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Research Article

Role of System Resilience in Dealing with Threats Using an Entropy-Based TOPSIS Approach: A Case Study in an Oil Products Distribution Company

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Abstract

Objectives: The current study aimed at assessing the ability of system resilience against threats using an integrated method based on entropy and technique for order of preference by similarity to ideal solution (TOPSIS) in an oil company.

Methods: The threats were identified through field observation, literature review, and expert opinion in the industry. Afterward, the required data were gathered, and the resilience status was examined using three structured questionnaires for each category of the threats. The weights of resilience criteria computed for each group of the threats using entropy, and were then ranked through the TOPSIS method.

Results: Learning (0.34) and anticipating (0.15) had the highest and lowest impacts on the category of regular threats, respectively. In the case of irregular threats, anticipating (0.31) and monitoring (0.21) had the highest and lowest impacts, respectively. As for unexampled threats, learning and Anticipating (0.26) had the highest impact, and responding (0.23) had the lowest impact. The results of TOPSIS analysis indicated that regular threats, irregular threats, and unexampled threats were ranked in the first, second, and third positions with scores of 0.52, 0.48, and 0.46, respectively.

Conclusions: To ameliorate resilience in complicated systems, managers should strengthen RE-related indicators along with working on the indicators which are in poor condition. The findings of this study can be used by managers and decision-makers to identify system weaknesses and improve comprehensive technical and applied plans.

Keywords: Entropy, NIOPDC, Oil Company, Resilience, Threats, TOPSIS

1. Background

Today, complex socio-technical systems such as oil and gas industries are facing various threats due to their complex nature. According to resilience engineering (RE), which refers to a system's intrinsic capability to adjust its performance during and after changes or disruptions in the system so that it can keep its functionality in predicted and unpredicted situations (1-3), threats are categorized as regular, irregular, and unexampled events (4). Therefore, these systems should be able to identify and handle a variety of threats. As the name implies, regular threats such as operators' errors and failure of some part of a process happen frequently. Irregular threats are unique, unusual, and highly diverse accidents that cannot be handled following standard procedures. For instance, the failure of main and backup systems simultaneously is an infrequent accident. Unexampled threats such as the Chernobyl accident and the COVID-19 pandemic are, however, events that happen rarely and are beyond the common experience of organizations (5).

Since irregular threats and unexampled events happen rarely and are considered exceptions, they cannot be described using the linear models employed in safety management for regular threats. It seems that their distinguished characteristic is that they emerge from specific situations. Therefore, it is necessary to devise a proper way to deal with the situations and conditions that are likely to lead to such accidents. This goal cannot be addressed using barriers; instead, it requires new techniques such as performance adaptability or RE (6).

Resilience has been defined in literature in many different ways; consider, for example, two definitions: (1) Resilience refers to the capability of a system to create foresight, to recognize, to anticipate the changing shape of risk before adverse consequences happen; (2) resilience is the inherent ability of a system to adapt its functioning before and during disturbances, so that it can continue operations after a major mishap or in the presence of continuous stresses (7). In general, resilient systems or organizations feature four capabilities as follows: (1) Giving a strong and flexible response to threats; (2) monitoring trends and even their performance; (3) anticipating risks and opportunities and the reciprocal effects of events; and (4) learning from experiences (8-11). These four capabilities are, indeed, resilience cornerstones to describe and analyze system performance in various activities and during different disruptions (12).

Multi-criteria decision making (MCDM) approaches are widely used tools that examine complicated problems. They help managers and other decision-makers evaluate a variety of criteria and rank alternatives (13, 14). Selecting the decision-making method and the weighting method are two main challenges in MCDMs. There are a variety of techniques to tackle these problems; however, given technical matters and the nature of the problem here, the Entropy technique was used to determine the weight of each resilience criterion against a threat and TOPSIS to rank the threats.

To the best of the authors' knowledge, there has been no study in the literature to assess the role of system resilience based on the four criteria of resilience (i.e., responding, learning, monitoring, and anticipating) in dealing with the three groups of threats (i.e., regular, irregular, and unexampled ones).

2. Objectives

However, NIOPDC was investigated as a case study whose main objective was to assess the role of system resilience against diverse threats using an integrated approach based on Entropy and TOPSIS. In Table 1, the specifications of this study have been listed in comparison with other similar studies.

