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Research Article

Resilience appraisal for Iranol oil company: Application of adaptive neuro-fuzzy inference system

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Abstract

In recent years, resilience has gained significant attention for understanding how organizations can prepare for and respond to turbulent environments. Despite extensive empirical research, previous studies highlight the need for greater clarity in measuring organizational resilience. This study proposes an advanced framework for resilience assessment in Iranol Oil Company, a leading lubricant and petroleum product manufacturer in Iran, during 2024. Unlike conventional approaches, this research employs an Adaptive Neuro-Fuzzy Inference System (ANFIS), which effectively integrates expert knowledge and data-driven learning to enhance predictive accuracy. The ANFIS model, leveraging Gaussian membership functions, captures complex, nonlinear relationships between resilience factors, making it superior to traditional statistical and fuzzy logic models in handling uncertainty and imprecise data. A structured methodology was implemented, involving a two-round fuzzy Delphi method to refine resilience indicators across five dimensions: organizational adaptability, collaborative factors, change management, HR management, and production management. Data collection included 126 qualified employees, with a training-testing-validation split ensuring model accuracy and generalizability. The ANFIS model demonstrated exceptional predictive performance, with mean square errors of 0.00244, 0.00279, and 0.00113 for training, testing, and validation datasets, respectively. Sensitivity analysis confirmed the robustness of the model under extreme conditions. Practical implications of this study extend beyond Iranol, providing a scalable approach for resilience assessment in various industries. By adopting ANFIS-based resilience evaluation, organizations can gain data-driven insights into their adaptability, innovation potential, and workforce engagement. This methodology enables companies to proactively identify vulnerabilities, optimize crisis management strategies, and enhance long-term sustainability in uncertain environments.

Keywords:
Organizational Resilience;
Oil and Gas Industry;
Adaptive Neuro-Fuzzy Inference System (ANFIS);
Iranol

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1. Introduction

Organizational resilience refers to a company's ability to anticipate, withstand, adapt to, and recover from disruptions while maintaining operations and pursuing growth. It involves adaptive capacity, crisis management, and strategic innovation to navigate uncertainties (Homayounfar et al., 2025). Scholars have studied resilience from diverse perspectives, framing it as both a dynamic capability and a strategic asset. Duchek (2019) emphasizes resilience as essential for organizational survival and development in uncertain environments, while Bărbulescu et al. (2021) highlighted its role in addressing crises across natural, economic, and social domains. Linnenluecke (2017) describe resilient organizations as those capable of thriving amidst disturbances, leveraging their adaptive capacity to gain strategic advantages. The idea of resilience, therefore, extends beyond mere recovery—it encompasses proactive learning, adaptability, and innovation, ensuring long-term sustainability and competitiveness (Wang et al., 2022). Moreover, resilience is a dynamic property, requiring organizations to continually adapt their operations, anticipate disruptions, and maintain functional stability in volatile environments (Hollnagel & Woods, 2017). Such adaptability not only ensures survival but also promotes growth and innovation, even in the face of uncertainty.

From a theoretical perspective, resilience is often analyzed through the lens of dynamic capabilities (DC) theory. Dynamic capabilities, as described by Hillmann and Guenther (2021), enable firms to absorb external shocks, recover effectively, and even improve their competitive standing. Resilient organizations exhibit these capabilities by leveraging resources to navigate disruptions, sustain operations, and capitalize on emerging opportunities. Scholars such as Duchek et al. (2020) have further emphasized the role of anticipation and proactive adaptation, underscoring resilience as a strategic asset that empowers firms to transform challenges into growth opportunities.

Despite its prominence in organizational research, resilience remains a complex and multifaceted construct (Hillmann, 2021). This lack of consensus stems from the diverse contexts in which resilience is studied, ranging from small and medium-sized enterprises to multinational corporations operating in volatile industries (Alfi et al., 2024). This perspective aligns with Duchek’s (2019) assertion that resilience encompasses not only recovery but also innovation and sustained performance amidst turbulence.

The importance of resilience has become particularly evident in recent years, marked by unprecedented disruptions such as the COVID-19 pandemic, global supply chain disruptions, and geopolitical conflicts. These events have underscored the need for organizations to develop robust resilience frameworks to ensure business continuity and competitive advantage (Napier et al., 2024; Tavakol et al., 2023). Resilience has proven especially critical for industries characterized by volatility, such as oil and gas (O&G). The O&G sector faces unique challenges, including fluctuating oil prices, geopolitical uncertainties, and evolving regulatory landscapes. In this context, resilience is not merely a desirable trait but a strategic necessity, enabling firms to maintain production, manage crises, and pursue sustainable growth (Lisdiono et al., 2022). Firms in this sector must navigate a rapidly changing landscape, characterized by environmental concerns, technological advancements, and shifting consumer demands. Resilience, therefore, is not only a mechanism for survival but also a driver of competitive advantage, enabling firms to adapt, innovate, and thrive in dynamic environments (Napier et al., 2024).

Iranol, a leading producer of lubricants and base oils in the region, exemplifies the significance of resilience in a complex and uncertain environment. Operating amidst economic sanctions, geopolitical tensions, and fluctuating market conditions, the company’s ability to adapt and innovate has been central to its sustainability and growth. Resilience in this context involves more than crisis management—it requires a strategic approach that integrates proactive risk assessment, adaptive learning, and innovation.

By leveraging advanced analytical tools such as Adaptive Neuro-Fuzzy Inference Systems (ANFIS), this study aims to develop a structured resilience assessment framework by integrating both qualitative and quantitative insights to enhance the accuracy of resilience evaluation. It seeks to identify key resilience dimensions within Iranol Oil Company, focusing on organizational adaptability, collaboration, change management, HR management, and production efficiency. Additionally, the study aims to assess the predictive accuracy of ANFIS in resilience measurement by comparing its performance with traditional statistical models. Finally, the research provides practical recommendations for Iranol and similar industrial firms to strengthen their resilience, improve adaptability, and enhance crisis management strategies in volatile environments.

2. Literature Review

In organizational literature, resilience is often characterized by a firm’s ability to respond quickly, recover faster, and develop more effective operational strategies under pressure (Linnenluecke, 2017). At the organizational level, resilience is frequently viewed in passive terms, focusing on the ability to recover from sudden, disruptive events that pose a threat to normal operations. Munoz et al. (2022) asserted that resilience is one of three primary organizational responses to disruption, defining it as the ability to bounce back from performance downturns. This definition contrasts with the concepts of antifragility, which describes the capacity to emerge stronger from crises, and robustness, which pertains to the ability to withstand disruptions without significant change. This distinction highlights resilience as an adaptive response that enables organizations to recover after a crisis, rather than simply enduring or remaining unchanged.

