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RESEARCH ARTICLE

A Multi - Criteria Decision Support Model for The Management of Construction Project Risks

Aynur Kazaz, Gökçen Arslan

Akdeniz University, Faculty of Civil Engineering, Civil Engineering Department, Antalya, Türkiye

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Abstract

Technological developments, the increase in the world population and rapid changes in customer needs have increased the competitive environment in the construction sector. The highly competitive environment has brought risk management to a much more critical position for construction companies. Construction projects are exposed to many risks due to their unique nature. Successful risk management requires a realistic assessment of these many and varied risks and the identification and implementation of appropriate strategies. Within the scope of the study, first of all, construction project risks were determined and grouped based on expert opinion and literature review. AHP method, which is one of the multi-criteria decision-making techniques, was used to prioritize risks. Strategies that can be taken against the identified risks were determined in line with expert opinions and Fuzzy TOPSIS technique was used to choose among the strategies that could be applied. It is thought that the obtained model can help decision makers in risk management in construction projects.

1. Introduction

In today's rapidly changing, developing, and globalizing world; technological, economic and political changes cause to increasing of uncertainties. In an environment of increasing uncertainty, companies need to understand and successfully implement the risk management system in order to determine their future strategies and achieve their goals and missions. Construction projects are exposed to lots of various risks, from the design stage to the tender process, from construction to delivery, and even to operation processes. These risks cause the construction projects not to be completed in the desired time, at the desired quality and at the determined cost. These risks, which arise in different processes of the project, adversely affect one or more of the project stakeholders if they are not managed effectively. Construction projects that have various risks according to the project structure, size, complexity and construction type; are among the priority project types that risk management should be applied.

The aim of this study is to generate a decision support model for the prioritization of the risks frequently encountered in construction projects and the risk strategies that can be applied. For this purpose, initially, based on literature review and expert opinions, construction project risks and measures that can be taken against those risks have

Correspondence Gökçen Arslan gokcenarslan@akdeniz.edu.tr

been determined. Considering the main objectives of the projects, the ranking of the project risks was carried out through the AHP (Analytical Hierarchy Process) technique. Fuzzy-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique was used to select among the risk measures that can be applied for prioritized risks. It is thought that the findings can guide risk management practices in the construction industry and foreseen that the developed model can be improved by restructuring for different construction projects in future studies and, contribute to the literature.

2. Literature review

Compared to other sectors in the construction sector; scope, quality, time, and cost deviations are observed more frequently. The long-term and complex stages of construction projects, the fact that each project has different characteristics, being under the influence of external factors, it's high cost, diversity of techniques used in construction and dynamic organizational structure cause this situation [1-3]. Construction projects are carried out with the participation of many stakeholders such as employers, designers, contractors, subcontractors, suppliers. The risks that may affect these participants at different processes and levels, and the effective analysis and management of these risks pose a major challenge for practitioners in the industry [4]. Al-Bahar and Crandall [5] define the risk management process for contractors as follows: Risk management is a set of processes consisting of systematically identifying risks, analyzing identified risks, and developing strategies against risks in order to eliminate, reduce or control risks. Risk management is the systematic application of management policies, procedures and practices, communication, consulting, context and identifying, analyzing, evaluating, processing, monitoring and reviewing risks. The main purpose of risk management is to identify, evaluate and control risks for project success [6, 7].

