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Safety Costs evaluation in Construction Industry Using Risk Assessment Approach

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Establishing safety at work is one of the essential and necessary conditions for starting, performing, ending and exploiting work. Due to the importance of this issue, in the present study, the evaluation and management of safety risks in the construction industry in the direction of human health using multi-criteria decision-making techniques have been done. In the framework of the proposed method, safety risks in construction projects were first extracted according to the study of previous researches and opinion polls of experts and experts, who are divided into four general categories including machinery, fire, work at height and unexpected accidents. Then the questionnaire is designed based on these risks and is distributed among the statistical sample. After reviewing the validity and reliability of the questionnaire, the mentioned factors are ranked based on the costs of providing workforce for safety and health of workforce using the fuzzy hierarchical analysis method. The results of fuzzy hierarchical analysis method show that the factor of people getting stuck between machines is the most important that should be considered in all stages. The next most important factor is the accident with the machines. The third factor is the throwing of materials from machines. Thus, due to financial constraints in this regard, in order to manage safety in construction projects, it is necessary frst to consider the factors that have priority. In the end, based on the obtained rankings, suggestions are provided in order to ensure the health of human resources.

Keywords*: safety and health, risk assessment, hierarchical analysis method, construction industry*

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1. Introduction

Due to their nature, industrial environments are exposed to severe hazards and damages, and as the technology grows, the hazards and damages are potentially expanding. Establishing safety at work is one of the essential and necessary conditions for starting, performing, ending and exploiting work. However, in many cases, due to various cultural, social, economic and various

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technical issues, it is neglected and, in many cases, leads to various accidents and numerous human and financial losses. In the construction industry, which is one of the most critical and influential critical industries in the development and growth of social and economic indicators of countries, for the above reasons, as well as the wide range of related activities and organizational operations, there are always various dangers that can be ignored. Timely necessary measures in this regard will undoubtedly cause irreparable damage (Mehdi Nia, 2012). In fact, safety management systems in order to achieve the goal of zero accident rates always need to be evaluated and reviewed. By knowing more about the influential factors and the impact of each of them, we can identify the best effective techniques according to the variable nature of construction projects in various fields, and in addition to applying, general safety factors such as safe thinking, justification, training, creating a culture and adhering to effective safety management methods, to improve the safety of construction projects (Taghinejad, 2017).

construction industry, accounts for about 47% of the annual work-related deaths in Iran. This shows the negligence and inefficiency of employers, contractors and workers. Of course, the existing weaknesses and legal loopholes should not be ignored. Many previous types of research have been done in this field, the result of which is the available statistics of casualties and damages caused by work, and their ultimate goal is to show a picture of safety deficiencies and to express the existing conditions in construction from a health point of view, safety and environment (Rezazadegan, 2016). Due to the importance of these issues, the present study manages and evaluates safety risks to identify the costs of providing safety and health of workforce in the construction industry. For this purpose, safety risks are extracted according to PMBOK standard and then ranked using the Analytic Hierarchy Process (AHP), which is one of the multi-criteria decisions making techniques (MCDM).

2. Research background

Shams and Monir Abbasi (2016), in their research, have evaluated the safety risks of constructing high-rise concrete buildings using a combination of FMEA methods and fuzzy logic. The FMEA method is one of the techniques that can identify and evaluate the potential hazards of the work environment and its cause and effects. The most significant risks identified in the present study are in line with previous research and the report of the National Social Security Organization and have also been approved by safety experts. Cheraghi Bidgoli (2016) has examined the level of maturity of health and safety performance in construction projects. The level of maturity assessment is based on Marco's maturity model, which is in accordance with Schwartz's comprehensive quality management approach in four stages of planning, implementation, monitoring and action. According to Marco's maturity model, the health and safety performance of dam and network projects is at a high level of maturity, as well as construction, road construction, tunnel and bridge projects are at a medium level of maturity.

