Determining the Effective Factors Leading to Incidence of Human Error Accidents in Industrial Parks Construction Projects: Results of a Fuzzy Delphi Survey

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Abstract

The implementation of construction projects is always associated with several incidents for various reasons. Previous research studies advocated that human errors are one of the main causes of accidents in these projects. This paper aims to determine the effective factors leading to the occurrence of accidents caused by human errors in Industrial Parks Construction Projects (IPCPs) based in Iran. For this purpose, four rounds of the fuzzy Delphi survey were conducted with the presence of fifteen experienced experts engaged in the HSEE (health, safety, environment and energy) department of Industrial Parks in Iran. The reliability and validity of the questionnaire were reviewed and confirmed. Based on the results of the Delphi survey, forty-one factors contributing to human errors in the implementation of IPCPs were determined and classified into nine main groups. The survey findings manifested that the identified effective factors have a strong effect on the occurrence of construction accidents caused by human errors. The results of this research study have provided various major project stakeholders and safety managers with a useful decision-aid tool to make more pragmatic decisions in managing, reducing and avoiding the occurrence of construction site accidents particularly caused by human errors associated with IPCPs.

Keywords: *Construction projects, Site safety, Human errors, Industrial Parks, Fuzzy Delphi technique, Iran.*

1. Introduction

The construction industry is one of the most dangerous industries in terms of work-related losses, injury rates, and workers' compensation (Muneeswaran et al., 2020). In the construction industry, injuries leading to death, serious occupational injuries and lost work time occur due to their unique nature and a high number of accidents cause severe human and financial damage to communities (Manu, 2021). Continuous changes in the work environment, use of various resources and tools, unsuitable working conditions, unsustainable employment and also unsuitable working environments are among the characteristics of the construction industry that cause accidents (Jahani, 2017). Some accidents cause physical damage and destruction of part of the project, which will hurt the work efficiency of other project staff. In this regard, paying attention to the principles of safety and prevention of accidents and diseases caused by work in worksites is a high priority in projects, especially large ones (Hoła and Szóstak, 2017). Therefore, it seems that there are no shortcomings in terms of legal principles, but in general, the statistics of work-related accidents in Iran compared to developed countries, show an unacceptable increase (Shao et al., 2019). According to reports, construction project accidents in Iran are in a higher rank compared to global scales (Mohseni et al., 2015). Now, according to the evaluation and research, it has been determined that most accidents are caused by negligence and on-observance of safety principles in the use of inappropriate machinery and equipment. Previous studies show that human error is one of the main causes of accidents in construction projects.

Construction projects involve remarkably diverse and complex activities, so such projects always carry many inherent risks during execution. Of course, these risks vary according to the conditions and environment of construction projects. For example, project risks and threats are different in urban and industrial environments (Ayhan and Tokdemir, 2020). Naturally, the implementation of Industrial Parks construction projects (IPCPs) is associated with more complexities. Artisans and their social issues and expectations, and influential groups that are formally or informally sensitive about projects or their consequences, are among the items that complicate projects and the consequences of accidents. Physically limited space, the activity of industrial units, the high volume of light and heavy machinery traffic and the environment in which the project is implemented, enhance the complexity of implementation and accident prevention and increase its risk. Therefore, the effects and consequences of non-observance of safety and accidents of human error are very costly for stakeholders and sometimes will be irreparable. In this regard, benefiting from the experiences of previous projects is one of the most important measures to be taken in large construction projects in industrial environments (Goh and Ubeynarayana, 2017). By reducing and controlling human error, project risks and hazards can be greatly reduced (Shao et al., 2019). The purpose of learning from human error is to identify the source of risks and uncertainties, and their effects and provide an appropriate management response to these risks. Effective risk management includes four processes: risk identification, risk evaluation, risk response, and risk assessment and monitoring (Zhang et al., 2019). These processes aim to minimize the effects of risks on project objectives by eliminating or sharing risks.

A review of the research literature indicates that relatively extensive studies have been conducted in the fields related to human error and the factors affecting them in urban construction projects (Goh and Ubeynarayana, 2017; Shao et al., 2019; Zhang et al., 2019). While the research literature shows few studies on the factors affecting human error in industrial environments (Bussier and Chong, 2022; AbdulKarimi, 2018). Implementation of IPCP is very challenging due to the special working conditions and the specific type of building use (Chi et al., 2015). Therefore, this study to determine the factors affecting accidents caused by human errors in the IPCP in the developing country of Iran tries to fill the gap between previous studies. Identifying the influential factors in accidents caused by human errors can play a key role in project management decisions. Therefore, the present study seeks to answer the following questions: (1) What factors are effective in the occurrence of accidents caused by human errors in the IPCPs? (2) What is the importance of the effective factors in the occurrence of accidents caused by human errors in the implementation of IPCPs? To answer the research questions, first, to accurately identify the factors affecting the events caused by human errors, the research literature was comprehensively reviewed. Then, using the Delphi survey technique in four different rounds, it was screened to match the factors extracted from the research literature with the IPCPs in Iran. Then the final identified factors were evaluated, and the most crucial factors were identified. The results of this study can help stakeholders as decision facilitators to make better decisions in managing, reducing, and avoiding human errors associated with these construction projects.

2. Literature Review

2.1. Human errors in the construction industry

Human error is part of our daily experience (Bussier and Chong, 2022). Occupational accidents have killed more than 300,000 people and injured more than 300 million worldwide each year (Amiri et al., 2014). According to researchers, the cost of occupational accidents in the construction industry may include up to 15% of the total cost (AbdulKarimi, 2018). Workplace safety is a major concern in many countries. Among the various industries, the construction sector is known as the most dangerous workplace. Construction accidents not only cause human suffering but also lead to a lot of financial losses. Incident analysis is essential to prevent the recurrence of similar incidents in the future and to prepare scientific risk control programs, (Zhang et al., 2019).

Studies of human factors show that human error is the reason for about 80% of major accidents that have affected safety, environment or ergonomics (Jahani, 2017). Many attempts have been made to define and classify human error. For example, Tixier et al. (2017) have defined error as an unauthorized action when the permissible operating limits are defined by the system. One of the most important classifications that have been accepted since its introduction as a suitable model for describing human function is the model proposed by Reisen (1990). He proposed an error modeling system based on the classification of Skill, Knowledge and Rule (S-K-R)-Based Behavior (Toole et al., 2017). Human error must be considered beyond tangible events. Errors in economic planning or military orders should also be investigated and analyzed in their place and depending on the intended purpose (Lee et al., 2018).

