

Identifying and Prioritizing the Indicators Influencing the Performance of the Permit-to-work System Using Hybrid Fuzzy Delphi Method - Improve Analytic Hierarchy Process Methods: An Exploratory Cross-sectional Study

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Abstract

Aim: This study aimed to identify and prioritize the main indicators that influence the performance of the permit-to-work (PTW) using hybrid fuzzy Delphi-improve analytic hierarchy process (IAHP) methods. **Materials and Methods:** By the fuzzy Delphi method, indicators that affect PTW are classified into seven main groups and 41 subindicators based on experts' opinions; in the final stage, indicators and subindicators were weighted and prioritized using the IAHP methods. **Results:** The results of the IAHP method showed that accountability (0.178), preventive measures and risk avoidance (0.165), and training and qualification (0.141) are the most important ingredients also; the results revealed that identification of work-related hazards (0.221), preformation of gas test (0.173), signature of responsible person for safety (0.232), the record of the work steps (0.213), period of permit validity (0.153), and period of training courses (0.351) had most important among the subindicators. **Conclusion:** The results of this study can be used as a practical guide to plan the implementation of corrective measures for improving the performance of the PTW system and conduct an audit to identify the strengths and weaknesses of the PTW system in process industries.

Keywords: Analytic hierarchy, Delphi techniques, manufacturing industry, processes

INTRODUCTION

Process industries are companies that extract, transport, and process raw materials to manufacture semi-finished or high-quality end products using physical, mechanical, and chemical processes.^[1] These industries are prone to accidents like fire and explosion due to the consumption, production, and storage of explosive and flammable materials. Therefore, work safety principles must be evaluated in these industries.^[2] The global importance of safety measures is evident in incidents such as the 2012 Amuay refinery explosion in Venezuela, the 2018 Vohburg refinery explosion in Germany, the 2020 Daesan explosion in South Korea, and the 2016 fire accident at Bouali Sina Petrochemical Complex Plant in Iran.^[3-5]

Safety specialists and experts have conducted several studies to identify the causes of accidents in process industries. According to studies conducted by the HSE of England,

76% of accidents in refineries, petrochemicals, and chemical companies are related to repair and maintenance activities.^[6] Within this, 30% of accidents related to repair and maintenance activities were caused by defects in the permit-to-work (PTW) system.^[7]

The PTW system is a documented system used to control activities with inherent risks. It is also a part of the safety

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management program, which helps identify, evaluate, and adjust the risks associated with unusual and dangerous tasks.^[8] Examples of using the PTW system in process industries include entering enclosed spaces, performing electrical work, and transporting hazardous chemicals. Failure in any component can affect the performance of others, ultimately leading to system failure.^[9] To evaluate the performance and efficiency of a system in achieving workplace safety, it must be regularly monitored and corrected using information on its indicators.^[10]

The Delphi method is a structured process used in qualitative research to identify fundamental elements and explore phenomena. It involves multiple rounds of information collection and group consensus.^[11] However, because the decisions made by experts are highly subjective in this method, it is suggested that fuzzy numbers instead of definite numbers are used for collecting experts' opinions.^[12] The fuzzy Delphi method (FDM) was first introduced in 1988 by Kaufman and Gupta. In the FDM, it has been tried to combine the traditional Delphi method with fuzzy theory concepts.^[13]

Multicriteria decision-making methods should be used to determine the weight of influencing factors.^[14] Among multicriteria decision-making models, the use of analytic hierarchy process (AHP) is more common. This method is one of the most famous multiobjective decision-making techniques, which was first invented by Saaty in 1970.^[15] AHP reflects natural behavior and human thinking. This technique examines complex problems based on their interactions and converts them into a simple form and solves it. AHP can be used when the decision-making process is faced with several competing options and decision criteria. The basis of this decision-making method lies in pairwise comparisons. In this method, if the number of criteria increases, the number of paired comparisons increases, and on the other hand, answering in pairs is time-consuming and tiring for the expert, and if these paired comparisons are not answered correctly, the comparisons become inconsistent. To improve this problem, Li *et al.* presented an improved method of hierarchical analysis in 2013.^[16]

To improve the performance of the PTW system in creating a safe environment or working conditions, it is vital that the indicators influencing the performance of the PTW system are identified, as well as the importance or weight of each of these indicators is determined. Therefore, this study was aimed to identify and prioritize indicator influencing the PTW system using the FDM-improve AHP (IAHP) in a petroleum refinery.