3. Methods

3.1. Data Analysis

The mentioned threats (i.e., regular, irregular, unexampled) were determined through field observation (e.g., visiting industry sites by researchers), literature review, and consultation with experts (e.g., talking to experts and receiving their advice during ten two-hour sessions) in the mentioned industry. Afterward, data related to each threat was collected with three structured questionnaires. Then, experts (9 people) were asked to state their judgment on the importance, transparency, simplicity, necessity, and relevance of the questions for each threat based on five scales (very high, high, medium, low, and very low). It is noteworthy that the experts' competence in completing the questionnaire had been determined based on the three indicators of education level, familiarity with the subject under study, and work experience. Each questionnaire contained 20 items where each component of resilience (i.e., learning, responding, monitoring, and anticipation) was covered by five questions.

All employees of the operational unit of the company (48 people) participating in this study were male, with an average of 17 years of work experience, and in the age range of 40 - 50 years. The response rate was 100%. The reliability and validity of the questionnaire were calculated, and the validity of the tool was deemed acceptable. Cronbach's alpha values for regular threats, irregular threats, and unexampled events were equal to 0.954, 0.977, and 0.980, respectively. A general view of the study design is illustrated in Figure 1.

3.2. Evaluation Tools

There were numerous mature assessment tools and frameworks for resilience, such as AHP and DEA. Some evaluation methods are too simple to explain the complex situation, and excessive dependence on the judgment of experts causes a deviation from the real situation. After conducting a comparative analysis of different evaluation methods, entropy-TOPSIS was selected as the evaluation method in this study. It is a comprehensive evaluation method that combines

Table 1. Characteristics of This Study Versus Other Studies

Study and Year	Threats	Organizational Resilience	Context	Method		Objective	
				Entropy	TOPSIS	Weighting Indicators	Ranking Threats
This study	√	√	Petrochemical plant	√	√	√	√
Hsu et al. (2022) (15)		√	Relay manufacturers			√	√
Yazdani et al. (2022) (16)	Risk factor	√	Agriculture and food supply chain			√	
Zarei et al. (2021) (17)		√	Gas refinery			√	
Sweya et al. (2020) (18)	√	√	Water supply organization			√	√
Hamedi and Mehdiabadi (2020) (19)		√	Education system			√	
Salehi et al. (2020) (20)		√	Petrochemical plant	√	√	√	
Salehi and Veitch (2020) (21)		√	Petrochemical plant			√	
Mzougui et al. (2020) (22)		√	Automotive industry			√	
Rehak et al. (2019) (23)	√	√	Electrical energy infrastructure			√	√
Motevali Haghighi and Torabi (2018) (24)	√	√	Healthcare			√	√
Loh et al. (2017) (25)	√	√	Supply chain			√	√

Abbreviation: TOPSIS, technique for order of preference by similarity to ideal solution.

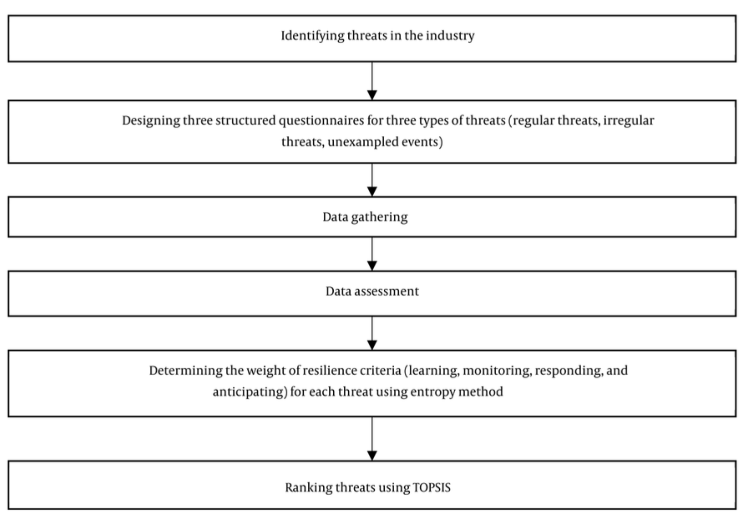


Figure 1. The study diagram

entropy and TOPSIS. Its logical principle is that entropy gives an objective weight to each object. Then, TOPSIS is used to measure the distance between different object index values to evaluate the optimal solution. Finally, the evaluation steps are completed by sorting the objects to be evaluated according to the distance value (26).