The importance of organizational resilience has been further accentuated by the increasing need for organizations to navigate a wide range of internal and external challenges, such as market volatility, technological disruption, and natural disasters. As the ability to adapt, recover, and even thrive in the face of these disruptions has become more critical, scholars have noted that organizational resilience is not a one-size-fits-all concept but varies based on the specific business context and external shocks (Hillmann & Guenther, 2021). Research into this area has proliferated over the past decade, with an increasing number of studies examining resilience through diverse lenses, from corporate governance to supply chain management (Kazemi et al., 2024; Forliano et al., 2023).

Numerous studies have underscored the critical role of organizational resilience in helping businesses anticipate, adapt to, and transform in response to external environmental factors (Rodrigo et al., 2023). For example, Chowdhury et al. (2021) conducted a systematic review of research on the impact of COVID-19 on supply chains, focusing on the role of technology in implementing resilience measures and ensuring business continuity. Similarly, Bento et al. (2021) examined organizational resilience in the oil and gas sector, categorizing the existing researches into key areas such as conceptualizations, methods, and the relationship between resilience and safety. Engidaw (2022) investigated challenges faced by Ethiopian small businesses during COVID-19, highlighting the need to manage expectations, strengthen relationships with stakeholders, and diversify product delivery methods to endure the crisis. Zambrano et al. (2022) explored the impact of COVID-19 on Brazil's water sector, evaluating organizational resilience. Using the Resilience Maturity Scale method (BS 65000:2014), they assessed resilience before and during the pandemic based on six core resilience elements. The results from Brazilian water companies, revealed that local companies were more affected by the pandemic and highlights the need for improved preparedness. Mokline and Abdullah (2021) argued the need for organizations to focus on enhancing employees' psychological resilience, which in turn strengthens overall organizational resilience.

Pokhriyal et al. (2022) analysed the oil and gas industry's response to past and recent disruptions, including the pandemic-induced recession. The study emphasizes strategies like automation, digitalization, and optimization to mitigate risks and boost profitability. A resilience roadmap is proposed to guide the industry's adaptation and growth during challenging periods. Ozanne et al. (2022) examined the role of social capital and dynamic capabilities in enhancing organizational resilience in SMEs of Australia and New Zealand during the COVID-19 pandemic. The results indicate that internal social capital directly impacts resilience. Dynamic capabilities mediate the relationship between social capital and resilience. Lopes de Sousa Jabbour et al. (2023) investigated how circular economy business models enhance organizational resilience, with a focus on the mediating role of Industry 4.0 technologies and customer engagement. The study concluded that circular economy practices significantly contribute to resilience. Sun et al. (2023) proposed a framework to evaluate the resilience of the global oil and gas trade network in 2010, 2015, and 2020. Their findings indicate that the oil trade network is shrinking over time, while the gas trade network initially became more connected but later declined. Under simulated attacks, oil trade networks withstand intentional attacks better, whereas gas trade networks are more resistant to random attacks. Trieu et al. (2023) explored how IT capabilities and organizational ambidexterity support resilience and performance in SMEs, emphasizing the role of government support in optimizing resources and ensuring sustainable growth. Kim et al. (2024) used organizational resilience as a framework to address pandemic-related challenges, identifying key themes across organizational levels, including leadership, operations, and individual units.

McAlister et al. (2024) explored the dynamics among organizational characteristics affecting infrastructure management during disruptions using a multi-layered system dynamics approach. The study developed causal models across physical, financial, communication, and knowledge layers to evaluate resilience. Rahi et al. (2024) designed a comprehensive scale to evaluate organizational resilience within the oil and gas sector, comprising ten key indicators and 40 specific items. This framework provides stakeholders with a valuable tool for analysing organizational strengths and areas for improvement. Chivunga et al. (2024) assessed organizational resilience in Malawi’s power grid operator by linking resilience parameters and capacities through a case study. They identified 20 resilience indicators, categorized into five capacities, revealing significant weaknesses, particularly in transformative capacity due to financial constraints. Khan et al. (2024) redefined organizational resilience by categorizing its attributes under process, structure, and strategic actions, drawing from cross-disciplinary foundations. They propose conjectures and propositions for multinational enterprises (MNEs), integrating ideas from social, mechanical, and ecological literature. Liang and Li (2024) investigated the impact of organizational resilience on firm growth, focusing on how strategic change and managerial myopia mediate this relationship. They find that organizational resilience positively influences firm growth, with strategic change and managerial myopia serving as mediators. Environmental uncertainty moderates this relationship, enhancing the link between resilience and strategic change while weakening the link between resilience and managerial myopia.

Ekram et al. (2024) examined key logistics factors contributing to disruptions in the oil and gas sector, proposing strategies to enhance resilience. They highlighted flexibility, redundancy, visibility, and collaboration as crucial elements for minimizing disruptions. Their study specifically focuses on improving the resilience of Egypt's oil and gas supply chain. Napier et al. (2024) presented a dynamic process model for organizational resilience, emphasizing its importance for MNEs in navigating change, adapting to adversity, and sustaining success. The model identifies five multilevel elements of resilience: individual, organizational, ecosystem, institutional, and global. Lin and Fan (2024) investigated the relationship between supply chain integration, organizational resilience, and sustainable performance in Chinese agriculture firms. The findings revealed that supply chain integration positively influences organizational resilience, which partially mediates the link between supply chain integration and sustainable performance. Additionally, digital technology usage positively moderates the relationship between internal supply chain integration and organizational resilience.

Shela et al. (2024) explored how collective mindfulness acts as a micro foundation for leveraging organizational resources—such as human capital, financial resources, and IT infrastructure—to build organizational resilience. Using the COA framework, they demonstrate the model's robustness and highlight firm size's moderating effect on financial resource utilization. Jiang et al. (2024) conducted a bibliometric analysis of 342 studies on organizational resilience using CiteSpace and VOSviewer, identifying research hotspots like crisis management and corporate social responsibility.

They found dispersed collaboration networks among prolific scholars and highlighted China, the United States, and England as leading contributors. Sharma et al. (2024) examined the role of Industry 4.0, smart supply chains, and agility in boosting sustainable business performance. The study highlights Industry 4.0's contribution to sustainability and its link to agility through smart practices. Table (1) summarized the more important resilience studies in 5 last years.

