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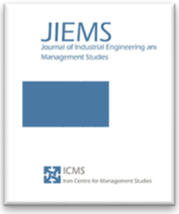

Project portfolio selection to improve safety in the construction industry under fuzzy environments

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Abstract

Generally, the safety management system (SMS) introduced in 1980 focuses on reducing the risk of potential injuries and fatalities in the construction industry. The key to considering the challenges of project safety management and risk assessment in the construction industry as a hazardous industry because of its peculiar nature is important. In line with this, this article aims at employing decision-making techniques to ensure the safety requirements of construction projects. Additionally, a questionnaire under fuzzy environments for identifying the candidate locations and strategies associated with each specific location was conducted. Also, the Empirical Bayesian (EB) approach has been considered to estimate the expected frequency of accidents. The objective of the novel proposed approach is to find the optimal safety project selection with respect to the economic indicators and time value of money under uncertain circumstances. For this purpose, a mathematical optimization model is proposed, and its efficiency is demonstrated by a numerical case study. The results of optimizing the mathematical model indicate that by modifying two factors, namely the safety level and uncertainty coefficient, several scenarios can be explored for cost reduction and a decrease in the number of construction projects. By maintaining a constant safety level of 1.37 (as determined by industry experts) and increasing the uncertainty coefficient from 0 to 0.2, costs decrease by a factor of 1.7, accompanied by a decrease in the number of construction projects by one unit. Furthermore, when the uncertainty coefficient is held constant at 0.2, costs can be reduced up to four times by reducing the safety level from 1.37 to 1. This decision-making framework can significantly contribute to minimizing building accidents and enhancing safety in construction projects. The discoveries from this article are useful for construction safety specialists indeed, in light of the fact that they can improve safety management system (SMS) performance in their workplace by increasing the industry practitioners' comprehension of SMS.

Keywords: safety management; construction industry; fuzzy logic; fuzzy hierarchical analysis; occupational accidents.

Paper Type: Original Research

1. Introduction

Safety is a critical concern in various industries as it involves unpredictable accidents resulting from unsafe and hazardous conditions. Numerous studies have demonstrated that there is a high susceptibility to occupational accidents among individuals under similar circumstances, as indicated by statistical analysis of accident data. Therefore, it is essential to identify influential variables related to occupational accident occurrence based on the expertise of experienced individuals and model them using decision-making methods. In this context, the utilization of fuzzy logic to interpret ambiguous variables in a mathematical framework proves effective and offers logical and inferential solutions for safety managers when faced with uncertain conditions. Furthermore, fuzzy hierarchical analysis can be employed to prioritize safety variables and determine their significance for implementation in construction and other relevant industries. For this particular study, experts identified potential locations for occupational accidents in the construction industry and assigned weights to them using the fuzzy hierarchical analysis approach. Additionally, safety measures suitable for each location were presented in the form of a mathematical model, facilitating informed management and engineering decisions aimed at reducing the occurrence of occupational accidents.

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Safety projects due to their vast scope, the project manager cannot effectively prioritize projects and determine the impact of each project on safety performance. This paper provides an opportunity for safety managers to effectively prioritize safety projects and assess the impact of each project on safety by utilizing an economic-based approach and considering uncertainties in construction safety problems. Due to the comprehensive range of operations, construction projects are one of the riskiest events in most countries of the world. Therefore, an optimally designed safety management system focuses on associated injuries, illnesses, and indirect costs. Besides, the implementation of construction work involves several stages in which people deal with various machines, tools, and materials. These features increase the likelihood of accidents occurring in the workforce. Therefore, tools and machines must be regularly inspected. In this regard, more contemporary perspectives are also emerging that affect profound changes at various levels of planning, processes, and specialized sections like the civil, industrial, and education departments. Training engineers in this regard can play a significant role in modifying the attitude of youthful specialists and following these principles in their specialized activities (2004; Biniecka et al., 2005). The health and safety executive management system is a control tool for improving the state of condition, precautions, environment, and quality issues. This operation system creates a suitable framework for the establishment and implementation of environmental management standards (ISO14000), occupational safety and condition control measures (OHSAS18001) by simultaneously examining these three factors (health, safety, and quality). From the viewpoint of previous research, paying attention to the standards of occupational health and safety and adherence to these principles has carried out a principal role in minimizing the economic losses of industrial units. This will lessen the probability of damage to equipment and financial loss and reduce the number of casualties (Biniecka et al., 2005). Besides, from the viewpoint of managerial insight with respect to the experience in health and safety, risk management, and data analytics, it's necessary to consider safety management system's elements of an effective health and safety system like risks, training, contractors, incidents, to enhance safety performance.

