SCIENTIFIC OASIS

Decision Making: Applications in Management and Engineering

Journal homepage: www.dmame-journal.org
ISSN: 2560-6018, eISSN: 2620-0104

A Step-By-Step Hybrid Approach Based on Multi-Criteria Decision-Making Methods And A Bi-Objective Optimization Model To Project Risk Management

Mohammad Khalilzadeh[1,*], Sayyid Ali Banihashemi[2] and Darko Božanić[3]

1 CENTRUM Católica Graduate Business School, Lima, Peru. Pontificia Universidad Católica del Perú, Lima, Peru
2 Department of Industrial Engineering, Payame Noor University, Tehran, Iran
3 Military academy, University of Defence in Belgrade, Belgrade, Serbia

ARTICLE INFO

Article history:
Received 2 February 2023
Received in revised form 23 October 2023
Accepted 19 November 2023
Available online 10 January 2024

Keywords: Project risk management; Fuzzy BWM; Fuzzy WASPAS; Bi-objective mathematical model; Augmented Epsilon-Constraint.

ABSTRACT

Project success and achieving project objectives and goals highly depend on effective and thorough risk management implementation. This study provides a comprehensive and practical methodology for project risk management. In this paper, firstly, the risks were collected by analyzing the historical documents and literature. Then, the collected risks were screened using brainstorming and categorized into five groups. Subsequently, a questionnaire was made and the identified risks were validated using the Fuzzy Delphi technique. Also, the relationships between risks were determined using the Interpretive Structural Modelling (ISM) method. Moreover, the weights of the criteria used to rank the risks were calculated through the Fuzzy Best-Worst Method. Subsequently, the major risks were determined using the fuzzy WASPAS method. Furthermore, a novel bi-objective mathematical programming model was developed and solved using the Augmented Epsilon-Constraint (AEC) method to choose the optimal risk response strategies for each critical risk. The results demonstrated that the proposed framework is effective in dealing with construction project risks.

1. Introduction

Contractors are constantly looking for methods to enhance their productivity, minimize their costs and increase their profit based on their organizational strategy [1]. However, poor project management and delays in its various stages have always imposed a lot of losses and played a major role in increasing the costs of organizations. On the other hand, these costs may be considerably reduced by identifying the factors causing delays in the completion of projects by creating a systematic method and taking effective steps to reduce or eliminate these factors as well as allocating resources to them according to organizational strategic priorities. Since contractors perceive construction projects as the strategic planning options, choosing the right projects and accurately and timely implementing those projects seem to be extremely important [2].

* *Corresponding author.*
E-mail address: khalilzadeh@pucp.edu.pe

https://doi.org/10.31181/dmame712024884

Potential risks may rise from various characteristics and aspects of a project [3]. Risks have the potential to positively or negatively influence the project objectives such as cost, time, and quality. As a result, when managers fail to effectively address the risks with negative and detrimental consequences on the project, issues like poor quality, cost and time increase may happen [4]. Many researchers and organizational managers extensively acknowledge the significance of project risk management to guarantee the success of the project. In general. the project risk management contains three steps [5]: risk identification, risk assessment, and responding to risks. Potential risks are identified and recorded in the first step. Then, the identified risks are evaluated in the risk assessment stage, their descriptions are modified, and their related consequences and probabilities are estimated. In the response to risk step, proper actions are recognized, evaluated, selected, and finally executed according to the existing knowledge of the project risks to mitigate the occurrence of the risk and/or negative effects to a tolerable level. Subsequently, appropriate measures are chosen to respond to the risks aimed at addressing the risks forecasted in the project implementation [6]. In general, the primary aim and goal of this research is to develop and select the risk response strategies by focusing on the risk identification and assessment process.

Meanwhile, construction projects have unique features such as a long-life cycle, complex processes, stressful environment, and sometimes conflicting interests of stakeholders, which will inherently render many uncertainties during the project. The occurrence of delays in the engineering, procurement, implementation, and operation phases seems to be one of the common issues and problems in construction projects so that the amount of delay is so much in many cases that would even question the economic justification of the project. To prevent delays, the project manager needs to know what factors have caused delays and what measures should be taken to overcome them. On the other hand, according to the technical and support needs of each project, the impact of each delay factor in the implementation of the project may vary, and these factors are recognized in the form of project risks for the managers of organizations. Therefore, the analysis of risks is considered as a crucial factor in choosing the right construction projects [7]. Murray-Webster and Hillson [8] defined risk in the most recent definition as uncertainty that can positively or negatively affect one or more goals. Also, the Reformation Committee of the American Insurance and Risk Association has expressed its view on risk as follows: Risk is the uncertainty of the outcome of an event that has a probability of occurrence. In general, project risks are the result of the uncertainty that exists in all projects and their components. Project risk management has been identified and recognized as a fundamental job for proper identification and evaluation of risks to ensure the minimization of the errors and deviations from the project plan [9].

Most of previous studies have focused on identifying and analyzing project risks, and less studies on risk response selection can be found. However, these research works have generally used multi-criteria decision-making (MCDM) or single-objective mathematical models to select risk response strategies. Further to best of the authors' knowledge, no research exists that exploited multi-objective mathematical programming model for selecting the optimal risk response strategies. Therefore, the present research seeks to fill the existing research gap by providing a hybrid and comprehensive approach. The first contribution of this research is the use of ISM to examine the relationships of project risks, which is inspired by the future suggestions of Wu *et al.* [5]. The second and third contributions of the current study are the application of the fuzzy WASPAS method to determine critical risks and choose multiple risk response strategies through presenting a novel bi-objective mathematical programming model.

The proposed approach of this paper includes the following steps: First, the risks are collected using historical documents and literature review. Then, the risks associated with the implementation of the concrete skeleton of a five-star hotel are identified, and finalized using the fuzzy Delphi Method and expert judgement. Subsequently, the relationships between risks are determined and analyzed using the ISM method followed by categorizing them based on the driving and dependence powers. Afterwards, the importance weights of evaluation criteria are calculated using the Fuzzy Best-Worst Method (FBWM). In fact, five criteria of the intensity of the cost effect, the intensity of the time effect, the intensity of the quality effect [10], the probability of occurrence, and detectability are utilized in this study to analyze the risks. In the next step, the identified project risks are prioritized and ranked using the Fuzzy WASPAS method, and thereby, the critical risks are distinguished for developing appropriate response strategies. Finally, a bi-objective optimization model is proposed to select the optimal risk response strategies. The Augmented Epsilon-Constraint (AEC) method is also utilized to solve the proposed bi-objective optimization model.

The framework of this paper is organized as follows: In the second section, the research literature is reviewed. The third section thoroughly explains the research methodology. In the fourth section, the implementation steps of the proposed methodology in a construction project as a case study are presented and the computational results are presented. The fifth section provides the managerial discussion and practical implications. Finally, the paper concludes in the sixth section along with some suggestions for further studies.

2. Literature review

Fernando *et al.* [11] studied the financial risks influencing construction contractors in Sri Lanka and identified the most basic financial risks through expert's opinions using unstructured interviews and questionnaire. The findings showed that the most serious financial risk influencing contractors is related to changes in the price of materials. Also, future contracts were found to be the most common risk hedging technique used by contractors to deal with identified financial risks. Ahmadi *et al.* [10] provided a comprehensive framework for managing major risk events of highway construction projects in three stages as follows: identifying potential hazards, evaluating and prioritizing the identified risks based on the state analysis model, and the effects of fuzzy failure, and identifying the appropriate response. The cost, time, and quality are the major factors and criteria for ranking and prioritizing the risks weighted using the Analytic Hierarchy Process (AHP). They proposed a new system to identify the appropriate risk response strategy for risk-generating events based on the risk factor, control number, and risk allocation.

Dehdasht *et al.* [12] assessed the project risks combining the DEMATEL and Analytic Network Process (ANP) methods. They suggested a risk assessment method that identifies the crucial risk factors with a direct impact on the success of the project. This approach in turn contributes to developing policies to ensure reliable planning of energy supply. The research data was collected in 2016 through performing interviews with experts working in oil and gas construction projects in Iran. According to the results, the experts in oil and gas construction projects are more concerned about financial and technical aspects since the weight of these risk groups is considerably higher than other risk dimensions. Also, according to experts, some of the most important risk factors in oil and gas construction projects include failure in the financial allocation of the project, errors in the design plans, delays in the audit and payment of the contractor's monthly temporary statements, and the poor quality of the prepared materials or shortage of materials. Fattahi and Khalilzadeh [13] used the fuzzy weighted risk priority Number (FRPN) to assign to each failure. They calculated the weight of the factors of the mode analysis model, failure effects, and the weight of failure modes using a hybrid approach of Fuzzy AHP and Fuzzy MULTIMOORA methods. They considered a steel factory in Iran as a case study to demonstrate the application and advantages of the proposed fuzzy hybrid method. Their findings suggested that the "Average fuzzy weighted risk priority numbers (AFWRPNs) have decreased by 56% compared to the "Average corrected fuzzy weighted risk priority numbers (ACFWRPNs). Rahimi *et al.* [14] proposed a hybrid approach based on Failure Mode Effects Analysis (FMEA) and ISO 3100 for the construction project risk management. This hybrid approach was not a very accurate approach in providing a proper risk response. Thus, they suggested a mixed integer programming (MIP) model for choosing the optimal risk response strategies for the project. The model was based on the synergy between project risk responses with the potential to consider different criteria in the objective function and optimize them regarding the defined projects. Ultimately, they applied two meta-heuristic algorithms to solve the model.

Kassem *et al.* [15] evaluated the risk factors existing in the construction projects in in Yemen. The findings revealed that internal risks and changes during project implementation are the first and second influencing factors followed by the instability of the government, inaccurate estimation of the project cost, delay of the government in making decisions, inaccurate project schedule estimation, political situation, and civil war. Mahmoudi *et al.* [16] presented a model for managing the risks in the foreign contracts. The identified risks were then considered as criteria to prioritize the contracts. They used the BWM method combined with the Gray Relational Analysis (GRA) method for prioritizing contracts after acquiring the opinions of experts. The results showed that the additional cost of the contract seems to be the most appropriate option for outsourcing construction projects. Zhang and Sun [17] employed a hybrid method of DEMATEL and ANP to weigh the risks resulting from leaving the train at the railway station. They also used the Delphi method to identify risk response strategies and then ranked risk response strategies with the TOPSIS method. Badalpur *et al.* [18] utilized the WASPAS method for identifying and qualitatively assessing the risks of a road construction project in Iran. The project risks were identified in this project by brainstorming method using an expert team, and the effects of these risks on the success criteria of the project, including time, budget, and quality were determined using the opinions of three experts. The research three criteria of the project were then weighted using Shannon's Entropy method. Finally, the project risks were ranked by employing the WASPAS method and the critical risks of the project were determined to enable the project team to enter the risk response phase. Khalilzadeh *et al.* [19] provided a FMEA technique for risk analysis and assessment in the oil and gas planning phase. First, 19 major safety and operational safety risks in projects were categorized into six groups using the Delphi method. The factors were distinguished through the review of the project documents, checklist analysis, and expert consultation. Then, they determined the risks' weights using the Fuzzy SWARA method. The FMEA and PROMETHEE methods were then used to identify the priority of the main risk factors. They finally developed a binary multi-objective optimization model to select the risk response strategies and used the AEC method. Hiyassat *et al.* [20] identified 62 risks in a construction project in Jordan and categorized them into 14 groups by reviewing the relevant literature. Then, two factors of the probability of occurrence and the intensity of effect were determined to rank the risks. The risks were rated using expert judgement and questionnaire to find out the major risks for developing the risk response strategies. Also, Erol *et al.* [21] weighted the causes of the construction project risks with the Delphi and ANP methods. Table 1 presents a summary of the related studies.