When the studies conducted by different researchers on the classification of construction project risks are examined, it is observed that financial, construction, political, design and managerial risks take place in the common denominator. Numerous studies have also been conducted on prioritization of construction project risks. For example, Befrouei and Taghipour [8] stated in their study that the factors that most affect cost risk are tight programming schedule, increase in material prices and disagreement between stakeholders. In the same study, it was revealed that the factors affecting the time risk the most were the tight programming schedule, design revisions and prolongation of bureaucratic procedures. It has been revealed that tight programming schedule, problem of communication between stakeholders and lack of skilled workforce have a high impact on the quality risk and; is also stated that tight schedule, noise pollution from the construction and the lack of information about the construction site have the highest impact on environmental risks. It has been also stated that the factors that affect the occupational health and safety risk the most are tight work schedule, insufficient security measures and ineffective subcontractor management. In the study conducted by Lin and Chen [9], the researchers stated that the risk groups that affect the project objectives the most are the contractor, subcontractor and design risks, and the external risks do not have much effect on the project objectives. Insufficient site control, faulty construction, insufficient training to the operators, and lack of knowledge and experience of the design team were the risk factors that most negatively affected the project objectives. On the identification and assessment of sustainable construction project risks, El-Sayegh et al. [10], 30 risks were classified under management, technical, green team, green material, and economic risk groups. The top 5 risk factors with the highest impact were employer's financing shortage, faulty sustainable design, design changes, tight schedule and faulty scope definition. In another research, a risk analysis was carried out for a construction project in Vietnam, which will be carried out with the design-build delivery method chosen as a case study. Within the scope of the study, a total of 28 risks were determined and these risks were divided into 5 different groups as political and legal, economic and financial, construction, design, contract and tender risks. As a result of the risk analysis, it has been stated that the top 3 risk factors are delay in project approval, inflation and faulty design-design change factors [11].

Risk assessment can also be approached as a multi-criteria decision-making problem, as risk management itself involves multiple decision makers' perspectives and multiple aspects from different levels [12, 13]. In line with this view, multi-criteria decision-making techniques have also been used in many studies on risk management practices in construction projects. For instance, Ahmadi et al. [14] developed a decision support model for the selection of risk responses with the help of multi-criteria decision-making techniques, in which they identified risk and risk responses specific to road projects. As a result of the study, the first five risk events that are most effective in the highway project were insufficient budget allocation, delay in payments, increase in tar prices, contractor's equity shortage and sudden price increase in other materials other than tar. For the risk of increase in tar prices; four risk responses have been identified: Allocating an additional budget, developing a new design using compressed concrete instead of tar, accepting price increases, and pre-procurement and storage of tar. As a result of the analysis made by using multi-criteria decision-making techniques among the identified risk responses, it was revealed that the most effective risk response would be a design change. Beltrão and Carvalho [15] developed a decision support model based on the Fuzzy AHP technique in order to create a risk breakdown structure for public construction projects in Brazil and to prioritize construction risks. Within the scope of their studies, they identified 54 risks under 8 main risk groups. From 8 main risk groups, including social, project, construction, financial, economic, political, environmental, and managerial risks; it has been revealed that the most effective risk group were project and political risks. The most effective project risks were identified as bid package and contract deficiencies, cost underestimation or overestimation and design errors. It was stated that the risks of corruption, bureaucracy and political interference were the risks with the highest impact within the political risk group. Based on risk factor, it was stated that the three most effective risks were, respectively, difficulty in environmental licensing, design revision request during construction and corruption risk. Dikmen et al. [16] developed a web-based risk assessment tool for estimating cost probabilities in construction projects, taking into account the complexity factor. The researchers suggested that the developed tool can be used in the tender preparation process of construction projects and can improve the quality of decisions by improving communication between decision makers by visualizing risk-related information.

3. Methodology

Due to the characteristics of construction projects, the importance of risk management practices in construction projects is increasing day by day. The stages of identifying and analyzing risks, developing strategies against risks and monitoring risks constitute the risk management process. As in all sectors, it is critical to identify risks and create response strategies for risk management in construction projects. Within the scope of this study, a hybrid decision support model based on the AHP-Fuzzy TOPSIS technique has been developed in order to identify and prioritize risks and risk responses. In the first part of the study, risk and risk strategies were determined in line with expert opinion and literature review. The identified risks have been weighted with the help of the AHP technique, taking into account the cost, duration, quality, sustainability and occupational health and safety criteria determined as the main objectives of the construction projects. After the weighting of the project risks, the Fuzzy-TOPSIS technique was used for the selection of the determined risk measures. The flow chart of the methodology is given in Fig. 1.

