

A Fuzzy Analytic Hierarchy Process-TOPSIS Framework for Prioritizing Emergency in a Petrochemical Industry

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Abstract

Background: Petrochemical industry has experienced a variety of accidents and the number of emergency situation in this industry is high. Therefore, prioritizing these situations is important. The aim of this study was to determine the effective criteria for the selection of emergency scenario and prioritize them for corrective actions. **Subjects and Methods:** Delphi technique was used to determine and prioritize the appropriate criteria for the selection of high-risk emergency scenarios. Then, the weights of selected criteria were obtained using fuzzy hierarchical analysis and finally, using the fuzzy TOPSIS technique, the criteria for emergency scenarios were prioritized for corrective actions. **Results:** The most important criteria for the selection of dangerous emergencies included the amount of loss, damage, and probability. According to the weight of these criteria, emergency situations were prioritized. The most important emergencies included fire in the chemical storage, hydrogen leakage at the cylinder fitting in the Alfin unit, and extreme gas leakage in one of the power plant turbines. **Conclusions:** Using this approach, high-priority emergencies can be identified, and it is suggested that planning for controlling these situations and preventing crises should be prioritized by managers.

Keywords: Crisis management, emergency, fuzzy analytic hierarchy process, fuzzy TOPSIS, petrochemical

INTRODUCTION

Today's petrochemical industry is associated with the everyday lives of people which in practice, life is unimaginable without using it. This industry plays a key role in life and also plays a very important role in the global economy, including Iran.^[1] The petrochemical industry produces chemical products of raw materials from oil or natural gas, and one of the industries that have been linked to many of the daily needs, including clothing, pharmaceuticals, food, electronics, agriculture, and health. A significant portion of the workforce in Iran is also employed in this industry.^[2,3]

Due to the range of hazardous materials, hardware complexities, and operations at high temperatures and high pressures,

petrochemical industries are considered as one of the most accident-prone industries, and every year, there are a lot of costs and damage in these industries due to accidents.^[4,5] These industries have caused disastrous events from the past and impose huge costs on societies and industries, as well as

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a lot of human injuries. To cope with these situations, it is necessary to minimize the risk of accidents and subsequently damage by modifying working environments and applying better working practices. One of the ways to reduce the effects of accidents is to limit the effects, cost, and damages caused by accidents and one of the most important ways to reduce effects is emergency response.^[4] An emergency response is defined as “applying science, technology, planning, and management to deal with extreme events that can injure or kill large numbers of people, do extensive damage to property, and disrupt community life.” These effects include deaths, injuries, injury-related disability, destruction, and pollution, effect on production and equipment, and social effects.^[6] Effective emergency response plans play a key role in preventing a lot of injuries, damage, and costs.^[7] This emergency situation not only caused damage to the industry but also affected the stability and credit of the corporation, threatening challenges in the industries. Such an emergency may occur at any time, and hence, risk management and proper and effective response to emergencies are critical to controlling the risks and reducing the injury and damage. Studies have also shown that correct management in emergency response is an important factor in responding correctly in these situations.^[8] As a result, today industries take measures to prevent such situations, as well as to reduce injuries and damage.

Emergencies in each industry are different according to the type of industry, devices, materials, and process, and are defined in each industry according to the characteristics of the industry. In the process of responding to emergencies, speed and efficiency are very important.^[9] Furthermore, in response to emergencies, adequate basic resources such as human resources, financial resources, equipment and technology, appropriate policies, and proper and adequate knowledge of the organization about emergency are also among the requirements for the appropriate response to crises.^[9]

Emergencies are defined on the basis of a comprehensive assessment of the existing risks in the industry.^[10] To cope with all defined emergencies, sufficient preparation, as well as proper training, is essential, but due to the uncertainty about the exact type of occurred emergency, and also due to the unpredictability of this situation, the response must be flexible and creative, and emergency response teams should be ready to respond to all possible situations.^[11]

Emergency response plans are designed before the occurrence of these conditions, and necessary measures to prevent crisis occurrence are considered in these plans. Implementing and practicing these scenarios is important before the occurrence of undesirable events to ensure their operation in emergencies as well as to evaluate and identify weaknesses and to eliminate possible barriers to implementation of these scenarios. Implementing these scenarios is important to optimize and make the necessary changes.^[12]