Table 1
Recent studies on organizational resilience

Author	Contribution	Application Area	Tools/Techniques Used
Emenike and Falcone (2020)	Reviewed the supply chain resilience (SCR) literature in the energy sector, including O&G	Energy sector	Systematic literature review
Bevilacqua et al. (2020)	Developed a method for analysing the domino effect, uncovering hidden pathways that influence SCR.	Fashion industry	Fuzzy cognitive maps
Ivanov and Das (2020)	Modelled the ripple effect of the COVID-19 pandemic on global supply chains, taking into account various disruption factors	Generic SC	Simulation model
Bravo and Hernandez (2021)	Assessed organizational resilience using financial and operational metrics	O&G companies	Empirical study
Ali et al. (2021)	Proposed a comprehensive perspective on reactive strategies for SCR in addressing disruptions caused by COVID-19	Food industry	Qualitative study
Bento et al. (2021)	Reviewed organizational resilience studies	O&G industry	Literature Review
Mokline and Abdullah (2021)	Explored the importance of enhancing employees' psychological factors to foster individual resilience	Different companies	Qualitative study
Pokhriyal et al. (2022)	Created a roadmap to evaluate, analyse, and reduce risks during a pandemic	O&G industry	Qualitative study
Ozanne et al. (2022)	Investigated the role of social capital and dynamic capabilities in strengthening organizational resilience	SMEs	SEM-PLS
Zambrano et al. (2022)	Assessed Brazilian water companies in relation to their resilience maturity in COVID 19 pandemic	Water sector	Qualitative-quantitative survey
Trieu et al. (2023)	Explored how IT capabilities and organizational ambidexterity enhance the resilience and performance of SMEs	SMEs	SEM-PLS
Kim et al. (2024)	Incorporated three existing perspectives of organizational resilience (attribute, process and multi-level views) into an integrated model	Healthcare employees	Grounded theory
Lopes de Sousa Jabbour et al. (2023)	Examined the relationship between circular economy and resilience through the mediating effects of Industry 4.0 and customer integration	Manufacturing firms	SEM-AMOS
Rahi et al. (2024)	Proposed a framework to assess organizational resilience within the oil and gas industry	O&G industry	Conceptual study
Shela et al. (2024)	Explored how collective mindfulness acts as a micro foundation for leveraging organizational resources to build organizational resilience	Manufacturing companies	SEM-PLS
Jiang et al. (2024)	Conducted a literature review on organizational resilience	Organizational resilience	Literature Review
Ekram et al. (2024)	Highlighted the logistics perspective in the Egyptian O&G supply chain	O&G SC	Mix Method
Liang and Li (2024)	Investigated the impact of organizational resilience on firm growth, by mediating role of strategic change and managerial myopia	Manufacturing companies	Regression
McAlister et al. (2024)	Explored the dynamics among organizational characteristics affecting infrastructure management during disruptions	Water infrastructures	System Dynamics
Chivunga et al. (2024)	Assessed organizational resilience in Malawi's power grid operator by linking resilience parameters and capacities	Power sector	Qualitative study
Napier et al. (2024)	Presented a dynamic process model for organizational resilience	Multinational enterprises	Qualitative study
Lin and Fan (2024)	Investigated the relationship between supply chain integration, organizational resilience, and sustainable performance	Agriculture firms	SEM-PLS
Sharma et al. (2024)	Defined the role of digitalization in achieving sustainable business value, by the mediating role of supply chain agility, resilience, and smartness	UK SCs	SEM-AMOS and ANN

Despite the growing body of research on resilience, particularly in the context of organizational dynamics and theoretical frameworks, there remains a significant gap in the application of advanced analytical tools to assess resilience in specific industrial contexts, such as the oil and gas (O&G) sector. Few studies have focused on modelling the complex interdependencies between various resilience factors in this sector, and even fewer have applied advanced techniques to dynamically capture these relationships. Moreover, the impact of socio-economic and cultural factors, particularly in regions like Iran, on organizational resilience has yet to be sufficiently addressed in the literature.

This research aims to fill these gaps by employing the Adaptive Neuro-Fuzzy Inference System (ANFIS) for resilience appraisal within Iranol, an O&G company. ANFIS offers a sophisticated approach for capturing the dynamic relationships and uncertainties inherent in resilience factors, addressing the limitations of traditional methods. By incorporating fuzzy logic and neural networks, ANFIS allows for the modelling of complex, nonlinear relationships that may otherwise be difficult to quantify. Additionally, this research will explore how socio-economic and cultural factors specific to Iran can influence organizational resilience, offering insights into the contextual adaptation of resilience strategies in O&G companies. This novel application of ANFIS will provide a more nuanced understanding of resilience, supporting better decision-making and fostering effective stakeholder engagement in the context of Iranol's operations.

3. Research Methodology

This study applied a systematic approach for measuring Iranol company's resilience in 2024. Iranol Oil Company is a major producer of lubricants and petroleum-based products in Iran. The company operates with two refineries located Tehran and badan, while several manufacturing units across the country work for blending and packaging lubricants. It has approximately 1,240 employees across various departments.
The required data to implement the model, collected from the experts of Iranol headquarter in Tehran. As the analytical tool, ANFIS is chosen for analysing the resilience level. So, at the first step a literature review was conducted to determine the initial resilience indicators. Analysing the importance of these indicators based on fuzzy Delphi in 2 rounds revealed that 24 indicators are of more importance than 0.7 threshold and determined as the main resilience indicators. To ensure the consistency and reliability of the Delphi results, a consensus index was calculated to measure the level of agreement among the experts. The validity of the Delphi results was further ensured through a test-retest procedure, where a subset of the experts was re-interviewed to check for consistency in their responses. These validation procedures helped ensure the robustness of the identified resilience indicators and their relevance to the Iranian oil industry.
Next, all indicators categorized in 5 groups which together used to assess Iranol's resilience. Accordingly, the appraisal systems consisted of a main FIS with 5 inputs and 1 output, while the inputs were also the outputs of the subsystems of fuzzy inference systems with different inputs (See Table 2).
The key parameters of the ANFIS model, including the number of membership functions and the training algorithm, were determined through an iterative process that balanced prediction accuracy with computational efficiency. A backpropagation-based learning algorithm was employed to optimize the fuzzy inference system's parameters. This approach adjusts the membership function parameters during the training process to minimize the mean squared error (MSE) between the predicted and actual resilience values. For implementing ANFIS, the Gaussian membership function was chosen because of its smooth, bell-shaped curve, which is particularly effective in modeling uncertainty and handling imprecise data in organizational resilience assessments. Gaussian functions are also well-suited for capturing the fuzzy nature of human judgment in evaluating resilience factors. They provide flexibility in defining the degree of membership, which is crucial when dealing with qualitative inputs and expert assessments in organizational resilience. The Gaussian membership function's ability to model gradual changes in input variables also improves the precision of the model in predicting resilience levels. The research framework illustrated in Fig (1).