Hakimnia and Rouhnia (2016), in their research, have reviewed the indicators of sustainable management of health, safety and environment (HSE) in construction workshops. In such an environment, which is possible only in the shadow of integrated management and internal and external coordination, increasing productivity is a matter of course it is considered the nature of work. By employing a large part of the country's labour force, the construction industry has a significant contribution to the health and well-being of its workforce. Also, leading this sector to comply with sustainable environmental standards requires the use of comprehensive and efficient management. Mobaraki et al. (2016) conducted a study to determine the status of safety, health, environmental management (HSE) and safety atmosphere in construction sites. In this cross-sectional study, 111 male construction workers were randomly selected. The findings showed that the safety, health and environmental situation and safety atmosphere in the workshop are relatively acceptable, but with valuable and practical training and continuous improvement of the system can be made more favourable.

Rezazadegan (2016) states that injuries caused by non-compliance with the principles of health, safety and environment in construction sites each year in the country take many of victims. To enable activists to minimize human and financial losses due to non-compliance with HSE in construction projects. In this way, while talking to experts in the construction industry, forensic experts and experts in the field of labour and social security, we have tried to use the previous research and the statistics of related organizations to provide a suitable solution. Bansbardi and Fallah (2017) conducted a study with the aim of to investigate and prioritize the factors affecting the safety management of construction workshops in Mashhad. Findings obtained from the analysis of pairwise comparisons of safety management criteria of construction sites showed that the criteria of safety unit structure, monitoring and control and reporting, machinery and equipment and tools, personal protective equipment and health, barriers, respectively. Moreover, warning signs and information, energy, storage and storage of materials and materials gained the most importance and priority as factors affecting the safety management of construction workshops in Mashhad.

3. Material and Method

In any research, the nature, goals and scope of the research must first be determined to achieve the facts using good rules and tools. The research process is when the researcher tries to test his hypotheses by scientifically processing the data. The present study is a descriptive research based on the classification based on the method of data collection, and there is correlation in the research group in which the relationship between variables is analyzed based on the purpose of the research. Also, the present study is quantitative in terms of data collection and quantitative in terms of data nature. The statistical population of the study includes all managers, experts and experts in the field of safety and construction in P with a history of more than ten years. Due to the small size of the population and the unavailability of an expert in this field, a statistical sample is selected in a purposeful non-random manner. Thus, 12 people were selected from the statistical population. In this research, two methods are used to collect information: the library and field methods. The data collection tool in the present study is a questionnaire, and the data analysis method is hierarchical analysis. In order to rank safety risks in construction projects using hierarchical analysis, a questionnaire based on pairwise comparisons was designed based on extractive factors in the research model.

The questionnaire used in this study consists of two main parts, the first part is related to demographic questions, and the second part includes pairwise comparisons related to the risks. In this study, SPSS and EXCEL software are used to process the data extracted from the questionnaires and summarize them. Data analysis was performed in two parts: descriptive statistics and hierarchical analysis method. According to previous research, safety risks are extracted in construction projects. The data collection tool, which is a questionnaire in this research, is designed, and after confirming the validity and reliability of the questionnaire, the research data are collected. The theoretical foundations of research are also obtained from the library method. In the library method, by referring to Persian and Latin books and articles, some of the necessary information will be collected, and useful research articles used. Safety risks in construction projects are ranked in terms of the cost of providing safety using the hierarchical analysis method. Safety risks in construction projects are ranked in terms of workforce health using the hierarchical analysis method. The final risk rating is calculated by multiplying the previous two ratings. According to the results, appropriate solutions to improve safety in construction projects are provided.

4. Results and Discussion

4-1 Descriptive statistics

In this part of the research, the statistical sample (respondents) was first described. The statistical sample of the research includes 12 managers, experts and experts in safety and construction with a history of more than ten years. In tables 1-3, the demographic characteristics of the statistical sample are introduced. Table 1 presents the age range of the statistical sample of the research. As can be seen, most people are between 41 and 50 years old. Since an essential part of understanding the nature of the problem under study, i.e. identifying risks, is a time-consuming nature, this age range among respondents can be a positive sign of understanding many risks among them.