Due to the presence of primary, intermediate and final hazardous materials, along with the hardware complexity,

the number of emergencies in process industries such as petrochemicals is high and devoting more time, costs, facilities and resources for preventing and controlling, selecting, and prioritizing the emergency is critical to taking corrective action and should be done with great care. Given the existing limitations, including the lack of a standardized procedure for selecting and prioritizing emergencies, and the impossibility of improvement and correction of all emergencies with respect to time and cost, the aim of this study was to prioritize emergency situations using appropriate criteria.

Due to the lack of specific criteria for selecting and prioritizing emergencies, first, it was necessary to determine the criteria for choosing and prioritizing emergencies using the opinions of health professional and Delphi technique, then the weights associated with each of the selected criteria will be obtained using the fuzzy hierarchical analysis, and finally, the emergency situation will be prioritized for corrective actions using the Technique for order preference by similarity to ideal solution (TOPSIS) fuzzy technique.

SUBJECTS AND METHODS

This qualitative and applied study was conducted in a petrochemical complex in Markazi Province, Iran, in 2018. The steps involved in this article are as below:

Setting up a team to monitor and run the Delphi

Due to the lack of appropriate criteria for emergency scenarios, the Delphi technique was used to determine these criteria in this study. The goal of implementing the Delphi technique is to gain access to the most reliable agreement of a group of experts on a specific topic, using a questionnaire, and a panel of experts based on their feedback.^[13,14]

Selecting Experts

In this study, teams consisted of a group of supervisors and counselors were formed to review the objectives of the study, as well as supervise the selection of members of experts. In this Delphi study, a panel of experts consisted of 12 professors of medical faculty members, 7 managers of the relevant departments, and 11 safety officers from petrochemical industry.

Setting up the questionnaire for the first round

In this step, open questions were designed to collect experts' opinions and identify and determine the desired criteria.

Reviewing the questionnaire in written form (solving the inferential ambiguities and grammar check).

Sending the first questionnaire to experts

At first, an open question was designed and sent to 10 experts in a pilot way to examine their answer, understand, and grasp about the designed questionnaire.

Analysis of the answers reached in the first round

According to the results of the pilot study, the questionnaire was sent to 30 of the mentioned individuals. Then, the first

phase responses were analyzed; common criteria were extracted, scaled and grouped and hence that similar answer was placed under the same homogeneous groups.

Preparation of a second-round questionnaire with required revisions

After determining the evaluation criteria, the group analytic hierarchy process (AHP) method was utilized to evaluate the expert’s opinion. In addition, the AHP method was used to decide and select multiple options and compare them with each other as well as in the face of complex systems. In this method, verbal phrases were determined for paired comparisons of the criteria, and the criteria were evaluated by a questionnaire designed in a pairwise comparison to determine the weight and priority of the criteria.^[15]

Sending the second questionnaire to the experts of the previous step:

A designed checklist was sent to 30 previous experts to determine the relative weight of each criterion.

Analysis of the reached answers in the second round

The following steps were performed to determine the relative weights for the criteria using the fuzzy hierarchical analysis and determine the verbal expressions for pairwise comparison of the criteria using Table 1.

- Forming a pairwise matrix by using triangular fuzzy numbers
- Calculating the inconsistency rate of the matrix.

Prioritizing emergency using fuzzy TOPSIS method

To prioritizing the emergency, using defined criteria and the fuzzy TOPSIS method, a questionnaire with 11 options and 11 criteria was designed and sent to 30 experts, and they were asked to score to options based on criteria using a linguistic scale according to Table 2, to prioritizing the emergency according to these scores.

TOPSIS method steps are as follows:

- To determine the criteria and control options and form the main matrix
- To insert the results of the experts’ opinions based on the TOPSIS questionnaire
- To enter the weight of the criteria calculated by the fuzzy AHP (FAHP) method
- To scale up the criteria and options
- To calculate the positive ideal and negative ideal solution
- To prioritize options and choose the best options.