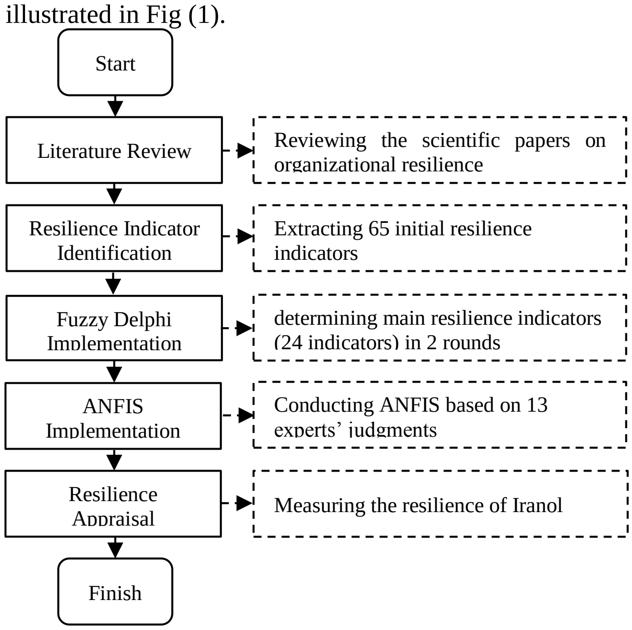

Fig. 1. Research framework

- Adaptive Neuro-Fuzzy Inference System (ANFIS)

ANFIS, first introduced by Jang (1993), integrates the fuzzy if-then rule system and artificial neural network to form a robust neuro-fuzzy system. ANFIS offers a simplified yet effective data-driven learning paradigm that employs fuzzy logic principles to map inputs to desired outputs. It achieves this by utilizing highly integrated neural network processing units and weighted information pathways to transform numerical inputs into corresponding outputs (Arslankaya, 2023). By applying neural network-based learning algorithms, ANFIS dynamically adjusts the parameters of a fuzzy inference system (Daneshvar et al., 2021). The choice of membership functions, are dependent on the nature of the problem to be solved. This research applied a Gaussian membership function to maps the crips input to the fuzzy sets (Govindharaj et al., 2024).
ANFIS consists of a fuzzy layer (input layer), product layer, normalization layer, defuzzification and summation layer. The architecture of ANFIS, depicted in Fig. (2), consists of six distinct components, each fulfilling a specialized function (Arslankaya, 2023). The firast layer consists of two inputs x and y. At the second layer, called the fuzzy layer, the membership degree containing the input and output functions at each node is computed, while the multiplication of the signal for the input in each layer is computed in the third layer (product layer). At the normalization layer (forth layer), the output is a fraction of the firing strength of the node to the sum of all firing strength of the other nodes, while the signal from the normalization layer is multiplied by the fuzzy rule's function at the defuzzification layer (fifth layer). The total output is estimated at the summation (sixth layer) by adding all signals from all layers using a summation function. The Takagi–Sugeno fuzzy technique in the ANFIS controller is depicted by a rule-based system with two inputs, a and b, and one output in a fuzzy inference system.

Rule 1: If a *is* A_1 *and* b *is* B_1, $F_1 = S_1 a + r_1 b + t_1$ (1)

Rule 2: If *a is* A_2 *and b is* B_2, $F_2 = S_2a + r_2b + t_2$ (2)

Where A_1, A_2, B_1, B_2 represent the membership functions while *a* and *b* are input parameters. F_1 *and* F_2 are acquired outputs from the system, whereas *s*, *r*, and *t* are nodal consequent parameters.

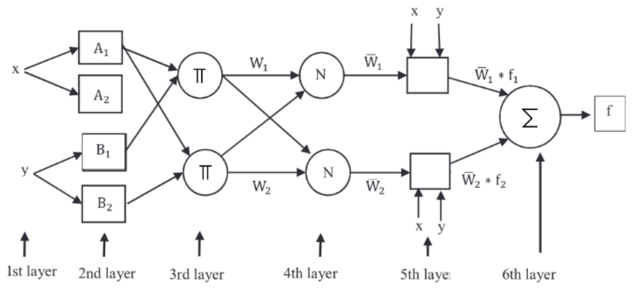

Fig. 2. ANFIS structure with two inputs

ANFIS demonstrates exceptional efficacy due to its ability to provide the necessary dataset, a wide selection of membership functions, robust generalization capabilities, and enhanced interpretability through fuzzy rules. Additionally, it seamlessly integrates linguistic and numerical information for efficient problem-solving (Alitasb, 2024). The six operational layers of ANFIS are described in the following (Arslankaya, 2023).

Layer 1: Every node in this layer is the input node where the input variables are passed to other layers. No transaction takes place.

Layer 2: It is the layer where the blur function takes place. The nodes in this layer can be adjusted, and the fuzzy sets belonging to the input variables obtained from the first layer have membership functions. The output of this layer shows the degree of the respective membership functions and is shown in Eq. 3. The most used functions in the literature for the membership function are triangle, trapezoid, and generalized-bell and gaussian functions.

$$O_{2,i} = \mu_{A_i}(x) \qquad O_{2,j} = \mu_{B_i}(y) \qquad (3)$$

Layer 3: It is the rule layer. Each node in this layer represents the rules and numbers created according to the Fuzzy Logic system. For the most preferred classical operator in ANFIS, each node is labeled with the symbol $\prod$ and expresses the product of all input variables as in Eq. 4.

$$w_i = \mu_{A_i}(x)\mu_{B_i}(y) \ldots \qquad (4)$$

Layer 4: It is the normalization layer. Each node in this layer accepts all incoming nodes in the rule layer as input values, and the normalized trigger level of each rule is calculated in the layer. The formula used in this layer is given in Eq. 5.

$$\overline{w}_i = \frac{w_i}{\sum_{n=1}^{k} w_k} \qquad (5)$$

Layer 5: It is the defuzzification and results layer. The weighted result values of a given rule are calculated at each node in this layer. Eq. 6 is used when calculating these result values.

$$O_{4i} = \overline{w}_i f_i = \overline{w}_i(p_i x + q_i y + r_i) \qquad (6)$$

Layer 6: It is the output layer of the method. In this layer, the output values from the fifth layer are processed, and the actual value, which is the system's output, is obtained with the result found with the help of Eq. 7.

$$f_{cikis} = \sum_{i=1}^{n} \overline{w}_i f_i = \sum_{i=1}^{n} \overline{w}_i\,(p_i x + q_i y + r_i) \qquad (7)$$

4. Results and Discussion

To validate the proposed model within the practical context of Iranol Company, a panel of organizational experts was asked to participate in analytical phase. Specifically, a group of 13 experts from Iranol company participated in the evaluation process. These experts were selected based on stringent criteria, including their theoretical knowledge, practical experience, willingness to engage, and capacity to provide meaningful contributions to the research. All discussions, analyses, and assessments related to the identification and comparison of resilience indicators were conducted in close collaboration with these experts, ensuring the results were firmly rooted in both theoretical insights and practical applications. In this research, resilience indicators identified using a qualitative method, which its results are presented in Table (2).