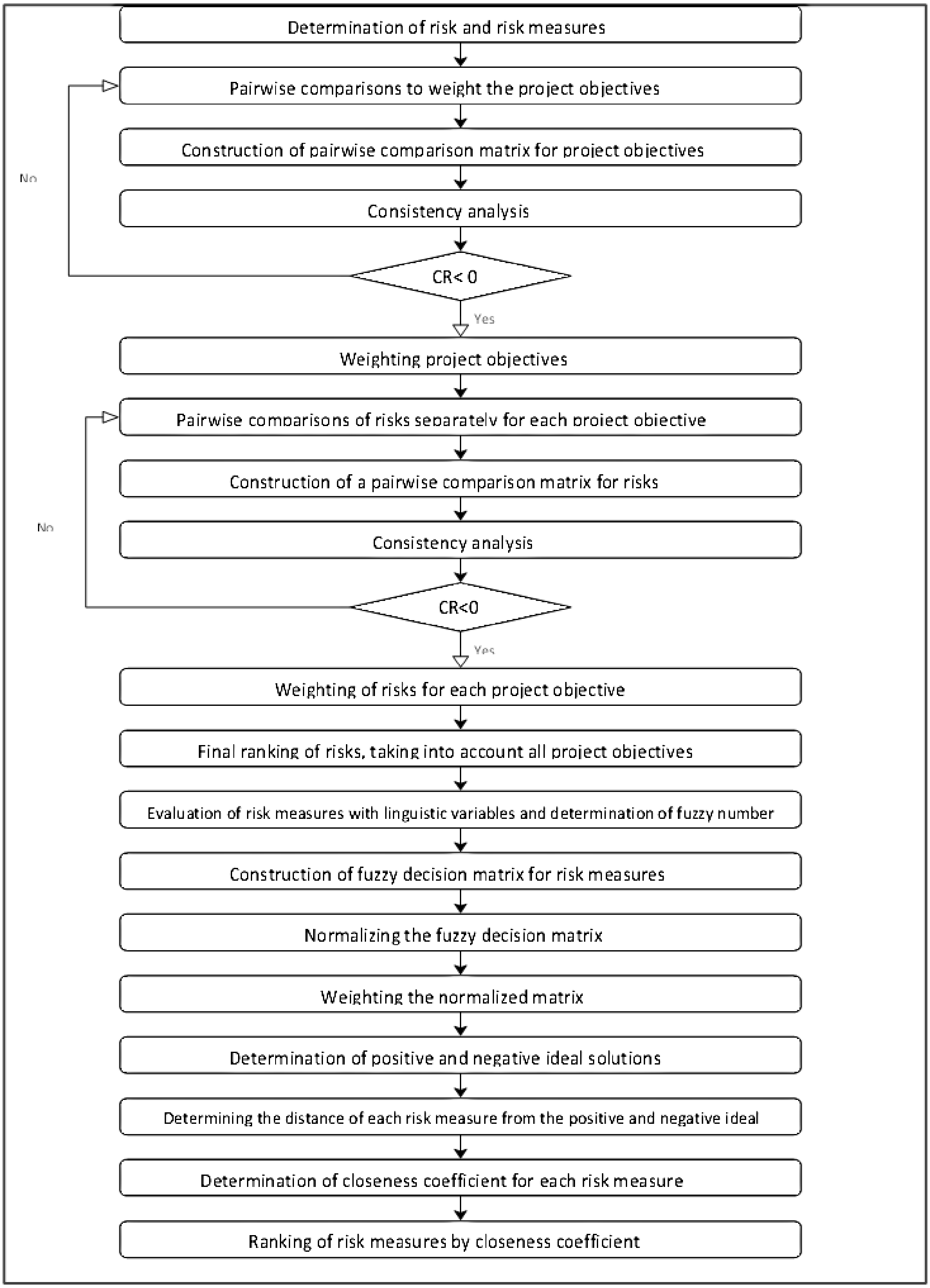

Fig. 1. Framework for risk and risk measure prioritization by the proposed model

4. Findings and discussion

In addition to the literature review in order to determine the risks; Interviews were also held with experts who have experience in the design, procurement, construction and management processes of construction projects. Within the scope of the study, ten experts who took part in different processes of various projects were asked to answer semi-structured questions in online and face-to-face interviews. Demographic information for the experts whose opinions were taken are given in Table 1. The questions conveyed to the experts within the scope of the interviews are as follows:

• What are the main risk factors that may adversely affect the objectives of construction projects?