The weight of resilience criteria (learning, monitoring, responding, and anticipating) for each threat was calculated through the entropy method. Thereafter, the threats were ranked using TOPSIS. Entropy and TOPSIS are further explained in the following sections.

Table 2. Resilience Criteria for Regular Threats

Entropy Steps	N	Learning	Monitoring	Responding	Anticipating
Decision matrix	48	4.875	5.287	4.937	5.225
Normalized decision matrix	48	0.0206	0.0207	0.0208	0.0208
Computing entropy value	48	- 0.0347	- 0.0347	- 0.0348	- 0.0348

Table 3. Entropy Values, Degree of Divergence and Entropy Weight of Each Criterion

Entropy Values	Learning	Monitoring	Responding	Anticipating
E_j	0.991	0.993	0.994	0.996
$1\text{-}E_j$	0.009	0.007	0.006	0.004
Sum $(1\text{-}E_j)$	0.026			
θ_j	0.34	0.26	0.25	0.15

3.3. Entropy

Entropy was used to calculate the weight of resilience criteria related to each threat (i.e., learning, responding, monitoring, and anticipation). The MCDM matrix contained "m" alternatives and "n" criteria. Here, 48 alternatives (m = 48) and four criteria (n = 4) were assumed for each group of the threats. In addition, there are x_{ij} (i = 1, 2, m; j = 1, 2, ..., n) entries in the MCDM matrix, which indicate the value of the ith alternative for the jth criterion (5, 10, 27). The normalized decision matrix is obtained using dimensionless values (x_{ij}) based on Equation 1:

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \; i\,;\; 1,\; 2, \ldots, m;\; j = \; 1,\; 2, \ldots,\; n$$

The values of entropy and divergence level of the criteria are obtained using Equations 2 - 4 respectively:

$$E_j = -\frac{1}{\ln{(m)}} \sum_{i=1}^{m} P_{ij} ln\left(P_{ij}\right);\; j = \; 1,\; 2,\; \ldots,\; n$$

$$d_j = \left|1 - E_j\right|;\; j = \; 1,\; 2, \ldots,\; n$$

$$\theta_j = \frac{d_j}{\sum_{j=1}^{n} d_j};\; j = \; 1,\; 2, \ldots,\; n$$

3.4. Technique for Order of Preference by Similarity to Ideal Solution

Technique for order of preference by similarity to ideal solution was used to rank the three categories of threats, namely regular, irregular, and unexampled ones (m = 3). In TOPSIS, the optimal ranking occurs when the distance from the positive ideal solution is minimum and the distance from the negative ideal solution is maximum (28). Equation 5 was used to calculate the normal decision matrix (n_{ij}):

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}};\; i = \; 1,\; 2, \ldots, m;\; j = \; 1,\; 2, \ldots,\; n$$

The weighted normalized decision matrix is obtained through Equation 6, where (W_j) represents the weight of the jth criterion and

$$\sum_{j=1}^{n} w_j = 1$$

$$v_{ij} = w_j\, n_{ij};\; i \; = \; 1,\; 2, \ldots, m;\; j = \; 1,\; 2, \ldots,\; n$$

Positive and Negative Ideal Solutions are calculated through Equations 7 and 8 in this paper, "i" refers to the profit criterion, and "j" refers to the cost criterion in all the aforementioned equations.

$$A^+ = \left\{v_1^+; \ldots; v_n^+\right\} = \left\{\left(maxv_{ij} | i \in I\right);\; \left(minv_{ij}\, | i \in J\right)\right\}$$

$$A^- = \left\{v_1^-; \ldots; v_n^-\right\} = \left\{\left(maxv_{ij} | i \in I\right);\; \left(minv_{ij}\, | i \in J\right)\right\}$$

The distance from each alternative to the positive and negative ideal solutions is calculated via Equations 9 and 10:

$$d_i^+ = \left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2\right\}^{\frac{1}{2}};\; i \; = \; 1,\; 2, \ldots, m$$

$$d_i^- = \left\{ \sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2 \right\}^{\frac{1}{2}}; \ i = 1, 2, \ldots, m$$

The relative closeness to the Positive Ideal Solution was determined using Equations 11 and 12.

$$R_i = \frac{\left(d_i^-\right)}{\left(d_i^+ + d_i^-\right)}; \ i = 1, 2, \ldots, m$$

$$d_i^- \geq 0 \ and \ d_i^+ \geq 0; \ then \ R_i \in [0; 1]$$

Technique for order of preference by similarity to ideal solution assigns the best rank to the alternative (threat) with the minimum distance from the Positive Ideal Solution and the maximum distance from the negative ideal solution.