MATERIALS AND METHODS

This cross-sectional, descriptive study aimed at identification and prioritization main indicators of the PTW system in a petroleum refinery located in South Iran in 2021 by adopting fuzzy Delphi-IAHP methods. The detailed description of the three steps of the study is provided below.

Fuzzy-Delphi method

A team of 25 experts, including academic and industrial experts, was formed. They were briefed on the study's purpose and the subject's importance. The academic experts were selected from professors and doctoral students in occupational health with a research history in safety and familiarity with the PTW system. Industrial experts were also selected from among the safety department experts and senior employees and employees of the control room and the head of operational units, who have at least 10 years of work experience, who are qualified to issue and supervise the process of implementing the PTW system in the oil refinery. Like the traditional Delphi method, the opinions of experts are collected. In this method, linguistic variables were used to design a questionnaire and collect experts' opinions [Table 1].

Based on the collected opinions, the fuzzy value of each of the questions was calculated as follow. It is assumed that the linguistic expression of *j* criterion from the point of view of expert with *i* number among *n* experts is $W_{ij} = (a_{ij}, b_{ij}, c_{ij})$ that the value of *j* is equal to $j = 1, 2, 3, \dots, m$ and the value of *i* is equal to $i = 1, 2, 3, \dots, n$. In this way, the fuzzy value of *j* criterion was calculated from the equations 1 to 3, which is equal to $W_j = (a_j, b_j, c_j)$.

$$a_j = \min \{a_{ij}\} \tag{1}$$

$$b_j = \frac{1}{n} \sum_{i=1}^n b_{ij} \tag{2}$$

$$c_j = \max \{c_{ij}\} \tag{3}$$

The condition of consensus or expert agreement was achieved when 70% of the experts gave the same answer to one of the answer options for each criterion.^[12]

Improve analytic hierarchy process method

The detailed description of the IAHP method is provided below.^[16]

Determine the importance of ingredients

At first, an anonymous questionnaire was given to all the members of the expert panel and they were asked to determine the importance of each ingredient on the performance of the PTW according to the Likert scale from 1 to 10.

Formation of pairwise comparison

In order to construct the pairwise comparison, the equation 4-5 were used.

$$\text{If } u_i \geq u_j, \text{ the matrix element } a_{ij} = \max(u_i - u_j, 1) \tag{4}$$

Table 1: Linguistic variables and importance of spectrum score

Linguistic expression	Importance spectrum score
Very little importance	1
Little importance	2
Medium importance	3
Great importance	4
Very important	5

$$\text{If } u_i < u_j, \text{ the matrix element } a_{ij} = \frac{1}{(u_j - u_i)} \quad (5)$$

After construct the pairwise comparison matrix, the next steps include normalization, calculating the relative weight, estimating the final weight, and calculating the compatibility rate. All these steps were performed similar to the classical AHP method.

Data analysis

All calculation steps of FDM and IAHP are perform with Microsoft Excel 2019 software program.

RESULTS

The average age of the expert panel was 41, with an average work experience of 15 years. Additional demographic information is presented in Table 2.

The result of fuzzy-Delphi method

The results of the FDM showed that six ingredients affecting performance of PTW system include risk identification and

assessment, accountability, communication, training and qualification, transparency in content, and documentation with a consensus of over 70%. Table 3 reports the results of the FDM.

Result of improved analytic hierarchy process

The results of the IAHP method showed that accountability (final weight of 0.178), preventive measure and risk avoidance (final weight of 0.165), and training and qualification of employees (final weight of 141) are the most important ingredients affecting the performance of the PTW system, respectively. Furthermore, the documentation with the final weight of 0.123 is the least important ingredient. In other words, it has the least impact on the performance of the PTW system. Table 4 demonstrates the final weight and priority of indicators and subindicators of PTW system based on IAHP method.

