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Research Paper

Application of FAHP-TOPSIS Method for Weighting and Prioritizing Resilience Indicators in a Combined Cycle Power Plant

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ABSTRACT

Background & Aims of the Study: Resilience means the ability of a system to predict, tolerate, and adapt to various disturbances and recover quickly to its original state. This study aims to weigh and prioritize the indicators affecting the resilience in a combined cycle power plant using the combined method of FAHP-TOPSIS.

Materials and Methods: This is a descriptive-analytical and cross-sectional study conducted at the beginning of 2021 in the Kashan Combined Cycle Power Plant. In the first step, a literature review and semi-structured interviews with 25 experts were conducted to identify the indicators affecting resilience. A total of 20 affecting indicators were identified and divided into three groups: situational awareness, vulnerability, and adaptability. In the next step, we used the Fuzzy Analytical Hierarchy Process (FAHP) to determine the indicators' weights of each group. In the end, we used the TOPSIS method to perform the final prioritization of the indicators.

Results: The final results of prioritizing the indicators that affect resilience based on the outcomes of the TOPSIS method showed that the three indicators of structural stability (final weight=1), senior management awareness of the roles and responsibilities (final weight=0.075), and understanding and risk acceptance (final weight=0.067) play the most important roles, while logistics support index (final weight=0.029) is the least important indicator in determining the level of resilience.

Conclusion: By recognizing and prioritizing the indicators affecting the level of resilience, corrective and preventive measures can be defined and implemented to improve safety and increase the resilience in combined cycle power plants based on the importance of each indicator. Also, the method introduced in this paper can be used as a scientific technique to identify and prioritize resilience indicators in other process industries such as oil and gas and petrochemical industries.

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1. Introduction

The electric power industry is one of the most important economic and industrial infrastructures in many countries. The growing global need for electricity, especially in developing countries, demands electricity and the development of power plants, which has been very rapid in Iran in recent years [1]. In the last few years, advances in technology have increased the complexity of process systems which has led to large-scale accidents [2]. Incidents such as a fire in combined cycle power plants are inevitable. Using the fuzzy degree of reliability approach, Shirali et al. showed the turbine's risk of explosion or fire in the combined cycle power plant and the severe outcomes of such accidents [3]. Fires in these power plants can lead to death, injury, reduction of production, equipment failure, and severe financial losses [4]. Using Dow's fire and explosion index (F&EI), Sadeghi et al. estimated the financial damage caused by a fire in a combined cycle power plant to be $ 4.12 million US [5]. However, to prevent human and financial losses because of fire in these power plants, measures such as assessing the fire risk, monitoring fire alarm systems, and increasing the level of resilience are recommended [6-8].

The concept of resilience was first proposed by Hauling in ecology; however, various definitions of resilience have been proposed in accidents [9]. One of the common and practical definitions of safety is the inherent ability to adjust the performance before, during, and after changes or disturbances in a system that can maintain the required performance in both predictable and unpredictable conditions [10]. Resilient organizations can overcome accidental crises and emergencies with low costs because of their readiness, planning, and high flexibility [11]. In this regard, much attention has recently been paid to resilient organizations in the face of crises and emergencies. Researchers have tried identifying the characteristics of resilient organizations or societies to introduce the required indicators for creating them [12].

In recent years, national and international researchers have considered identifying and prioritizing resilience indices using multi-criteria decision-making techniques [13, 14]. Among the studies conducted in Iran, we can mention the study by Askaripoor et al. [15]. They used fuzzy logic and a hierarchical analysis method to prioritize the risk factors affecting fire occurrences in combined cycle power plants. In another study, Jafari et al. applied the fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to determine the weight and ranking of resilience engineering indices in a refinery complex [16]. Shirali et al. also designed and conducted a study to determine the weight and prioritization of resilience indices using the analytical network process (ANP) network analysis process method in a metal company [17]. D. Tadic et al. evaluated and ranked the factors that affect organizational resilience using the two-stage fuzzy AHP-Fuzzy TOPSIS method [18]. Akaa et al. utilized the AHP method to prioritize fire-fighting solutions in steel structures [19]. Alshehri et al. employed the Delphi and AHP methods to identify and prioritize resilience indices in disasters [20]. Piprani also used the AHP method to evaluate the indices that affect the resilience of the textile industry in Pakistan [21]. Regarding what was accomplished, applying multi-criteria decision-making methods in various fields of science is important. Because of the country's need to generate electricity, the construction and operation of combined cycle power plants have also increased.