• What would be the most effective risk measures for the successful completion of construction projects?

In the light of the results of the literature research on the determination and classification of risks in construction projects and the expert opinions; 7 main risk groups were determined. as design risks, contractual risks, political risks, financial risks, management and organizational risks, construction risks and environmental risks (Table 2). As shown in Table 3, 20 risk measures that can be taken against the risks determined for construction projects have been determined in line with previous studies and expert opinion.

The main targets set for the successful conclusion of construction projects generally consist of cost, time, quality and safety criteria. Considering the energy crisis, which the critical importance of it continues to increase in recent years, it is clearly seen that it would be more beneficial to include the sustainability criterion among the success targets of construction projects. Within the scope of this study, cost, time, quality, occupational health and safety and sustainability criteria for construction projects have been determined as criteria to be considered for a successful project. Within the scope of the study, initially, the weights of these criteria were tried to be determined. In the weighting of the criteria, AHP technique was used in line with the expert opinion.

Table 1. Profile of respondents

Category		Number
Proficiency	Civil Engineer	5
	Mechanical Engineering	2
	Electrical Engineering	1
	Architecture	2
Role	Project manager	4
	Site manager	2
	Designer	3
	Owner	1
Organization	Conractor	7
	Client	3
Budget responsible (USD$)	≤ 1 Million	3
	1 - 10 Million	4
	10 - 100 Million	3
Experience in construction sector (year)	≤10	1
	10 - 20	3
	20 -30	2
	≥ 30	4
Education level	Bachelor	6
	MSc or PhD	4

Table 2. Risk classification and explanations

Risk Code	Risk Classification	Risk Explanations
CR01	Design Risks	Incompatibility between design projects, incorrect design, low performance of the design team, design revision demand
CR02	Contractual Risks	Lack of contract documents, Uncertainty in contract clauses, Unbalanced responsibility (risk) distribution, Unclear project scope
CR03	Political Risks	Business interruption due to security problems such as War, coup, terrorism, etc., Prolongation of bureaucratic procedures, Embargo and quota applications, Nationwide strike
CR04	Financial Risks	Cash flow shortage, incorrect cost estimation, increase in materials and labor prices, economic crisis
CR05	Management and Organization Risks	Delayed management decisions/approvals, Wrong selection of contractor/subcontractor/consultant firm, Wrong supplier selection, Selection of contract type that is not suitable for the project, Low performance of the project team, Ineffective/Insufficient organizational structure, Stakeholder communication problem, Layout plan problem, Incorrect/insufficient planning
CR06	Construction Risks	Faulty construction practices, Poor quality of material/equipment, Incorrect construction technique / method, Geological problems, Low labor force performance, Occupational accident, Insufficient material/equipment
CR07	Environmental Risks	Adverse weather conditions, Natural disasters (earthquake, flood, erosion, fire, etc.), Ecological damage potential, Epidemics

Table 3. Measures against risks

Risk Measure Code	Risk Measures
RM1	Artificial Intelligence Based Decision Support Systems
RM2	Detailed examination of contract clauses/ consultancy for the prep of contracts
RM3	Checking on -site feasibility
RM4	Keeping good relations with bureaucratic structures
RM5	Detailed preparation of insurance policies
RM6	Effective market analysis and good feasibility study
RM7	Effective and Realistic Planning/Work Program
RM8	BIM -based project management
RM9	Ensuring the reliability of credit institutions
RM10	Including the escalation condition in the contract
RM11	Performing Life Cycle Analysis
RM12	Influencing risk premiums on business items
RM13	Adopting the lean management understanding
RM14	Effective procurement and resource planning
RM15	Organizing events to increase productivity
RM16	Ensuring regular and effective construction site/project control
RM17	Providing regular and effective trainings to employees
RM18	Accurate information of employees on OHS and taking optimum OHS measures
RM19	Clear Determination of the Scope of the Project
RM20	Defining force majeure clearly and accurately in contracts, adding clauses about cost increase and delays caused by natural disasters