1.1. Importance of safety in the construction industry

There have been critical developments in the construction of places in the world over the last century as this growth has increased the dangers of working in houses and has killed and injured many construction workers every year. The probability of an accident cannot be completely eliminated, but with some safety and security considerations, it can be significantly reduced. This means you can achieve your protection goals by properly managing the plan and handling the way things are done (Yoon et al., 2013). Concerning this aspect, the Occupational Safety and Health Administration have identified falls as a primary cause of construction injuries and damages. These organizations reported in 2005 that 224.1 craftsmen lost their lives over a year, causing 15% of the industry's compensation to construction workers (Bianchini et al., 2017). Construction operations, after working at mine, have the most considerable number and severity of work-related accidents compared to other occupations. It should be unoverlooked, however, that the scope of activity of the construction industry is higher than that of other businesses, and the nature of its work involves the use of massive machinery and equipment and extensive manufactured raw materials, which increase the rate of accidents. The physical mistake represents the leading cause of 70 to 90 percent of work-related accidents in the industry. Significant historical incidents that have occurred so far, like Fliesburg (England, Petrochemical Industries, 1947), Bhopal (India, Chemical Industries, 1984), and numerous other events that have happened due to human fault, and those manlike beings are more than 90% of industrial accidents indicate the importance of the human factor and physical error. Economic progress is based on the health of the workforce, and social development requires the protection of their prerogatives, including the right to physical and mental state. Severe illnesses and accidents in the professions impose an enormous burden on the national economy in terms of medical costs, the creation of disabilities, and factors such as lost work time and reduced production. Therefore, given that health and safety failures cause global and financial losses, this is solely a compelling reason to justify workplace conditions and protection development plans. Fig. 1 shows the overall change in the number of fatal accidents at work in various industries. Apparently, the construction industry has the most share of accident work.

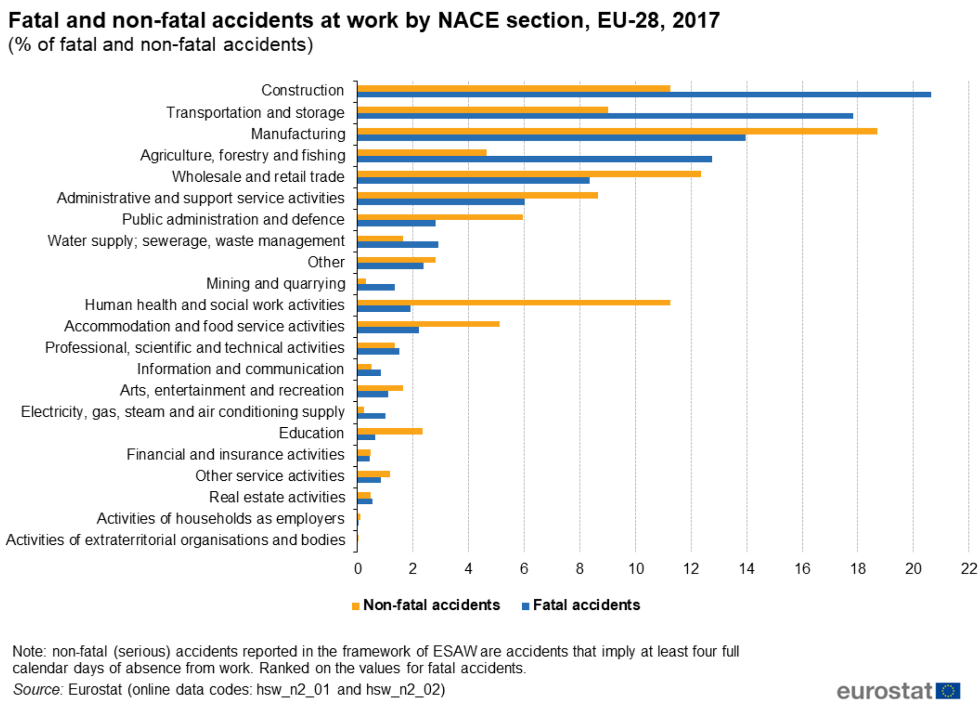

Figure 1. Number of accidents at work (2017)

This study assesses the framework of decision-making and safety support of construction companies for establishing, evaluating, and measuring findings that are supposed to reduce construction accidents, and considering the increase in construction, even a minor impact of these benefits can decrease duplication. In most cases, the purpose of safety orders and performances is to ensure that any action, whether small or large, about its side effects constitutes an essential step in implementing assurance and improving function and decision-making to minimize accident rates. The severity of construction crashes is extraordinarily high due to their specific features, with a substantial percentage of accidents causing death. The elevated incidence of injury and subsequent fractures may indicate factors like failure to equip workshops with appropriate safety features, lack of access to first aid facilities in the briefest possible time, as well as the shortage of awareness of how equipment is operated correctly and how it is performed. Accordingly, the leading causes of accidents in the construction industry are: lack of success of the surveillance system, falling from a height, collapsing construction materials, frustration with properly utilizing personal protective equipment, failure to observe safety tips, and repeated repetitive operations. This paper is prepared as follows. In section 2, notable lines of research and the principal topics within the field of construction safety management systems were reviewed. In section 3, the proposed methodology used in this paper with the aim of choosing the optimal safety project based on economic indicators is presented. In sections 4 and 5, procedure descriptions and alternative features of mathematical programming models are illustrated as a case study. Finally, conclusions and key remarks are given in section 6.