Table 1
Brief review of relevant studies

Reference	Problem parameter		Methodology													
			MCDM									Others				
	Definitive	Fuzzy	BWM	AHP	ANP	TOPSIS	DEMATEL	PROMETHEE	MULTIMUTA	SWARA	WASPAS	Survey	FMEA	SPSS	ISM	SEM
Fernando *et al.* [11]				X												
Ahmadi *et al.* [10]	X			X								X	X			
Dehdasht *et al.* [12]		X			X		X					X				
Rahimi *et al.* [14]	X												X			
Fattahi and Khalilzadeh [13]		X		x					X							
Kassem *et al.* [15]	X											X				X
Mahmoudi *et al.* [16]	x		X				X									
Khalilzadeh *et al.* [19]		X						X		X			X			
Zhang and Sun [17]		X			X	X	X					X				
Badalpur *et al.* [18]		X									X	X				
Hiyassat *et al.* [20]		X										X				
Erol *et al.* [21]		X			X											
Present study		x	X				X				X	X			X	

Examining the literature review indicates that most studies in the field of risk management have used other approaches such as field studies (Survey), statistical analysis, and the FMEA method. On the other hand, some research works have employed the MCDM techniques for risk analysis and assessment, of which AHP and TOPSIS are the most frequent. Further to the authors' knowledge, no study found that applied the combination of Fuzzy BWM, WASPAS and mathematical programming model to the construction project risk management.

3. Methodology

The present research is an applied study in terms of the type of objective and a descriptive-survey in terms of data collection method. This is a survey study since some questionnaires were designed to identify and analyze the risk factors in the studied project.

A combination of tools and techniques for identifying project risks was employed to identify the project risks [22]:

1. Study of the project and the documents of the project and the organizational process assets,
2. Library studies,
3. Preparation of an initial checklist and risk breakdown structure,
4. Forming a panel of experts and preparing the final list of project risks through brainstorming and validation of the risks using the Fuzzy Delphi technique

The identified risks were leveled and dependencies between risks were determined using the ISM method and MICMAC analysis of the conceptual relationships. Then, the risks with high dependence and high driving power were chosen as potential risks for evaluation and assessment using the fuzzy WASPAS technique. Afterwards, five criteria including the intensity of cost effect, the intensity of time effect, the intensity of the qualitative effect, the probability of occurrence, and detectability were considered for prioritizing the risks [10]. In addition, the Fuzzy Best-Worst fuzzy Method (FBWM) was employed to rank the criteria used for risk assessment.

In the next step, the identified risks were prioritized using the Fuzzy WASPAS method, and thereby, critical risks were distinguished to assign response strategies. Finally, a bi-objective model was proposed to choose the optimal response strategies to each critical risk. The Augmented Epsilon-Constraint (AEC) method was also utilized to solve the proposed multi-objective optimization model.

3.1 Data gathering

The questionnaires were provided according to the identified criteria and factors and were sent to the professionals and experts of the studied organization, and the mentioned experts rated the performance based on the criteria. The library method was used in this research for designing the primary model, subsequently, a questionnaire was used to obtain the experts' opinions. Another questionnaire was also employed to collect data related to the research.

3.2 Questionnaire validation

Four researcher-made questionnaires were utilized in the current study. To design the fuzzy Delphi questionnaire, the items included the final list of the identified risks. According to Table 2, A group of 15 individuals consisting of experts of the organization was chosen to ensure the content validity of the selected items. Then, the validity of the content of each item was examined using the fuzzy Delphi questionnaire. Thus, the experts and professionals were requested to announce their viewpoints and opinions regarding the rejection and acceptance of all items. The questionnaires were then collected and analyzed according to the steps mentioned in sections 3-7. Ultimately, the final items for which the threshold value (β) was greater than 5.6 were selected for future analysis [23].

Three other questionnaires were designed to examine the validity of the questionnaire after determining the items, which were presented to the supervisors and experts of the organization, and the face and content validity of the questionnaires were confirmed. These questionnaires were as follows:

1. Interpretive structural equations (for examining conceptual relationships and leveling between risks)
2. Fuzzy BWM (for determining the weights of risk factors evaluation indicators)
3. Fuzzy WASPAS (to identify critical risks)
4. The reliability of the questionnaire

In general, the data collected in this research was examined through the Best-Worst questionnaire to assess the reliability of the results obtained by the characteristic of the BWM technique. If this characteristic takes a value less than 0.1 in all questionnaires, the results will be highly reliable.

3.3 Statistical population and sampling

The sampling method in this research was a non-probability and purposive judgmental sampling approach. Since only experts and project managers in the studied organization (Paydar Pey Sazeh Company) were familiar with the project risk concepts in the present research, thus, this sampling method had to be used. The reason for using this sample as a research sample was the relatively acceptable background and experience of these people in the relevant topics. Hence, a sample of 15 experts was selected to collect the required data. Of these, 4 people were with less than 15 years of work experience, 9 people had between 15 and 25 years of experience, and 2 people with greater than 25 years of experience. In terms of education, 7 people had a bachelor's degree, 6 people had a master's degree, and 2 people had a doctorate degree. In Table 2, the respondents are presented based on their responsibility and frequency in the organization or in the research project.

Table 2
Information of experts

Type of Responsibility	Responsibility	Frequency
Organizational	Strategic manager of the organization	1
	PMO Manager of the Organization	1
Projectized	Project Manager	1
	Project Executive Manager	1
	Project Engineering Manager	1
	Project Director of Workshop	1
	Design and Field Project Senior Engineers	6
	Project Planning and Controlling Manager	1
	Project Planning and Controlling Senior Engineers	2
	Overall	15

3.4 Fuzzy sets theory

Fuzzy sets theory can deal with ambiguity, subjectivity, and imprecision through quantifying the linguistic and verbal variables associated with individual or group decision-making. Different types of fuzzy numbers such as triangular, trapezoidal and pentagonal have been introduced with their membership functions [24]. The triangular fuzzy number (TFN) as the most frequently-used fuzzy number was chosen in this research due to its membership function structure and the simplicity of fuzzy mathematical operations [25].

For the TFNs $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the mathematical operations are presented in the following equations [26]:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (1)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (2)$$

$$\tilde{A}_1 \oslash \tilde{A}_2 = (l_1, m_1, u_1)/(l_2, m_2, u_2) = (l_1/l_2, m_1/m_2, u_1/u_2) \quad (3)$$

$$\lambda \tilde{A}_1 = (\lambda l_1, \lambda m_1, \lambda u_1), \lambda > 0 \quad (4)$$

If $\tilde{A}_i = (l_i, m_i, u_i)$ is a TFN, then, the best non-fuzzy performance of $\tilde{A}_i$ is calculated based on the graded mean integration representation (GMIR) method using the Eq. (5). This method is simple and practical and does not require the mental preference of any decision-maker. Therefore, this technique was used in this research [27,28]:

$$R(\tilde{A}_i) = \frac{1}{6}(l_i + 4m_i + u_i) \quad (5)$$

3.5 The fuzzy Delphi method

The fuzzy Delphi method was presented by Ishikawa *et al.* in 1993. In fact, the fuzzy Delphi method is a combination of conventional Delphi method and fuzzy sets theory [29]. Hofstede *et al.* [30] realized that using the fuzzy Delphi method for collective decision-making can lead to a common understanding of the opinions of experts.

The steps of the fuzzy Delphi method are as follows:

Step 1: Collecting the experts' opinions.

First, the members of the expert committee of the company were asked to identify the importance of each risk using the Five-point Likert scale shown in Table 3.

Table 3
TFNs corresponding with the verbal variables

Linguistic terms	Very low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
TFN	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(8, 9, 10)

Step 2: Calculating the fuzzy numbers

Based on Eq. (6), all opinions of the expert committee members (k) are aggregated:

$$W_j = (a_{jL}, b_{jM}, c_{jN}) = \left(\min_k a_{jL}^k, \left(\prod_{k=1}^{k} b_{jM}^k \right)^{\frac{1}{k}}, \max_k c_{jN}^k \right) \quad (6)$$

where,

W_j: Aggregated TFNs of risk j,

J: Set of risks,

k: Set of experts,

a_{jL}: The minimum value of experts' evaluations,

b_{jM}: The geometric mean of all experts' evaluations for risk jth,

c_{jN}: The maximum value of experts' evaluations

In this step, the maximum and minimum amounts of the experts' opinions were set as the two endpoints of TFNs and the geometric mean as the degree of membership of TFNs. Afterwards, the fuzzy number of each of the evaluated risks had to be defuzzificated using the simple center of gravity method according to Eq. (7) to obtain the final weight of each risk.

$$P_j = \frac{a_{jL} + b_{jM} + c_{jN}}{3} \quad (7)$$

Where P_j, the defuzzificated value, indicates the cumulative importance of each risk.

Step 3: Determining major risks

The threshold value (β) needed to be determined to determine the list of risks. The threshold value depends on the fuzzy verbal scale and experts' preference; i.e., the more the series of fuzzy linguistic scales, the smaller β would be and vice versa. In the proposed research, the 9-point fuzzy scale (Tables 2 and 3) was employed, and therefore, as stated in the research of Zhang [23], the threshold value for a fuzzy 9-point scale was considered equal to β = 5.6 [31].

Step 4: Selecting the final risks

The final step in the fuzzy Delphi validation process is to create a final list of factors according to the threshold value, which is as follows:

If $P_j \geq \beta$, then, the risk component is selected; otherwise, if $P_j \leq \beta$, then the risk component is eliminated.

3.6. Interpretive structural modeling (ISM)

Interpretive structural modeling (ISM) was introduced by Warfield in 1974 [32]. The ISM method specifies the relationship between variables. In fact, interpretive structural modeling is structuring elements and determining the conceptual relationship between dimensions. In other words, the complexity between the elements can be overcome [33]. In general, the ISM process includes the following steps [34]:

Step 1: Identifying the variables related to the problem

In this step, the risk factors confirmed through the fuzzy Delphi method are considered as variables.

Step 2: Forming the structural self-interaction matrix (SSIM)

At this stage, the risk factors are examined in pairs and the respondent determines the relationship of risks using the following symbols:

V: A one-way relationship from i to j

A: A one-way relationship from j to i

X: A two-way relationship from i to j and vice versa

O: The variables i and j have no relationship with each other.

Step 3: Creating the initial "Reachability Matrix (RM)"

In this step, the structural self-interaction matrix turns into a binary matrix and the initial reachability matrix is obtained. By changing the symbols "A" and "O" to zero and "X" and "V" to one, the structural self-interaction matrix is transformed into a binary matrix, which is called the initial reachability matrix. The 0-1 placement rule is as follows:

If the relationship between two risks (i, j) in the self-interaction matrix is V, in the RM matrix, the relationship between i, j is replaced with "1" and vice versa, the relationship between i, j is replaced with "0".

If the relationship between two risks (i, j) in the self-interaction matrix is A, in the RM matrix, the relationship between i, j is replaced with "0" and vice versa, the relationship between i, j is replaced with "1".