Table 1: Status of statistical sample in terms of age variable

Feature	Value	Frequency	Percent
Age	Less than 30 years	2	17
	From 31 to 40 years	3	25
	From 41 to 50 years	5	41
	More than 51 years	2	17

Table 2 presents the marital status of the statistical sample of the research. As can be seen, most of the sample is married. Table 3 presents the gender status of the statistical sample of the research. As can be seen, most of the sample is male. Table 4 presents the educational status of the statistical sample of the research. As can be seen, most people have a bachelor's degree. This can ensure that the researcher has a sufficient understanding of the people in answering the questions and correctly determining the intended criteria.

Table 2: Statistical sample status in terms of the marital status variable

Feature	Value	Frequency	Percent
Marital status	Single	3	25
	Married	9	75

Table 3: Status of statistical sample in terms of gender variable

Feature	Value	Frequency	Percent
Gender	Single	3	25
	Married	9	75

Table 4: Status of statistical sample in terms of education variable

Feature	Value	Frequency	Percent
Education	Diploma	0	0
	Associated degree	2	17
	Bachelor	6	50
	MA	3	25
	Doctorate	1	8

4.2 Classification of safety risks in construction projects using the fuzzy hierarchical analysis method

Although the purpose of using the hierarchical analysis method is to obtain the opinion of experts and specialists, however, the conventional hierarchical analysis method does not accurately reflect the way of human thinking because, in pairwise comparisons of this method, exact numbers are used. Other factors that often criticize hierarchical analysis include unbalanced scales in judgments, uncertainty, and inaccuracy in pairwise comparisons. Due to the fuzzy nature of pairwise comparisons, decision-makers are often unable to express their views explicitly on advantages, which is why they prefer to present an interval rather than a fixed number in their judgments. To overcome these problems in this part of the research, safety risks in construction projects are ranked using the multi-criteria decision-making method of fuzzy hierarchical analysis.

4-2-1 Ranking of safety risks in construction projects from the perspective of safety costs

The steps of Chang method of fuzzy hierarchical analysis are as follows (Cooney, 2016). Draw a hierarchical diagram. A hierarchy is a graphical representation of a real complex problem, topped by the overall goal of the problem and the following levels of criteria. First, safety risks in construction projects were identified and selected from reputable sources and articles through surveys of specialists and experts, which were provided to managers and experts in the field of construction projects for scoring. Assign appropriate language variables to weight the criteria. In order to evaluate the quality of the options, it is necessary to use language variables and the Likert spectrum. Therefore, in order to collect the opinions of decision-makers, questionnaires were distributed among the decision-makers for polling to weigh the criteria (Table 5). Formation of even comparison matrix Ã using fuzzy numbers. The pairwise comparison matrix is defined as eq.1. This matrix contains the following fuzzy numbers eq.2.

Table 5: Significance and corresponding fuzzy numbers

Importance	Fuzzy numbers
Equal importance (N)	(1 , 1 , 3)
Medium importance (L)	(1 , 3 , 5)
Strong importance (M)	(3 , 5 , 7)
Very strong importance (MH)	(5 , 7 , 9)
Absolute importance (H)	(7 , 9 , 9)

$$\tilde{A}=\begin{pmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & 1 \end{pmatrix} \tag{1}$$

$$\tilde{a}_{ij}=\begin{cases} 1 & i=j \\ \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} & i\neq j \\ \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & i\neq j \end{cases} \tag{2}$$

To normalize the matrix, the sum of the columns of the pairwise comparison matrix is first calculated. If $M_1=(l_1,m_1,u_1)$ and $M_2=(l_2,m_2,u_2)$ both numbers are fuzzy, we use Equation 3 to calculate the sum of the fuzzy numbers eq.3. Each matrix component is then divided by its column total. We use Equation 4 to divide two fuzzy numbers. To calculate the final weight vector, the average of the rows of the normal matrix must be taken. The average of two fuzzy numbers is defined as eq.5. The values for this step are listed in Table 6 and indicate the priority and importance of these indicators.

$$M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \qquad (3)$$

$$\frac{M_1}{M_2} = (\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}) \qquad (4)$$

$$\frac{M_1 \oplus M_2}{2} = (\frac{l_1 + l_2}{2}, \frac{m_1 + m_2}{2}, \frac{u_1 + u_2}{2}) \qquad (5)$$

Table 6: Calculating the fuzzy weight of safety risks from a safety cost perspective