Given that accidents such as fires and explosions in these industries are inevitable, increasing the resilience of these power plants can be a control strategy to reduce human and financial losses. Increasing the resilience rate depends on recognizing the factors and indices that affect it. This is while not all indices that affect resilience are equally important. Therefore, using multi-criteria decision-making methods to identify the most important indices in the face of fire accidents in combined cycle power plants can be helpful. Thus, the present study aims to weigh and prioritize resilience indices in a combined cycle power plant using the combined method of Fuzzy Analytical Hierarchy Process (FAHP)-TOPSIS.

2. Materials and Methods

Forming a team of experts and identifying indices affecting resilience

This research is a descriptive-analytical and cross-sectional study conducted at the beginning of 2021 in the Kashan Combined Cycle Power Plant. To form a team of experts in this study, at first, we prepared a list of all available personnel working in the combined cycle power plant with at least 10 years of experience. Then, we contacted them by phone and explained the purpose of the study. The inclusion criteria of experts were the willingness to participate and on-time completion of the paired comparison questionnaire. A total of 35 staff members declared their readiness to join the team of experts. Next, ten people were excluded from the study because of not completing the pairwise comparison questionnaire on time. Finally, pairwise comparisons were performed based on the opinions of the 25 experts. Because of the outbreak of COVID-19 and the need to comply with health protocols, all interviews were conducted through social networks. In a semi-structured interview, instead of having a limited number of questions, the researcher had a framework of different topics to explore. The researcher used these topics to gather the necessary information. At the end of the interview, 20 indices were categorized into three groups: situational awareness indices, key vulnerability indices, and adaptability capacity indices. First, the indices of each group were weighed using the fuzzy hierarchical analysis. Then, three important indices from each group were selected and prioritized using the TOPSIS method to identify the most important priorities.

Calculating the weight of resilience indices using the FAHP method

The following steps were performed to calculate the weight of resilience indices using the fuzzy hierarchical analysis method [13].

Step 1: Creating a hierarchical structure

In this step, identified indices were adjusted in a hierarchical structure (Table 1).

Step 2: Defining fuzzy numbers and making pairwise comparisons

In this step, a pairwise comparison was performed using fuzzy triangular numbers. An anonymous questionnaire was sent to the experts through social networks, and they were asked to compare the indicators affecting fire resilience in pairs using the verbal expressions in Table 2.

Step 3: Forming a matrix of pairwise comparisons using fuzzy numbers

The pairwise comparison matrix is formed according to Equation 1 [14].

$$1.\ A=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \widetilde{a2n} \\ \vdots & \vdots & \ddots & \vdots \\ n1 & a_{n2} & \cdots & 1 \end{bmatrix}$$

Step 4: Calculating Si for each row of pairwise comparisons

Si, a triangular fuzzy number, is obtained from Equation 2 [22]:

$$2.\ Si=\sum\nolimits^{m}_{j=1}M^{j}_{gi}\ \otimes[\sum\nolimits^{m}_{j}=\sum\nolimits^{m}_{j=i}M^{j}_{gi}]^{-1}$$

$$[\sum\nolimits^{n}_{i=i}\sum\nolimits^{m}_{j=i}M^{j}_{gi}]^{-1}\ and \sum\nolimits^{n}_{i=i}\sum\nolimits^{m}_{j=i}M^{j}_{gi}\ and \sum\nolimits^{m}_{j=i}M^{j}_{gi}$$