If the relationship between two risks (i, j) in the self-interaction matrix is X, in the RM matrix, the relationship between i, j is replaced with "1" and vice versa, the relationship between i, j is replaced with "1".

If the relationship between two risks (i, j) in the self-interaction matrix is O, in the RM matrix, the relationship between i, j is replaced with "0" and vice versa, the relationship between i, j is replaced with "0".

Step 4: Creating the final reachability matrix

After the initial reachability matrix was obtained, the final reachability matrix would be obtained by introducing transferability into the relationships between risks.

Step 5: Determining the level of dimensions

At this stage, by obtaining the final reachability matrix to determine the level of risks, two reachable and predecessor sets were defined followed by obtaining their intersection. Thus, the reachable set is a set in which the number of risks appears as one in the rows and the predecessor set is a set in which the number of risks appears as one in the columns. The next column of the table (intersection) will be completed by obtaining the intersection of these two sets. The first line where the intersection of two sets is equal to the reachable set would be specified as the first level of priority. After determining the level, the risk or risks whose level has been determined were deleted from the table, and this process would be repeated until the levels of all the remaining risks are determined, and after determining the final level, the final form of risks would be drawn using the determined levels.

Step 6: Analyzing the driving and dependence power (MICMAC chart)

In the MICMAC analysis, the risks are divided into four groups based on the driving and dependence power (which is extracted from the RM matrix). The first category includes independent risks that have weak driving and dependence power. These risks are almost not connected to the system and have few and weak connections with the system. The second category involves dependent risks, which have low driving power but strong dependence. The third category includes connected risks, also called linking risks, which have high driving power and at the same time a lot of dependence. These risks are non-stationary since any changes in them can affect the system, and ultimately, the system feedback has the potential to change these risks again. The fourth category involves key independent risks, which have strong driving power but weak dependence. These risks act as the foundation of the model and they should be emphasized at the beginning of operationalizing the system.

3.7 The Fuzzy Best-Worst Method (FBWM)

The Fuzzy Best-Worst Method (FBWM) is one of the powerful methods in solving the MCDM problems, which is utilized to obtain the weights of options and criteria [35]. BWM has been extensively applied to various problems in recent years [27,28,36]. This method dramatically reduces the number of pairwise comparisons by only performing reference comparisons. Thus, the experts merely need to determine the priority of the best criterion over other criteria and the priority of all criteria over the worst criterion. This method generally performs much more efficiently and faster than other existing methods in determining weights in MCDM problems through removing secondary comparisons. This method provides an initial insight into the most influential (best) criteria and the most affected (worst) criteria by creating cause and effect groups [37,38]. The verbal expressions and consistency index (CI) of FBWM are provided in Table 4.

Table 4
The verbal expressions and consistency index (CI) of FBWM

Linguistic terms	Equally important (EI)	Weakly important (WI)	Fairly Important (FI)	Very important (VI)	Absolutely important (AI)
TFN	(1, 1, 1)	(0.67, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
CI	3	3.80	5.29	6.69	8.04

The steps of this method for achieving the optimal fuzzy weights are as follows:

Step 1: Creating a set of decision criteria

In this step, the criteria were obtained by reviewing the literature and experts' opinions and considered as $\{c_1, c_2, \dots, c_n\}$. As stated in the introduction section, the risk factors assessment criteria are as follows:

1. The intensity of cost effect (c_1)
2. The intensity of time effect (c_2)
3. The intensity of qualitative effect (c_3)
4. Probability of occurrence (c_4)
5. Error detectability (c_5)

Step 2: Determining the best and worst criteria

Based on the set of decision criteria, decision-makers have to identify the best criteria (w_B) as well as the worst criteria (w_w).

Step 3: Performing fuzzy reference comparisons for the best criterion

The fuzzy preferences of the best criterion over all criteria were determined using the decision-makers' verbal expressions (displayed in Table 4). The obtained fuzzy preferences were then converted into TFNs. The best-to-others fuzzy vector was obtained as follows:

$$\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \dots, \tilde{a}_{Bn}) \quad (8)$$

where,

$\tilde{A}_B$: The best-to-others fuzzy vector

$\tilde{a}_{Bj}$: The fuzzy preferences of the best criterion compared to other criteria j and $j = 1,2,\dots,n$. so that $\tilde{a}_{BB} = (1,1,1)$.

Step 4: Performing fuzzy reference comparisons for the worst criterion

Similarly, the fuzzy preferences of all criteria were determined over the worst criteria. Then, the obtained fuzzy preferences were converted into TFNs. The fuzzy others-to-worst vector was obtained as follows:

$$\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \dots, \tilde{a}_{nW}) \tag{9}$$

where,

$\tilde{A}_W$: The others-to-worst fuzzy vector

$\tilde{a}_{jW}$: The fuzzy preferences of the best measure j over the worst w_B and $j = 1,2, \dots, n$ so that $\tilde{a}_{WW} = (1,1,1)$

Step 5: Determining optimal fuzzy weights $(\widetilde{w}_1^*, \widetilde{w}_2^*, \dots, \widetilde{w}_n^*)$

To obtain optimal fuzzy weights of criteria, the maximum absolute difference $\left\{\left|\frac{\widetilde{w}_B}{\widetilde{w}_j} - \tilde{a}_{Bj}\right|, \left|\frac{\widetilde{w}_j}{\widetilde{w}_W} - \tilde{a}_{jW}\right|\right\}$ is minimized for all js, formulated as the following constrained optimization problem.

$$\min \max_j \left\{\left|\frac{\widetilde{w}_B}{\widetilde{w}_j} - \tilde{a}_{Bj}\right|, \left|\frac{\widetilde{w}_j}{\widetilde{w}_W} - \tilde{a}_{jW}\right|\right\}$$

$$s.t. \begin{cases} \sum_{j=1}^{n} R(\widetilde{w}_j) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1,2, \dots, n \end{cases} \tag{10}$$

So that $\widetilde{w}_B = (l_B^w, m_B^w, u_B^w)$, $\widetilde{w}_j = (l_j^w, m_j^w, u_j^w)$, $\widetilde{w}_W = (l_W^w, m_W^w, u_W^w)$, $\tilde{a}_{Bj} = (l_{Bj}, m_{Bj}, u_{Bj})$, and $\tilde{a}_{jW} = (l_{jW}, m_{jW}, u_{jW})$. Assuming $\tilde{\xi} = (l^\xi, m^\xi, u^\xi)$ and considering $l^\xi \le m^\xi \le u^\xi$, if it is $\tilde{\xi}^* = (k^*, k^*, k^*)$ ،$k^* \le l^\xi$, then, model 10 can be converted to model 11:

$$\min \tilde{\xi}^*$$

$$s.t. \begin{cases} \left|\frac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj})\right| \le (k^*, k^*, k^*) \\ \left|\frac{(l_j^w, m_j^w, u_j^w)}{(l_W^w, m_W^w, u_W^w)} - (l_{jW}, m_{jW}, u_{jW})\right| \le (k^*, k^*, k^*) \\ \sum_{j=1}^{n} R(\widetilde{w}_j) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1,2, \dots, n \end{cases} \tag{11}$$

By solving model 11, optimal fuzzy weights $(\widetilde{w}_1^*, \widetilde{w}_2^*, \dots, \widetilde{w}_n^*)$ could be obtained. The maximum consistency index (CI) achieved according to the different verbal expressions of the decision-makers for the Fuzzy Best-Worst method is presented based on Table 4. According to the consistency indices, the consistency ratio was obtained using the consistency ratio $CR = {}^{\xi^*}/_{CI}$ Equation. Obviously, the closer the CR value to zero, the higher the consistency of the obtained results would be.

3.8 The fuzzy WASPAS method

The WASPAS (Weighted Aggregates Sum Product Assessment) method, which employs the advantages of the Weighted Sum Model (WSM) and Weighted Product Model [39]. WASPAS has been utilized in many studies in the area of MCDM due to its high accuracy, especially for the qualitative analysis of risks [18]. The fuzzy spectrum used in this method to assess risk factors and determine the critical risk factors of implementing the foundation and the concrete skeleton of the five-star Iran Mall Hotel is defined as described in Table 5. The general processes of this method are described briefly in the following:

Table 5
The verbal phrases for rating risks

LINGUISTIC TERMS	VERY LOW (VL)	LOW (L)	MEDIUM (M)	HIGH (H)	Very High (VH)
TFN	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(8, 9, 10)

Step 1: Gathering the opinions of the expert committee and forming the fuzzy decision matrix of the option (risk factors) and criteria (intensity of the cost effect, intensity of the time effect, intensity of the qualitative effect, the probability of occurrence, and errors detectability)

Step 2: Normalizing the decision matrix

In this step, the decision matrix was normalized using the following formulas. Eq. (12) and (13) were used to normalize positive criteria and negative criteria, respectively.

$$\tilde{\bar{x}}_{ij} = \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}}, \qquad j \in B \tag{12}$$

$$\tilde{\bar{x}}_{ij} = \frac{\min_j \tilde{x}_{ij}}{\tilde{x}_{ij}}, \qquad j \in C \tag{13}$$

Where, $\tilde{\bar{x}}_{ij}$ ‹$\forall i, j$ is the fuzzy degree (fuzzy performance value) of the potential option $A_i, i = 1,2 \ldots . m$ compared to the criterion $C_j, j = 1,2 \ldots , , n$.

Step 3: Calculating the normalized fuzzy weight matrix $\hat{\tilde{X}}_q$ through Eq. (14)

This matrix is obtained by multiplying the criterion weight by the normal matrix.

$$\hat{\tilde{X}}_q = \begin{bmatrix} \hat{\tilde{x}}_{11} & \hat{\tilde{x}}_{12} & \cdots & \hat{\tilde{x}}_{1n} \\ \hat{\tilde{x}}_{21} & \hat{\tilde{x}}_{22} & \cdots & \hat{\tilde{x}}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \hat{\tilde{x}}_{m1} & \hat{\tilde{x}}_{m2} & \cdots & \hat{\tilde{x}}_{mn} \end{bmatrix}; \hat{\tilde{x}}_{ij} = \tilde{\bar{x}}_{ij}\tilde{w}_j \qquad i = 1,2 \ldots . m;\ j = 1,2 \ldots , , n \tag{14}$$

Step 4: Calculating the fuzzy matrix $\hat{\tilde{X}}_p$ through Eq. (15)

This matrix is obtained from the elements of the normal fuzzy matrix to the power of the fuzzy weight.

$$\hat{\tilde{X}}_p = \begin{bmatrix} \bar{\bar{\tilde{x}}}_{11} & \bar{\bar{\tilde{x}}}_{12} & \cdots & \bar{\bar{\tilde{x}}}_{1n} \\ \bar{\bar{\tilde{x}}}_{21} & \tilde{x}_{22} & \cdots & \bar{\bar{\tilde{x}}}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \bar{\bar{\tilde{x}}}_{m1} & \bar{\bar{\tilde{x}}}_{m2} & \cdots & \bar{\bar{\tilde{x}}}_{mn} \end{bmatrix}; \bar{\bar{\tilde{x}}}_{ij} = \tilde{\bar{x}}_{ij}^{\tilde{w}_j} \qquad i = 1,2 \ldots . m;\ j = 1,2 \ldots , , n \tag{15}$$

Step 5: Calculating the optimal values for each option based on Eq. (16) and (17)

$$\tilde{Q}_i = \sum_{j=1}^{n} \tilde{\tilde{x}}_{ij}, \qquad i = 1,2 \dots . m \tag{16}$$

$$\tilde{P}_i = \prod_{j=1}^{n} \tilde{\bar{\bar{x}}}_{ij}, \qquad i = 1,2 \dots . m \tag{17}$$

Step 6: Defuzzifying the values of $\tilde{Q}_i$ and $\tilde{P}_i$ to definite values

At this stage, the defuzzificated values are obtained by using Eq. (5).