Sudani (2018) stated that many events occur in the world every year. Some of these accidents lead to damage to the environment and others lead to harm to humans. Environmental disasters, such as the release of various pollutants, affect water, soil, and air. Occupational accidents occurring due to non-compliance with health and safety principles can threaten people's health, disability and even death in acute cases. Accidents are usually the result of unsafe conditions or unsafe acts. In general, financial, or human losses are the negative consequences of industrial accidents.

Errors can impose direct and indirect costs on organizations. In such a way that some of the incurred expenses cannot be reimbursed by the insurance. Only direct costs may be paid by insurance companies and therefore other costs are imposed on the organization (Love et al., 2018). The consequences of human error can be from minor to very severe, in addition, they may vary from one situation to another, from one job to another, or from one piece of equipment to another. Concerning equipment, the consequences of human error may fall into three categories: (i) equipment operation is stopped completely; (ii) the equipment operation is not completely stopped, and (iii) equipment operation delays are negligible. Human errors in engineering can be classified under different classifications. The seven common classifications are as follows: (1) maintenance errors; (2) operator errors; (3) design errors; (4) assembly errors; (5) inspection errors; (6) error management; and (7) participatory errors (Zhou et al., 2016).

2.2. Factors affecting human errors in the construction industry

According to the research literature review, various researchers in the field of human engineering have stated that many general factors significantly increase stress on a person and in turn lead to a significant deterioration in his reliability (Liao et al., 2018; Love et al., 2018). Some of these general factors are as follows: Poor health, the possibility of redundancy at work, working with people with unpredictable moods, serious financial problems, working under very high pressures, not having the right expertise to do the work in progress Performing, experiencing problems with a spouse or children or both, poor chances for promotion, and excessive demands on people in the workplace (Zhou et al., 2016). Past experiences show that there are many reasons for human error. Some important items include poor training, poor equipment design, poor motivation, complex work, poor equipment operation and maintenance methods, insufficient workplace lighting, poor management, etc. (Hasanzadeh et al., 2017).

In another study, Azhdari et al. (2017)investigated the causes of accidents caused by human error in maintenance operations in the petrochemical industry. They identified and documented nineteen different causes of human error. They classified the identified factors into four levels unsafe actions, unsafe supervision, preconditions for unsafe practices, and organizational effects. They acknowledged that increasing the effectiveness of staff training and improving employee performance monitoring have the greatest role in reducing the occurrence of human error events in petrochemical maintenance operations, respectively. Similarly, Jahani, (2017) classified human errors leading to accidents in one of the cement factories into 4 categories. The results of this study show that most errors are associated with the first level, i.e., errors due to unsafe actions. They also cited skill-based error, poor industrial environment, inadequate monitoring, and poor resource management as important causes of error.

AbdulKarimi (2018) consider the lack of strong safety culture as the main reason for many accidents. Mohajeri (2017) have examined the four criteria of cost, quality, time, safety, and ergonomics to evaluate human errors in the implementation of a road construction project with emphasis on ergonomic principles. They identified and assessed a total of 20 risks of error. Salimi (2017) also acknowledged that the implementation of construction projects is always affected by many dangers such as: falls on people and equipment, injuries, burns, electric shocks, accidents, falls, etc. He stated that the incidence of these accidents in Iran is about three times the global average and often the feedback of these accidents is very heavy for projects.

Morais et al. (2018) have studied the analysis of human reliability of human actions and external factors through the project life cycle. They introduced factors such as inadequate skills, insufficient information, inadequate quality control, inadequate communication, inadequate working hours, design problems, management issues, social pressures, and inadequate task allocation as factors in the occurrence of human error. Shi et al. (2019) stated that considering the nature of construction activities, construction workers usually work in partnership; therefore, interpersonal effects among workers play a key role in shaping and influencing the safety behaviors of construction workers. Amiri et al. (2014) have examined occupational accidents in road construction projects. They cited factors such as improper driving of road construction machinery, burnout, heat, poor hygiene, and collision with machinery as the most important causes of accidents in this type of project.

Xu et al. (2019) have reviewed the development of an incident learning model to assess the ability of construction workers during safety training. Improving the safety performance of construction workers lies strongly in the safety training and training of technologies, materials, and organizations. The results of their research also showed that age, experience, business, type of project, type of organization and site environment affect the characteristics and learning abilities of workers, which leads to various levels of safety perception, awareness, and performance (Chan et al, 2021). In addition, Dhalmahapatra et al. (2019) investigated the causes of crane accidents. Cranes serve in the manufacturing industry to transport materials in complex work environments. They stated that the complexity involved in machine-human interaction in the workplace puts it at risk. They also acknowledged that the number of accidents that occurred during construction and maintenance activities increased over the weekend (Saturday and Sunday).

A review of the research literature shows that although many studies have been conducted on human error, a comprehensive list of factors affecting the occurrence of human error in the manufacturing industry, especially in industrial areas, is not available. Therefore, to fill the gap in previous studies, this study seeks to determine the effective factors in the occurrence of accidents caused by human error in the IPCPs (Table 1). In this regard, based on a comprehensive review of the research literature, fifty-four effective factors in the incidence of human error were identified and categorized into seventeen groups, which were used as the first-round questionnaire of the Delphi technique (Table 2). This categorization is based on research background (previous research studies) and expert opinions.

Table 1. Examples of human errors-related studies based on a review of research literature

Location	Type of project	Techniques adopted	Number of human-related factors identified	References
Worldwide	Industrial sectors	Cognitive reliability and error analysis	53	Moura (2017)
Poland	Construction industry	Dynamic discreet process	15	Hoła and Szóstak (2017)
China	Construction industry	Bayesian networks and human factors analysis and classification system	35	Xia et al. (2018)
China	Construction industry	Dissipative structure	10	Liu et al. (2020)
Worldwide	Industrial sectors	Bayesian networks	39	Morais et al. (2020)
Iran	Industrial sectors	SWARA	41	Rafieyan et al. (2022)
China	Construction industry	Human factors analysis and classification system	27	Song et al. (2022)
Iran	Construction industry	Delphi survey technique	35	Chan et al. (2022)

Table 2. Effective factors leading to the occurrence of human errors based on a review of research literature

No.	Groups	Factors	References
1	Act at the wrong time	timing	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
2		duration	(Hollnagel, 1998, Moura, 2017)
3	The action of the wrong type	Force	(Hollnagel, 1998, Moura, 2017)
4		Space	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
5		Speed	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
6		Direction	(Hollnagel, 1998, Moura, 2017)
7	Acting on the wrong equipment	Wrong equipment	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
8	Action in the wrong place	Sequence	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
9	Observation	Missing observation	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
10		Wrong view	(Hollnagel, 1998, Moura, 2017)
11		Misdiagnosis	(Hollnagel, 1998, Moura, 2017)
12	Interpretation	Error detection	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
13		Wrong argument	(Hollnagel, 1998, Moura, 2017)
14		Decision error	(Hollnagel, 1998, Moura, 2017)
15		Delayed interpretation	(Hollnagel, 1998, Moura, 2017)
16		Incorrect prediction	(Hollnagel, 1998, Moura, 2017)