In this equation, "i" represents the row number and "j" represents the column number. In this relation, fuzzy numbers are paired matrices. It can also be determined from Equations 3-5, respectively:

$$3.\ \sum\nolimits^{m}_{i=1}\sum\nolimits^{j}_{gi}=(\sum\nolimits^{m}_{i=1}l_j\ M^{m}_{i=1}m_j\ \sum\nolimits^{m}_{j=1}u_j)$$

$$4.\ \sum\nolimits^{n}_{i=i}\sum\nolimits^{m}_{i=1}\sum\nolimits^{j}_{gi}=(\sum\nolimits^{n}_{i=1}l_j\ M^{n}_{i=1}m_j\ \sum\nolimits^{n}_{j=1}u_j)$$

$$5.\ [\sum\nolimits^{n}_{i=i}\sum\nolimits^{m}_{j=i}M^{j}_{gi}]^{-1}=\left(\frac{1}{\sum^{n}_{i=i}u_i}\cdot\frac{1}{\sum^{n}_{i=i}m_i}\cdot\frac{1}{\sum^{n}_{i=i}J_i}\right)$$

Step 5: Calculating the magnitude of s_i relative to each other

In general, if $M_1=(l_1, m_1, u)$ and $M_2=(l_2, m_2, u_2)$ are two fuzzy triangular numbers. The magnitude of M_1 relative to M_2 is defined as follows [23] (Equation 6):

$$6.\ V\ (M_2M_2\geq M_1)M_1=hgt(M_1\cap M_2M_1\cap M_2)$$

$$\mu_{M2}(d)=\begin{cases} 1 & if\ m2\geq m1 \\ 0 & if\ J1\geq u2 \\ \dfrac{J1-u2}{(M_2-u2)-(m1-J1)} & otherwise \end{cases}$$

On the other hand, the magnitude of a triangular fuzzy number is obtained from K of another triangular fuzzy number from Equation 7:

$$7.\ V\ (M\geq M1,\ M2,\ \ldots=V$$

$$[(M\geq M1) and\ (M\geq M2)\ and \ldots\ldots and\ (M\geq M_k)]$$

$$M_i=Min\ V\ (M\geq i=1,\ 2,\ 3,\ldots,\ K$$

Step 6: Calculating the weight of the criteria and options in the pairwise comparison matrices

Equation 8 was used for the following purpose:

$$8.\ (=Min\ V\ (k=1,\ 2,\ \ldots.,\ N,\ k\neq iS_i\geq S_k)$$

Therefore, the non-normalized weight vector will be as follows Equation 9:

9. $w=d(A_1).d(A_2)\ ....d(A_n))^T$

$(i=1,\ 2, ..., N)$

Step 7: Calculating the final weight vector

The weight vector calculated in the previous step must be normalized; therefore, the final weight is calculated from Equation 10 to calculate the final weight vector [24].

10. $w=d(A_1).d(A_2)\ ....d(A_n))^T$

Prioritizing resilience criteria using the TOPSIS approach

At this stage, experts were provided with an anonymous questionnaire, and they were asked to determine the significance of criterion “i” based on criterion “j”, using the Likert scale provided in Table 3 [13].

Then, by integrating experts’ opinions from the TOPSIS approach, the prioritization of resilience indices was determined. Solving the problem with the TOPSIS method requires the following six steps [25].

Step 1: Quantifying and unscaling the decision matrix (N)

Equation 11 was used for unscaling:

11. $n_{ij}=\dfrac{a_j}{\sum_{i=1}^{m} a_{ij}^2}$

Step 2: Obtaining a balanced unscale matrix (V)

In this step, the unscaled matrix (N) is multiplied by the diameter matrix of the weights ($W_n \times _n$).

Step 3: Determining the ideal positive solution and the negative ideal solution(Vj$^-$)

In this step, the best values for the positive indices are the largest, and the smallest values are for the negative indices. Also, the worst values for positive indices are the smallest values and for negative indices are the most significant values.