Table 2
Main indicators of organizational resilience

Concept	Indicators	Authors
Organizational Adaptability	Flexible & Agile Structure	Barasa et al., 2018; Duchek, 2019; Kamali Chirani and Homayounfar (2023); Khan et al., 2024; Garrido-Moreno et al., 2024; Chivunga & Blanchard, 2024
	Flexible Culture	
	Aligned Goals	
	Leadership Style & Traits	
Collaborative Factors	Team Learning	Sellberg et al., 2018; Barasa et al., 2018; Stone and Rahimifard, 2018; Bento et al., 2021; Garrido-Moreno et al., 2024; Chivunga & Blanchard (2024); McAlister et al., 2024; Jiang et al., 2024
	Knowledge Management	
	Effective Communication	
	Employee Participation	
	Trust Development	
Change Management	Individual/ Organizational Readiness	Altay et al., 2018; Barasa et al., 2018; Stone and Rahimifard, 2018; Bento et al., 2021; Trieu et al. 2023; Kamali Chirani and Homayounfar (2023); Chivunga & Blanchard (2024); Zhang et al., 2024; Garrido-Moreno et al., 2024; Jiang et al., 2024
	Adaptability Capacity	
	Continuous Environmental Monitoring	
	Innovation & Creativity	
	Creative Organizational Climate	
	Diversity Management	
HR Management	Employees Training	Barasa et al., 2018; Stone and Rahimifard, 2018; Chivunga & Blanchard (2024); Jiang et al., 2024; Garrido-Moreno et al., 2024; Shela et al, 2024
	Attention to Human Capital	
	HR Recruitment	
	HR Empowerment	
Production Management	Resource Management	Bento et al., 2021; Chivunga & Blanchard (2024); Shela et al, 2024; Trieu et al. 2023; Garrido-Moreno et al., 2024; Chivunga & Blanchard (2024); Jiang et al., 2024; Zhang et al., 2024; Karman et al., 2024; Khan et al., 2024
	Relationship Management	
	Process Improvement	
	Cost Control	
	Product Development	

4.1. Defining fuzzy logic system

- *Defining input variables*

In line with Table 2, the model was established as in Fig. (3) to evaluate the resiliency of Iranol company. So, we defined a system with five inputs including 'Organizational Capabilities, 'Collaborative Factors', 'Change Management', 'HR Management' and 'Production Management' and one output as 'Organizational Resilience'. The input variable 'Organizational

Adaptability' depends on 'Flexible and Agile Structure', 'Flexible Culture', 'Aligned Goals' and 'Leadership Style & Traits' is different. The input variable 'Collaborative Factors' depends on 'Team Learning', 'Knowledge Management', 'Effective Communication', 'Employee Participation' and 'Trust Development' is different. The input variable 'Change Management' depends on 'Individual/ Organizational Readiness', 'Adaptability Capacity', 'Continuous Environmental Monitoring', 'Innovation & Creativity', 'Creative Organizational Climate' and 'Diversity Management', is different. The input variable 'HR Management' depends on 'Employees Training', 'Attention to Human Capital', 'HR Recruitment', and 'HR Empowerment', is different. Finally, the input variable 'Production Management' depends on 'Resource Management', 'Relationship Management', 'Process Improvement', 'Cost Control' and 'Product Development' is different.

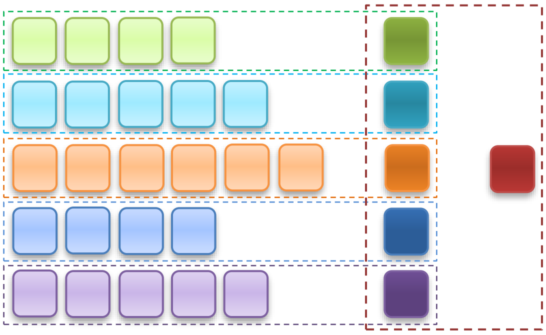

Fig. 3. Structure of the resilience indicators

The structure of the main fuzzy system is presented in Fig. (4). As previously mentioned, the main fuzzy system considers five inputs, based on them rules have been defined.

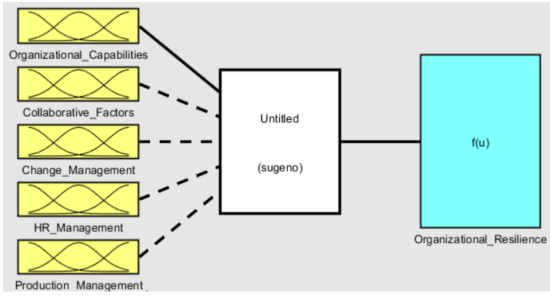

Fig. 4. Structure of the main FIS model

As mentioned earlier, each of the five inputs in the main FIS- Organizational Capabilities (A), Collaborative Factors (B), HR Management (C), Change Management (D), and Production Management (E)- has its own sub-FIS with various inputs. The structures of all five sub-FISs are outlined below (Fig. 5).

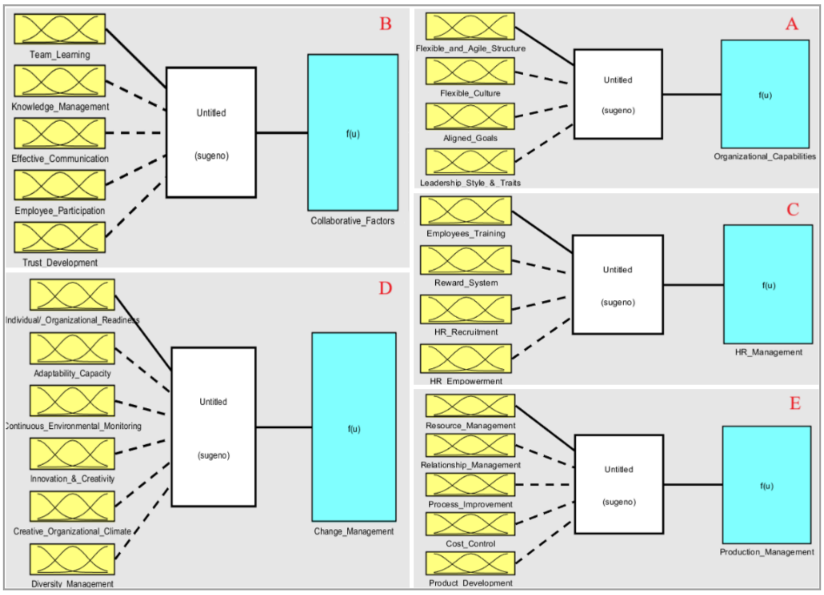

Fig. 5. Rule viewer

- *Defining membership functions*

In this research among the different membership functions, Gaussian, in chosen to for all inputs and outputs. This function ensures the differentiability conditions for the input and output variables in the ANFIS system, making it suitable for use given the continuity of input and output values. Verbal expressions include; Low (L), Medium (M), and High (H), and specified values encompasses the range [0 1]. It is important to note that the range of variations for both input and output variables in questionnaire has been determined based on a Likert scale.