Step 7: Calculating the value of the integrated function of the utility of each option.

Eq. (18) is used to calculate the value of the utility integrated function for each option and also enhance the accuracy in ranking and the effectiveness of the decision-making process in the fuzzy WASPAS method.

$$K_i = \lambda Q_i + (1-\lambda) P_i, \qquad \lambda \in [0,1] \tag{18}$$

In general, the value of λ is considered equal to 0.5 [40].

3.9 The proposed bi-objective mathematical programming model

A bi-objective mathematical model is proposed to evaluate and select the project risk responses. The proposed model seeks to choose a set of measures in such a way to optimize the relevant objective functions besides meeting the system constraints based on the fact the existing risks are seen as threats to the project and the effect of the strategies would be positive. The objective functions are related to time and cost, and the model's goal was to reduce the project completion delay time as well as the project cost. The constraints in the model are related to time and cost according to the goals. The time constraint means that those strategies need to be chosen so that the time required for their implementation and the influence on time do not exceed the specified time limit. Also, the cost constraint suggests that those strategies need to be chosen so that their cost and impact on the cost do not exceed the specified budget and cost. Considering the objectives function and constraints, those strategies should be selected that can be applied to the constraints and can optimize the objective function. According to the case study, the following assumptions are considered in the proposed model:

The number of critical risks is known.

The number of response strategies to each risk is known.

Whole project cost, total project duration, and the total budget considered for the strategies are known.

The order of execution of the desired strategies is not important.

It is possible to choose several strategies for each risk.

The parameters of time and cost are uncertain.

Each risk in the model has a probability of occurrence, the value of which is a specific number between zero and one that is obtained through the characteristic of the fuzzy WASPAS method.

Sets

i	The set of risks	$i = \{1,2,\dots,m\}$
j	The set of strategies	$j = \{1,2,\dots,n\}$

Parameters

P_i: The probability of occurrence of the risk "i"

W_{ij}: The cost of executing strategy "j" against risk "i"

L_{ij}: The time spent to implement strategy "j" against risk "i"

E_{ij}: The effect of the strategy on the cost caused by the occurrence of risk "i", the amount of cost reduced after the implementation of the strategy "j" to overcome the occurrence of the risk "i"

S_{ij}: The effect of the strategy on the time delay caused by the occurrence of the risk "i", the number of days improved after implementing the strategy "j" to overcome the occurrence of the risk "i"

C_i: The cost caused by the occurrence of the risk "i"

T_i: The time delay caused by the occurrence of the risk "i"

D: The ultimate delay in the implementation of the project

Decision variables

x_{ij} is equal to 1 if strategy j is assigned to risk I; otherwise, it is equal to 0.

Bi-objective mathematical programming model

$$MinZ_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} P_i W_{ij} x_{ij} \tag{19}$$

$$MinZ_2 = \sum_{i=1}^{m}\sum_{j=1}^{n} P_i L_{ij} x_{ij} \tag{20}$$

$s.t$

$$\sum_{j=1}^{n} W_{ij} x_{ij} \le C_i \qquad \forall\, i \tag{21}$$

$$\sum_{j=1}^{n} L_{ij} x_{ij} \le T_i \qquad \forall\, i \tag{22}$$

$$\sum_{j=1}^{n} x_{ij} \ge 1 \qquad \forall\, i \tag{23}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} E_{ij} x_{ij} \ge \sum_{i=1}^{m}\sum_{j=1}^{n} W_{ij} x_{ij} \tag{24}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} S_{ij} x_{ij} \ge \sum_{i=1}^{m}\sum_{j=1}^{n} L_{ij} x_{ij} \tag{25}$$

$$\sum_{i=1}^{m} T_i - \sum_{i=1}^{m}\sum_{j=1}^{n} S_{ij} x_{ij} \le K \tag{26}$$

$$x_{ij} \in \{0,1\} \qquad \forall\, i,j \tag{27}$$

The objective function consists of two sections. The first section, Equation (19), attempts to minimize the costs of implementing the response strategies to the risks. The second section, Equation (20), seeks to minimize the durations of implementing the response strategies to the risks. Eq. (21) guarantees the choice of those strategies to prevent the cost of implementing strategies in each risk from exceeding the loss caused by the risk (i.e., the loss that each risk causes to the project) according to the cost constraint. Constraint (22) guarantees that those strategies will be chosen so that the time required to implement the strategies in each risk would not exceed the delay caused by each risk. Constraint (23) indicates that at least one strategy needs to be selected from all the strategies available concerning each risk. Constraint (24) indicates that those strategies should be chosen according to the cost constraint that the effect of existing strategies against each risk on the cost of the project would be greater than or equal to the cost of implementing those strategies. Constraint (25) suggests that those strategies should be selected due to the time constraint that the effect of existing strategies on the completion time of the project would be greater than or equal to the implementation time of those strategies. Constraint (26) suggests that those strategies should be chosen according to the time constraint that the difference of the total delay caused by the existing risks on the project completion time would be higher than the effect of the maximum delay of the project. Eventually, the constraint (27) also specifies the types of the model decision variables.

3.10 Augmented Epsilon Constraint (AEC) method for solving the proposed model

The steps of the AEC method are expressed as follows:

1. Choose one objective function as the primary objective.
2. Solve the problem each time regarding the selected objective function, and obtain the optimal values.
3. Split the interval between any two optimal values of the sub-objective functions into specified numbers and gain a table of values for $\varepsilon_2, \dots, \varepsilon_n$.
4. Solve the problem each time with the primary objective function with each of the values $\varepsilon_2, \dots, \varepsilon_n$.
5. Report the Pareto solutions found.

As described, the first and the second objective functions were respectively considered as the main objective function and sub-objective functions in the proposed AEC method. Then, "*n*" failures were considered for each target and a maximum of *2n* Pareto solutions in total were gained for each problem. Afterward, the best solution found for the objective functions was shown among the Pareto points of the AEC method.

4. Results

The implementation results of the proposed hybrid approach in this research are presented in this section.

4.1 Case study

The construction project of a five-star hotel in Tehran city, the capital city of Iran was considered as the real case study. There is one main contractor together with more than 20 subcontractors. This hotel comprises 18 floors and about 105,000 square meters of floor area, is located in the eastern part of Iran Mall Entertainment-Business Complex in the 22nd district of Tehran. It has 395 residential rooms and non-residential sections, including the amphitheater, a reception hall, sports complex, art gallery, etc. The total project duration was estimated to be six years and the project was launched in 2016.

This study was confined to a part of the project including the design, procurement, and execution of the concrete foundation and skeleton of the project due to the following two reasons with the discretion of the supervisors and experts of the project:

1. There are too many risks in this project due to the dimensions and size of the project, a large number of beneficiaries, the neighborhood of part of the project with other projects being implemented by the Iran Mall Group, etc.

2. In this project, according to the abovementioned factors, besides the height of the project, the specific type of architecture and spaces with specific uses such as the Spa on the 13th and 14th floors, the amphitheater on the 1st and 2nd floors, and the significance of the uniformity of the concretes' standards produced by different manufacturers, the expert committee of the project concluded that the sub-project of design, supply, and implementation of the concrete foundation and skeleton of the project is extremely important for the success of the project.

4.2 Identification and validation of risks

As aforementioned, a combination of risk identification methods was employed to identify the project risks, which includes the following steps:

At this stage, the risks of the studied project activities in the organization were first identified through reviewing and revising previous research, available and accessible records and documents in the organization, including the lessons learned from previous projects of the organization, available documents and evidence in the area of the contract, the project charter, the document of recording the risks identified at the beginning of the project, and evaluating the status of the project through the study of reports and correspondence, the relevant recorded minutes. Then, an initial checklist of the risks found in the project and similar projects was prepared.

In the next step, the risks were classified into the following categories according to the nature of the risks and inspired by the classification presented by Albarkoki [41] as well as the opinions of experts, including the organization's PMO manager, the project manager, the engineering manager, the executive director, and the project planning and control manager:

A. Materials, equipment, and machinery area
B. Executive operations area
C. Managerial area
D. Studies and design area
E. Safety and health area

1. This initial list was then provided to the expert committee of the organization and the goals of the research were explained to them. Afterward, an expert committee consisting of 15 organization and project experts was formed according to Table 2. With the participation of these people and using the brainstorming technique, the number of risks identified in the checklist was reduced to 24 risks and 6 risks were added to them by experts. Therefore, a list containing 30 final risks was prepared.
2. These risks were again provided to the expert committee for validating the identified risks. Using the fuzzy Delphi method, they finalized the initial list of the project risks. The results are given in Table 6.

Table 6
The identified risks and reviewed resources for the construction project of implementing the concrete foundation and skeleton of the five-star hotel

Row	Area	Related risks	Sources
1	Materials, equipment, and machinery	Unavailability of machinery and equipment (R1)	[42], [43], [44], [22]
2		The reduced efficiency of transportation machines (R2)	[42], [43], [22]
3		Failure to timely supply the required materials (R3)	[44], [22]
4		Failure of batching (R4)	Expert opinions
5		Weakness in the material and equipment storage system (R5)	[43]

Row	Area	Related risks	Sources
6		Failure of pumps (R6)	Expert opinions
7		Damages to the equipment due to environmental and workshop factors (R7)	[22]
8		Insufficient batching power (R8)	Expert opinions
9	Executive operations	Delay in the execution of core walls (R9)	Expert opinions
10		Collision of machinery with obstacles existing around the foundation (R10)	[44], [22]
11		Failure to meet the prerequisites of the tower structure in the foundation section (R11)	[44]
12		The difficulty of concreting (R12)	Expert opinions
13		Increasing thermal gradient (R13)	Expert opinions
14		Failure to timely communicate plans and design details (R14)	[42], [43], [22]
15		Slippery access road during rain (R15)	[44], [41]
16		Fracture of scaffolding fasteners during scaffolding operations (R16)	[22]
17	Managerial	Lack of financial ability of the contractor to provide consumables (R17)	[43], [45], [44], [22]
18		Insufficient documentation of documents and records (R18)	[22]
19		Poor coordination and communication between the executive agents of the contractor (R19)	[43], [45], [22]
20		Work interferences and bureaucracy (R20)	[45]
21		Weakness in choosing reinforcement and formwork contractors (R21)	[45], [22]
22		Delay in the delivery of land and resolution of conflicts (R22)	[42], [43], [44], [22]
23	Studies and design	Failure to pay attention to the requirements and needs of the structure in the design (R23)	[43], [45], [22]
24		Weakness in geotechnical and structural studies (R24)	[43], [45], [22]
25		Insufficient compressive strength of concrete (R25)	[22]
26		Delay in providing foundation reinforcement drawings (R26)	[43], [45]
27	Safety and health	Occurrence of accidents due to non-observance of safety precautions during executive operations (R27)	[46], [47], [22]
28		Increased carbon monoxide caused by the accumulation of machinery (R28)	[22]
29		Fire (R29)	[46], [43]
30		Occurrence of safety incidents (R30)	[46], [47]

Then, the conceptual relationships and the leveling among the approved risks were determined by the expert committee by applying the steps presented in the method of interpretive structural modeling. In general, after achieving all levels, the leveling of risks was reported according to Table 7:

Table 7
The process of leveling the risk factors considered in the studied problem

Level	Risk Factor
Level 1	R_9, R_{20}, R_{21}, R_{24}, R_{25}, R_{26}, R_{30}
Level 2	R_{11}, R_{12}, R_{23}, R_{28}, R_{29}
Level 3	R_7, R_{14}, R_{27}
Level 4	R_{21}
Level 5	R_8, R_{17}
Level 6	R_{10}, R_{15}
Level 7	R_{13}, R_{18}
Level 8	R_{19}
Level 9	R_2, R_{16}
Level 10	R_1, R_3, R_4, R_5, R_6

Also, the research model can be shown in Figure 1 in terms of the power of influence and dependence. Accordingly, only risks R1, R3, R4, R5, and R6 are of an independent type. These factors have low dependence and high direction (guidance). In other words, high effectiveness and low susceptibility are the characteristics of these factors. R11 and R20 risks are of dependent type; these factors have strong dependence and weak guidance. Basically, these factors are highly influenced by the system and have little influence on the system. The rest of the risks are of an interface type. These factors have high dependence and high driving power. In other words, the effectiveness and susceptibility of these criteria are very high, and every small change in these variables causes fundamental changes in the system. Therefore, the set of risks R2, R7, R8, R9, R10, R12, R13, R14, R15, R16, R17, R18, R19, R21, R22, R23, R24, R25, R26, R27, R28, R29, and R30 were chosen as potential risks for evaluation using the hybrid FBWM-FWASPAS technique.