Step 4: Gaining the distance of each option to the positive and negative ideals

The Euclidean distance of each option from the positive ideal was calculated using Equation 12, and the distance of each option to the negative ideal was calculated using Equation 13 *(dj$^-$)*:

12. $di^+=\sqrt{\ } \sum_{i=1}^{n} (V_{ij}-Vj^+)^2\ i=1,2,...,m$

13. $di^-=\sqrt{\ } \sum_{i=1}^{n} (V_{ij}-Vj^-)^2\ i=1,2,...,m$

Step 5: Determining the relative proximity of an option to the ideal solution

At this stage, the relative proximity of each option to the ideal solution was calculated using Equation 14 *(CL*)*:

14. $CL^*=\dfrac{di^-}{di^-+di^+}$

Data analysis

In this study, all calculations related to the fuzzy hierarchical analysis method and the TOPSIS method were performed using MATLAB software (MATLAB 2018a).

3. Results

The results of the first phase of pairwise comparisons in the group of indices related to situational awareness showed the following indices as the most important indicators of this group: management awareness of roles and tasks with a final weight of 0.219; perceptions and acceptance of risk with a final weight of 0.171; and, awareness of safe points with a final weight 0.165 (Table 4).

Also, the results of pairwise comparisons of the vulnerability group shown in Table 5 demonstrated the following three indices as the most important indicators of this group: structural stability, human resources, and operational facilities with the weights of 0.135, 0.180, and 0.217, respectively.

Table 6 also shows the pairwise comparisons in the adaptability group. Based on the results, the following three indices are the important indicators of this group: literacy level of the staff and managers (final weight=0.299), lessons learned from accidents (final weight=0.223), and logistical support (final weight=0.21).

Table 1. Indicators and sub-indicators of fire resilience in emergencies

Group	Indicators
Situational Awareness	Roles and responsibilities
	Perception of danger
	Awareness of intra-organizational communication
	Insurance awareness
	Equipment recognition
	Awareness of the number of fireboxes
	Identify risk points
	Situational awareness
Vulnerability	Operating machines and equipment
	Number of hydrant valves in the power plant
	Emergency water supply station
	Correct location of stations
	The ability of human resources
	Operational facilities
	Equipment efficiency
	Structural stability of stations
Adaptability	The literacy level of staff and managers
	Lessons learned from events
	Chart
	Motivational actions
	Logistic support

Archives of Hygiene Sciences
Qom University of Medical Sciences

The results of the second stage and the final pairwise comparisons with the TOPSIS method showed that, respectively, three indices of structural stability (final weight=0.168), senior management awareness of roles and responsibilities (final weight=0.145), and risk perception and acceptance (final weight=0.138) play the most important roles. In comparison, three indices of lessons learned from past accidents (final weight=0.082), awareness of safe points (final weight=0.077), and logistical support (final weight=0.069) have the least role in increasing the level of resilience against fire (Table 7).

4. Discussion

In recent years, the issue of increasing the resilience to disasters has become a vital area; thus, we are now discussing the simultaneous and reciprocal movement of sustainable development and disaster management to increase the level of resilience. In 2011, Norris studied strategies to improve the level of resilience in organizations [26]. The results showed that resilience in organizations requires accurate and continuous evaluation of three important indices, including situational awareness, sensitivity management, and adaptive capacity. The findings are consistent with the results of the present study. The results of our study demonstrated that, with a final

Table 2. Linguistic scale and its synonymous triangular fuzzy numbers

Fuzzy Number Scales	Linguistic Scales	Fuzzy Numbers
1	Equal importance	(1, 1, 1)
2	Equal importance to slightly more	(1, 2, 3)
3	A little more importance	(2, 3, 4)
4	A little more importance to more importance	(3, 4, 5)
5	More important	(4, 5, 6)
6	More important to much more important	(5, 6, 7)
7	Much more important	(6, 7, 8)
8	Much more important to absolute importance	(7, 8, 9)
9	Absolute importance	(8, 9, 10)

Table 3. Comparison table of the value of solution "i" to criterion "j" in the TOPSIS method

Values	Comparison Status of "i" With "j"	Explanation
1	The same	Elements i and j are of equal importance.
3	A little preferred	The element i is slightly more important than j.
5	Very preferred	The element i is more important than j.
7	Very much preferred	The element i is much more important than j
9	Absolutely preferred	The element i is more important than j.
8-2-4-6	Intermediate	Shows intermediate values