2. Related works

The broad kind of published articles and the variety of studies titled to improve safety overall performance are growing. Many studies have been performed on safety management; for instance, Fini et al. (2018) employed an innovative approach to improving the safety of construction industry employees by optimizing the distribution of workers' workload. In this structure, the auditory, visual, and psychological needs of the work are allocated to the worker, and then the number of workloads identified is minimized, and the process is simulated for testing. In the field of construction safety, Poh et al. (2018) study the machine learning approach used to develop key indicators to determine construction areas according to the risk levels of each of the indexes. Guo studied the embodiment of construction safety management technology visualization. The main focus is on directing, enabling, and improving safety management performance. This article points out that technology visualization programs are tremendously helpful in correcting risky behavior. The construction industry in Hong Kong is growing, and investment in the security sector has been about 30% in the past two decades. However, the accident rate was around 50% in the last decade. Contrary to this result, researchers have recognized uncertain issues in the causal relationship between safety investment and immunity performance. In doing so, in a study conducted by Lu et al. (2016), instead of focusing on finding the consequence of the relationship between reliability investment and precautions performance, a practical framework for how different safety expenditures interact with independent parameters such as human and environmental factors has been discussed. In the study conducted by Ju et al. (2022), it has been focused on the risk levels in the safety of the construction industry by considering the factors of disaster-inducing. The purpose of this study is to monitor and provide an advance warning about possible risk levels using a mathematical model based on game theory in order to reduce the probability and severity of disasters. Due to workplace accidents in the metro construction industry, Xu et al. (2021) analyze accident causes (fatal injury and fatality) by developing an improved approach to identify safety risk factors from a volume of construction accident reports using text mining methodology. As the results show, the method presented in this article is effective in identifying potential factors of accidents as well as the degree of importance of each factor. Identifying these factors helps decision-makers and safety experts in their decisions. Winge et al. (2019) used comparative analysis to diagnose safety management factors in construction industry projects. Risk management and site management are known as the desired factors. The purpose of the method used in this article is to identify connections between the factors and safety performance. The results reveal that the average score on 12 safety management factors was higher among projects with high safety performance compared to projects with low safety performance, and it will be useful for construction stakeholders.Recent studies indicate that the relationship between investment and safety performance is influenced by a dependability culture that combines various elements like commitment and worker participation. Guo et al. (2016) employed an integrated model to enhance the harmlessness behavior of construction workers and improve the mechanism of the critical aspects of safety factors. The study found that immunity management requirements stem from social support reporting and production pressure. It should be mentioned that production pressure comprises a critical factor in the system that provides profound implications for safety knowledge, safety participation, and immunity assessment. The causes of workplace accidents can be numerous, but mainly due to a lack of production planning and organization, unsafe work environment, and human factors, which may be of psychological origin or reflect social or cultural issues or organizational training. Since human behavior is related to subjective factors, it makes them more challenging to research because problems or mental disorders may be directly recounted to work activities. In this regard, the study of Vasconcelos and Junior (2015) showed workplace accidents were due to a lack of management, methods, and operational plans. Safety measures related to operations, training, and design have been proposed. As a result, an average of 6.9 % of severe and fatal accidents in the construction industry can be prevented if proper design measures are taken. AECL and CANDU organizations have developed a process to reduce physical errors in work operation and maintenance. Recent experience in power plant operations shows that human error represents a contributing factor to operational inefficiency, equipment failure, and significant power plant events. Power station designers and organizations reaffirm approaches to preventing human mistakes and reducing their impacts on improving factory processes and safety. Chen-Wing and Davey (1998) described a systematic approach and the principles chosen to eliminate human error in the design. They believe that employing the proposed approach would lead to the development of low-risk plans for human error and its consequences at the plant. Sanni-Anibire et al. (2020) presented a risk assessment approach for enhancing construction safety performance. The study has employed pairwise comparisons and weighting-by-ranking surveys for establishing risk scores. In this study, the method developed was utilized in an ongoing car park construction project. In light of foreign and based on the six-sigma strategy, the expected value of project safety performance was 2.33-sigma, which indicates that 228.739 accidents may occur in every million opportunities. Alarcón et al. (2016) suggested strategies for improving safety performance in construction firms. They analyzed the effectiveness of 1180 construction firms and 221 individual ways applied in these companies to reduce injury rates. From this research viewpoint, practices related to crashes and incidents investigation sustained a slight negative impact on the accident rate. That is to say, the higher the percentage of prevention practices implemented in a strategy, the lower the accident rate. Cressler and Moore (2016) proposed a financial model to measure fatal and horrific injuries from 2003 to 2012. In this study, two aspects of the impact of death and injury in the construction industry in 41 states were examined. Applying the financial model results in findings of notable improvement in construction safety. Gunduz and Ahsan (2018) proposed a method for identifying remarkable safety factors affecting the construction industry. The methodology undertaken in this study was implemented by survey research analyzed by Spearman's rank correlation and T-test. As a consequence, some features, e.g., providing immunity training, campaigns, and awareness to employees by a contractor, are considered as the most important safety factors. Zhou et al. (2015) reviewed preceding research within the discipline of analysis of the safety management system related to the construction industry. They mentioned that peer-reviewed papers published in the field of safety management systems are increasingly helping practitioners and industries to improve safety performance. In this study, 439 review articles focused on three topics, including aspects of the safety management process, site workers, and the evaluation of accident causes. Liao and Chiang (2015) were concerned with worker's compensation factors, giving 574 occupational fatality cases were studied and examined by using evaluation of correlation coefficients and analysis of variance (ANOVA). The outcomes of this research may be used to establish effective compensation guidelines and occupational safety plans. Tam et al. (2004) evaluated the status of construction safety management in China. In this case study, they investigated risk-prone activities on construction sites and distinguished factors affecting construction site safety. The results of the study indicate that the factors of poor safety awareness of top management, lack of training, poor safety awareness of project managers, and reckless operations have the greatest effect on safety performance. Yiu et al. (2019) conducted a questionnaire to explore the significant benefits and obstacles of implementing a safety management system. The research results suggest that four important benefits of better project management are: more reliable conditions, reduced harm to workers, regarding safety management, while the top five obstacles were put safety as a lower priority, worker's high turnover rates, tight project schedules, obstruction by subcontractors and inactive participation were identified for the safety management system implementation. Tanasijevic et al. (2019) use an effective evaluation of a developed model supported by fuzzy techniques for a case study in the field of examination bulldozers. During this study, some indicators and hybrid characters such as measured values and expert judgments were utilized to access a reliable level of effectiveness. Carnero (2015) He presents a methodology, applied in healthcare organizations, to pick out an optimal portfolio in maintenance departments. In achieving this purpose, an evaluation of the internal and external benefits of each project was conducted by combining the Taguchi loss function and the multi-criteria additive model. The results state that organizations can employ this methodology for determining the current status of their maintenance departments. De Oliveira et al. (2015) put forth a portfolio management approach by employing an integrated model to classify projects and allocate projects. The analysis relies on two stages; a multiple decision criteria aid (MCDA) for classifying projects and project managers (initial stage) and mathematical programming for project allocation (secondary stage) have been carried out. The proposed model indicates that classifying and allocating projects can be applied in an efficient way. Spalek (2015) established a conceptual model to evaluate project management maturity. The proposed model emanated from four assessment areas. Human resources, methods and tools, and environments comprise the three factors that represent a traditional approach, and knowledge management depicts a novel technique to maturity measurements. As a result, the suggested model was established in over 100 companies to verify its practical application. Tsai (2011) applied a fuzzy ranking approach to assessing the quality performance of goods. The straightforward calculation process is practically capable of comparing similar fuzzy numbers. Furthermore, an absolute ranking was used in this research. The conclusion of this study state that the suggested approach confirms an effective way to evaluate quality performance through practical examples. Table 1 summarized comparison of mentioned studies. In the table provided, the first column pertains to each case study, while the second column denotes the research method employed. The third and fourth columns respectively indicate the location of data collection and the primary focus of the case study. For instance, Ju et al. (2022) utilized the game theory model to assess safety risk levels. Notably, the majority of the case studies listed in the table center around accidents within the construction industry.