No.	Groups	Factors	References
17	Planning	Incomplete design	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
18		Prioritization error	(Hollnagel, 1998, Moura, 2017)
19	Temporary people in the project	Error retaining information	(Hollnagel, 1998, Moura, 2017)
20		Fear	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
21		Distractions	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
22		Fatigue	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
23		Work variety	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
24		Neglect	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
25		Stress	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
26		Physiological	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
27	Permanent people in the project	Functional defects	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
28		Improper learning	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
29		Tendency to think in a certain way	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
30	Equipment failure	Hardware failure	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
31		Software failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
32	Processes	Improper construction method	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
33	Information issues	access to information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
34		Vague information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
35		Incomplete information	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
36	Communications	Incomplete communication	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
37		Communication failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
38	Organizing	Failure to organize	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
39		Improper quality control	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
40		Management problem	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
41		Design failure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
42		Social pressure	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
43	Training	Insufficient skills	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
44		Insufficient knowledge	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
45	Environmental conditions	Improper temperature	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
46		Inappropriate sound	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
47		Unfavorable weather	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
48		Inadequate lighting	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
49		Undesirable humidity	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
50		Adverse environmental conditions	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
51	Work conditions	type of employment	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
52		Irregular working hours	(Liu et al., 2020, Morais et al., 2020, Moura et al., 2017)
53		Inadequate team support	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)
54		Improper work design	(Hollnagel, 1998, Morais et al., 2018, Moura et al., 2017)

3. Research Methodology

The present study was conducted to determine the effective factors in the occurrence of accidents caused by human error in the IPCPs by descriptive survey method. For this purpose, the effective factors in the occurrence of accidents caused by human error were first studied through the literature, then the list of factors was then reinforced using the four-phase fuzzy Delphi survey method - already used for similar research studies (see Khosravi et al., 2020).

3.1. Fuzzy Delphi Survey

The members of the Delphi panel consisted of fifteen experts with more than 20 years of experience in the HSEE (health, safety, environment, and energy) department of Industrial Parks. There is no strong and explicit rule on how to select and hire professionals who respond to the Delphi questionnaire. However, it should be noted that the quality of experts is more important than their number (Khosravi et al., 2020). Hence, participants in the Delphi survey of experts and critics who must have sufficient knowledge and experience in a similar subject should have sufficient time to participate and effective communication skills (Lee et al., 2018). In terms of the number of specialists involved, this is usually less than 50 and often from 10 to 20 (Sarvari et al., 2021). The number of specialists depends on factors such as sample homogeneity, Delphi objective, the scope of difficulty, quality of decision, ability of the research team, internal and external credibility, data collection time, available resources and scope of the problem studied (Sarvari et al., 2019).

In the classical Delphi method, the opinions of experts are expressed in definite numbers, while experts use their mental variables to express opinions, and this indicates the probability of uncertainty in this situation. The probability of uncertainty is more compatible with fuzzy sets. Therefore, it is better to prepare the data in natural language from experts and analyze it using fuzzy sets. For this purpose, Ishikawa et al. (1993) proposed a method to integrate the conventional Delphi method with a fuzzy theory called the fuzzy Delphi method. In this method, membership functions are used to show the opinion of experts. The advantage of the fuzzy Delphi method is that it considers each of the ideas and combines them to reach a group agreement (Chen and Lee, 2013; Lee et al., 2018; Dabiri et al, 2022). The steps of this method are a combination of the conventional Delphi method and the analysis of the data of each step using the definitions of fuzzy set theory. Fuzzy numbers are used for expert fuzzy comments. Fuzzy numbers are fuzzy sets defined with numerical data in case of uncertainty about a phenomenon (Bui et al., 2020). The steps of the fuzzy Delphi method in the present study are as follows: (1) Identifying the research indicators using a comprehensive review of the theoretical foundations of the research: In the present study, the factors were identified based on a detailed and comprehensive review of the research literature; (2) Collecting the opinions of decision-making experts: At this stage, after identifying the group of experts, a decision-making group consisting of experts related to the research topic was formed and questionnaires were sent to determine the relationship between the identified indicators, where the linguistic variables were used to express the importance of each indicator. The triangular fuzzy method has been developed for expert systems, decision-making and risk evaluation, and it has been successful in use (Bui et al., 2020; Garg and Rani, 2022). Triangular fuzzy numbers have been used in this study and Table 3 shows linguistic terms and triangular fuzzy numbers used; (3) Verification and screening of indicators: This is done by comparing the obtained value of each index with the threshold value. The threshold value is calculated in several ways, which is the value of 0.7 as the threshold value. To do this, we must first calculate the triangular fuzzy values of expert opinions. Then, to calculate the mean value of n respondents' comments, their fuzzy means must be calculated. In the present study, the threshold value is considered to be 0.8 to ensure; (4) The stage of consensus and completion of fuzzy Delphi: Consensus means that the respondents have reached a general decision about the factors and it is a stage after which nothing special happens in the groups (Rivera, 2018).

Table 3. Linguistic terms and triangular fuzzy numbers

Linguistic terms	Triangular fuzzy numbers
Extreme	(0.75, 1.0, 1.0)
Demonstrated	(0.5, 0.75, 1.0)
Strong	(0.25, 0.5, 0.75)
Moderate	(0, 0.25, 0.5)
Equal	(0, 0, 0.25)

Based on previous studies and initial monitoring by researchers, the first stage Delphi questionnaire including fifty-four factors affecting the incidence of human error accidents was developed in seventeen groups. The steps were such that to determine the fact that the identified factors can be considered effective factors in the occurrence of accidents caused by human error in the Industrial Parks in Iran, fifteen experts were asked to present their opinion. The results of the first round indicated that out of fifty-four factors, five factors were removed from the questionnaire and two factors were added. In the second round, a new questionnaire with fifty-one factors was sent to the experts. In this round, forty-two factors had the necessary validity, but it was necessary to combine two factors with other similar cases and with close meanings. Thus, in the third round, a new questionnaire with forty factors was sent again to the experts. In this round, thirty-eight factors have the necessary validity and based on the new theories of experts, three items were added. In the fourth round, forty-one factors were sent back to the experts and then at this stage, all experts concluded that all forty-one identified factors could be identified as effective factors in the occurrence of accidents caused by human error in Iran's Industrial Parks. These forty-one identified factors were classified into nine groups: wrong action, observations/interpretations, planning/processes, equipment, organizing, individual activities, environmental conditions, rescue, and technology. Figure 1 portrays the overall methodological framework for the study. The final questionnaire was reviewed and approved based on face validity, content, and structure (Table 4). The face validity of the questionnaire was confirmed based on the opinions of several respondents, and the construct validity of the questionnaire was confirmed using the confirmatory factor analysis coefficient. Judgmental criteria were also applied in scale purification with statistical criteria (Wieland et al., 2017) which was implemented from the fuzzy Delphi survey.