- *Setting* fuzzy rules

In the rule-setting stage, rules are created for different combination of given inputs and output. At the membership function determination stage, it is possible to calculate how many rules should be developed. For instance, for the research main fuzzy inference system, 3 * 3 * 3 * 3 * 3 = 243 rules could be created for the output (Organizational Resilience). The rules were created on MATLAB following the general logic above. Number of developed rules for the main FIS is equal to 67 due to experts' opinions. The interface that allows reaching the prediction value by manually entering the input values for the main FIS presented in Fig. (6). The template set to create the rules will be as follows:

If Organizational Adaptability is = "…" and Collaborative Factors is = "…" and Change Management is = "…" and HR Management is = "…" and Change Management is = "…", Then Organizational Resilience is= "…".

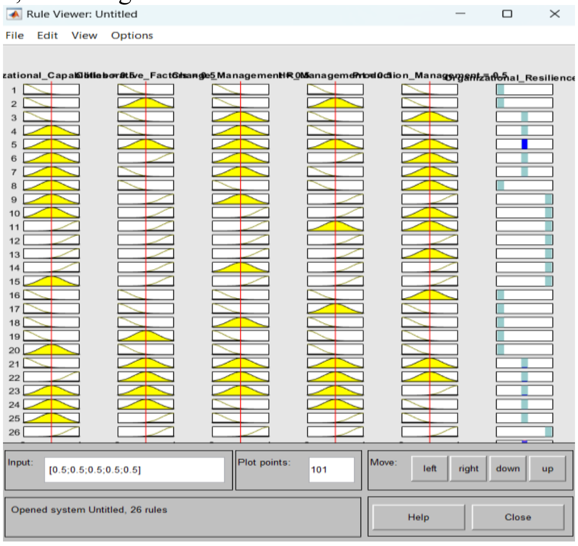

Fig. 6. Graphical representations of the rules for the main FIS

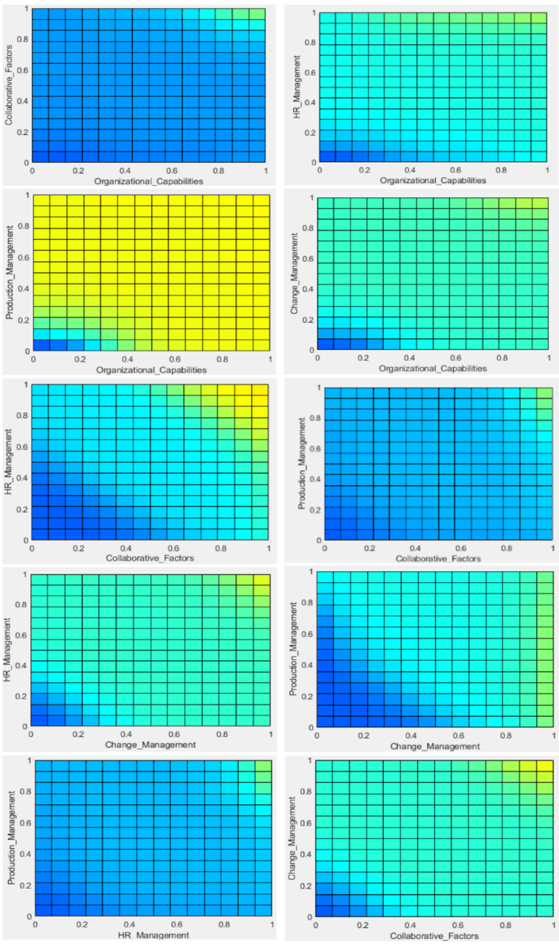

Fig. 7. Graphical representations of the rules for the main FIS

4.2. *Developing the ANFIS model*

- *Structuring the ANFIS model*

The structure of the ANFIS network is formed based on nodes and interconnecting links that connect the model's inputs to its output. The output of each node depends on the parameters leading to that node, and the learning rule determines how these parameters are adjusted. According to the research model, six ANFIS structures have been fitted, which can be defined as follows. Fig (8) illustrates the ANFIS structure of the main system.

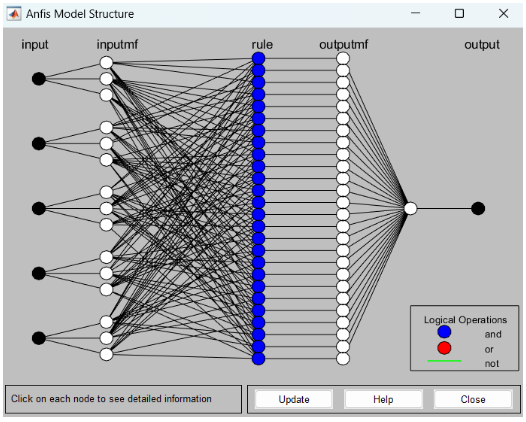

Fig. 8. ANFIS structure of the Main system

The ANFIS structure for five sub systems is also presented in Fig (9).

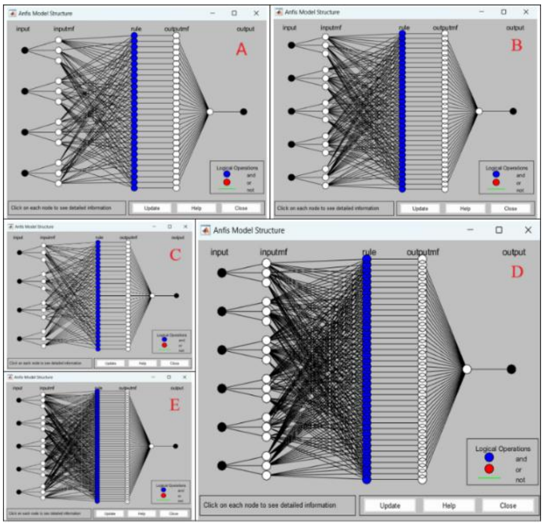

Fig. 9. ANFIS structure of the sub systems

In the above Figure, Section A illustrates the Organizational Capabilities, with four inputs. Section B represents the ANFIS structure of the Collaborative indicators, with five inputs. Section C illustrates the Change Management indicators, which has six inputs. Section D displays the HR Management concept, with four inputs. And finally, Section E represents the ANFIS structure of the Production Management, with five inputs.