Table 1. Comparative study on the safety performance based on some features

Study	Application	Data collection	Study Focus
Ju et al. (2022)	Game theory model	China	Safety Risks Levels
Xu et al. (2021)	Text mining	China	Safety Risks Factors
Sanni-Anibire et al. (2020)	Six sigma	Saudi Arabia	Risk Assessment
Winge el al. (2019)	Comparative analysis	Norway	Safety Management Factors
Poh et al. (2018)	Machine Learning	Singapore	Forecasting Safety Risks
Guo et al. (2017)	Survey Research	Literature Review	Visualization Technology
Lu et al. (2016)	Agent-based Modeling	Hong Kong	Safety Investments and Enhance Safety Performance
Guo et al. (2016)	Structural Equation Modeling (SEM)	New Zealand	Reduce Unsafe Behavior
Vasconcelos and Junior (2015)	Physical Measurements	Survey	Analyze Workplace Accidents
Chen-Wing and Davey (1998)	Designing Safety Process	Survey	Reduce Human Errors
Sanni-Anibire et al. (2020)	Risk Assessment	Eastern Province of Saudi Arabia	Enhance Safety Performance
Zhou et al. (2015)	Survey research	Review	Safety performance, site workers and accidents
Liao and Chiang (2015)	ANOVA	Taiwan	Worker's compensation
Current study	Mathematical programming	Tehran	Enhance safety performance, Reduce hazardous accidents

3. Proposed methodology

This study adopts a systematic approach to choosing a safety project based on economic indicators. The selection of a safety project should be performed in such a way as to create a level of security and safety for the candidate places. The first step aims at choosing the candidate locations with regard to the hazardous factor by using the Empirical Bayesian approach. In the next step, strategies associated with each specific location were conducted. In the third step of this study, an effective questionnaire under a fuzzy environment is presented to collect expert opinions on each place and solution. In the final step, the project costs associated with each solution are estimated by taking into account the time value of money and the inflation rate of 10%. Fig.2 illustrates the primary process of research conducted in this article.