AHP was developed by Thomas L. Saaty in 1977 and provides a structured approach to the determination of multiple criteria and importance levels. AHP is mainly based on pairwise comparisons of criteria. In this study, project risks were accepted as criteria, and measures that could be taken against risks were accepted as alternatives. AHP technique was used to prioritize risks (criteria) and, Fuzzy-TOPSIS technique was used in the selection of risk measures (alternative). The pairwise comparison scale used to prioritize risks according to project objectives is given in Table 4.

The comparison matrix used for the weighting of the project objectives, the normalized matrix and the weights of the project objectives are shown in Table 5 and Table 6.

In order to evaluate the consistency of pairwise comparisons in the AHP technique, the consistency index (CI) should be determined, and the consistency ratio (CR) should be below 0,10. The equations given below are used to calculate the consistency index and consistency ratio (Eqs. 1-2).

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

Table 4. Pairwise comparison scale

Importance level	Value Definitions	Description
1	Equality	Each activity contributes equally.
3	Less important	As a result of experience and evaluations, an activity is a little more preferred than the other.
5	Quite important	As a result of experience and evaluations, one activity is much more preferred than the other.
7	Very important	An activity is preferred very strongly compared to the other.
9	Highly important	An activity is preferred as the highest possible degree compared to the other.
2,4,6,8	Intermediate values	If words are insufficient to make an assessment, a value in the middle of numerical values is given.

Table 5. The comparison matrix of the priority of the project objectives

	Cost	Time	Quality	Sustainability	Safety
Cost	1.00	3.00	7.00	8.00	4.00
Time	0.33	1.00	5.00	8.00	3.00
Quality	0.14	0.20	1.00	4.00	0.33
Sustainability	0.13	0.13	0.25	1.00	0.25
Safety	0.25	0.33	3.00	4.00	1.00

Table 6. Normalized comparison matrix and criterion weights of project objectives

	Cost	Time	Quality	Sustainability	Safety	Weight	Ranking
Cost	0.54	0.64	0.43	0.32	0.47	0.48	1
Time	0.18	0.21	0.31	0.32	0.35	0.27	2
Quality	0.08	0.04	0.06	0.16	0.04	0.08	4
Sustainability	0.07	0.03	0.02	0.04	0.03	0.04	5
Safety	0.14	0.07	0.18	0.16	0.12	0.13	3

λmax, which will be used in the calculation of the consistency index and consistency ratio, indicates the largest eigenvalue of the matrix, n indicates the number of criteria, and RI indicates the random index. The consistency ratio (CI) in ranking the project objectives was found to be 0.070 and it was accepted because it was less than 0.10. It has been determined that the most important criterion among the project objectives was the cost and, the cost criterion is followed by time, OHS, quality and sustainability factors, respectively. The processes followed in the sequence of the project target criteria were also applied in the prioritization of the risks for each project target separately. The risk rankings obtained as a result of considering each project objective separately are given in Table 7.

Table 7. Ranking of construction project risks in line with the project objectives