- *Data gathering*

In order to train fuzzy inference system (FIS) a structured questionnaire was designed based on the five input variables and their sub-components. Then, senior managers, department heads, and employees involved in organizational processes were asked to fill the questionnaire using a five-point scale from "Strongly Disagree" (1) to "Strongly Agree" (5). Among 1240 employees, 126 qualified employees including 6 Senior managers, 14 department heads, and 102 employees involved in organizational processes filled the questionnaires. We splited data into training (70%), testing (20%) and validation (10%) datasets for evaluation.

- *Training the fuzzy inference system*

In the first stage, the ANFIS model was trained using the supervised learning (SL) and based on the data of 88 questionnaires. This process reduces learning error throughout training, optimizes most initial membership functions, and integrates them into the ANFIS structure. For updating the membership function parameters, hybrid learning approach is used which integrates backpropagation with the least squares estimator (LSE) to enhance efficiency. Since error variation is directly related to error magnitude, this criterion is commonly used to determine when to stop training. After 35 training epochs, the ANFIS and Sub-ANFIS models reached an acceptable error level. The calculated error rates for the ANFIS model across different phases (training, testing, and validation) are as follows:

Table 3
Estimated Mean Square Error (MSE)

ANFIS Model	Training Error ($\times 10^{-3}$)	Testing Error ($\times 10^{-3}$)	Validation Error ($\times 10^{-3}$)
Organizational Resilience	2.44	2.79	1.13
Organizational Adaptability	3.99	3.21	3.42
Cultural Dimension	2.78	4.02	1.56
Economic Dimension	1.44	1.76	1.38
Educational Dimension	2.06	3.96	1.43
Collaborative Factors	0.150	0.138	0.356

- *Model Validation and Testing*

To assess the validity of the model, the generalization capability of the fuzzy inference system has been examined, and the issue of overfitting has also been evaluated accordingly. The graphs comparing the estimated values with the actual values of the training and validation data for all ANFIS structures indicate their alignment. Next, Figure (10) illustrates the alignment between the main ANFIS model output and its predicted values for the training datasets. The average calculated training error, based on multiple iterations in the main ANFIS model, is 0.00244.

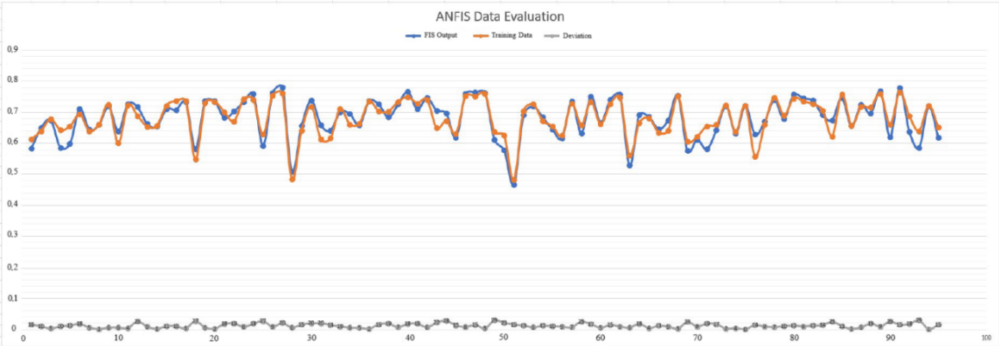

Fig. 10. Comparison between ANFIS output and training data

A similar graph has also been plotted using the testing and validation data. The validation data was introduced into the model for the first time, and due to the alignment between the predicted and actual values for this dataset, the appropriateness of the model confirmed. Figures (11) and (12) illustrate the results.

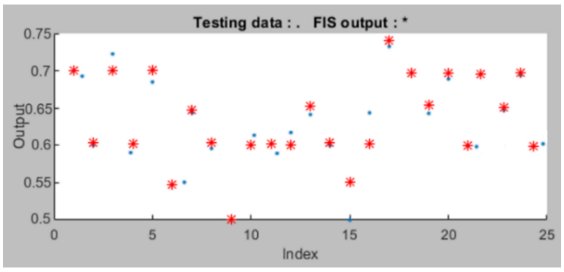

Fig. 11.Comparison between ANFIS output and testing data

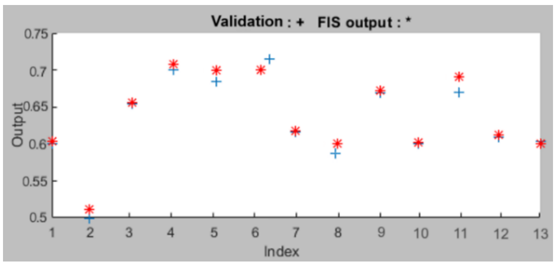

Fig. 12.Comparison between ANFIS output and validation data

As seen in the above graphs, the alignment of testing and validation data with the results of ANFIS main system were confirmed. For these data, the calculated error is 0.00279 and 0.00113, respectively. Model validation and testing implemented for all five sub ANFIS to optimize fuzzy rule weights and enhance model precision and make better resilience measurement metric.

In addition, to validate the model's behaviour, the limit condition test has been utilized in this research. In this test, the designed Fuzzy Inference System (FIS) is examined under various extreme conditions (Low, Medium and High), and the model's sensitivity to input changes is analysed. In this study, the input values are assumed to range between 0 and 1. For the main FIS, the limit condition test for organizational resilience demonstrates that the model completely behaves logical in response to input changes.

Table 4
Limit Condition Test for Main ANFIS

Type	Indicator	Value		
Inputs	Organizational Adaptability	0	0.5	1
	Cultural Dimension	0	0.5	1
	Economic Dimension	0	0.5	1
	Educational Dimension	0	0.5	1
	Collaborative Factors	0	0.5	1
Output	Organizational Resilience	0.00313	0.5	1

For all Five sub-FISs this test was implemented, where the showed logical behavior.

4.3. Evaluation of organizational resilience

In this step, the trained ANFIS model was used to evaluate organizational resilience based on real-time data. To implement the model and assess the resilience of Iranol company, a simple questionnaire similar to Table (5) was designed based on resilience indicators and distributed among experts to assess the resilience of the organization based on 0-1 scale. All responses were aggregated using the geometric mean and normalized to apply in the sub-ANFISs and main ANFIS model for measuring the total resilience score.
After collecting the data, the output value was calculated for each sub-ANFIS, and create in input values for the main ANFIS model. The output of the main ANFIS was computed as the Iranol resilience score.