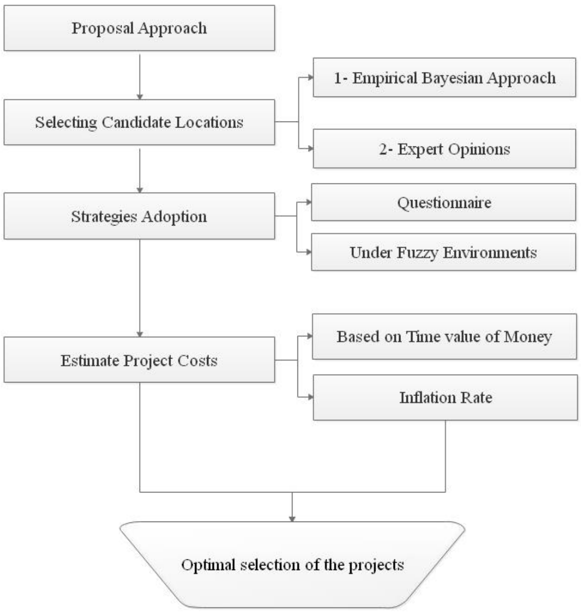

Figure 2. Proposed methodology to select optimal projects

4. Research methodology

In view of the over, questionnaire research was planned by considering 14 hazardous places influencing construction safety performance. In this regard, employing a combination of two qualitative and quantitative approaches has been tried to realize the goal of the research, which is to enhance safety performance by considering select optimal safety projects based on uncertainty and economic indicators. In this study, the common high-risk places among their strategies (listed in Table 5) were identified by using the Empirical Bayesian method, which is universally accepted as an unbiased estimation of the expected accident frequency. Furthermore, the accident prediction processes for the analysis framework are based on the Empirical Bayesian method. In section 4.1, a mathematical model based on the decision-making method under uncertain circumstances is employed to ensure the safety projects are selected effectively with respect to the economic indicators. The proposed model proves how an optimal level of safety can be achieved by the solutions provided by construction industry specialists. The parameters of the proposed model are provided below.

Table2. Nomenclature

Sets and Parameters	
C_{ij}	The net value of fixed and variable annual costs of strategy j at location i
J	Set of strategies with j = 1, 2,…, mi
I	Set of locations (places) with i = 1, 2,…, n
D_i	Set of incompatible strategies in location I
$\tilde{a}_{ij}$	Triangular fuzzy number center
ar_{ij}	Distance of center of triangular fuzzy numbers to the right end
n	Number of locations (places)
SF	Design safety level
λ_r	Uncertainty of safety related to arij
λ^*	Minimum acceptable uncertainty
m_i	Set of strategies in location i

In the following model formulation, X_{ij} is an assignment-type decision binary variable defined if a strategy visits a place which is introduced by Eq. (1).

$$x_{ij} = \begin{cases} 1 \; if\ the\ safety\ solution\ j\ is\ used\ in\ place\ i \\ 0 \; otherwise \end{cases} \tag{1}$$

4.1. Mathematical modeling

The optimization model presented in this section aims at the issue of safety in the construction industry by improving safety performance to reasonably achieve reliable operation.

$$MIN\ Z\ = \sum_{i=1}^{n} \sum_{j=1}^{m_i} (c_{ij} x_{ij}) \tag{2}$$

$Subject\ to$:

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} (\tilde{a}_{ij} x_{ij}) + \lambda_r \sum_{i=1}^{n} \sum_{j=1}^{m_i} (ar_{ij} x_{ij}) \geq n * SF \qquad \forall i = 1,2,\dots,n, \qquad \forall j = 1,2,\dots,m_i \tag{3}$$

$\forall i = 1,2,\dots,n\ \forall j = 1,2,\dots,m_i$

$$\lambda_r \leq \lambda^* \tag{4}$$

$$\sum_{j=1, j\in Di}^{m_i} x_{ij}\ \leq 1 \qquad \forall i = 1,2,\dots,n \tag{5}$$

$$(5) \sum_{j=1}^{m_i} x_{ij}\ \geq 1 \qquad \forall i = 1,2,\dots,n \tag{6}$$

Eq. (2) indicates the objective function for minimizing the total costs, which depends on whether strategy J is used in place I. It is important to designate the project cost with reference to the economic indicators and the time value of money. Therefore, all costs calculated in this study include the initial cost and annual maintenance cost, taking into account the inflation rate of 10% per year, obtained by Eq. (7) as follows.

$$Net\ value = C_0 +\ M_c\ (1 + i)^n \tag{7}$$

Where, C_0 represents the inial cost; n is the number of years (considered 3 years in this study); M_c and i indicate the maintenance cost and inflation rate, respectively.
Constraint (3) contains two terms that show the possible places with the most dangerous accident-prone have minimum safety requirements. Constraint (4) ensures that the uncertainty of safety is less than the minimum defined and acceptable uncertainty. According to constraint (5), it is mentioned that the strategies implemented in place (I) must be incompatible with each other. Besides, we have to make sure that only one incompatible strategy is performed at each place. The assumption that the number of strategies can be implemented at least once in each place is forced by constraint (6). With respect to the managerial insight, it should be mentioned that choosing alternative strategies under uncertainty in mathematical programming can alter the appropriate path to gain high safety performance in the construction industry. On the other hand, the fuzzy theory used in this study remains a principle of acting in unpredictability that is capable of mathematically integrating many concepts, variables, and mathematically inaccurate systems and grounds for reasoning, inference, control, and Provided decision-making in conditions of uncertainty. How fuzzy sets are created and their membership function defined depends on their context and scope. Explaining a fuzzy set for our concept is completed by defining an appropriate membership function for it. In the literature on the fuzzy set theory, several standard membership functions are introduced, one of which is a triangular membership function. This triangular membership function is as follows:

$$\text{trn(x: a,b,c)} = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \leq\ x \leq b \\ \frac{c-x}{c-b} & b \leq\ x \leq c \\ 0 & x > c \end{cases} \tag{8}$$

In Equation. (8), trn (x: a,b,c) is a membership function for a fuzzy set on the universe of discourse x , where each element of x is mapped to a value between 0 and 1. This value is called membership value or degree of membership. This triangular membership function is defined by a lower limit a , an upper limit c , and a value b , where a < b < c. In this paper, linguistic variables in the very low to extraordinary range were applied to express the importance of each index in improving safety performance and were used by experts to judge rhetorical variables to fuzzy triangular numbers. Project specialists then determined the effect of each indicator on improving safety performance with very low to considerably high values. For this purpose, professionals were first surveyed to determine the weight of each criterion and sub-criterion relative to the target, and as in the table below (Table 3), the linguistic variables were converted to fuzzy triangular numbers, and the mean of specialist opinion was calculated.

Table 3. Example of converting linguistic variables

Rank	Rank Equality	Linguistic Variables		
Very high	5	0.85	1	1
High	4	0.6	0.8	0.9
Average	3	0.35	0.5	0.65
Low	2	0.1	0.2	0.4
Very low	1	0	0	0.15

5. Case Study

The importance of safety in the construction industry incorporates some features which need to be considered in terms of our proposed approach. In this regard, because of the risks involved in construction, the most likely 14 hazardous places were identified by five HSE experts, that shown in Table 2. A questionnaire was used for this purpose. Safety strategies for potentially hazardous places are additionally provided in Table 5. It should be noted at this specific point that the experts' opinions on linguistic variables are expressed, and how these variables are converted to fuzzy numbers is presented in Table 3. Table 4 shows the most hazardous places, along with the expert opinion in the form of fuzzy numbers.

Table 4. Expert opinion for candidate hazardous places

	Place (I)			
Expert 1	1 Metal structure of Diamond Hall (0.85,1,1)	2 Lift bar of Diamond Hall (0.6,0.8,0.9)	3 Concreting of Diamond Hall (0.35,0.5,0.65)	4 Cinema electricity (0.1,0.2,0.4)
Expert 2	5 Install facility of cinema (0.47,0.65,0.77)	6 Roof of garden (0.85,1,1)		
Expert 3	7 Install automobile exhibition glass (0.85,1,1)	8 Install helipad (0.1,0.2,0.4)	9 facility of cinema (0.47,0.65,0.77)	
Expert 4	10 Plate crystal gallery (0.35,0.5,0.65)	11 Metal structure of Diamond Hall (0.85,1,1)		
Expert 5	12 Plate crystal (0.35,0.5,0.65)	13 Install automobile exhibition glass (0.85,1,1)	14 Install mold UPSTAND (0.6,0.8,0.9)	

Table 5. Hazardous places among their strategies

		Strategy (J)			
		1	2	3	4
Places (I)	1	Crane	Rigger	Life Line	Climber
	2	Rigger	Specialist Operator	Technical Verification	Equipment for Lifting
	3	HSE Expert	Fence	-	-
	4	Electrician	Safety Connections	-	Personal Protective Equipment
	5	Stool	Scaffolding	Life Line and Life belt	-
	6	Safety Net	Rail Crane	Crane	-
	7	Crane	Man Basket	Safety Net	-
	8	Stool	Climber and Life Line	Crane and Man Basket	-
	9	Stool	Scaffolding	Life Line and Life belt	-
	10	Communication	Instructions	-	-
	11	Crane and Man Basket	Life Line	Climber	-
	12	Safety Net	Scaffolding	Life Line	-
	13	Life Line and Life belt	Crane	Scaffolding	-
	14	Life Line	Life Belt	-	-

In the subsequent step, a set of alternative safety improvement projects for each candidate place has been provided according to specialist opinions. The following table (Table 6) summarizes the experts' opinions on the importance of the site and the strategy chosen. Furthermore, it is necessary to note that expert common opinions on each strategy have been averaged.