Risk	Code	Fuzzy weight
Stuck people between machines	F11	(0.075 , 0.142 , 0.250)
Crash with machines	F12	(0.099 , 0.167 , 0.285)
Throwing materials from machines	F13	(0.054 , 0.100 , 0.176)
Improper use of tools	F14	(0.062 , 0.105 , 0.183)
Fire of flammable and chemical substances during work	F21	(0.037 , 0.068 , 0.122)
Fire due to damage to gas and electricity during operation	F22	(0.030 , 0.055 , 0.097)
Working with electrical appliances	F23	(0.024 , 0.043 , 0.080)
People fall from heights	F24	(0.027 , 0.046 , 0.084)
Explosion of oxygen capsules and under pressure	F25	(0.031 , 0.052 , 0.094)
Objects and materials fall from a height	F31	(0.027 , 0.045 , 0.078)
Burning materials and waste in the workshop	F32	(0.028 , 0.045 , 0.080)
Use of safety equipment	F33	(0.022 , 0.036 , 0.064)
Earthquake	F41	(0.013 , 0.019 , 0.029)
Storms and strong winds	F42	(0.010 , 0.015 , 0.024)
Floods and heavy rains	F43	(0.010 , 0.015 , 0.025)

Fuzzy numbers are then converted to definite numbers, for which the following equation is used. The results of this step are shown in Table 7.

$$\frac{l_1 + 4m_1 + u_1}{6} \tag{6}$$

Table 7. Rank of safety risks from the perspective of safety cost

Risk	Code	Mean score	Rank
Stuck people between machines	F11	0.148653733	2
Crash with machines	F12	0.175777709	1
Throwing materials from machines	F13	0.104819534	4
Improper use of tools	F14	0.1105269	3
Fire of flammable and chemical substances during work	F21	0.072033171	5
Fire due to damage to gas and electricity during operation	F22	0.057943214	6
Working with electrical appliances	F23	0.04633193	9
People fall from heights	F24	0.048976173	8
Explosion of oxygen capsules and under pressure	F25	0.055338079	7
Objects and materials fall from a height	F31	0.04743193	10
Burning materials and waste in the workshop	F32	0.048154406	11
Use of safety equipment	F33	0.038607456	12
Earthquake	F41	0.019551158	13
Storms and strong winds	F42	0.015806336	15
Floods and heavy rains	F43	0.01619244	14

4-2-2 Ranking of safety risks in construction projects from the perspective of human health

After normalization, a weighted average is taken from the values of each row, and the values obtained from the weighted average indicate the priority (degree of importance) of each index over the other. The values for the weights of each risk are shown in Table 8.

Table 8. Calculating the fuzzy weight of safety risks from a human health perspective

Risk	Code	Fuzzy weight
Stuck people between machines	F11	(0.75 , 0.142 , 0.250)
Crash with machines	F12	(0.099 , 0.167 , 0.285)
Throwing materials from machines	F13	(0.054 , 0.100 , 0.176)
Improper use of tools	F14	(0.062 , 0.105 , 0.183)
Fire of flammable and chemical substances during work	F21	(0.037 , 0.068 , 0.122)
Fire due to damage to gas and electricity during operation	F22	(0.030 , 0.055 , 0.097)
Working with electrical appliances	F23	(0.024 , 0.043 , 0.080)
People fall from heights	F24	(0.027 , 0.046 , 0.084)
Explosion of oxygen capsules and under pressure	F25	(0.031 , 0.052 , 0.094)
Objects and materials fall from a height	F31	(0.027 , 0.045 , 0.078)
Burning materials and waste in the workshop	F32	(0.028 , 0.045 , 0.080)
Use of safety equipment	F33	(0.022 , 0.036 , 0.064)
Earthquake	F41	(0.013 , 0.019 , 0.029)
Storms and strong winds	F42	(0.010 , 0.015 , 0.024)
Floods and heavy rains	F43	(0.010 , 0.015 , 0.025)

Fuzzy calculations are then converted to definite or non-fuzzy numbers that represent the weight and rank of each risk and can be seen in Table 9.