Table 4. Normal and abnormal weights of situational awareness group indicators

Indicators	Fuzzy Results			Abnormal Weight	Normal Weight	Priority
	Upper Limit	Medium	lower Limit			
Management awareness of roles and tasks	1.351	0.083	0.032	1.00	0.219	1
Understanding and accepting risk	0.662	0.163	0.039	0.777	0.171	2
Awareness of available safe points	0.609	0.154	0.035	0.751	0.165	3
Awareness of intra-organizational communication	0.556	0.029	0.139	0.714	0.157	4
Knowledge of how the equipment works	0.503	0.133	0.023	0.682	0.150	5
Awareness of the number of fire stations	0.273	0.055	0.018	0.410	0.090	6
Insurance awareness	0.164	0.012	0.026	0.210	0.046	7

Table 5. Normal and abnormal weights of vulnerability group indices

Indicators	Fuzzy Results			Abnormal Weight	Normal Weight	Priority
	Upper Limit	Medium	Lower Limit			
Structural stability	1.552	0.063	0.051	1.00	0.217	1
Ability of human resources	0.735	0.141	0.043	0.832	0.18	2
Operational facilities	0.708	0.136	0.042	0.623	0.135	3
Number of hydrant valves in the power plant	0.675	0.124	0.032	0.501	0.108	4
Emergency water supply station	0.581	0.114	0.031	0.429	0.093	5
Proper location of fire stations	0.432	0.113	0.031	0.418	0.090	6
Equipment efficiency	0.351	0.109	0.030	0.409	0.088	7
Operating machines and equipment	0.253	0.108	0.021	0.394	0.085	8

Archives of Hygiene Sciences
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weight of 0.085, the structural stability index against fire is the most important index in resilience against fire accidents in a combined cycle power plant. Consistent with these results, Obinna UkeniAkaa et al. used the AHP method to prioritize fire-fighting solutions in steel structures which were selected as the most appropriate fire-fighting strategy for strengthening and protecting the structure [18].

Askaripoor et al. also found that fire in the turbine of combined cycle power plants is the most important hazard in the industry [15]. They stated that the most important way to reduce fire damages in combined cycle power plants is to increase the stability of the structure, as well as the use of fire-resistant materials. These findings are consistent with the results of the present study. Our study showed that after the structural stability index, the senior management awareness index of roles and responsibilities index is the most important in the resilience of power plants against fire, with a final weight of 0.075.

Omidvar et al. utilized the fuzzy hierarchical analysis method to assess the level of resilience performance of the petrochemical industry [27]. Their results showed that the management commitment and risk perception index are crucial in determining resilience. The petrochemical industry is one of the process industries. Because of the high volume of storage and the production of highly flammable materials, these industries are at the risk of fire and explosion accidents; therefore, one of the most important indices to improve the resilience of these industries is the management commitment and risk perception (management commitment is manifested in various areas such as financing, safety commitment, production safety, auditing, and inspection). This finding is consistent with the present study.

Table 6. Normal and abnormal weights of adaptability group indices

Indicators	Fuzzy Results			Abnormal Weight	Normal Weight	Priority
	Upper Limit	Medium	Lower Limit			
The literacy level of staff and managers	1.712	0.457	0.070	1.00	0.299	1
Lessons learned from events	0.886	0.202	0.059	0.761	0.223	2
Logistic support	0.767	0.185	0.049	0.718	0.21	3
Motivational actions	0.531	0.106	0.035	0.567	0.166	4
Chart	0.259	0.048	0.024	0.354	0.104	5

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Table 7. Final prioritization of indices affecting resilience based on the TOPSIS method

Resilience Indicators	di⁻	di⁺	CL	Priority
Structural stability	1.324	0.912	0.085	1
Senior management awareness of roles and responsibilities	0.821	0.156	0.075	2
Understanding and accepting risk	0.813	0.142	0.067	3
Ability of human resources	0.789	0.136	0.059	4
Operational facilities	0.783	0.135	0.046	5
The literacy level of employees and managers	0.768	0.129	0.041	6
Lessons learned from past events	0.767	0.127	0.039	7
Awareness of safe places	0.753	0.116	0.037	8
Logistics support	0.749	0.105	0.029	9

Archives of Hygiene Sciences
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Pinion et al. also noted in their study that management commitment to safety increases staff self-reporting control over their jobs [28]. This finding indicates that to improve resilience, the greatest effort should be made to change the thinking of the senior management to value safety issues and accept them as values in the organization.