Table 6. Experts' mutual opinion for alternative safety improvement projects

Places (I)	Strategy (J) 1	2	3	4
1	(0.85,1,1)	(0.6,0.8,0.9)	(0.6,0.8,0.9)	(0.6,0.8,0.9)
2	(0.47,0.65,0.77)	(0.6,0.8,0.9)	(0.6,0.8,0.9)	(0.85,1,1)
3	(0.45,0.65,0.77)	(0.35,0.5,0.65)	(0.85,1,1)	(0.35,0.5,0.65)
4	(0.35,0.5,0.65)	(0.85,1,1)	(0.35,0.5,0.6)	(0.35,0.5,0.65)
5	(0.72,0.9,0.95)	(0.35,0.5,0.65)	-	-
6	(0.47,0.65,0.77)	(0.85,1,1)	-	-
7	(0.6,0.75,0.82)	(0.6,0.8,0.9)	-	-
8	(0.85,1,1)	(0.85,1,1)	(0.72,0.9,0.95)	-
9	(0.6,0.8,0.9)	(0.1,0.2,0.4)	(0.47,0.65,0.77)	-
10	(0.35,0.5,0.65)	(0.6,0.8,0.9)	(0.6,0.75,0.82)	-
11	(0.1,0.2,0.4)	(0.85,1,1)	-	-
12	(0.6,0.8,0.9)	(0.47,0.65,0.77)	-	-
13	(0.35,0.5,0.65)	(0.47,0.65,0.77)	-	-
14	(0.85,1,1)	(0.1,0.2,0.4)	(0.6,0.8,0.9)	(0.6,0.8,0.9)

The effectiveness of each strategy is an indicator of how effective the policy is. Accordingly, the larger the amount assigned to the strategy, the more effective it will be. In this study, which uses fuzzy numbers, it is necessary to select a number from the fuzzy number. The midpoint is the safest and the most probable case, and we have to choose from the middle to the maximum limit if we want to make an optimal decision. The smaller the gap between the selected number and the maximum limit is, the lower the uncertainty and the higher the level of effectiveness will be. Regarding the specialist's opinion and the degree of uncertainty, the desired effect will be selected. The difference between the middle and maximum limits will endure the decision-making period. After solving the mathematical model mentioned in section 4.1, taking into account the safety factor (SF) range of 1 to 1.5 and the uncertainty of safety 0 to 0.2 chosen by the experts, the decision table specifically for place 1 is presented below.

Table 7. Decision-making based on the cost function

Safety factor	Uncertainty of safety	Cost function	Number of executive plans
1.5	0.2	1,710,335,300	40
1.5	0.1	1,927,255,300	39
1	0.2	100,021,700	28
1	0.1	101,059,700	27
1.25	0.2	244,352,700	36
1.25	0.1	275,889,000	36
1.37	0.2	386,319,000	37
1.37	0.1	417,855,300	37
1.37	0	680,860,300	38

Once the mathematical model is optimally solved, only two answers can be implemented at the same time and are compatible with each other, and only one of the two strategies must be chosen with respect to the equation (6). In addition, the safety factor (SF) and the unpredictability coefficient values are respectively considered to be 1.37 and 0, which indicates the least uncertainty in decision-making. If the safety factor is constant and the uncertainty coefficient is 0.2, the costs are reduced by 1.7 times. Also, in this case, the number of executive plans decreases. As a consequence, The lower the decision uncertainty coefficient, the lower the costs directly. On the other hand, if the safety factor is reduced and equal to 1 and the uncertainty coefficient is assumed to be constant and equal to 0.2, the prices are expected to be lessened approximately by four times, and the number of executive plans will be reduced by 9 units. Accordingly, if the safety factor decreases and the uncertainty coefficient increases, the cost function of safety strategies will become smaller. Fig.3 indicates these relationships between the uncertainty of safety and cost function.

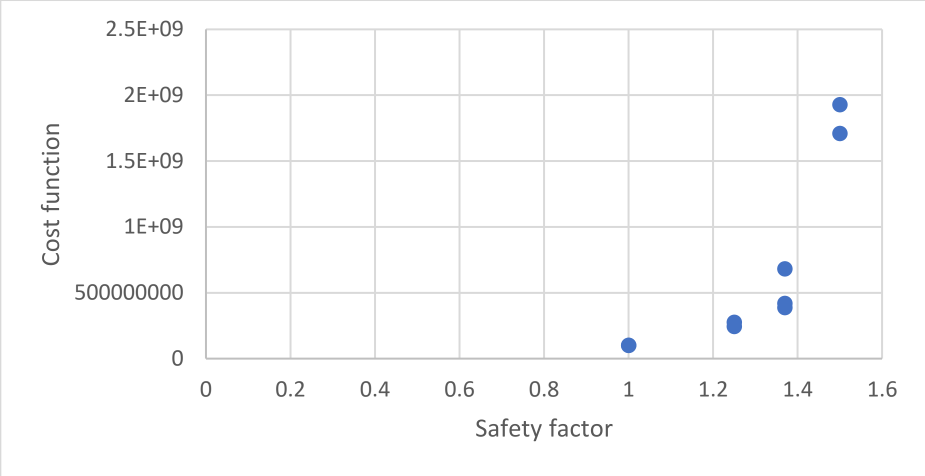

Figure 3. Effect of safety factor on the cost function

The status of how the safety factor is affecting the cost function is illustrated in Fig. 2. As shown in Fig.2, based on cost function evaluation, the best value of the safety factor among its possible values (see Table 7) is 1. In addition, in both Table.7 and Fig.2, the more the safety factor decrease, the less the cost function is. The results discussed formerly are supported by uncertainty. However, if uncertainty is unconsidered in the model, the results can be amended as follows.