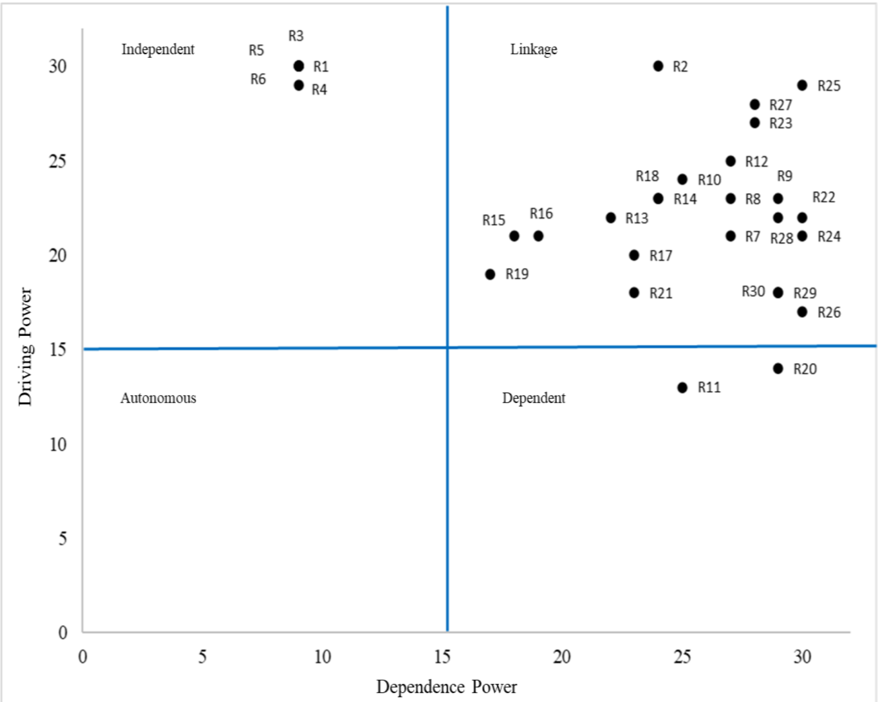

Fig. 1. The influence power-dependency diagram of the construction projects' risks

4.3 Determining critical risks

In this section, the weights of the evaluation indices of risk factors were determined according to step 1 of the FBWM method aimed at evaluating risk factors. These indices are as follows:

1. The intensity of cost effect (c_1)
2. The intensity of time effect (c_2)
3. The intensity of qualitative effect (c_3)
4. Probability of occurrence (c_4)
5. Error detectability (c_5)

The best and worst characteristics were identified among the above components through the collective agreement of experts. Accordingly, the criteria “intensity of time effect (c_2)” and error detectability (c_5) were chosen as the best and the worst criteria, respectively. Then, the priority of the best criterion over other criteria and also the priority of other criteria over the worst criterion were determined through collective and mutual agreement on the basis of the verbal scale provided in Table 5. Finally, the paired vector of the best criterion-other criteria as well as the paired vector of other criteria-the worst criterion was provided in Table 8.

Table 8

Results of the criteria pairwise comparison used for risk assessment

Pairwise comparison vector for the best criterion.	C_1	C_2	C_3	C_4	C_5
Best Criterion: C_2	WI	EI	WI	FI	VI
Pairwise comparison vector for the worst criterion.	Worst Criterion : C_5				
C_1	WI				
C_2	VI				
C_3	WI				
C_4	FI				
C_5	EI				

After obtaining the degree of priority for all the criteria, the non-linear programming model was formed as Eq. (28) to obtain the most favorable and optimal criteria’s weights:

$min\, k^*$

$$s.t.\begin{cases} \left|\frac{l_2^w}{u_1^w}-\frac{2}{3}\right| \le k, \left|\frac{m_2^w}{m_1^w}-1\right| \le k, \left|\frac{u_2^w}{l_1^w}-\frac{3}{2}\right| \le k \\ \left|\frac{l_2^w}{u_3^w}-\frac{2}{3}\right| \le k, \left|\frac{m_2^w}{m_3^w}-1\right| \le k, \left|\frac{u_2^w}{l_3^w}-\frac{3}{2}\right| \le k \\ \left|\frac{l_2^w}{u_4^w}-\frac{3}{2}\right| \le k, \left|\frac{m_2^w}{m_4^w}-2\right| \le k, \left|\frac{u_2^w}{l_4^w}-\frac{5}{2}\right| \le k \\ \left|\frac{l_2^w}{u_5^w}-\frac{5}{2}\right| \le k, \left|\frac{m_2^w}{m_5^w}-3\right| \le k, \left|\frac{u_2^w}{l_5^w}-\frac{7}{2}\right| \le k \\ \left|\frac{l_1^w}{u_5^w}-\frac{2}{3}\right| \le k, \left|\frac{m_1^w}{m_5^w}-1\right| \le k, \left|\frac{u_1^w}{l_5^w}-\frac{3}{2}\right| \le k \\ \left|\frac{l_3^w}{u_5^w}-\frac{2}{3}\right| \le k, \left|\frac{m_3^w}{m_5^w}-1\right| \le k, \left|\frac{u_3^w}{l_5^w}-\frac{3}{2}\right| \le k \\ \left|\frac{l_4^w}{u_5^w}-\frac{3}{2}\right| \le k, \left|\frac{m_4^w}{m_5^w}-2\right| \le k, \left|\frac{u_4^w}{l_5^w}-\frac{5}{2}\right| \le k \\ \frac{1}{6}\sum_{j=1}^{5}\left(l_j^w+4m_j^w+u_j^w\right)=1 \\ l_1^w \le m_1^w \le u_1^w, l_2^w \le m_2^w \le u_2^w, l_3^w \le m_3^w \le u_3^w, l_4^w \le m_4^w \le u_4^w, l_5^w \le m_5^w \le u_5^w \\ l_1^w \ge 0, l_2^w \ge 0, l_3^w \ge 0, l_4^w \ge 0, l_5^w \ge 0 \end{cases} \tag{28}$$

The GAMS software was exploited to solve this model. Finally, the fuzzy optimized weights for all criteria as well as the characteristic ξ^* were illustrated in Table 7. Eq. (5) was employed for defuzzification of the obtained optimal weights. According to Table 4, CI for the pairwise comparisons is 6.69 considering that $\tilde{a}_{BW} = (2.5, 3, 3.5)$. Thus, the consistency ratio is equal to 0.084, suggesting a very high consistency rate of the results, since the value is less than 0.1. Table 9 expresses the final weights of the criteria employed for risk assessment.

Table 9
The final weights of the criteria used for risk assessment

Risk Assessment Factors	Fuzzy optimal weights	De-Fuzzy optimal weights	Rank	Ξ*	CR
Cost Impact: C_1	(0.167, 0.195, 0.231)	0.196	2	0.562	0.084
Time Impact: C_2	(0.263, 0.304, 0.304)	0.297	1		
Quality Impact: C_3	(0.167, 0.195, 0.213)	0.193	4		
Probability: C_4	(0.157, 0.201, 0.201)	0.194	3		
Detection: C_5	(0.103, 0.125, 0.136)	0.123	5		

After determining the weights of the assessment components of the risk factors of construction projects using the verbal variables provided in Table 3, the 23 identified potential risks were ranked by performing the fuzzy WASPAS method step by step based on the indicators of the intensity of the cost effect (C_1), the intensity of the time effect (C_2), the intensity of the quality effect (C_3), probability of occurrence (C_4), and error detectability (C_5). In general, the values related to $\tilde{Q}_i$ and $\tilde{P}_i$ as well as the value of the integrated utility function (K_i) are given for each risk factor in the following table. It should be noted that the parameter λ is considered equal to 0.5. Accordingly, the risk factors were ranked according to the values of Q_i, P_i, and the characteristic K_i. Also, the risk with the highest value of K_i characteristic is given a higher priority than other risk factors. Table 10 shows the values of Q, P, and K for each risk.

Table 10
The values of Q, P, and K for each risk

Risks	$\tilde{Q}$	$Q^{De-fuzzy}$	$\tilde{P}$	$P^{De-fuzzy}$	K
R_2	(0.209,0.632,0.958)	0.616	(0.286,0.611,0.870)	0.600	0.608
R_7	(0.208,0.611,0.911)	0.593	(0.284,0.589,0.825)	0.577	0.585
R_8	(0.207,0.585,0.997)	0.591	(0.253,0.566,0.906)	0.571	0.581
R_9	(0.144,0.619,0.907)	0.588	(0.207,0.598,0.822)	0.570	0.579
R_{10}	(0.252,0.620,0.948)	0.614	(0.338,0.601,0.857)	0.600	0.607
R_{12}	(0.232,0.578,0.981)	0.588	(0.304,0.560,0.891)	0.572	0.580
R_{13}	(0.193,0.618,0.995)	0.610	(0.265,0.600,0.905)	0.595	0.603
R_{14}	(0.226,0.585,0.919)	0.581	(0.308,0.567,0.831)	0.568	0.574
R_{15}	(0.242,0.649,0.922)	0.627	(0.310,0.628,0.833)	0.609	0.618
R_{16}	(0.249,0.615,0.895)	0.601	(0.312,0.595,0.809)	0.584	0.592
R_{17}	(0.321,0.639,0.946)	0.637	(0.418,0.620,0.858)	0.626	0.631
R_{18}	(0.206,0.489,0.864)	0.504	(0.282,0.465,0.779)	0.487	0.496
R_{19}	(0.238,0.609,0.903)	0.597	(0.325,0.589,0.818)	0.583	0.590
R_{21}	(0.190,0.425,0.856)	0.457	(0.262,0.408,0.770)	0.444	0.451
R_{22}	(0.172,0.510,0.939)	0.525	(0.240,0.492,0.854)	0.510	0.517
R_{23}	(0.245,0.514,0.775)	0.512	(0.341,0.487,0.693)	0.497	0.505
R_{24}	(0.204,0.552,0.887)	0.550	(0.288,0.532,0.802)	0.536	0.543
R_{25}	(0.215,0.582,0.863)	0.568	(0.303,0.562,0.775)	0.554	0.561
R_{26}	(0.202,0.489,0.828)	0.498	(0.281,0.471,0.744)	0.485	0.491
R_{27}	(0.190,0.578,0.911)	0.569	(0.264,0.557,0.826)	0.553	0.561
R_{28}	(0.215,0.482,0.894)	0.506	(0.302,0.458,0.809)	0.491	0.498
R_{29}	(0.195,0.477,0.857)	0.493	(0.279,0.458,0.771)	0.480	0.487
R_{30}	(0.168,0.511,0.722)	0.489	(0.244,0.493,0.640)	0.476	0.483

It was decided relying on the opinions of the expert committee to determine the critical risks that the factors with K_i characteristic value higher than or equal to 0.570 would be finalized as critical risks for planning to assign multiple strategies. Accordingly, the risks R2, R7, R8, R9, R10, R12, R13, R14, R15, R16, R17, and R19 as well as the characteristic K_i were considered as the probability coefficients of each risk as the input of the bi-objective mathematical model.