After collecting completed questionnaires by the experts, along with a pairwise matrix and determining the priority, the information was extracted and the first information processing was performed by Excel. Then, the MATLAB software version 9 (R2016a) was used to calculate the average score of 30 specialists who participated in the study, which presented in a geometric mean method, and the coefficients of each of the pairwise matrix.

RESULTS

The aim of this study was to determine the effective criteria

for selecting emergencies and prioritize emergencies in a petrochemical industry using the Delphi model and determine the weights of criteria, using the fuzzy hierarchical model. By completing 30 questionnaires sent by experts and examining their opinions, 21 criteria were extracted. In the other review session, given that some criteria were conceptually identical, the number of criteria was excluded due to the inadequacy of the present study, the number of effective criteria for choosing an emergency was reduced to 11 criteria, which are shown in Table 3.

According to Table 3, the amount of loss with 100% approval received the highest percentage of accountability.

The selected criteria in this step were sent back to the experts for a paired comparison. Finally, the weight of each criterion,

Table 1: Verbal variables for paired comparison of decision criteria

| Linguistic | Fuzzy number | Scale of fuzzy number |
|----------------|--------------|-----------------------|
| Equal | 1 | 1, 1, 1 |
| Weak advantage | 2 | 1, 2, 3 |
| Not bad | 3 | 2, 3, 4 |
| Preferable | 4 | 3, 4, 5 |
| Good | 5 | 4, 5, 6 |
| Fairly good | 6 | 5, 6, 7 |
| Very good | 7 | 6, 7, 8 |
| Absolute | 8 | 7, 8, 9 |
| Perfect | 9 | 8, 9, 10 |

Table 2: The linguistic and fuzzy scales

| Linguistic variable | Score | Fuzzy equivalent |
|---------------------|-------|------------------|
| Very poor | 1 | 0, 0, 1 |
| Poor | 2 | 0, 1, 3 |
| Medium poor | 3 | 1, 3, 5 |
| Fair | 4 | 3, 5, 7 |
| Medium Fair | 5 | 5, 7, 9 |
| Good | 6 | 7, 9, 10 |
| Very good | 7 | 9, 10, 10 |

Table 3: Effective criteria for selecting and prioritizing emergencies

| Criteria | n (%) |
|----------------------------------------------------------------|-----------|
| Amount of loss | 30 (100) |
| Damage | 29 (96.6) |
| Probability | 28 (93.3) |
| Impact on production | 20 (70) |
| The spatial extent of the incident | 19 (63.3) |
| Social consequences of the incident (attitude to organization) | 16 (53.3) |
| Toxicity | 12 (40) |
| Environmental effects | 11 (36.6) |
| Readiness level | 10 (33.3) |
| Ability to detect (before and after incident) | 8 (26.6) |
| Quantity (volume) of released material | 8 (26.6) |

according to the importance of the criteria against each other, was analyzed by the fuzzy hierarchy process analysis method. The weight of the criteria is shown in Table 4.

The inconsistency rate in this study was 0.074, which is less than an acceptable limit of 0.1, and is appropriate. According to Table 4, damage had the highest relative weight, which was equal to 0.209. Other criteria are shown with their relative weights in Table 4.

As shown in Table 4, two criteria, such as the ability to detect and readiness level, were positive and the other criteria were negative. The most important criteria based on their relative weight were damage (0.209), amount of cost (direct and indirect) (0.130), and probability (0.097).

The results of determining the proximity coefficient, the distance from the positive and negative ideal, and the ranking of emergencies, using the TOPSIS fuzzy method, are shown in Table 5.

Emergency rankings, using the fuzzy TOPSIS method, showed that fire in chemical storage with a coefficient of 0.731 was the most important emergency and the hydrogen leak from the cylinder joints in the olefin unit with a coefficient of 0.624 was the second.