In 2017, Jafari Nodooshan et al. identified and prioritized organizational resilience indices in a refinery complex using the fuzzy TOPSIS method [16]. The results showed that the senior management commitment index, with a final weight of 0.035, was a higher priority than other indices. The difference between the industries and the lack of structural stability index in the study of Jafari Nodoshan et al. can be the reason for the difference between the two studies [16].

The results of Caroline Catalan's study in 2011 showed that one of the important and effective indices of the organization's resilience is the risk acceptance and recognition index, which is consistent with the present study [9]. Risk acceptance and recognition are possible using fire risk assessment [29]. Fire risk assessment is a useful tool for identifying potential fire hazards and factors influencing its occurrence, determining the safety status, and planning for emergencies [30]. It is possible to identify the potential points for fire in the combined cycle power plants, define and create control measures to prevent fire, and increase resilience using risk assessment [31]. Another important indicator, according to the results, is the ability of human resources with a weight of 0.059.

The heart of the activities of organizations and industries is human resources. Proper management of human resources includes job satisfaction, job stress reduction, and work-family conflict reduction. Proper management of these resources will ultimately lead to increased safety and resilience of the organization [32]. Subsequent indices in order of priority in determining the level of resilience in the face of fire include operational facilities, the literacy level of personnel and managers, learning from accidents, awareness of safe points, and logistical support.

Operational facilities are another important indicator in determining fire resilience. Regardless of the types and causes of fire, operational facilities, such as fire alarms and extinguishing systems, are essential equipment that must be considered in the design. Meanwhile, pumping stations are the main part of the fire extinguishing system [33].

One of the most important measures of managers and supervisors is to provide safety training, which shows their practical support for safety. A study conducted in an oil refinery showed that training has the greatest impact on managerial and organizational factors affecting safety promotion [34]. Because of the changing nature of risks and the increasing complexity of social-technical systems, new approaches to upgrading safety management systems are becoming absolutely necessary.

One of the new approaches is resilience engineering, which because of its novelty in the field of safety, must be identified as indices to examine the strengths and weaknesses of the organization, and then priorities need to be identified to plan and improve its status. This study provides helpful information to managers of combined cycle power plants. Based on the findings of this study, three indices of structural stability, senior management awareness of roles and responsibilities, and risk acceptance and perception have the greatest impact compared to other indices that affect the rate of resilience to fire accidents in combined cycle power plants. As a result, it is possible to improve the level of resilience by improving each of the introduced indices based on priority. Regarding the limitations of this study, the internal relationships between indices have not been studied. In addition, the present study was conducted under the influence of the COVID-19 pandemic, which caused the interview process to be done online, and it was not possible to access more experts. Therefore, the effect of internal relationships between criteria using the ANP network analysis method with a larger number of experts is recommended for future studies. Meanwhile, the results can be compared with the present study.

5. Conclusion

Identifying, weighing, and prioritizing indices that affect resilience can enable industry managers and decision-makers to identify the organization's strengths and weaknesses and define and implement corrective measures to raise the resilience in organizations more purposefully. The technique introduced in this study can also be used to identify, weigh, and prioritize resilience indices in other process industries where the risk of accidents is high.

Ethical Considerations

Compliance with ethical guidelines

All stages of this research have been carried out under the supervision of this company's research and development committee.

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Authors' contributions

Conceptualization and Data analysis: Seyed Mehdi Mousavi; Writing-original draft: Mahsa Jihadi Naeini; Writing-review & editing and Data collection: Farzad Behzadinejad.

Conflict of interest

The authors declared no conflict of interest.

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