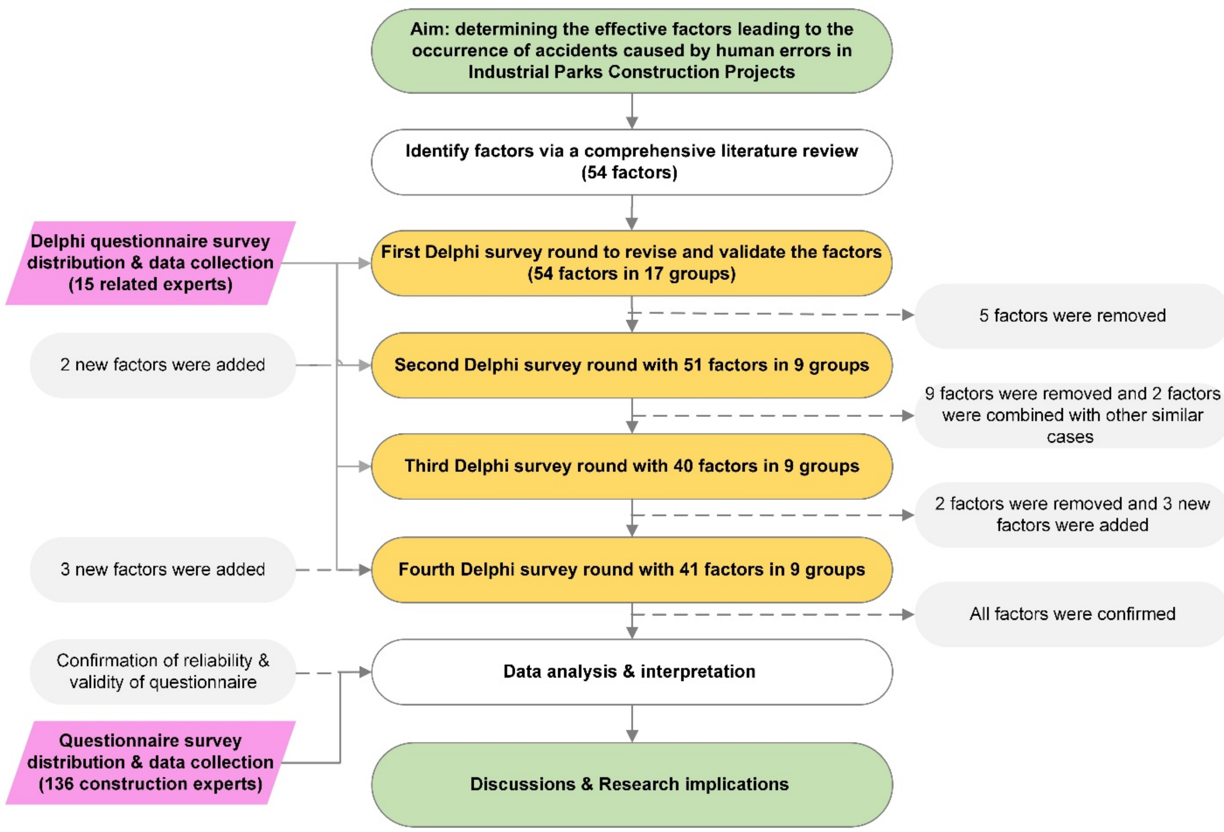

Figure 1. Overall methodological framework for the study

Table 4. Results of the fourth stage of the fuzzy Delphi survey for the factors affecting the occurrence of accidents in IPCPs

No.	Groups	Factors	Descriptions/definitions
Q_1	Wrong actions	Time	Wrong time action/wrong time allocation.
Q_2		operational	Lack of attention to the observance of priority and delay in the implementation stages.
Q_3		Tools	Using inappropriate tools to perform executive operations.
Q_4		Place	Performing operations in the wrong place.
Q_5	Observations/Interpretations	Improper quality control	Failure to perform or defect in quality control of executive steps.
Q_6		Ignore the symptoms	Signs of danger have been given but not considered.
Q_7		False argument	The incorrect argument that leads to the accident.
Q_8		Incorrect diagnosis/prediction	The main event has been predicted, but its side effects have been ignored.
Q_9		Lack of access or defect in observations	Inability to access complete information for decision-making.
Q_{10}		Delayed interpretation	The interpretations required to make the decision have been delayed.
Q_{11}		Failure to perform the necessary controls	Failure to perform the necessary step controls.
Q_{12}	Planning/Processes	Improper design	Choosing the wrong design according to the current situation.
Q_{13}		Prioritization/scheduling error	Wrong prioritization in planning.
Q_{14}		Improper construction method	The selected method is inappropriate.
Q_{15}	Equipment	Equipment failure	Failure to perform timely repairs and maintenance.
Q_{16}		Software error	Switching off the warning or error reporting systems.
Q_{17}		Equipment deduction	Lack of proper equipment to perform executive operations or their wear.
Q_{18}	Organizing	Improper chart	An organizational chart is inappropriate for this type of project.
Q_{19}		Assigning inappropriate tasks	Assigning wrong or incomplete tasks.
Q_{20}		Absence of an HSE safety officer	Absence of the HSE officer on the worksite during the operation.

No.	Groups	Factors	Descriptions/definitions
Q_{21}		Absence of workshop supervisor	Absence of the worksite supervisor during the operation.
Q_{22}		Lack of training	The workforce is not professionally trained.
Q_{23}		Improper working hours	Performing operations at inappropriate hours.
Q_{24}	Individual activities	Physical defects	Occupational medicine is not done for the workforce and the worker does not have a work permit.
Q_{25}		Fear – stress	Fear or stress in performing executive operations.
Q_{26}		Distractions	The desired force is forgetful.
Q_{27}		carelessness	Jokes or the like.
Q_{28}		Variety of work	Performing various tasks with a limited number of personnel.
Q_{29}		Fatigue	Incompatibility of the duration of work with the type of work.
Q_{30}		Improper learning	The inability of the force to learn.
Q_{31}	Environmenta l conditions	Improper temperature	Inadequate air temperature during the operation.
Q_{32}		Improper sound	Inadequate noise or error signals.
Q_{33}		Inadequate humidity	Inadequate air humidity during operations.
Q_{34}		Inadequate lighting	Inadequate lighting during executive operations.
Q_{35}	Relief and secure	Failure to implement a fire alarm system	Implementation of a fire alarm system in the place of storage of incendiary cases.
Q_{36}		Lack of firefighting	Deployment of firefighting less than 5 minutes from the project site.
Q_{37}		Lack of emergency medical teams	Deployment of relief teams less than 5 minutes from the project site.
Q_{38}		Lack of safety equipment	Deployment of safety equipment required in the project by the type of executive operations.
Q_{39}	Technology	Excessive reliance on technology	Given the lack of development of artificial intelligence and the reliability of technology, the system should not be left alone.
Q_{40}		Technology does not conform to existing conditions	Using technology in similar processes regardless of available variables.
Q_{41}		Lack of familiarity with technology	Lack of familiarity with technology, both in choosing and managing it.