DISCUSSION

This study was aimed to identify and prioritize ingredient affecting the PTW system in process industries using the fuzzy-Delphi and IAHP method. According to the finding of FDM, seven main indicators, including risk identification and assessment, Preventive measures and risk avoidance, accountability, communication, training and qualification, documentation, and transparency in content, play an important role in performance of PTW system. In various industries, studies have shown that risk identification and assessment play a crucial role in the PTW system. Yan CK *et al.* investigated the relationship between the PTW system and accidents in process industries and found that failure to perform proper risk assessment is a leading cause of system failure and accidents.^[9] Frank Lees noted that approximately 30% of work permits issued in the chemical industry contain defects in identifying risks and training workers.^[10] Mirderikvand *et al.* assessed the PTW system on an oil platform using HSE-UK and SHELL checklists. The study revealed that inadequate risk assessment is a significant noncompliance.^[17] In the present study, the PTW system’s performance is significantly influenced by risk identification and assessment, which has a final weight of 0.165 and is the second most important indicator. The first rank is given to accountability with a final weight of 0.178. This may

Table 2: Demographic information of exert panel

Variable	Number of experts
Job	
Safety officer	10
Supervisor	6
Site man	3
Academic	6
Major	
Occupational health	6
Safety engineering	7
HSE	8
Industrial engineering	4
Education level	
Bachelor	8
Master	10
PhD	7
Level of familiarity with PTW (based on self-expression)	
Moderate	2
Good	8
Very good	15

PTW: Permit-to-work

Table 3: Results of the fuzzy Delphi method

Ingredients of PTW	Spectrum of importance					Fuzzy value aggregation			Defuzzified value	Percentage of consensus
	Very low	Low	Medium	High	Very high	L	M	U		
Training and qualification	-	-	-	22	3	4	4.12	5	4.31	0.88
Preventive measure and risk avoidance	-	-	4	18	3	4	3.96	5	4.23	0.72
Documentation	-	-	3	19	3	3	3.24	4	3.37	0.76
accountability	-	-	-	23	2	4	4.08	5	4.29	0.92
Communication	-	-	3	20	3	3	3.36	5	3.68	0.80
Transparency in content	-	-	-	23	2	4	4.08	5	4.29	0.92
Risk identification and assessment	-	-	4	18	3	4	3.96	5	4.23	0.72

PTW: Permit-to-work

Table 4: The final weight and priority of indicators and subindicators of permit-to-work system based on improve-analytic hierarchy process method

Indicators that influence the PTW system	Indicators weight	Sub - indicators	Sub - indicators weight	Priority	Inconsistency index
Accountability	0.178	Signature of the person requesting the permit	0.161	5	0.039
		Signature of the responsible person for safety	0.232	1	
		Signature of the person receiving the permit	0.181	4	
		Signature of the person performing the work	0.215	2	
		Signature of the person performing the gas test measurement	0.211	3	
Risk identification and assessment	0.165	Identification of work-related hazards	0.221	1	0.013
		Identification of health and environmental risks	0.141	5	
		Identification of equipment hazards	0.132	6	
		Familiarity with risk assessment methods	0.151	4	
		Evaluation of periodic PTW system	0.161	3	
		Education and legal certificates	0.191	2	
		period of training courses	0.351	1	
		Work experience and knowledge level of employees	0.241	2	
Training and qualification	0.141	Need to update training	0.221	4	0.061
		Establishing a mechanism to identify the competence of employees	0.87	3	
		Use of PPE appropriate to the work	0.171	2	
		Preformation of gas test	0.173	1	
Preventive measures and risk avoidance	0.135	Preformation of separation and isolation	0.149	3	0.027
		Monitoring the implementation of the safe method of work execution	0.131	5	
		Providing emergency resources and equipment	0.129	6	
		Advise on precautionary measures	0.132	4	
		Familiarity with actions in emergency situations	0.115	7	
		Proportion of the permit to the type of activity	0.110	8	
		Readability of the permit	0.133	2	
Transparency in content	0.129	Proper completion of the permit form	0.132	3	0.093
		Period of permit validity	0.153	1	
		Clarity of permit code and number	0.111	7	
		Description of the work	0.117	5	
		Description of the work location and its special conditions	0.119	4	
		Description of start and finish time of work	0.116	6	
		Communication among employees and supervisor	0.162	4	
		Communication among other related units	0.221	3	
Communication	0.128	Communication among employers, contractors, and employees	0.299	2	0.003
		Internal communication among employees	0.317	1	
		Filing and maintaining the permit form	0.133	7	
		Availability of permit copies	0.162	5	
Documentation	0.123	Permit revocation	0.142	4	0.081
		Record of work steps	0.213	1	
		Registration of measures of work hazards, PPE, measures in emergency situations, etc.	0.177	3	
		Documentation of equipment calibration certificate	0.201	2	
		Documentation of documents related to training and qualification of employees	0.155	6	