4.4 The response strategies to major risks

When one of the mentioned risks occurs, depending on whether the risk is borne by the contractor or the employer, that person needs to take the necessary measures to deal with and control the risk. It should be noted that the response to the risk should be designed when the cause and effect of each risk have been considered and analyzed well [48, 49]. At this stage, it is decided what strategy has to be adopted to encounter the risk. Choosing a risk response strategy is made due to the nature of the risk and the timing of the risk response and also considering that the risk occurs in which time interval [50, 51]. Thus, the risks within the project were chosen as the examined risks of this research due to the conditions and importance of the risk occurrence and their effects as well as the opinions of experts and scholars in the industry. Hence, the response strategies to the examined risks in the project were gathered using interviews with various specialists and experts in the project of implementing the concrete foundation and skeleton of the five-star Iran Mall Hotel and asking for their opinions. Among their answers, the final list was set and confirmed. Table 11 presents the solutions related to the response strategies to the critical risks. This table is the result of gathering the experiences of people involved in these projects, and yet, another strategy may be considered and chosen over these strategies in the conditions of other projects at the discretion of project managers and stakeholders.

Table 11
The list of major risks and corresponding response strategies for implementing the concrete foundation and skeleton of the five-star hotel construction project

Row	Risk	Strategies (source: interviews with experts)
1	The reduced efficiency of concrete transportation machines (R_2)	1. Hiring traffic skilled experts 2. The use of signboards 3. Developing a traffic management system for machinery and previous training of drivers
2	Damages to the equipment due to environmental and workshop factors (R_7)	1. Employing a powerful workshop supervisor or hiring an HSE officer by the contractor 2. Strictness in the use of equipment by the supervisor or (employer) 3. Replacement and availability of replacement equipment
3	Insufficient batching power (R_8)	1. Accurate study of batching power 2. Signing a contract with 4 batching for distribution of construction pressure 3. Provision and establishment of portable batching in Iran Khodro land
4	Delay in the execution of core walls (R_9)	1. Ordering the templates for pillars and core walls 2. Identifying and choosing the contractor for core walls and pillars 3. Signing a contract for the execution of core walls and pillars
5	The collision of machinery with existing obstacles around the foundation (R_{10})	1. Preparing a topographic map of the access ramp and the peripheral area of the western development 2. Identifying the peripheral effects of the foundation 3. Determining the location of deploying the machinery and equipment and access routes
6	The difficulty of concreting (R_{12})	1. The detailed examination of the type, number, and power of the required machinery 2. The use of 9 ground pumps at the same time 3. Designing the location of deploying the pumps
7	The increased thermal gradient (R_{13})	1. Using two specialized groups to examine the issue and design the pre-cooling system 2. Implementation of water and ice pre-cooling and post-cooling system by cool water pipes 3. Implementation of a post-heating system of the concrete surface through isolation
8	Failure to timely communicate and provide plans and design details (R_{14})	1. Preparation of plans and the completeness of plans before starting work (the employer management and ability) 2. Hiring a competent consultant 3. Using electronic facilities to transfer information
9	Slippery access road during rain (R_{15})	1. Replacing the access ramp 2. Correcting the slope of the ramp and directing surface waters to the side of the road 3. Construction of an absorption well at the foot of the ramp
10	The fracture of the scaffolding fasteners during scaffolding operations (R_{16})	1. Compliance with scaffolding safety instructions according to Article 12 of the National Building Regulations 2. Usage of healthy and fine scaffolding 3. materials with no technical defect

Row	Risk	Strategies (source: interviews with experts)
		4. Inspection of scaffolds and connections used before the scaffolding
11	The lack of financial ability of the contractor to provide consumables (R_{17})	1. Evaluation of the contractor in terms of financial ability 2. Financing of the contractor by the employer 3. Getting loans
12	Poor coordination and communication between the executive agents of the contractor (R_{19})	1. Establishing the project control system with the contractor's management 2. Conducting scheduled and regular meetings between executive agents 3. The use of experienced managers

4.5 Allocating response strategies to major risks

Once the responding strategies to the risks were identified, each strategy was assessed to choose the most appropriate ones for each risk. Therefore, a set of responding strategies to each critical risk was determined through solving the proposed mathematical programming model. The input parameters of the investigated problem can be seen in Tables 12-16. It should be noted that the results were analyzed for the case study with a specific cost and due date specified in the project contract. In addition, due to the unavailability of all input data, some data were randomly generated using a uniform distribution function. The problem was solved using the GAMS optimization software version 24.1.2. Subsequently, the results of allocating the strategies to the project risks are presented.

Table 12
The cost of implementing the response strategy i^{th} for the risk j^{th}

Risk	Strategy			Risk	Strategy		
	1	2	3		1	2	3
R_2	119	124	95	R_{13}	141	102	121
R_7	85	122	97	R_{14}	119	147	81
R_8	136	118	135	R_{15}	124	111	109
R_9	111	81	103	R_{16}	134	100	134
R_{10}	87	99	111	R_{17}	126	114	122
R_{12}	122	136	141	R_{19}	105	87	95

Table 13
The duration of implementing the response strategy i^{th} for the risk j^{th}

Risk	Strategy			Risk	Strategy		
	1	2	3		1	2	3
R_2	12	6	14	R_{13}	5	10	10
R_7	15	10	13	R_{14}	6	7	12
R_8	7	17	5	R_{15}	8	18	18
R_9	14	17	10	R_{16}	7	13	9
R_{10}	6	15	5	R_{17}	10	17	12
R_{12}	8	17	10	R_{19}	6	18	9

Table 14
The effect of implementing the response strategy on the risk cost

Risk	Strategy			Risk	Strategy		
	1	2	3		1	2	3
R_2	123	156	181	R_{13}	130	145	169
R_7	119	152	121	R_{14}	192	127	153
R_8	163	116	135	R_{15}	113	101	200
R_9	114	116	144	R_{16}	126	153	114
R_{10}	128	113	117	R_{17}	176	182	135
R_{12}	130	200	111	R_{19}	123	197	140

Table 15
The effect of implementing the response strategy on the risk duration

Risk	Strategy			Risk	Strategy		
	1	2	3		1	2	3
R_2	17	20	26	R_{13}	17	29	25
R_7	22	20	21	R_{14}	11	30	17
R_8	28	30	27	R_{15}	20	20	14
R_9	28	27	25	R_{16}	20	25	25
R_{10}	27	14	18	R_{17}	23	15	21
R_{12}	15	11	26	R_{19}	29	30	27

Table 16
Other problem data

Risk	Probability of occurrence of risk *i* (P_i)	The incurred cost caused by the occurrence of the risk *i* (C_i)	The delay caused by the occurrence of risk *i* (T_i)
R_2	0.986	1,250	24
R_7	0.975	1,530	36
R_8	0.971	1,835	52
R_9	0.968	1,472	60
R_{10}	0.986	1,852	25
R_{12}	0.972	1,723	62
R_{13}	0.981	1,687	35
R_{14}	0.971	1,385	36
R_{15}	0.992	1,568	45
R_{16}	0.980	1,753	52
R_{17}	1.000	1,568	56
R_{19}	0.978	1,657	41

According to the experts' opinions, the maximum delay in the implementation of the construction project (D) is considered equal to 100 days.

In this section, the AEC method was used by considering one of the objective functions as the main objective function and other objective functions as the problem constraints. The GAMS optimization software version 24.1.2 and CPLEX solver were used on a notebook with Intel Core i7 processor, 32 GB of RAM and Microsoft Windows 10 Ultimate operating system to solve the model. The model was run 1000 times of the AEC method and the results are provided in Table 16. It should be noted that 43 Pareto points were obtained, and the values related to the objective functions (cost and time) for each Pareto point are presented in Table 17. Also, Figure 2 depicts the Pareto front obtained by solving the proposed model by the AEC method.

Table 17
Obtained Pareto points

Point	1	2	3	4	5
Z_1	1,657.11	1,670.01	1,694.62	1,718.87	1,747.30
Z_2	189.74	179.82	173.06	165.28	161.46
Point	6	7	8	9	10
Z_1	1,752.19	1,780.62	1,824.43	1,847.46	1,850.21
Z_2	161.36	157.54	156.54	156.47	155.51
Point	11	12	13	14	15
Z_1	1,854.43	1,858.65	1,867.05	1,869.45	1,878.78
Z_2	153.74	153.52	152.75	152.7	152.66
Point	16	17	18	19	20
Z_1	1,879.25	1,882.78	1,887.69	1,887.75	1,891.07
Z_2	152.61	150.66	150.62	149.82	148.77
Point	21	22	23	24	25
Z_1	1,894.48	1,898.04	1,907.10	1,909.74	1,918.86
Z_2	148.71	148.01	147.72	146.06	145.78
Point	26	27	28	29	30
Z_1	1,922.36	1,924.44	1,927.80	1,931.36	1,931.81
Z_2	145.07	144.8	144.79	144.09	143.92
Point	31	32	33	34	35
Z_1	1,934.12	1,935.69	1,943.06	1,945.14	1,947.39
Z_2	143.13	143.02	142.14	141.87	141.07
Point	36	37	38	39	40
Z_1	1,957.76	1,967.44	1,971.77	2,104.18	2,116.38
Z_2	140.88	139.21	138.15	138.06	137.92
Point	41	42	43		
Z_1	2,124.94	2,143.29	2,143.29		
Z_2	135.23	135.14	135.14		