3.2. Empirical Questionnaire survey

The construct validity of the questionnaire was confirmed using factor analysis via SmartPLS software. In this research, exploratory factor analysis (EFA) was first carried out, followed by confirmatory factor analysis (CFA) in trying to validate the generated factor groupings. It is typical to utilize CFA using the same data as the EFA. Using the same data helps to demonstrate the model's robustness (Neumann et al., 2017).

To perform factor analysis using the principal components analysis method and to prove the data correlation matrix in the population is not zero, the sampling adequacy index (KMO value) and Bartlett's test of sphericity were used. The results showed that the index (KMO value) is 0.859 and the Chi squared value calculated for Bartlett's sphericity test is statistically significant (sig<0.01). This means that the unity of the correlation matrix was rejected and the data is sufficient for factor analysis and sample size (Table 5). In addition, the Pebble diagram (Figure 2) is provided as one of the most traditional graphical methods for selecting the appropriate number of clustered factors from the allowable eigenvalues. As can be seen in Figure 2, after the tenth factor, the slope of the graph is horizontal and the addition of the tenth factor did not have much effect on increasing the variance. Therefore, the graph shows the number of 2 extractable factors (with eigenvalues greater than 1), which explains 78.102% of the total variance.

Table 5. Bartlett's test of sphericity and KMO scale of incidents caused by human errors

Bartlett's test of sphericity			**KMO value (index)**
Sig.	df	approx. Chi squared	KMO measure of sampling adequacy
0/001	820	5925/486	0/859

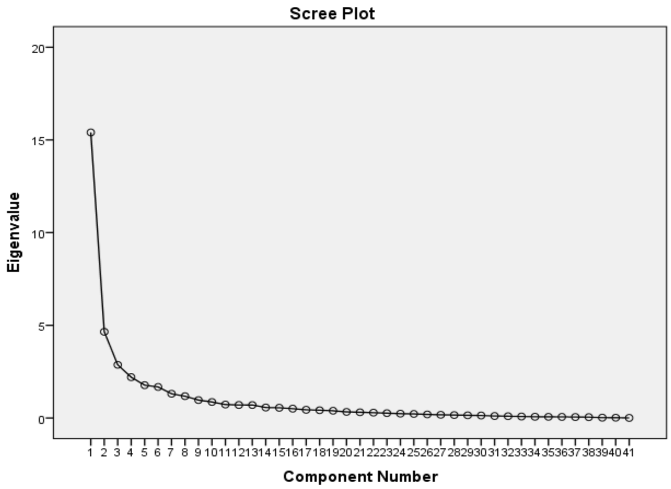

Figure 2. Pebble diagram related to the extracted factors of the scale of incidents caused by human errors

Moreover, inclined rotation was used to extract and name the factors due to the positive correlation of the factors. The results of inclined rotation showed that the first factor 37.566, the second factor 11.345, the third factor 6.997, the fourth factor 5.367, the fifth factor 4.320, the sixth factor 4.087, the seventh factor 3.189, the eighth factor 2.871 and the ninth factor 2.359 and in total, all factors together explain 78.102 % of the total variance (Table 6). In total, all 41 items had a factor loading of at least 0.4 (Table 7); it means that all items on the scale have a significant factor loading.

Table 6. Values of eigenvalue and variance explained by each factor extracted by factor analysis

Factors	Eigenvalue	% of variance explained
Wrong actions	15.402	37.566
Observations/Interpretations	4.652	11.345
Planning/Processes	2.889	6.997
Equipment	2.200	5.367
Organizing	1.771	4.320
Individual activities	1.676	4.087
Environmental conditions	1.307	3.189
Relief and secure	1.177	2.871
Technology	1	2.359

Table 7. Factorial structure matrix of the scale of incidents caused by human errors

Factors	Factor Loadings								
	1	2	3	4	5	6	7	8	9
Q_{1}									0.811
Q_{2}									0.742
Q_{3}									0.592
Q_{4}									0.405
Q_{5}	0.922								
Q_{6}	0.923								
Q_{7}	0.892								
Q_{8}	0.865								
Q_{9}	0.962								
Q_{10}	0.886								
Q_{11}	0.711								
Q_{12}								0.743	
Q_{13}								0.843	
Q_{14}								0.667	
Q_{15}						0.783			
Q_{16}						0.812			
Q_{17}						0.748			
Q_{18}			0.672						
Q_{19}			0.603						
Q_{20}			0.628						
Q_{21}			0.597						
Q_{22}			0.652						
Q_{23}			0.626						
Q_{24}		0.708							
Q_{25}		0.783							
Q_{26}		0.833							
Q_{27}		0.826							
Q_{28}		0.641							
Q_{29}		0.797							
Q_{30}		0.675							
Q_{31}					0.695				
Q_{32}					0.779				
Q_{33}					0.811				
Q_{34}					0.840				
Q_{35}				0.798					
Q_{36}				0.855					
Q_{37}				0.838					
Q_{38}				0.779					
Q_{39}							0.708		
Q_{40}							0.726		
Q_{41}							0.747		

Moreover, Figure 3 lists the factor loadings related to all questions. Since the values of all factor loadings of the questions are larger than (0.3), it can be concluded that the model manifests good fitness. In addition, the values related to convergent validity, model reliability and fitness indices have been reported in Table 7 and the values related to divergent validity calculations of the model have been presented in Table 8.