Project Target	Risk Code	Project Risks	Weight	Ranking	Consistency Rate
Cost	CR04	Financial Risks	0.41	1	0.062 < 0,10
	CR05	Man. and Org. Risks	0.24	2	
	CR06	Construction Risks	0.14	3	
	CR01	Design Risks	0.08	4	
	CR03	Political Risks	0.07	5	
	CR07	Environmental Risks	0.04	6	
	CR02	Contractual Risks	0.02	7	
Time	CR05	Man. and Org. Risks	0.37	1	0.040 < 0.10
	CR04	Financial Risks	0.30	2	
	CR06	Construction Risks	0.14	3	
	CR01	Design Risks	0.08	4	
	CR02	Contractual Risks	0.04	5	
	CR07	Environmental Risks	0.03	6	
	CR03	Political Risks	0.03	7	
Quality	CR06	Construction Risks	0.36	1	0.042 < 0.10
	CR05	Man. and Org. Risks	0.25	2	
	CR04	Financial Risks	0.19	3	
	CR01	Design Risks	0.09	4	
	CR02	Contractual Risks	0.05	5	
	CR07	Environmental Risks	0.03	6	
	CR03	Political Risks	0.02	7	
Sustainability	CR07	Environmental Risks	0.33	1	0.095 < 0.10
	CR01	Design Risks	0.22	2	
	CR04	Financial Risks	0.19	3	
	CR05	Man. and Org. Risks	0.12	4	
	CR06	Construction Risks	0.08	5	
	CR02	Contractual Risks	0.03	6	
	CR03	Political Risks	0.02	7	
Safety	CR06	Construction Risks	0.39	1	0.091 < 0.10
	CR05	Man. and Org. Risks	0.25	2	
	CR07	Environmental Risks	0.15	3	
	CR01	Design Risks	0.10	4	
	CR04	Financial Risks	0.05	5	
	CR02	Contractual Risks	0.04	6	
	CR03	Political Risks	0.02	7	

Consistency ratios for the pairwise comparisons of risks, which were made by considering each project objective, were calculated as less than 0.10 and the ranking of the risks was carried out. In the continuation of the study, a final ranking was made for the risks by using the project target weights for the case where all the project objectives are considered together. As shown in Table 8, in the risk ranking made for the situation where all of the cost, time, quality, OHS and sustainability targets are included; It is seen that financial, management and organization and construction risks have critical importance and taking precautions against these risks will contribute to the successful conclusion of the projects. It is also thought that financial risks may have a much more critical importance for construction projects, especially for developing countries whose economic stability has not been ensured. It is estimated that financial difficulties have the highest impact among the identified risks as they can cause both managerial problems and poor construction quality. Management and organizational risks, on the other hand, were thought to be caused by the traditional management approach away from the use of information technologies, inadequate decision mechanisms and the lack of competent personnel. It is assumed that the first two risk groups will seriously affect the construction risks. It is believed that unstable cash flow, poor site order and inadequate site control will adversely affect construction quality, especially material and equipment quality. In addition, it is thought that the irregular site environment and the lack of OHS, and technical knowledge will increase the probability of occupational accidents, and this could have a negative effect on the construction process.

For a successful risk management determining the measures to be taken against the risks and monitoring the risks are inevitable as identifying and classifying risks. In this part of the study, it is aimed to determine the most appropriate risk measures for the prioritized risks. For this purpose, risk measures were accepted as an alternative and Fuzzy TOPSIS technique was used for the most ideal alternative selection.

The TOPSIS method was first developed by Hwang and Yoon [17]. The main purpose of this method is to select the alternative with the shortest distance to the positive ideal solution and the longest distance to the negative ideal solution. In other words, while minimizing the loss criteria in the TOPSIS method, maximizing the benefit criteria is taken into account [18, 19]. However, the traditional TOPSIS method relies on exact values without considering uncertainty, but human judgments are inherently imprecise and subjective. Assuming that TOPSIS method will be insufficient in the problem of prioritizing risks and risk measures, fuzzy TOPSIS method is thought to be more appropriate.

As the first step in the evaluation of alternatives; expert opinion was sought on how effective the risk measures were for the identified risks through the linguistic variables shown in Table 9. A fuzzy decision matrix was created in line with the views received using triangular fuzzy numbers.