4. Results

Entropy and TOPSIS were used to analyze the collected data. The resilience criteria for each threat were weighted using entropy, and then the threats were ranked using TOPSIS.

4.1. Entropy Results

The results of entropy weighting to calculate resilience criteria for each threat are shown in Tables 2 and 3. The Entropy steps to determine the weights of resilience criteria for regular threats are as follows (Table 2): First, the decision matrix is developed; then, a normalized decision matrix is computed using Equation 1; afterward, the entropy values and the divergence of the criteria are obtained using Equations 2 and 3; the entropy weights of the criteria are then calculated via Equation 4.

To determine the weights of criteria for Irregular threats and Unexampled threats, the same method was followed.

As depicted in Figure 2, the highest and lowest weights of the criteria in regular threats were obtained for learning (0.34) and anticipating (0.15), respectively. This indicates that learning and anticipating have the highest and lowest impacts, respectively. Similarly, the highest and lowest weights of the criteria in irregular threats were obtained for anticipating (0.31) and monitoring (0.21). For unexampled threats, the highest and lowest weights of the criteria were obtained for learning/anticipating (0.26) and responding (0.23), respectively.

In Figure 2, the weighting results of the four resilience criteria for each threat are listed using the entropy method, which can be utilized for future decision-making. Based on the obtained weights, the alternatives (threats) were ranked using TOPSIS.

4.2. Technique for Order of Preference by Similarity to Ideal Solution Results

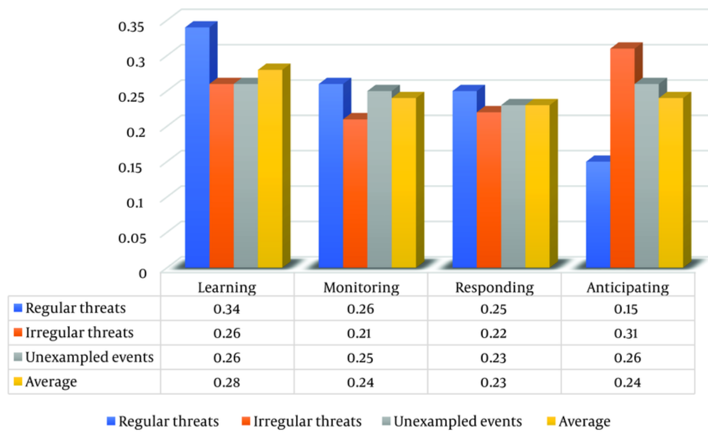
The weight of each criterion is the sum of all its indices. To rank the criteria, the average final weight was calculated using the TOPSIS method. One of the main objectives of this study was to rank the three types of threats (i.e., regular, irregular, unexampled). Technique for order of preference by similarity to ideal solution was used as an MCDM approach to rank these threats.

In Table 4, a decision matrix for 144 (3 × 48) alternatives is listed. The first step in the TOPSIS method was to calculate the normalized weight matrix using Equation 5. Next, a normalized weighted decision matrix was obtained using Equation 6. It is worth noting that the weighted decision matrix was calculated by multiplying the normalized decision matrix by the total weight of the four dimensions, which was obtained using the entropy method. Positive and negative ideal solutions were calculated using Equations 7. The results are shown in Table 5. Finally, the ranking of all alternatives (threats) was determined based on their relative adjacency to the ideal solutions.

The results of the ranking through the TOPSIS method indicated that regular threats, Irregular threats, and Unexampled events are ranked in the 1st, 2nd, and 3rd positions, respectively (Table 6).

5. Discussion

Today, a variety of threats affect organizational performance. Organizational resilience is one of the main criteria that address threats. Given the importance and extent of resilience's effect on organizations and societies' capability to respond to threats, resilience has become one of the new topics in crisis management in both developed and developing countries (29). Thus, the necessity of conducting this study to identify the weaknesses in the organizational resilience level is clear-cut. Based on this, the results obtained in the four main



	Learning	Monitoring	Responding	Anticipating
Regular threats	0.34	0.26	0.25	0.15
Irregular threats	0.26	0.21	0.22	0.31
Unexampled events	0.26	0.25	0.23	0.26
Average	0.28	0.24	0.23	0.24

Figure 2. Weights of resilience criteria in each threat

criteria—learning, monitoring, responding, and anticipating—of RE will be discussed in the following.