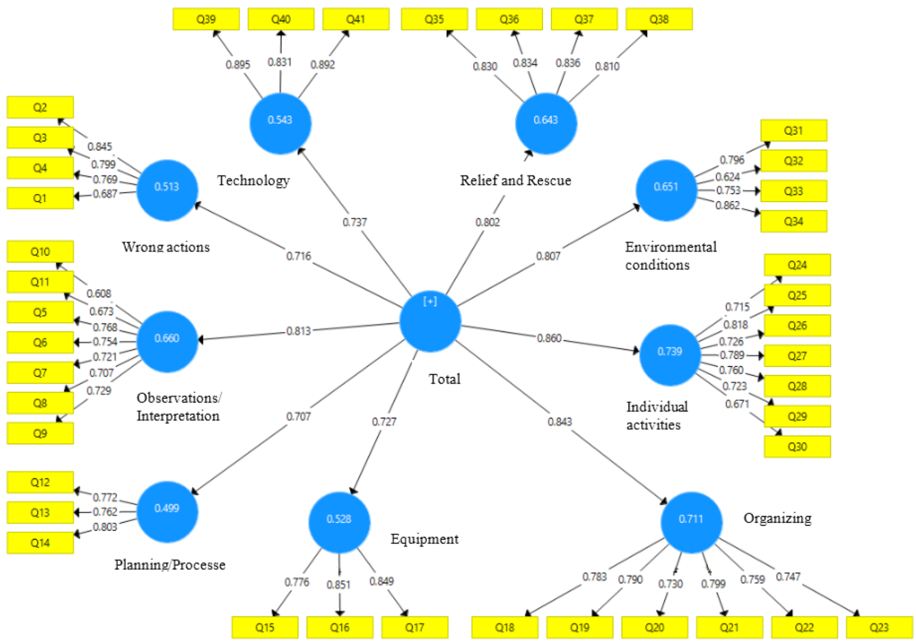

Figure 3. Factor loadings of the questions listed in the research questionnaire

According to Table 8, the values of Cronbach's alpha and combined reliability for all variables are greater than (0.7) also, the value of convergent validity is greater than (0.5) for all variables, so the reliability of the model is favorable. The obtained values for R^2 indicate the optimal fitness of the structural model. In addition, according to the value of Q^2, it can be concluded that the prediction power of the model is good. In general, the model can predict the relevant values well. On the other hand, the values obtained for variable F2 indicate that the effect size of the model is desirable. Also, the value of (GOF) obtained is 0.486, which indicates the desirable fitness of the model.

Table 8. Indicators of convergent validity, model reliability and fitness test

Variables	Cronbach's alpha	Combined reliability	Convergent validity AVE	Communality values	R^2	Q^2	F^2	GOF
Wrong actions	0.870	0.858	0.604	0.364	0.513	0.281	1.055	0.486
Relief and Rescue	0.847	0.897	0.685	0.469	0.643	0.409	1.800	
Planning/Processes	0.700	0.822	0.607	0.368	0.499	0.278	0.998	
Equipment	0.767	0.865	0.682	0.465	0.528	0.337	1.118	
Technology	0.844	0.906	0.762	0.580	0.543	0.392	1.189	
Organizing	0.861	0.896	0.591	0.349	0.711	0.388	2.466	
Environmental conditions	0.758	0.847	0.583	0.399	0.651	0.353	1.863	
Individual activities	0.865	0.897	0.554	0.306	0.739	0.378	2.836	
Observations/Interpretations	0.836	0.877	0.505	0.255	0.660	0.304	1.945	

According to the values obtained in Table 9, the values of the root (AVE) on the main diameter of the matrix are greater than the lower values of each cell, so the divergent validity model is acceptable.

Table 9. Divergent validity of the model using Fornell and Larker values

No.	Groups	1	2	3	4	5	6	7	8	9
1	Wrong actions	0.777								
2	Relief and Rescue	0.446	0.827							
3	Planning/Processes	0.491	0.509	0.779						
4	Equipment	0.425	0.454	0.516	0.826					
5	Technology	0.430	0.754	0.442	0.451	0.873				
6	Organizing	0.564	0.581	0.496	0.683	0.535	0.769			
7	Environmental conditions	0.507	.755	0.553	0.552	0.661	0.569	0.764		
8	Individual activities	0.517	0.629	0.509	0.607	0.565	0.742	0.634	0.744	
9	Observations/Interpretations	0.705	0.541	0.668	0.518	0.456	0.559	0.547	0.626	0.710

Finally, the questionnaire was prepared based on a 5-point Likert scale of measurement and distributed among experts. This study used a purposive sampling method in selecting the respondents to the survey, which was conducted by other researchers for similar research questions (Tamošaitienė et al., 2021). According to the subject of the study, the statistical population includes architects, engineers, construction management specialists, insurance experts and HSEE experts of the company of the Industrial Parks. Experts and respondents were selected based on relevant hands-on working experience (Malek et al., 2020). In the present study, the sample size was calculated using Cochran's sample size formula. Cochran's formula used is provided as follows (Cochran, 1954):

$$n_0 = \frac{Z^2pq}{e^2} \qquad eq.1$$

p is the proportion of the population (0.5) and q is 1-p (0.5). e is the margin of error (0.05) and Z is the standard error (1.96). If the population is small, it is written as follows (equation 2):

$$n = \frac{n_0}{1+\frac{n_0-1}{N}} \qquad eq.2$$

N is the population size and n_0 is Cochran's sample size. 220 people were considered as the population of the study based on Cochran's formula, 140 is the calculated Cochran's sample size and the same number of blank questionnaires were distributed, of which 136 completed questionnaires were received. Table 10 shows the respondents background in the questionnaire survey. The response rate of the survey was found as 97.14%. The available sampling method was used in this study.

Table 10. Respondents' background of the empirical questionnaire survey

Feature	**Code**	**Number (%)**
Gender	Men	104 (76.5)
	Women	32 (23.5)
Age	<30 years old	15 (11)
	30–50 years old	52 (38.2)
	>50 years old	69 (50.8)
Educational level	Bachelor's degree	59 (43.4)
	Master's degree	54 (39.7)
	PhD degree	23 (16.9)
Tenure in the construction sector	<10 years	34 (25)
	10–20 years	76 (55.9)
	>20 years	26 (19.1)
Tenure in safety management	<10 years	73 (53.7)
	10–20 years	39 (28.7)
	>20 years	24 (17.6)
Job position	Architect	5 (3.7)
	Engineer—Civil, Electrical, and Mechanical	59 (43.4)
	Safety Manager	13 (9.5)
	General Manager—insurance	12 (8.8)
	Project Manager	11 (8)
	Senior Project Manager	31 (22.9)
	University Professor	5 (3.7)

4. Results of the Fuzzy Delphi Survey

The analysis of this study was performed using SPSS statistical software at two levels of descriptive and inferential statistics. In the descriptive statistics section, statistical characteristics such as frequency, percentage, mean and standard deviation have been used, and in the inferential statistics section, the Kolmogorov-Smirnov test, single-sample t-test and Friedman test have been used.