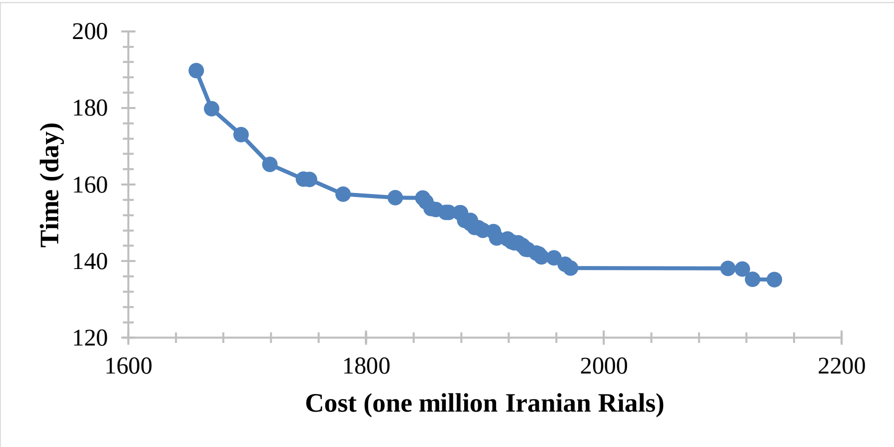

Fig. 2. The Pareto frontier created based on cost and time objectives

Then, the results were submitted to the company's expert committee (including the project manager, two project consultants, and two project planning and control experts) and they were asked to select the most appropriate solution. Since the cost and time factors of the project highly matter to the management, the expert committee had consensus on choosing the Pareto point number 20 for analysis due to the cost constraints and the project scheduling. At this point, $Z_1 = 1{,}891.07$ and $Z_2 = 148.77$. Subsequently, in order to allocate the response strategies to each of the critical risks, the Pareto point number 20 of the Pareto front (selected by the experts) was considered, shown in Table 18**.**

Table 18
Assignment of response strategies to the identified critical project risks

Risk	Strategy			Risk	Strategy		
	1	2	3		1	2	3
R_2		•	•	R_{13}		•	
R_7	•			R_{14}		•	
R_8	•		•	R_{15}	•		
R_9		•	•	R_{16}	•		
R_{10}	•		•	R_{17}	•		
R_{12}			•	R_{19}	•		•

5. Discussions

Project risk management is not confined to simply identify risks and measure the probability of their occurrence and potential impacts. It is needed to develop different alternative response strategies and finally choose the best ones according to the organization's capability and existing resources. Hence, appropriate risk response plans can help the organization minimize losses and negative consequences during the project lifecycle [52].

5.1 Managerial Discussions

In this study, the steps of the risk management were practically followed and implemented based on the Project Management Body of Knowledge (PMBOK). To this end, the main risks of the design, procurement (supply) of goods, and implementation of the concrete foundation and skeleton of the construction project of a five-star hotel in Tehran, the capital city of Iran, were identified and assessed providing a comprehensive methodology, which can be applied to other projects in other industries by making little changes in the risk breakdown structure. In addition, the bi-objective optimization model was proposed to assist the decision-makers and managers with choosing the best possible risk response strategies. Therefore, the findings of this research can help project managers to take appropriate decisions to respond to similar project risks aimed at reducing and minimizing the negative effects or preventing the occurrence of these risks during project execution.

5.2 Practical implications

The implementation of the concrete foundation and skeleton of the five-star hotel in Tehran, Iran was considered as a real case study to validate the proposed approach. The risks related to the construction projects were initially extracted through studying the historical documents and data. These risks were then examined and analyzed by the company's experts and confirmed by the Fuzzy Delphi method. Then, the relationships between risk factors were determined using the ISM method. Subsequently, the importance weights of five criteria (including the intensity of the cost effect, the intensity of the time effect, the intensity of the quality effect, the probability of occurrence, and detectability) used for prioritizing risks were obtained by utilizing the FBWM method. Based on the findings of the FBWM method, the intensity of the time effect component (0.297), the intensity of the cost effect (0.196), the probability of occurrence (0.194), the intensity of the quality effect (0.193), and detectability (0.123) were ranked first to fifth, respectively. In the next step, the project risks were prioritized and ranked using the Fuzzy WASPAS method, and thereby, critical risks were detected to assign the response strategies. According to the results, the risk of "the lack of financial ability of the contractor to provide consumables" ranked first with an importance coefficient of

0.631. The risks of "access road slippage during rain" with an importance coefficient of 0.618 and "the decreased efficiency of concrete transportation machines" with an importance coefficient of 0.608 were ranked second and third. Finally, a bi-objective mathematical programming model was presented to allocate multiple response strategies to each of the risks. The AEC method was also utilized to solve the proposed bi-objective optimization model and find the optimal risk response strategies assigned to the critical risks explained as follows:

The reduced efficiency of concrete transport machines (R2): The use of signboards and developing a traffic management system for machinery and prior training of drivers are recommended to the managers of the studied company aimed at reducing the harmful effects of this risk.

Damages to the equipment due to environmental and workshop factors (R7): Employing a powerful workshop supervisor or hiring an HSE officer by the contractor is recommended to the managers of the studied company aimed at reducing the harmful effects of this risk.

The inadequacy of batching power (R8): An accurate study of batching capacity and the provision and installation of portable batching in the land of automotive company are recommended to the managers of the studied company aimed at reducing the harmful effects of this risk.

Delay in the implementation of core walls (R9): It is recommended to the managers of the studied company to identify the contractor of core walls and pillars and sign a contract for the execution of core walls and pillars to mitigate the harmful consequences of this risk.

The collision of machinery with existing obstacles around the foundation (R10): It is recommended to the managers of the studied company to prepare a topographical map of the access ramp and the peripheral area of western development and determine the location of deploying the machinery and access routes to mitigate the detrimental consequences of this risk.

The difficulty associated with concreting (R12): It is suggested to the managers of the studied company to design the location of deploying the pumps aimed at reducing the harmful effects of this risk.

The increased thermal gradient (R13): It is recommended to the managers of the studied company to implement the water and ice pre-cooling system and post-cooling system by cool water pipes aimed at reducing the harmful effects of this risk.

Slippery access road during rain (R15): It is recommended to the managers of the studied company to implement the water and ice pre-cooling system and post-cooling system by cool water pipes aimed at reducing the harmful effects of this risk.

Failure to timely communicate plans and design details (R14): It is recommended to the managers of the studied company to prepare the plans and completeness of the maps before starting the work (management and ability of the employer) aimed at reducing the harmful effects of this risk.

Slippery access road during rain (R15): It is recommended to the managers of the studied company to replace the access ramp in order to mitigate the negative impacts of this risk.

The fracture of scaffolding fasteners during scaffolding operations (R16): It is recommended to the managers of the studied company to follow the scaffolding safety instructions according to Article 12 of the National Building Regulations aimed at reducing the harmful effects of this risk.

The lack of financial ability of the contractor to provide consumables (R17): It is recommended to the managers of the studied company to evaluate the contractor in terms of financial ability aimed at reducing the harmful effects of this risk.

Poor coordination and communication between the executive agents of the contractor (R19): It is recommended to the managers of the studied company to establish a project control system with contractor management and use experienced managers to reduce and mitigate the negative and harmful impacts of this risk.

6. Conclusion

The accomplishment of projects within the specified time and cost is recognized as the most important success factor of the project in today's competitive world. Therefore, the importance of an appropriate and comprehensive risk management becomes more obvious for project success. However, the literature review showed that there have been few studies on this topic particularly the selection of risk response strategies. As a result, this paper proposed an innovative and reliable hybrid approach based on MCDM and mathematical optimization methods for the construction project.

In this study, several major project risks were identified using literature review, document analysis, brainstorming, and the fuzzy Delphi methods. It should be noted that there were numerous risks in the construction project, however, it was particularly important to identify the critical risks by a reliable and comprehensive methodology. To this end, the qualitative analysis of risks was made using the ISM method. Then, the risks were prioritized using a combination of FBWM and FWASPAS methods in order to distinguish the critical project risks. It was found that the most critical risk of the project is the lack of financial capability of the contractor to provide consumables. Afterwards, the expert committee nominated three different risk response strategies for each critical risk. In order to select the optimal risk response strategies for each critical risk, a bi-objective mathematical programming model was proposed and solved by the AEC method. According to the most critical risk of the project, the most important measure to reduce the harmful effects of this risk, which is the increased project time, would be the evaluation of the contractors before the selection in terms of financial capability by the managers of the organization. Difficulties in access to the experts and historical data can be stated as the main research limitations.

As some suggestions for future studies, other MCDM methods can be used for weighting criteria and ranking project risks. Also, other probabilistic approaches or combined approaches of fuzzy sets theory and artificial intelligence may be exploited in further research followed by comparing the obtained results. In addition, the robust optimization models can be employed to deal with uncertainty. Moreover, metaheuristic algorithms should be applied to solve the large size problems.

Author Contributions

Conceptualization, M.KH., and D.B.; methodology, M.KH., S.A.B., and D.B.; software, M.KH.; validation, M.KH. and S.A.B.; formal analysis, M.KH. and D.B.; investigation, M.KH., and D.B.; resources, S.A.B., and D.B.; data curation, M.KH.; writing original draft preparation, M.KH.; writing—review and editing, M.KH., S.A.B., and D.B.; visualization, M.KH.; supervision, M.KH, and D.B.; project administration, M.KH. and S.A.B. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Data availability statement

The datasets generated during and/or analysed during the current study are not publicly available due to the privacy-preserving nature of the data. However, they can be obtained from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

This article does not involve any studies with human participants or animals performed by any of the authors.

Acknowledgement

This research was not funded by any grant.

References

[1] Burr, A., Barber, F., Briggs, S., Breyer, W., Castellano, J., Gibbs, D. J., ... & Pickavance, K. (2016). Delay and disruption in construction contracts. Informa Law from Routledge. https://doi.org/10.4324/9781315673950

[2] Arditi, D., Nayak, S., & Damci, A. (2017). Effect of organizational culture on delay in construction. *International journal of project management*, *35*(2), 136-147. https://doi.org/10.1016/j.ijproman.2016.10.018

[3] Muriana, C., & Vizzini, G. (2017). Project risk management: A deterministic quantitative technique for assessment and mitigation. *International Journal of Project Management*, *35*(3), 320-340. https://doi.org/10.1016/j.ijproman.2017.01.010

[4] Zhang, Y., & Fan, Z. P. (2014). An optimization method for selecting project risk response strategies. *International journal of project management, 32*(3), 412-422. https://doi.org/10.1016/j.ijproman.2013.06.006

[5] Wu, D., Li, J., Xia, T., Bao, C., Zhao, Y., & Dai, Q. (2018). A multiobjective optimization method considering process risk correlation for project risk response planning. *Information Sciences, 467*, 282-295. https://doi.org/10.1016/j.ins.2018.07.013

[6] Zou, P. X., Zhang, G., & Wang, J. (2007). Understanding the key risks in construction projects in China. *International journal of project management, 25*(6), 601-614. https://doi.org/10.1016/j.ijproman.2007.03.001

[7] Dziadosz, A., & Rejment, M. (2015). Risk analysis in construction project-chosen methods. Procedia Engineering, 122, 258-265. https://doi.org/10.1016/j.proeng.2015.10.034

[8] Murray-Webster, R., & Hillson, D. (2021). Making risky and important decisions: A leader's guide. CRC Press. https://doi.org/10.1201/9781003145134

[9] Carvalho, M. M. D., & Rabechini Junior, R. (2015). Impact of risk management on project performance: the importance of soft skills. *International journal of production research, 53*(2), 321-340. https://doi.org/10.1080/00207543.2014.919423

[10] Ahmadi, M., Behzadian, K., Ardeshir, A., & Kapelan, Z. (2017). Comprehensive risk management using fuzzy FMEA and MCDA techniques in highway construction projects. *Journal of Civil Engineering and Management, 23*(2), 300-310. https://doi.org/10.3846/13923730.2015.1068847

[11] Fernando, C. K., Hosseini, M. R., Zavadskas, E. K., Perera, B. A. K. S., & Rameezdeen, R. (2017). Managing the financial risks affecting construction contractors: implementing hedging in Sri Lanka. *International Journal of Strategic Property Management, 21*(2), 212-224. https://doi.org/10.3846/1648715X.2017.1301592