Table 4: Relative weight of criteria based on the fuzzy analytical hierarchy process

| Criteria | Type of criteria | Relative weight |
|----------------------------------------------------------------|------------------|-----------------|
| Impact on production | Negative | 0.071 |
| Toxicity | Negative | 0.076 |
| Ability to detect (before and after incident) | Positive | 0.09 |
| Environmental effects | Negative | 0.074 |
| Damage | Negative | 0.209 |
| Social consequences of the incident (attitude to organization) | Negative | 0.075 |
| Quantity (volume) of released material | Negative | 0.078 |
| Readiness level | Positive | 0.095 |
| Probability | Negative | 0.097 |
| Amount of cost (direct and indirect) | Negative | 0.130 |
| The spatial extent of the incident | Negative | 0.005 |

DISCUSSION

There is a wide range of different emergencies in each industry, which exactly are not predictable. Emergency identification is one of the most important steps to prevent accidents, major disasters and crisis, and loss of resources, equipment and workforce as well as irreparable cost and environmental damages in the industry. Despite many efforts to prevent these events, the amount of loss caused by is estimated 70 billion dollars annually.^[16] Studies have shown that emergency response plans reduce these losses^[17] and emergency response systems can be reduced 6% of the loss due to accidents.

Studies show that emergency response plans often focus on a few specific activities and emergency situations in those activities, and procedures are defined and optimized in those particular situations and optimization of all emergencies is systematically less focused.^[18] Since emergencies are unpredictable, any emergency is considered a unique condition, as well all material and equipment are known as a source of risk to create uncontrollable conditions.^[19] Therefore, emergency response plans should be flexible; to improve the emergency measures and how to react to them, effectiveness methods should be used.

Since the studied petrochemical company was a large company with a large number of personnel, and given the high risks in this industry, the number of emergency scenario in this industry is high and using methods of increasing efficiency and carrying out corrective actions to improve emergency response for all ERPs cost a lot. Furthermore, some emergencies have a lot of damage and loss to the company; hence, these emergencies are more important for the company, and corrective action has priority to improve response in these emergencies; these emergencies must be selected correctly. In this study, dangerous emergencies were selected from among the emergencies for corrective action using a new approach.

Due to the lack of a specific standard for determining the emergencies^[20] and their prioritization, as well as the appropriate criteria for selecting and ranking these situations, in this study at first, an open question was designed and sent

Table 5: Coefficients of evaluation matrices and weight vector of criteria using the fuzzy TOPSIS

| Emergencies | Rating | Positive ideal solution | Negative ideal solution | Relative closeness |
|------------------------------------------------------------------------------------|--------|-------------------------|-------------------------|--------------------|
| Fire in the chemical warehouse of the central laboratory | 6 | 0.435 | 0.456 | 0.512 |
| Explosion of hydrocarbon vapours evacuated to industrial waste disposal routes | 9 | 0.555 | 0.338 | 0.378 |
| Fire in control room panels due to short circuit | 10 | 0.570 | 0.325 | 0.363 |
| Fire in pressurized equipment containing butadiene | 8 | 0.528 | 0.358 | 0.404 |
| Leak of naphtha from evacuating the tanker and fire in unloading naphtha platforms | 5 | 0.414 | 0.479 | 0.537 |
| Fire in a chemical warehouse | 1 | 0.239 | 0.650 | 0.731 |
| Explosion and fire in gas degassing tank (containing hydrocarbons) | 4 | 0.376 | 0.516 | 0.578 |
| Extreme gas leakage in one of the power plant turbines | 3 | 0.375 | 0.517 | 0.579 |
| Hydrogen leak from the cylinder joints in the olefin unit | 2 | 0.334 | 0.556 | 0.624 |
| Leakage leads to fire in container containing hexane-impregnated polymer | 11 | 0.576 | 0.316 | 0.354 |
| Gas leakage and fire at the main gas station of the steam unit | 7 | 0.467 | 0.425 | 0.476 |

TOPSIS: Technique for order preference by similarity to ideal solution

to 30 experts. By examining the completed questionnaire by the experts, 21 criteria were extracted. Due to the uniformity concept of a number of criteria and lack of relevance of some of them, the number of criteria fell to 11 criteria.

The study of Sheen *et al.* used a Delphi method to find the effective factors in the gas explosion emergency (Underground Pipeline Emergency Scenario). The results of this study highlighted the main priorities to prevent.^[21] In this study, the Delphi and FAHP techniques were used to determine critical criteria in emergencies and prioritize these situations using these criteria. The Delphi technique has been used for many years as a scientific method for reaching an agreement on an uncertain problem.