PTW: Permit-to-work, PPE: Personal protective equipment

be because site visits are not properly conducted due to low accountability and negligence, whereas risk identification and assessment are done at the workplace. The low accountability and negligence may be due to insufficient employee training and qualifications regarding the PTW system. A study revealed that responsibility, training, and risk assessment are essential dimensions that impact the PTW system’s performance.^[18] In

this regard, Ghahramani audited the PTW system of an oil and gas company and found that a significant noncompliance is the absence of proper training and qualifications for the personnel involved.^[19] Ghasemi *et al.* discovered that despite the existence of a PTW system to control nondaily activities, the high number of accidents during these activities occur because of the inadequacy of this system in preventing accidents. The

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main part of the inefficiency of the PTW system is related to the occurrence of human error in this system.^[20] The results of fuzzy Delphi in this study showed that the Training and qualification of employees is one of the effective criteria on the correct function of the PTW system. Training can lead to the reduction of human error in this system. The results of a study performed by Jahangiri *et al.* showed that there is the need to a method with an engineering approach for evaluating human error due to the process of issuing the work permit.^[21] Communication is an effective measure on the performance of the PTW system. The importance of this ingredient is related to effective communication between employees in terms of preventing interference and parallel work or ignoring requirements.^[22] The result of a study performed by Safdary *et al.* indicated that there is a significant relationship between the organization's performance and effective communication, which shows the importance and impact of correct communication on the systems performance.^[23] Jusoh *et al.* reported that lack of a method to evaluate all the factors and criteria affecting the performance of the PTW system, such as coordination, monitoring, training, and qualification of employees, is one of the main reasons for noncompliance in the implementation of the PTW system in an oil and gas exploitation company. It was suggested that these factors should be evaluated to reduce the existing deficiencies of the PTW system.^[24] One of the limitations of the present study was that the internal relationships between the ingredients were ignored. Hence, it is suggested that multicriteria decision-making methods with the ability for analysis of internal relationships, such as the ANP network analysis technique, are used in future studies in other process industries. Another limitation of this study is that it should also be noted that this study was based on the subjective judgments of Iranian experts, so it is possible that the results were affected by confounders such as the level of safety culture, organizational culture, and safety climate. Therefore, it is suggested that this study be conducted in oil refineries of other countries and its results be compared with the present study.

CONCLUSION

The study findings can serve as a practical guide to improve the performance of PTW system and conduct an audit to identify strengths and weaknesses in process industries. Furthermore, the method used in this study can be used as an approved scientific tool to identify the strengths and weaknesses of the PTW in the mining industry, steel and other businesses and industries in which there is a PTW system, in order to identify them. Finally, create a safer work environment.

Ethics code

The ethics code is: IR.TUMS.SPH.REC.1397.073, approved by Tehran University of Medical Sciences.

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Conflicts of interest

There are no conflicts of interest.

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