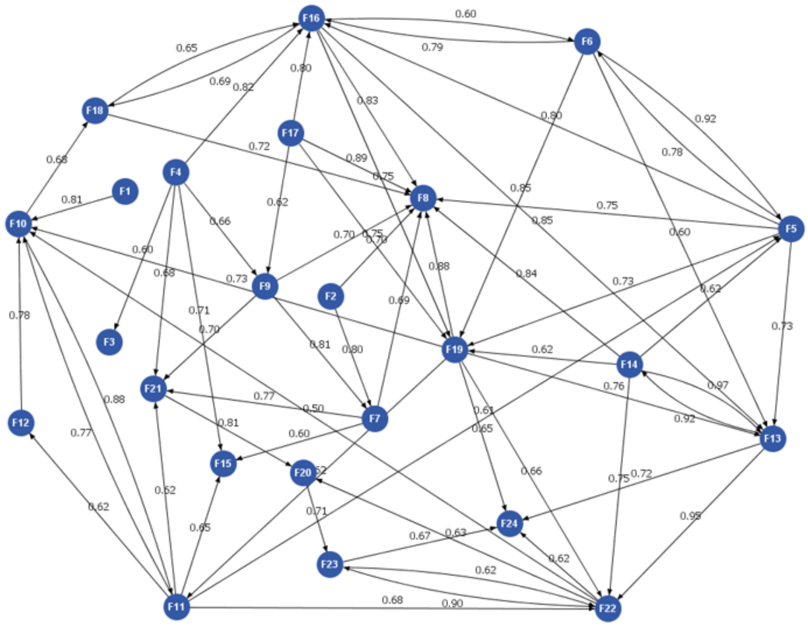

Fig. 3 Graphical structure with important causal relationships

Finally, the graphical interface illustrates the dynamic behaviour of the indicators contributing to organizational resilience, as analysed through Fuzzy Cognitive Mapping (FCM). The vertical axis likely indicates normalized or scaled values of influence or importance, while the horizontal axis represents progression over iterations, time, or levels of interconnection within the FCM model. The trends in the graph provide insight into the relative significance and behaviour of the 24 indicators (F1 through F24) over the course of the analysis (see Figure 4). It should be mentioned that the convergence index (ε) in this research considered 0.001.

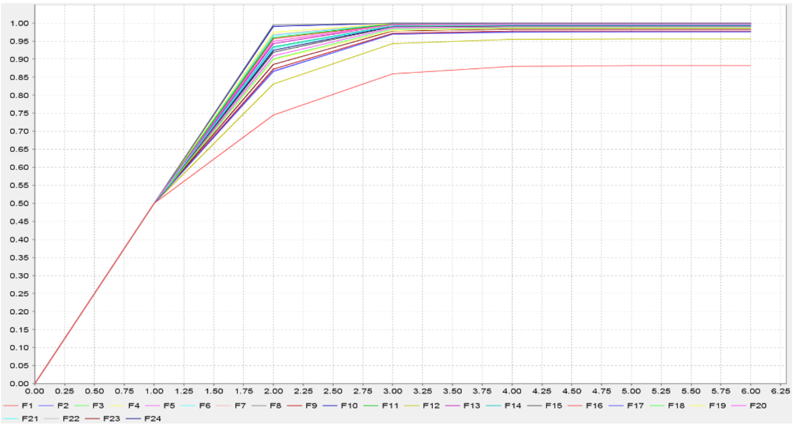

Fig. 4 The graphical interface results

A notable pattern is the rapid convergence of most indicators (except F1) to the highest influence value of approximately 1.0. This steep rise demonstrates that the majority of the indicators exhibit strong interconnections and quickly stabilize at high levels of influence within the resilience framework. Such a pattern suggests that these indicators play a dominant role in determining organizational resilience, with their impact becoming apparent early in the progression.

However, F1 (Flexible and Agile Structure) stands out as an outlier. Unlike the other indicators, its curve increases more gradually and stabilizes at a significantly lower level. This indicates that while it contributes to resilience, its influence is relatively limited compared to other indicators. Its lower centrality value in the earlier analysis supports this finding, highlighting its weaker role in the broader system.

On the other hand, indicators such as F8 (Employee Participation), F19 (HR Empowerment), F10 (Individual/Organizational Readiness), and F5 (Team Learning) consistently exhibit the highest values throughout the progression. This aligns with their high centrality scores from the tabular results, reinforcing their critical role in driving resilience. Their early convergence and sustained influence suggest they are foundational to creating a robust and adaptable organizational framework.

5 Conclusions

This study identified and prioritized the key indicators of organizational resilience in Iranol company using FCM. Findings highlight the central role of human-centric factors—such as HR empowerment, employee participation, organizational readiness, and team learning—in strengthening resilience, while structural elements (e.g., flexible culture and agile structures) play more supportive roles. These results emphasize that resilience emerges from the dynamic interaction of multiple factors rather than isolated indicators.

This research also extends the resilience literature by applying FCM to the oil and gas sector, demonstrating how feedback-rich, interdependent relationships among indicators can be systematically modeled. It contributes to theory by showing that human-centric capabilities outweigh structural factors in driving resilience within complex and high-risk industries.

As practical implications, empowering employees should be a priority for Iranol to enhance resilience. Managers can achieve this by fostering inclusive decision-making, promoting open communication, and creating opportunities for collaboration and engagement. Second, human resource empowerment should have the top priority of Iranols' resilience strategies. This includes providing ongoing training, promoting autonomy, and ensuring that employees are equipped with the skills and tools needed to navigate challenges effectively. Third, organizations must cultivate readiness at both individual and organizational levels. Proactive risk management, scenario planning, and regular drills can build a state of preparedness, ensuring Iranol's quick and effective responses during crises.

Despite its contributions, this study is subject to several limitations. While FCM is a powerful tool for modelling complex relationships, it is based on expert perceptions and may not fully capture dynamic real-world conditions. next, the study focuses on Iranol Company in a specific national and industrial context, which may constrain its applicability across different cultural or regulatory environments. Future research could address these limitations by conducting cross-industry or cross-country comparisons, and integrating complementary modelling techniques (e.g., system dynamics or agent-based modelling) to capture temporal dynamics and scenario-based analyses. This would help in developing tailored resilience frameworks that address unique challenges and opportunities. Integrating other analytical methods, such as agent-based modelling or system dynamics, with FCM also could offer a deeper understanding of the complex interactions among resilience indicators. These methods could provide complementary perspectives, enabling researchers to simulate the effects of various interventions on resilience outcomes. Additionally, future research could focus on the role of emerging technologies in building resilience. For example, examining how artificial intelligence, blockchain, or digital transformation initiatives influence organizational resilience could provide actionable insights for managers operating in technology-driven environments.

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