The most important criterion with the highest frequency of expert opinion (100% agreement), was the amount of loss. The amount of loss is divided into two categories of injury (death and injury) and cost of accident. According to the International Labour Organization, direct and indirect costs of accidents account for 4% of gross global production annually.^[22] In addition to the direct cost of accidents, many indirect costs are imposed on industries, workers and the community, which iceberg is a popular model to illustrate. Studies show that if “involuntary early retirement” taken into account, these values can also account for up to 15% of Gross Domestic Product (GDP).^[22] Moreover, human resources are the most important asset for an organization as well as the country, and the death and injury caused by occupational accidents not only impose economic burdens on industry and society but also impose many costs on workers and their families.

The injury caused by accident was second by 96.6% agreements. According to studies, there are 2.3 million deaths annually in the world; occupational accidents in developing countries account for a large proportion.^[22]

The next criterion was the probability with a 93.3% agreement. It is clear that the more probability of situations, additional measures should be considered to deal with. Studies also show that probability is very important for managers because of various interventions such as assessment and risk reduction and control measures are to reduce the probability of emergencies and mitigate the consequences.^[23]

The spatial extent of the accident (70%) and the effect on the production (63.3%) were the other criteria for choosing emergency situations. Some accidents may lead to secondary events inside or outside of the company. Due to the proximity the location of the industry to each other in the event of an emergency, it may also lead to disaster for the adjacent industries which are known as domino effects and according to Cozzani *et al.*, incidents such as fires and BLEVE can lead to these effects.^[24] Events such as Mexico City in 1984 and the Buncefield disaster in 2005^[19] were examples of domino effects.

The advantages of the existence of criteria for emergencies are that using these criteria can be ensured the suitability and quality of emergency response plans^[20] as well as to improve and update the ERP, and these criteria can be used as a guide.

In the next step, the final extracted criteria were sent to experts to pairwise to determine the importance of each criterion. In the final step, the TOPSIS fuzzy technique was used to prioritize emergencies. The results of the proximity coefficient, positive and negative ideal solution, as well as the ranking of the emergencies, are presented in Tables 4 and 5.

The results showed that the most important emergency in this petrochemical company was the fire in the chemical storage. The chemical storage of this company with an area of 10,000m² and chemical diversity of about 2200 chemicals, such as additives, catalysts, inhibitors, raw materials for the production, as well as oils and greases, plays a major role in repairing complex units. The company's dependence on these materials is daily and continuous, and hence, the occurrence of any incident in chemical depots can cause impairment in production, in addition to extremely severe damage due to the very diverse chemical properties in this section.

The next important emergencies in this petrochemical company were “hydrogen leakage at the cylinder fitting in the Alfin unit” and “extreme gas leakage in one of the power plant turbines.”

Studies have shown that there is a risk of fire and explosion in the petrochemical industry around the world due to specific characteristics of the petrochemical industry and can cause serious loss and damage.^[25,26] These accidents are often inevitable and have different causes.^[25] Most serious injuries and deaths in the petrochemical industry were mainly due to fire, explosion or leakage due to the high volume of toxic and hazardous materials, as well as processes at high temperatures and pressures.^[27] The accidents in the petrochemical industry in recent years also reflect this fact. Accidents such as the fire at the Petrochemical Complex of Imam, Mahshahr, and the fire at Buali Petrochemicals,^[28] as well as the explosion and fire in the Tianjin Port in China in 2016, which resulted in 6.866 billion Yuan (¥) cost and 44 death.^[29] Another study on 242 accidents of storage tanks in the petrochemical and refinery industry in the world over the course of 40 years showed that 85% of these accidents were caused by explosions and fires.^[30]

CONCLUSION

The results of this study showed that the most important emergencies in this industry were fire and explosion. Considering the desirable features of the fuzzy hierarchy analysis method, this method can be used to identify and prioritize emergency situations as a scientific and reliable method in the petrochemical industry and other industries and it is suggested that managers make plans for controlling these situations and preventing crises.

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Conflicts of interest

There are no conflicts of interest.

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