Table 8. Final risk ranking

Risk Code	Risk	Weight	Ranking
CR04	Financial Risks	0.31	1
CR05	Man. and Org. Risks	0.27	2
CR06	Construction Risks	0.19	3
CR01	Design Risks	0.09	4
CR07	Environmental Risks	0.06	5
CR03	Political Risks	0.04	6
CR02	Contractual Risks	0.03	7

Table 9. Linguistic variables and triangular fuzzy number equivalents in alternative evaluation

Linguistic Variables	Triangle Fuzzy Numbers
Very Good (VG)	(9,10,10)
Good (G)	(7,9,10)
Medium Good (MG)	(5,7,9)
Fair (F)	(3,5,7)
Medium Poor (MP)	(1,3,5)
Poor (P)	(0,1,3)
Very Poor (VP)	(0,0,1)

By using the fuzzy decision matrix, a normalized fuzzy decision matrix is obtained, and the matrix is denoted by "R" and expressed by $R = [rij]_{mxn}$. The equation shown in (3) and (4) was used for the normalization process of fuzzy decision matrix [20].

$R = [ri\ j]_{mxn}$ i =1, 2, …. m; j = 1,2, ….n;

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad c_j^* = max_i c_{ij} \tag{3}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad a_j^* = min_i a_{ij} \tag{4}$$

Weighted normalized decision matrix is created, since each existing criterion has different degrees of importance. The equation shown in (5) was used to determine the elements of this matrix [20].

$$V = [v_{ij}]_{mxn} \quad v_{ij} = r_{ij}\ x\ w_j \tag{5}$$

The values of FPIS (A^*), which is the fuzzy positive ideal solution, and FNIS (A^-), which is the fuzzy negative ideal solution, are shown in Eq. 6. [21].

$$A^* = (v_1^*, v_2^*, \dots, v_n^*)\ v_j^* = (1,1,1)\ v_j^- = (0,0,0) \tag{6}$$

For each of the alternatives, their distances from the fuzzy positive ideal solution and the fuzzy negative ideal solution are determined. The distance to FPIS (A^*) and FNIS (A^-) is given in Eq. 7.

$$d_i^* = \sum_{j=1}^{n} d(v_{ij}, v_j^*) \qquad d_i^- = \sum_{j=1}^{n} d(v_{ij}, v_j^-) \tag{7}$$

Closeness coefficients are used to rank the alternatives whose results are obtained. For each alternative, the closeness coefficients CC_i are determined by using the formula in (8) separately.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \tag{8}$$

Finally, the alternative selection process was completed by sorting all the alternatives from the largest to the smallest according to their closeness coefficients. Weighted normalized fuzzy decision matrix, FPIS (A^*), FNIS (A^-), and closeness coefficient (CC_i) are shown in Table 10.

When the final ranking of risk measures is examined, it is seen that the first five risks that can be most effective against risks are: BIM-based project management, use of artificial intelligence-based decision support systems, effective and realistic work schedule, effective procurement and resource planning and lean management approach (Table 11). In the light of the findings, it was concluded that the rapid change of technology and globalization can increase the risks of construction projects. However, these rapid changes can also provide facilitating access to information, achieving a systematic and effective decision-making and management environment with the help of technologies such as artificial intelligence, virtual reality, cloud systems, etc. Considering these benefits; it is thought that the increase in the pace of globalization and technological development can be used as a powerful tool for measures to be taken against risks and more successful construction projects can be realized.