The results of criteria weighting showed that Learning and Anticipating had the highest and lowest impacts on regular threats, respectively. Threats like product leakage, working with electricity, and similar issues were identified as regular threats in the organization under study. Workers with higher education exhibited a more positive attitude toward safety and showed less inclination toward unsafe practices. Well-educated individuals tend to be more informed about safety measures, leading to a better understanding and adherence to safety education and instructions at work. education significantly enhances resilience and reduces the risk of accidents in an industry (30, 31).

One of the most critical actions by managers and supervisors that demonstrates support for safety is safety education. Previous studies have highlighted that learning has the highest impact on managerial and organizational factors, showcasing its vital role in resilience. These findings underline the importance of education in addressing this category of threats, where knowledge is the most crucial factor in coping with regular threats. Anticipating received the lowest importance score in this category, as regular threats are generally predictable. A study by Shirali et al. ranked learning, responding, monitoring, and anticipating in the 3rd, 4th, 5th, and 7th positions, respectively (32). Similarly, a study conducted by Azadian et al. highlighted that RE significantly improves safety and reduces accidents. Their findings emphasized that learning plays a crucial role in reducing errors and enhancing preparedness (33).

Moreover, research by Huber et al. demonstrated that learning from organizational incidents positively impacts RE in high-risk process environments (34).

The results of Omidvar et al. showed that Learning was the least important criterion in the level of resilience (35). Similarly, Pecillo's study indicated that the four cornerstones—learning, monitoring, responding, and anticipating—were in the best status in polish companies. Among these, the companies demonstrated the best performance in Responding, which was directly linked to legal requirements mandating the implementation of safety management systems by upstream and downstream companies. However, learning from positive or neutral safety situations was identified as the least emphasized aspect (36).

The variation in findings can be attributed to differences in societal, environmental, geographical, and industrial conditions.

In the case of irregular threats, anticipating had the highest importance, while monitoring had the lowest. Irregular threats are incidents with low probability but

Table 4. Resilience Criteria for All Alternatives

Entropy Steps	N	Learning	Monitoring	Responding	Anticipating
Decision matrix	144	4.637	4.941	4.804	4.741
Normalized matrix	144	0.365	0.358	0.368	0.350
Normalized weighted decision matrix	144	0.105	0.086	0.084	0.084

Table 5. Ideal and Negative Ideal Solutions

Variable	Learning	Monitoring	Responding	Anticipating
Threats				
A^+	0.151	0.122	0.123	0.124
A^-	0.050	0.080	0.067	0.082

potentially catastrophic consequences. Although these events are unlikely to occur, their possibility cannot be ruled out, making it challenging to develop standard processes to address them. Consequently, anticipating becomes a critical aspect in managing such threats. Examples of irregular threats identified in the company included floods, earthquakes, and failures of the main pipeline transferring products to loading tanks. In such cases, authorities need to have pre-planned responses ready to address these incidents effectively. Madni and Jackson highlighted that RE is achievable in systems capable of controlling accidents through anticipation (37). Similarly, Dullmann and van Hoorn proposed a generative platform for assessing RE performance and approaches in microservice architecture. Their platform included a foundational metamodel, a production platform, and backup services to address problems through monitoring. However, their findings indicated that monitoring held greater significance compared to the results of the present study (38). In this context, Shirali and Tahmasbi identified monitoring and learning as having the highest weights in their study (39).

As for unexampled threats, nearly all the criteria had similar weights, with learning and anticipating (0.26) playing the most significant roles, and monitoring (0.25) and responding (0.23) having slightly lesser influence. The relatively equal weights suggest that all four criteria are of comparable importance when addressing these types of threats. Unexampled threats differ fundamentally from regular and irregular threats as they are unprecedented and unimaginable. Addressing them requires substantial shifts in thinking approaches rather than ad hoc measures. Examples of unexampled threats identified in the studied company include pandemics, large-scale floods, major earthquakes, and massive fire outbreaks in storage tanks. By definition, unexampled events demand innovative methods for control and recovery. Based on the results, improving resilience in response to these threats necessitates a comprehensive strategy aimed at enhancing all four resilience criteria: (1) Anticipating, (2) responding, (3) learning, and (4) monitoring.