A prerequisite for performing parametric tests is the normal statistical distribution of variables. In general, it can be said that parametric tests are based on mean and standard deviation. Now, if the distribution of society is not normal, it is not possible to deduce the results correctly. Therefore, by performing this test, if the significance (Sig) is zero, the normality of the distribution is concluded. Table 11 shows the test of the assumption of the normality of the population distribution. As shown in Table 11, the value of significance level in the whole research questionnaire is more than (0.05), therefore, the null hypothesis in this variable is confirmed at the 95% confidence level and the data distribution in the research variable follows the normal distribution. Therefore, parametric tests are used to examine the data.

Table 11. Kolmogorov-Smirnov test to assess the normality of research data

Variable	Significance level	Statistics	p-value	Variable	Test results
Factors influencing the incidence of accidents caused by human error in the industrial areas of Iran	**0.246**	**1.023**	**0.05**	H_0	**H_0 rejected**

H_0 : The data of the research questionnaire have a normal distribution
H_1: The data of the research questionnaire do not have a normal distribution

4.1. Factors affecting the occurrence of accidents caused by human errors

According to Table 12, the mean value of the total questionnaire on effective factors in learning from accidents caused by human error is equal to (4.219) and the mean value of the dimensions of the questionnaire in terms of wrong actions is (4.367), observations/interpretations (4.279), planning/Processes (4.289), Equipment (4.321), Organizing (4.216), Individual activities (4.171), Environmental conditions (4.150), Rescue (4.068) and Technology (4.105). Since the value of the P-Value is less than the value of (0.05), therefore, the identified factors in the nine groups and the whole questionnaire are significantly different from the test value, i.e., the number (3) and is in the above-mean state. On the other hand, considering that the upper and lower limits of the positive confidence interval have been obtained, it can be concluded that all factors and groups used are strong in effective factors in the occurrence of accidents caused by human error in the implementation of Industrial Parks in Iran.

Table 12. The results of the single-sample t-test

Dimensions	Number	Mean	Standard deviation	Test Value = 3			Lower limit	Upper limit
				t	df	P-Value		
Wrong actions	136	4.367	0.546	29.406	135	0.00	1.284	1.469
Observations / Interpretations	136	4.279	0.506	29.452	135	0.00	1.193	1.365
Planning / Processes	136	4.289	0.577	26.201	135	0.00	1.191	1.387
Equipment	136	4.321	0.591	26.055	135	0.00	1.220	1.421
Organizing	136	4.216	0.627	22.634	135	0.00	1.110	1.323
Individual activities	136	4.171	0.627	21.780	135	0.00	1.064	1.277
Environmental conditions	136	4.150	0.651	20.601	135	0.00	1.040	1.261
Relief and Rescue	136	4.068	0.740	16.830	135	0.00	0.942	1.193
Technology	136	4.105	0.757	17.015	135	0.00	0.976	1.233
The whole questionnaire	136	4.219	0.485	29.272	135	0.00	1.136	1.301

4.2. Importance of effective factors in the occurrence of accidents caused by human errors

The results of Table 13 show that the significance level for each of the identified groups and factors is less than the threshold of 0.05 ($P<0.05$), therefore, it can be concluded that there is a significant difference between the rank of groups and the factors identified in the occurrence of accidents caused by human error in the IPCPs.

Table 13. Friedman test results (the significant result of groups and factors of human errors)

Questionnaire	Chi-square	Degree of freedom	Significance level	Test results
9 groups	51.959	8	0.000	H_0 Rejected
Identified factors	183.657188.671	40	0.000	H_0 Rejected

H_0 **:** The average rank is equal
H_1 **:** The average rank is not equal

Based on the results of Table 14 in the Friedman test ranking, rank 1 has been allocated to the groups of wrong actions with a mean rank of (5.96), rank 2 to equipment with a mean rank of (5.45), rank 3 to planning/processes with a mean rank of (5.43), Rank 4 to the group of Observations/Interpretations with average rating (5.20), Rank 5 to the group of Organizing with a mean rank of (5.05), Rank 6 to the group of Individual activities with a mean rank of (4.65), rank 7 to Conditions Environment with a mean rank of (4.61), ranks 8 to technology with a mean rank of (4.40) and rank 9 to the group of rescue with a mean rank of (4.25).

Table 11 also shows that in the Friedman test ranking, time factors with a mean rank of (24.74), delayed interpretation with a mean rank of (24.36), incorrect diagnosis/prediction with a mean rank of (24.22), A tool with a mean rank of (23.96), failure to perform the necessary controls with a mean rank of (23.03), respectively, were identified as 5 factors affecting the incidence of human errors in the implementation of IPCPs in Iran. Also, factors of unfamiliarity with technology with a mean rank of (18.27), lack of safety equipment with a mean rank of (18.36), inappropriate learning with a mean rank of (18.46), incorrect reasoning with a mean rank of (17.99), non-implementation of fire alarm system with a mean rank of (17.91), respectively, we're recognized as the least effective factors among the studied factors.

Table 14. Results of the Friedman test for ranking the groups and factors of human errors identified in the occurrence of human errors

No.	Group (Mean rank)	Group rank	Factors	Mean rank	Rank in the group	Overall rank
1	Wrong actions (5.93)	1	Time	24.74	1	1
2			operational	22.99	2	6
3			Tools	23.96	2	4
4			Place	21.60	4	15
5	Observations / Interpretations (5.18)	4	Improper quality control	20.40	6	27
6			Ignore the symptoms	20.72	5	25
7			False argument	17.99	7	40
8			Incorrect diagnosis / prediction	24.22	2	3
9			Lack of access or defect in observations	20.78	4	24
10			Delayed interpretation	24.36	1	2
11			Failure to perform the necessary controls	23.03	3	5
12	Planning / Processes (5.40)	3	Improper design	21.53	2	16
13			Prioritization / scheduling error	22.75	1	7
14			Improper construction method	21.37	3	19
15	Equipment (5.42)	2	Equipment failure	21.64	3	14
16			Software error	22.56	2	9
17			Equipment deduction	22.57	1	8
18	Organizing (5.03)	5	Improper chart	22.05	2	12
19			Assigning inappropriate tasks	19.41	5	33
20			Absence of HSE safety officer	21.39	4	18
21			Absence of workshop supervisor	19.07	6	34
22			Lack of training	22.42	1	10
23			Improper working hours	21.70	3	13
24	Individual activities (4.62)	6	Physical defects	20.09	5	29
25			Fear - stress	20.28	4	28
26			Distractions	19.43	5	32
27			carelessness	21.22	2	20
28			Variety of work	20.85	3	23
29			Fatigue	22.25	1	11
30			Improper learning	18.86	6	37
31		7	Improper temperature	18.89	4	35