Table 5
Resilience appraisal for Iranol company

Concept	Indicators	Indicators Score	Concepts Score
Organizational Adaptability	Flexible and Agile Structure	0.59	0.62
	Flexible Culture	0.68	
	Aligned Goals	0.67	
	Leadership Style & Traits	0.63	
Collaborative Factors	Team Learning	0.55	0.68
	Knowledge Management	0.67	
	Effective Communication	0.74	
	Employee Participation	0.70	
	Trust Development	0.65	
Change Management	Individual/ Organizational Readiness	0.58	0.59
	Adaptability Capacity	0.54	
	Continuous Environmental Monitoring	0.74	
	Innovation & Creativity	0.73	
	Creative Organizational Climate	0.51	
	Diversity Management	0.60	
HR Management	Employees Training	0.78	0.69
	Attention to Human Capital	0.56	
	HR Recruitment	0.59	
	HR Empowerment	0.73	
Production Management	Resource Management	0.75	0.73
	Relationship Management	0.80	
	Process Improvement	0.55	
	Cost Control	0.70	
	Product Development	0.76	

As provided in Table (4), there are five key input dimensions, each consisting of multiple indicators that contribute to the overall resilience score. The overall resilience score of Iranol Oil Company was determined to be **0.68**, indicating a moderate-to-high level of organizational resilience. The findings indicate that Organizational Adaptability achieved a concept score of 0.62, reflecting the company's moderate flexibility and agility in responding to environmental and operational changes. Among the four indicators, 'Flexible Culture' scored the highest (0.68), suggesting that Iranol Oil Company fosters a work environment conducive to adaptability. However, 'Flexible and Agile Structure' received a lower score (0.59), indicating potential challenges in structural flexibility that may require attention. Collaborative Factors achieved the high concept score (0.68) among the five inputs. 'Effective Communication' (0.74) and 'Employee Participation' (0.70) and emerged as the strongest indicators, highlighting the company's strong internal engagement and communication strategies. 'Team Learning' received the lowest score (0.55), suggesting that there is room for improvement in fostering a learning culture that enhances collaborative resilience.
With a concept score of 0.59, Change Management showed moderate effectiveness in dealing with dynamic business conditions. 'Continuous Environmental Monitoring' (0.74) and 'Innovation & Creativity' (0.73) received the highest scores, indicating the company's proactive approach to innovation and external awareness. However, 'Adaptability Capacity' (0.54) and 'Creative Organizational Climate' (0.51) scored lower, signifying areas where the company could enhance its adaptability and creative problem-solving mechanisms. HR Management demonstrated a relatively strong concept score of 0.69, indicating an effective approach to workforce development and talent management. 'Employees Training' (0.78) and 'HR Empowerment' (0.73) were key strengths, signifying Iranol Oil Company's investment in employee growth and empowerment. However, 'Attention to Human Capital' (0.56) suggests that further improvements in recognizing and leveraging human capital could enhance overall resilience. Finally, Production Management achieved a strong concept score of 0.72, indicating efficient production processes and resource utilization. 'Relationship Management' (0.80) and 'Product Development' (0.76) emerged as key strengths, highlighting effective stakeholder management and innovation in product offerings. However, 'Process Improvement' (0.55) scored the lowest, suggesting the need for enhanced efficiency and continuous improvement in production operations (See Fig. 13).

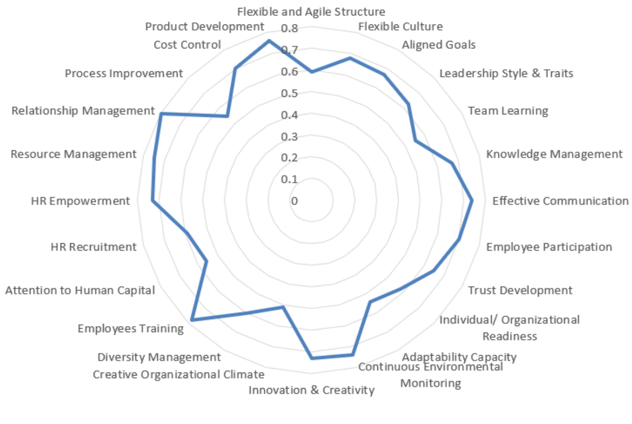

Fig. 13. Resilience indicators diagram

In brief, the strongest contributing factors were Collaborative Factors (0.70) and Production Management (0.72), while Change Management (0.59) lagged slightly behind. These findings suggest that while the company has strong collaborative and production capabilities, there is a need to strengthen adaptability, change readiness, and process improvements to achieve a more robust resilience framework.

5. Conclusion

This study employed an ANFIS model to measure organizational resilience for Iranol Oil Company in 2024. Through a systematic approach, 24 resilience indicators categorized into five main dimensions- Organizational Adaptability, Collaborative Factors, Change Management, HR Management, and Production Management- were identified using fuzzy Delphi methodology. These dimensions formed the basis of a hierarchical ANFIS structure, with five sub-FISs feeding into a main FIS to produce an overall resilience score. Data gathered from 126 qualified respondents was used to train, test, and validate the model, confirming its robustness and predictive accuracy. The results demonstrated strong alignment between predicted and actual outcomes, with low error rates across all phases, suggesting that ANFIS is a highly effective tool for resilience measurement.

The findings indicate that while the company demonstrates strong collaborative and production management capabilities, certain areas require improvement, particularly in Change Management and Organizational Adaptability. Enhancing adaptability capacity, fostering a more creative organizational climate, and refining process improvement strategies will contribute to a more resilient organization. Strengthening these dimensions will enable Iranol Oil Company to navigate uncertainties more effectively and sustain long-term competitiveness in the oil industry. Ultimately, the integration of resilience-enhancing strategies across all functional areas will be crucial for the company's continued growth and stability. The findings underscore that Iranol exhibits high resilience levels, driven by strengths in adaptability, collaborative practices, and production management. However, specific areas such as HR training and innovation in change management require further focus. These insights provide a foundation for targeted interventions aimed at enhancing the company's overall resilience in an increasingly volatile operational environment.

From a managerial perspective, leveraging ANFIS underscores the potential of data-driven tools for resilience assessment and strategic planning. Managers should integrate such models into performance management frameworks to identify critical gaps, prioritize resources, and address vulnerabilities. Senior leadership must foster an agile culture, align goals, and invest in leadership development to enhance adaptability. Emphasizing knowledge-sharing, effective communication, and team-learning initiatives can strengthen collaborative resilience and innovation. Employee empowerment through training, talent development, and trust-building should be prioritized to enhance human capital. Additionally, embedding resilience-focused practices in process improvement, resource management, and production strategies will bolster operational stability and preparedness during crises.

Future research can incorporate real-time data streams into the ANFIS framework can enable dynamic monitoring of resilience. This could help organizations proactively respond to evolving risks and uncertainties. They could investigate additional resilience indicators, such as those related to environmental sustainability, digital transformation, or cybersecurity. These areas are becoming increasingly relevant in organizational resilience. Additionally, Combining ANFIS with other decision-support tools, such as machine learning or optimization models, could enhance the accuracy and applicability of resilience assessment frameworks.

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