[12] Dehdasht, G., Mohamad Zin, R., Ferwati, M. S., Mohammed Abdullahi, M. A., Keyvanfar, A., & McCaffer, R. (2017). DEMATEL-ANP risk assessment in oil and gas construction projects. *Sustainability, 9*(8), 1420. https://doi.org/10.3390/su9081420

[13] Fattahi, R., & Khalilzadeh, M. (2018). Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. *Safety science, 102*, 290-300. https://doi.org/10.1016/j.ssci.2017.10.018

[14] Rahimi, Y., Tavakkoli-Moghaddam, R., Iranmanesh, S. H., & Vaez-Alaei, M. (2018). Hybrid approach to construction project risk management with simultaneous FMEA/ISO 31000/evolutionary algorithms: Empirical optimization study. *Journal of construction engineering and management*, *144*(6), 04018043. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001486

[15] Kassem, M. A., Khoiry, M. A., & Hamzah, N. (2019). Risk factors in oil and gas construction projects in developing countries: A case study. *International Journal of Energy Sector Management*, *13*(4), 846-861. https://doi.org/10.1108/IJESM-11-2018-0002

[16] Mahmoudi, A., Abbasi, M., Deng, X., Ikram, M., & Yeganeh, S. (2020). A novel model for risk management of outsourced construction projects using decision-making methods: a case study. *Grey Systems: Theory and Application*, *10*(2), 97-123. https://doi.org/10.1108/GS-09-2019-0038
[17] Zhang, H., & Sun, Q. (2019). An integrated MCDM approach to train derailment risk response strategy selection. *Symmetry*, *12*(1), 47. https://doi.org/10.3390/sym12010047
[18] Badalpur, M., & Nurbakhsh, E. (2021). An application of WASPAS method in risk qualitative analysis: a case study of a road construction project in Iran. *International Journal of Construction Management*, *21*(9), 910-918. https://doi.org/10.1080/15623599.2019.1595354
[19] Khalilzadeh, M., Ghasemi, P., Afrasiabi, A., & Shakeri, H. (2021). Hybrid fuzzy MCDM and FMEA integrating with linear programming approach for the health and safety executive risks: a case study. *Journal of modelling in management*, *16*(4), 1025-1053. https://doi.org/10.1108/JM2-12-2019-0285
[20] Hiyassat, M. A., Alkasagi, F., El-Mashaleh, M., & Sweis, G. J. (2022). Risk allocation in public construction projects: the case of Jordan. *International journal of construction management*, *22*(8), 1478-1488. https://doi.org/10.1080/15623599.2020.1728605
[21] Erol, H., Dikmen, I., Atasoy, G., & Birgonul, M. T. (2022). An analytic network process model for risk quantification of mega construction projects. *Expert Systems with Applications*, *191*, 116215. https://doi.org/10.1016/j.eswa.2021.116215
[22] Siraj, N. B., & Fayek, A. R. (2019). Risk identification and common risks in construction: Literature review and content analysis. *Journal of construction engineering and management*, *145*(9), 03119004. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001685
[23] Zhang, J. (2017). Evaluating regional low-carbon tourism strategies using the fuzzy Delphi-analytic network process approach. *Journal of Cleaner Production*, *141*, 409-419. https://doi.org/10.1016/j.jclepro.2016.09.122
[24] Pathinathan, T., & Ponnivalavan, K. (2015). Reverse order triangular, trapezoidal and pentagonal fuzzy numbers. *Annals of Pure and Applied Mathematics*, *9*(1), 107-117. http://www.researchmathsci.org/apamart/APAM-v9n1-12.pdf
[25] Can, G. F., & Toktas, P. (2018). A novel fuzzy risk matrix based risk assessment approach. *Kybernetes*, *47*(9), 1721-1751. https://doi.org/10.1108/K-12-2017-0497
[26] Wu, H. Y., Tzeng, G. H., & Chen, Y. H. (2009). A fuzzy MCDM approach for evaluating banking performance based on Balanced Scorecard. *Expert systems with applications*, *36*(6), 10135-10147. https://doi.org/10.1016/j.eswa.2009.01.005
[27] Afrasiabi, A., Chalmardi, M. K., & Balezentis, T. (2022). A novel hybrid evaluation framework for public organizations based on employees' performance factors. *Evaluation and Program Planning*, *91*, 102020. https://doi.org/10.1016/j.evalprogplan.2021.102020
[28] Afrasiabi, A., Tavana, M., & Di Caprio, D. (2022). An extended hybrid fuzzy multi-criteria decision model for sustainable and resilient supplier selection. *Environmental Science and Pollution Research*, *29*(25), 37291-37314. https://doi.org/10.1007/s11356-021-17851-2
[29] Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., & Mieno, H. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy sets and systems*, *55*(3), 241-253. https://doi.org/10.1016/0165-0114(93)90251-C
[30] Vermunt, A. H., Smits, M. T., Noorderhaven, N. G., & Hofstede, G. J. (1997). Wired international teams: Experiments in strategic decision making by multi-cultural virtual teams. In *Proceedings of the 5th European Conference on Information Systems (ECIS)* (pp. 321-336). Loebbecke. https://pure.uvt.nl/ws/portalfiles/portal/204522/annelies74098.pdf
[31] Padilla-Rivera, A., do Carmo, B. B. T., Arcese, G., & Merveille, N. (2021). Social circular economy indicators: Selection through fuzzy delphi method. *Sustainable Production and Consumption*, *26*, 101-110. https://doi.org/10.1016/j.spc.2020.09.015
[32] Warfield, J. N. (1974). Developing interconnection matrices in structural modeling. *IEEE Transactions on Systems, Man, and Cybernetics*, (1), 81-87. https://doi.org/10.1109/TSMC.1974.5408524
[33] Agarwal, A., Shankar, R., & Tiwari, M. K. (2007). Modeling agility of supply chain. *Industrial marketing management*, *36*(4), 443-457. https://doi.org/10.1016/j.indmarman.2005.12.004
[34] Zayed, E. O., & Yaseen, E. A. (2021). Barriers to sustainable supply chain management implementation in Egyptian industries: an interpretive structural modeling (ISM) approach. *Management of environmental quality: an international journal*, *32*(6), 1192-1209. https://doi.org/10.1108/MEQ-12-2019-0271
[35] Guo, S., & Zhao, H. (2017). Fuzzy best-worst multi-criteria decision-making method and its applications. *Knowledge-Based Systems*, *121*, 23-31. https://doi.org/10.1016/j.knosys.2017.01.010
[36] Kannan, D., Moazzeni, S., mostafayi Darmian, S., & Afrasiabi, A. (2021). A hybrid approach based on MCDM methods

and Monte Carlo simulation for sustainable evaluation of potential solar sites in east of Iran. *Journal of Cleaner Production*, *279*, 122368. https://doi.org/10.1016/j.jclepro.2020.122368

[37] Rezaei, J. (2015). Best-worst multi-criteria decision-making method. *Omega*, *53*, 49-57. https://doi.org/10.1016/j.omega.2014.11.009

[38] Rezaei, J. (2016). Best-worst multi-criteria decision-making method: Some properties and a linear model. *Omega*, *64*, 126-130. https://doi.org/10.1016/j.omega.2015.12.001

[39] Zavadskas, E. K., Turskis, Z., Antucheviciene, J., & Zakarevicius, A. (2012). Optimization of weighted aggregated sum product assessment. *Elektronika ir elektrotechnika*, *122*(6), 3-6. https://doi.org/10.5755/j01.eee.122.6.1810

[40] Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2015). Selecting a contractor by using a novel method for multiple attribute analysis: Weighted Aggregated Sum Product Assessment with grey values (WASPAS-G). *Studies in Informatics and Control*, *24*(2), 141-150. https://doi.org/10.24846/v24i2y201502

[41] Elbarkouky, M. M., Fayek, A. R., Siraj, N. B., & Sadeghi, N. (2016). Fuzzy arithmetic risk analysis approach to determine construction project contingency. *Journal of construction engineering and management*, *142*(12), 04016070. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001191

[42] Aziz, R. F. (2013). Ranking of delay factors in construction projects after Egyptian revolution. *Alexandria Engineering Journal*, *52*(3), 387-406. https://doi.org/10.1016/j.aej.2013.03.002

[43] Khodeir, L. M., & Mohamed, A. H. M. (2015). Identifying the latest risk probabilities affecting construction projects in Egypt according to political and economic variables. From January 2011 to January 2013. *HBRC journal*, *11*(1), 129-135. https://doi.org/10.1016/j.hbrcj.2014.03.007

[44] Marzouk, M. M., & El-Rasas, T. I. (2014). Analyzing delay causes in Egyptian construction projects. *Journal of advanced research*, *5*(1), 49-55. https://doi.org/10.1016/j.jare.2012.11.005

[45] Liu, J., Zhao, X., & Yan, P. (2016). Risk paths in international construction projects: Case study from Chinese contractors. *Journal of construction engineering and management*, *142*(6), 05016002. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001116

[46] Adeleke, A. Q., Bahaudin, A. Y., Kamaruddeen, A. M., Bamgbade, J. A., Salimon, M. G., Khan, M. W. A., & Sorooshian, S. (2018). The influence of organizational external factors on construction risk management among Nigerian construction companies. *Safety and health at work*, *9*(1), 115-124. https://doi.org/10.1016/j.shaw.2017.05.004

[47] Koulinas, G. K., Marhavilas, P. K., Demesouka, O. E., Vavatsikos, A. P., & Koulouriotis, D. E. (2019). Risk analysis and assessment in the worksites using the fuzzy-analytical hierarchy process and a quantitative technique–A case study for the Greek construction sector. *Safety science*, *112*, 96-104. https://doi.org/10.1016/j.ssci.2018.10.017

[48] Puška, A., Nedeljković, M., Prodanović, R., Vladisavljević, R., & Suzić, R. (2022). Market Assessment of Pear Varieties in Serbia Using Fuzzy CRADIS and CRITIC Methods. *Agriculture*, *12*(2), 139. https://doi.org/10.3390/agriculture12020139

[49] Puška, A., Nedeljković, M., Hashemkhani Zolfani, S., & Pamučar, D. (2021). Application of Interval Fuzzy Logic in Selecting a Sustainable Supplier on the Example of Agricultural Production. *Symmetry*, *13*(5), 774. https://doi.org/10.3390/sym13050774

[50] Mohan, V., Ota, M., & Iqbal, P. A. (2023). Comparative Study to Find the Optimal Ordering Quantity of the Risk-Neutral and Risk-Averse Newsvendor. *Yugoslav Journal Of Operations Research, 33*(3), 323-340. http://dx.doi.org/10.2298/YJOR210815015M

[51] Puška, A., Kozarević, S., Stević, Ž., & Stovrag, J. (2018). A new way of applying interval fuzzy logic in group decision making for supplier selection. *Economic Computation and Economic Cybernetics Studies and Research*, *52*(2), 217-234. https://doi.org/10.24818/18423264/52.2.18.13

[52] Karunathilake, H., Bakhtavar, E., Chhipi-Shrestha, G., Mian, H. R., Hewage, K., & Sadiq, R. (2020). Decision making for risk management: a multi-criteria perspective. In *Methods in chemical process safety* (Vol. 4, pp. 239-287). Elsevier. https://doi.org/10.1016/bs.mcps.2020.02.004