No.	Group (Mean rank)	Group rank	Factors	Mean rank	Rank in the group	Overall rank
32	Environmental conditions (4.58)		Improper sound	19.64	3	30
33			Inadequate humidity	21.48	1	17
34			Inadequate lighting	20.90	2	22
35	Relief and secure (4.32)	9	Failure to implement fire alarm system	17.91	4	41
36			Lack of firefighting	20.99	1	21
37			Lack of emergency medical teams	18.68	2	36
38			Lack of safety equipment	18.36	3	38
39	Technology (4.51)	8	Excessive reliance on technology	19.44	2	31
40			Technology does not conform to existing conditions	20.61	1	26
41			Lack of familiarity with technology	18.27	3	39

5. Discussion of Analytical Results

Nine groups have been identified based on the background of the research and the opinions of experts, for this purpose, a fuzzy Delphi survey was adopted. As the results of the present study show, in the group of wrong actions, time and instrumental factors are the most effective factors in this group in the occurrence of accidents caused by human errors in the construction industry. Doing the right thing at the wrong time can spell disaster in industrial projects. In the group of observations/interpretations, delayed interpretation and incorrect diagnosis/prediction are among the most important causes of accidents. Weak management and supervision can be one of the causes of delayed interpretation and incorrect diagnosis/prediction, which can be solved by continuous control. In planning/processes, rank 1 is for prioritization/scheduling errors, which can be caused by poor management. In equipment, the rank is 1 for equipment deduction; in organizing, it ranks 1st for lack of training; in individual activities, the rank is 1 for fatigue which could be due to a lack of financial resources. In environmental conditions, the rank is 1 for inadequate humidity which could be due to a lack of supervision. In relief and secure, the rank is

1 for lack of firefighting; in technology, the rank is 1 for technology does not conform to existing conditions which could be due to a lack of financial resources. According to rank 1, the main sub-factors are two important weaknesses: mismanagement and weak supervision and lack of financial resources; by strengthening these two issues, human error can be greatly reduced.

The results of this study are consistent with the results of previous studies. For example, Azhdari et al. (2016) have concluded that increasing the effectiveness of employee training and improving monitoring of employee performance plays a key role in reducing the incidence of human error events in the industry. Morais et al. (2018), factors such as inadequate skills, lack of sufficient information, inadequate quality control, inadequate communication, inadequate working hours, design problems, and management issues were identified as causes of human errors. Amiri et al. (2014) also found that factors such as burnout and heat are considered serious factors in the occurrence of accidents in construction industry projects. Xu et al. (2019) acknowledged that reducing the risks of human errors among construction workers lies strongly in the issue of education. The results of their research also showed that age, experience, and site environment are influential in the occurrence of accidents. Dhalmahapatra et al. (2019) have also considered the issue of lack of proper interaction between humans and technology in the occurrence of accidents caused by human errors.

Considering the results of previous research and the results obtained in the present study, it can be pointed out that in recent years, many efforts have been made by researchers to reduce human errors in the construction industry. However, the key stakeholders of construction projects (employers and contractors) to improve site safety performance in the construction industry still encounter many unknown ambiguities and challenges. At the same time, increasing site safety performance in the construction industry, which is one of the main factors in the success of projects, is a vital issue in the development of the construction industry. In this regard, a thorough study of the factors affecting the incidence of human errors, especially in developing countries, is far more essential. Focusing on the key contributing factors such as wrong actions, observations/interpretations, planning/processes, equipment, organizing, individual activities, environmental conditions, rescue, and technology, can be a positive step taken forward in reducing the existing practice gaps and improving site safety issues in the construction process. Due to their high ability to combat various scientific problems, artificial intelligence and deep learning method can be useful and applied in human error analysis for making improvements (Sorkhabi et al., 2022; Park et al., 2022).

6. Conclusions and research implications

This study aimed to identify and investigate the factors affecting the incidence of human errors in IPCPs based in Iran. For this purpose, effective factors in the incidence of human errors were extracted by reviewing the research literature, then it was monitored by performing four rounds of the fuzzy Delphi survey. Finally, forty-one important and influential factors were identified. The researcher-made questionnaire was developed based on forty-one factors classified into nine main groups including wrong actions, observations/interpretations, planning/processes, equipment, organizing, individual activities, environmental conditions, rescue, and technology, based on a 5-point Likert scale of measurement. The face and construct validity and the reliability of the questionnaire were examined and confirmed. Then an empirical survey questionnaire was distributed among the experts. Based on the Cochran sample size formula and using the available sampling method, 136 construction experts in Iran were selected as the statistical sample. After collecting the questionnaires, SPSS software was used to analyze the data and opinions gleaned. The findings of the study indicated that the identified factors in the occurrence of accidents caused by human errors in the IPCPs are in the above-mean situation, and all the identified factors can be considered strongly key factors in the occurrence of accidents caused by human errors in IPCPs in Iran. In addition, in the group rankings, the groups of wrong actions, equipment, planning/processes, observations/interpretations, organizing, individual activities, environmental conditions, technology, and rescue, were ranked from 1 to 9, respectively. In addition, in ranking the identified factors by considering all groups, time factors, delayed interpretation, incorrect diagnosis/prediction, tool, and failure to perform the necessary controls respectively were recognized as the five most effective factors in the occurrence of human errors in the implementation of IPCPs in Iran.

In terms of practical implications related to the results of this study, to reduce human errors in the construction industry, especially in developing countries, it is recommended to determine the relevant factors in advance and to set standards and protocols for organizations. A structured definition of safety management dramatically increases the chance of reducing and controlling human errors within the construction industry.

In terms of theoretical implications, this study helps to better manage site safety performance in construction projects by identifying the significant factors influencing the incidence of human errors in the implementation of IPCPs from a quantitative perspective - which, according to the authors' knowledge, has not been studied before. It demonstrates the control of the actions of people and equipment, as well as the proper planning of processes, allowing construction companies to help improve their effectiveness and productivity in site safety management. To succeed in effective safety management, construction companies may need proper organization, control of individual activities, improvement of environmental conditions, updating of the organization in terms of advanced technology application and increasing the facilities and equipment of rescue in their companies for achieving better safety excellence. Hence, some of the perceived future research directions and guidelines for deepening the identified findings are provided as follows for reference: What are the specific managerial and environmental capabilities that will allow construction companies to perform better in terms of site safety performance? How can technology development and deployment help construction companies to succeed in improving site safety management? What are the possible human error reduction or prevention strategies that can be adopted by construction companies?

Future research studies could augment the generalizability of the survey results by increasing the number of construction experts involved to evaluate the identified factors in a similar study. However, as suggested by (Sarvari et al., 2020), it will also be valuable and interesting to compare the effective factors affecting the incidence of human errors according to the level and pace of development of the countries under investigation (developed versus developing) to capture any discerned similarities and differences behind. Finally, the results of this study can assist different major project stakeholders and site safety management personnel as effective decision facilitators in handling, reducing, and preventing any human errors prone to the occurrence of construction site accidents in future.

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