Table 10. Weighted normalized fuzzy matrix and closeness coefficients

Risk Measures	CR01 (%9)	CR02 (%3)	CR03 (%4)	CR04 (%31)	CR05 (%27)	CR06 (%19)	CR07 (%6)	FPIS (A^*)	FNIS (A^-)	CC_i
RM1	0.079	0.010	0.002	0.271	0.236	0.137	0.032	6.248	0.767	0.109
RM2	0.016	0.029	0.014	0.163	0.142	0.100	0.020	6.547	0.485	0.069
RM3	0.079	0.010	0.002	0.106	0.142	0.100	0.032	6.562	0.471	0.067
RM4	0.016	0.005	0.035	0.057	0.092	0.035	0.020	6.786	0.261	0.037
RM5	0.005	0.022	0.029	0.223	0.092	0.065	0.058	6.538	0.494	0.070
RM6	0.031	0.010	0.002	0.271	0.092	0.035	0.011	6.582	0.453	0.064
RM7	0.047	0.010	0.002	0.271	0.261	0.137	0.020	6.266	0.750	0.107
RM8	0.087	0.016	0.002	0.271	0.261	0.166	0.053	6.152	0.857	0.122
RM9	0.016	0.005	0.002	0.223	0.092	0.100	0.003	6.591	0.443	0.063
RM10	0.005	0.026	0.007	0.223	0.142	0.100	0.003	6.520	0.507	0.072
RM11	0.079	0.002	0.002	0.223	0.049	0.035	0.053	6.592	0.442	0.063
RM12	0.016	0.026	0.007	0.271	0.142	0.100	0.011	6.453	0.574	0.082
RM13	0.065	0.022	0.007	0.223	0.236	0.166	0.011	6.290	0.730	0.104
RM14	0.016	0.010	0.002	0.271	0.261	0.166	0.011	6.277	0.739	0.105
RM15	0.065	0.005	0.002	0.106	0.236	0.166	0.003	6.441	0.585	0.083
RM16	0.031	0.016	0.007	0.223	0.236	0.184	0.011	6.313	0.708	0.101
RM17	0.031	0.002	0.002	0.057	0.142	0.137	0.032	6.634	0.402	0.057
RM18	0.016	0.002	0.002	0.057	0.142	0.166	0.032	6.617	0.417	0.059
RM19	0.079	0.029	0.002	0.163	0.142	0.137	0.011	6.464	0.563	0.080
RM20	0.016	0.029	0.007	0.223	0.142	0.065	0.053	6.496	0.535	0.076

Table 11. Final ranking on risk measures

Code	Risk Measures	Ranking
RM8	BIM -based project management	1
RM1	Use of artificial intelligence-based decision support systems	2
RM7	Effective and realistic planning/work program	3
RM14	Proper procurement and resource planning	4
RM13	Adopting the Lean Management Understanding	5
RM16	Ensuring regular and effective construction site/project control	6
RM15	Organizing events to increase productivity	7
RM12	Influencing risk premiums on business items	8
RM19	Defining the project scope clearly	9
RM20	Defining force majeure clearly and accurately in contracts, adding articles about cost increase and delays caused by natural disasters	10
RM10	Including the escalation condition in the contract	11
RM5	Detailed preparation of insurance policies	12
RM2	Detailed examination of contract articles / consulting for the preparation of contracts	13
RM3	Checking the applicability/feasibility on site	14
RM6	Effective market analysis and proper feasibility study	15
RM9	Ensuring the reliability of credit institutions	16
RM11	Performing Life Cycle Analysis	17
RM18	Accurate information of employees on OHS and taking optimum OHS measures	18
RM17	Providing regular and effective trainings to employees	19
RM4	Keeping good relations with bureaucratic structures	20

5. Results

This research aimed to develop an AHP-Fuzzy TOPSIS-based decision support model to identify and prioritize general risks related to construction projects and to choose between the measures that can be taken against these risks. Within the scope of this study, all project objectives were considered as a whole in the prioritization of risk and risk measures. A holistic approach has been tried to be achieved by including sustainability and safety objectives in addition to the basic project objectives such as cost, time, and quality in the developed model. The results of the study revealed that the risk group with the highest impact for construction projects is financial risks, while managerial and construction risks follow financial risks. The study also demonstrated that; BIM supported project management, the use of artificial intelligence-based decision support systems, realistic and effective work schedule, solid procurement and resource planning and the adoption of lean management approach are the most effective measures that can be taken against risks.

It is foreseen that the model developed within the scope of this study and the information obtained can guide the sector on risk management practices and contribute to the literature. Addressing construction project risks at a general level, failure to evaluate risk impact and probability levels separately, not considering sub-risk factors in the risk breakdown structure; constitutes the limitations of this study. In future studies, it is predicted that these limitations can be eliminated, and the model can be applied for specific construction projects by supporting artificial intelligence technologies.

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Author Contributions

A. Kazaz: Conceptualization, Methodology, Investigation, Resources, Supervision, Validation, Writing- Reviewing and Editing; G. Arslan: Methodology, Formal Analysis, Investigation, Data curation, Writing- Original draft, Visualization.

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Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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