Peat et al. qualitatively examined the four criteria of resilience in a study on workers' reactions to working in pharmacies in the UK during the COVID-19 pandemic, an example of unexampled events. Similar to the findings of the present study, all four criteria were deemed equally important (40). Shirali et al. analyzed various indices of RE in process industries and concluded that anticipating, responding, learning, and monitoring are key indices in evaluating resilience in sociotechnical systems (32). Additionally, Kitamura emphasized that the safety of a system can be achieved by improving the four dimensions of resilience: (1) Responding, (2) monitoring, (3) anticipating, and (4) learning (41).

Studies on resilient systems have often utilized a combination of MCDM methods, with entropy-based and TOPSIS approaches being among the most common. These methods focus on weighting and ranking alternatives in a comprehensive and integrated manner (39, 42, 43). Research based on this approach has demonstrated that it outperforms other standard methods.

Table 6. Technique for Order of Preference by Similarity to Ideal Solution Results for Ranking Threats

Alternative No.	Relative Closeness	TOPSIS Rank
Regular threats	0.524	1
Irregular threats	0.476	2
Unexampled events	0.463	3

Abbreviation: TOPSIS, technique for order of preference by similarity to ideal solution.

The advantages of this approach include flexibility, reliability, integrity, and greater acceptability of its structure (20, 44, 45). For example, Salehi et al. applied entropy and TOPSIS to weight and rank five petrochemical units in terms of technical, human, and organizational factors influencing crisis management (20).

Based on the TOPSIS ranking results, regular threats, irregular threats, and unexampled events ranked first, second, and third, respectively. Similar to many other organizations, the capability and readiness of the studied organization to address regular threats were higher than those for unexampled events. This is because regular threats are more predictable and manageable using standard methods, while unexampled events are less predictable and lie beyond the organization's common experience.

Since unexampled events are exceedingly rare, the organization tends to allocate fewer resources to addressing them and lacks mechanisms to identify and respond to such threats effectively. Conversely, regular threats pose a much higher risk and are more frequently encountered. As a result, the organization prioritizes readiness to manage these threats using established protocols and standard methods, leading to a higher level of preparedness for regular threats.

Feng and Trinh investigated the drivers of resilience safety culture in the construction environment. Their findings indicated that organizations could enhance resilience safety culture by systematically addressing regular threats, irregular threats, and unexampled events in construction sites (46).

Pillay (2018) studied RE and found that systems could manage regular threats, irregular threats, and unexampled events by utilizing the four resilience criteria: (1) Anticipating, (2) responding, (3) learning, and (4) monitoring. Anticipating refers to the ability of resilient organizations to focus on potential outcomes by understanding future expectations, including threats and opportunities, as well as potential changes, disruptions, and pressures. Responding is the ability to determine and implement appropriate measures to address threats through either prepared responses or adjustments to routine performance. Learning involves the capability to interpret and act on facts by deriving the right lessons from both successful and failed experiences. Monitoring pertains to the ability to identify and address critical issues, demonstrated by knowing what to observe in both the environment and the system itself. These criteria collectively form the foundation for resilient systems to adapt and respond effectively to diverse threats (47).

5.1. Limitations

Among the limitations of the present study were the small sample size and the non-cooperation of some employees in answering the questions.

5.2. Conclusions

Our findings indicated that the three questionnaires designed based on the four criteria of resilience were reliable and valid tools for assessing system resilience. The interventions focused on these four criteria, demonstrating that supporting these criteria enhances the capability of systems to adapt.

In other words, to improve resilience in complex systems, managers should strengthen RE-related indicators while addressing those indicators in poor condition. The results of the TOPSIS analysis showed that regular threats, irregular threats, and unexampled threats were ranked in the first, second, and third positions, with scores of 0.524, 0.476, and 0.463, respectively.

The findings of this study can assist managers and decision-makers in identifying system weaknesses and developing comprehensive technical and applied plans to enhance organizational resilience.

Footnotes

Authors' Contribution: B. J. and G. S. participated in the design of the study. B. J. contributed to data collection. V. S. contributed to data analysis and interpretation of results. B. J., G. S., and S. S. participated in the writing and editing of the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of authorship presentation.

Conflict of Interests Statement: The authors declared that they have no conflict of interest.

Data Availability: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

Ethical Approval: IR.AJUMS.REC.1399.900 .

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