Table 8. Decision-making based on cost function without considering uncertainty

Safety factor	Cost function	Number of executive plans
1.5	Infeasible	Infeasible
1	119247700	29
1.25	318834000	35
1.37	680860300	38

It is clearly unconcealed that the best decision-making occurs once the safety factor is equal to 1. This is precisely the same result as in the uncertainty condition mentioned before. In Table 8, compared to Table 7, when the factor of safety corresponds to 1, the cost function in the uncertainty condition (λ=0.2) is 1.19 times greater than in the circumstance while not uncertain. In addition, with relevance to this issue, the number of executive plans increase by one unit. Similarly, in the different safety factor values, the cost function will have lower values within the uncertainty circumstance. Therefore, despite the results, it is comprehensible that within the case of uncertainty, the selection of cost-effective safety projects and, therefore, the variety of implementation plans are diminished. Construction safety specialists may also scale back the costs of the projects, calculated according to the time value of money and economic indicators, by considering the uncertainties in safety project selection models. Fig.4 compares the uncertainty scenario, and the condition represents certainty based on a cost function.

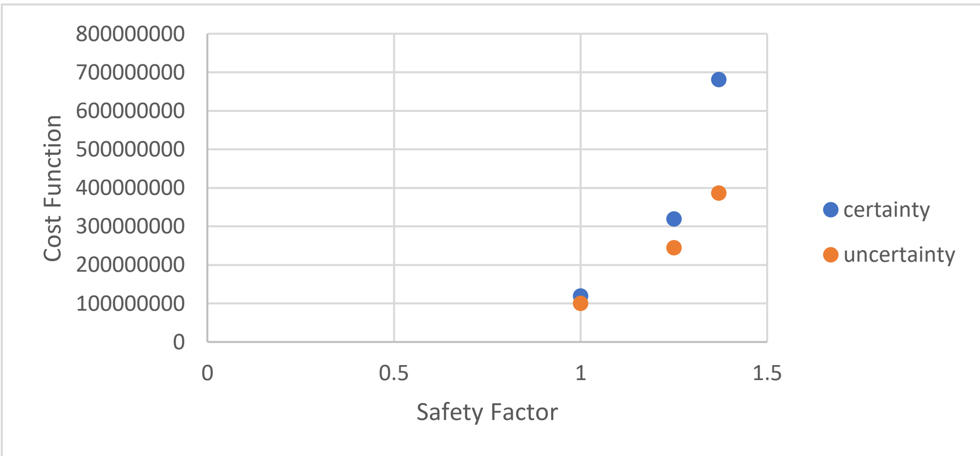

Figure 4. Compare uncertainty with a deterministic scenario based on the cost function

6. Managerial insights

Nowadays, due to the high number of occupational accidents and the significant proportion that is attributed to construction and civil engineering activities, it is imperative to establish a decision-making framework for safety management in order to mitigate accidents. In light of this objective, this study aims to propose an approach based on fuzzy logic to effectively identify potential accident-prone areas. Furthermore, a mathematical model is utilized to evaluate and present cost-effective solutions for each identified location. The findings of this research demonstrate that the approach employed can effectively prevent hazardous accidents in the construction industry and other related sectors, thereby offering safety managers various scenarios to consider.

7. Conclusion

According to the Iranian Social Security Organization, in 2012, accidents in the construction industry accounted for 26% of all workplace accidents in the country. Therefore, this research represents a fuzzy approach based on the questionnaire conducted by five experts in the field of the construction safety industry as a case study. Consistent with becoming aware of the effect of workers' compensation, this article concentrates on applicable factors, which include protection techniques alongside unsafe locations that had been defined and evaluated, and the operational costs of each of these precise policies become calculated separately. In step with the fuzzy concept, linguistic variables and their conversion to fuzzy numbers are used to weight assessment criteria. In the second phase of this research, a set of alternative safety improvement projects for every candidate place has been appropriately acquired. In addition, the importance of each place was defined along with the strategy adopted at that location. In order to achieve optimal safety project selection, a mathematical optimization model is proposed, and its efficiency is demonstrated by a numerical case study. By solving this optimization model, decision-making and scenario-based structures were accomplished as a standard example. As depicted in Table 7, the cost is diminished by a factor of 1.7, and the quantity of construction projects is reduced by one unit when the safety level is upheld at 1.37 (based on industry experts' assessments), and the uncertainty coefficient is elevated from 0 to 0.2. Moreover, by decreasing the safety level from 1.37 to 1 while keeping the uncertainty coefficient at 0.2, prices decrease by up to four times. Besides, a comparison between certain and uncertain conditions within the model was conducted in the case study, as illustrated in Table 8. Furthermore, other multi-criteria decision-making procedures, like AHP, can be utilized to conduct future studies, and the outcomes of these approaches can be contrasted with those of this work. The research findings accomplish significant enhancements to construction industries by contributing to dominant strategies like considering uncertainty and engineering economic techniques that may be applied by several researchers and practitioners and result in improving safety management system performance.

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