Table 9: Ranking of safety risks from the perspective of human health

Rank	Final weight	Code	Risk
2	0.136624	F11	Stuck people between machines
1	0.152027	F12	Crash with machines
3	0.104952	F13	Throwing materials from machines
4	0.099462	F14	Improper use of tools
5	0.066121	F21	Fire of flammable and chemical substances during work
6	0.063777	F22	Fire due to damage to gas and electricity during operation
10	0.0457	F23	Working with electrical appliances
9	0.048646	F24	People fall from heights
7	0.057537	F25	Explosion of oxygen capsules and under pressure
8	0.05483	F31	Objects and materials fall from a height
11	0.048493	F32	Burning materials and waste in the workshop
12	0.043579	F33	Use of safety equipment
13	0.020914	F41	Earthquake
14	0.01827	F42	Storms and strong winds

15	0.018001	F43	Floods and heavy rains

4-2-3 Final ranking of safety risks in construction projects

The final rating of each risk is calculated by multiplying the two ratings of that risk in terms of cost and workforce health. Thus, their ranking is according to Table 10. Thus, safety risks in the construction industry are in order of priority as shown in Table 11.

Table 10: Calculate the final weight of safety risks in the construction industry

Risk	Code	Weight from a safety cost perspective	Weight from a human health perspective	Final weight
Stuck people between machines	F11	0.148653733	0.136624425	0.020309731
Crash with machines	F12	0.175777709	0.152027031	0.026722963
Throwing materials from machines	F13	0.104819534	0.10495178	0.011000997
Improper use of tools	F14	0.1105269	0.099461703	0.010993194
Fire of flammable and chemical substances during work	F21	0.072033171	0.066120682	0.004762882
Fire due to damage to gas and electricity during operation	F22	0.057943214	0.063776544	0.003695418
Working with electrical appliances	F23	0.04633193	0.045700107	0.002117374
People fall from heights	F24	0.048976173	0.048646269	0.002382508
Explosion of oxygen capsules and under pressure	F25	0.055338079	0.05753671	0.003183971
Objects and materials fall from a height	F31	0.04743193	0.054830303	0.002600707
Burning materials and waste in the workshop	F32	0.048154406	0.048493064	0.002335155
Use of safety equipment	F33	0.038607456	0.043578766	0.001682465
Earthquake	F41	0.019551158	0.020913694	0.000408887
Storms and strong winds	F42	0.015806336	0.018269613	0.000288776
Floods and heavy rains	F43	0.01619244	0.018001157	0.000291483

Table 11: Prioritize safety risks in building projects

Risk	Code	Final weight	Rank
Stuck people between machines	F12	0.026722963	1
Crash with machines	F11	0.020309731	2
Throwing materials from machines	F13	0.011000997	3
Improper use of tools	F14	0.010993194	4
Fire of flammable and chemical substances during work	F21	0.004762882	5
Fire due to damage to gas and electricity during operation	F22	0.003695418	6
Working with electrical appliances	F25	0.003183971	7
People fall from heights	F31	0.002600707	8
Explosion of oxygen capsules and under pressure	F24	0.002382508	9
Objects and materials fall from a height	F32	0.002335155	10
Burning materials and waste in the workshop	F23	0.002117374	11
Use of safety equipment	F33	0.001682465	12
Earthquake	F41	0.000408887	13
Storms and strong winds	F43	0.000291483	14
Floods and heavy rains	F42	0.000288776	15

5. Conclusion

In the present study, safety risks have been evaluated and ranked from two perspectives: the cost of providing safety and health of human resources. The statistical population of the study includes all managers, experts and experts in the field of safety and construction with a history of more than ten years. Thus, 12 people have been selected from the statistical community. Due to the survey method, a questionnaire was designed based on these factors and after confirming the validity of the content and form; distributed among statistical samples. The reliability of the questionnaire was also confirmed using Cronbach's alpha. In order to analyze the research data, first using descriptive statistical methods, the demographic characteristics of the statistical sample were examined, according to which most of the sample is between 41 and 50 years old, most of them are men and married and mainly have a bachelor's degree. Since safety risks are not of equal importance, in the step after the hierarchical analysis method, two perspectives of cost and health were used to rank and determine the importance of each risk.

Data Availability

Requests for access to these data should be made to [the corresponding author email address:

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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