A Proposed Fuzzy-based Optimisation Model for Evaluating Construction Projects' Risk Response Strategies

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ABSTRACT: The construction industry is vulnerable to a variety of risks that can significantly affect project outcomes, including cost overruns, delays, and quality weaknesses. The effective management of construction risks is crucial to ensuring that projects are finished on time, within budget, and to the required quality standards. In order to address this issue, this paper develops a Fuzzy-based optimisation model for selecting the most appropriate construction risk response strategies by surveying construction experts in Iraq. A two-step research methodology was employed for data collection and analysis. In the first step, the Delphi technique was used to (1) identify the risks facing the construction industry in Iraq, (2) identify suitable response strategies for each risk factor, and (3) identify the decision components of risk response strategies. In the second step, a Fuzzy-based optimisation model for response strategies selection was developed, and a questionnaire survey was administered to evaluate the probability and impact of each risk and the decision components associated with each risk response strategy. The outputs of this research can assist decision-makers in evaluating the effectiveness of the strategies used to mitigate risks, enabling them to make informed decisions. Additionally, it can aid in gaining a deeper understanding of decision-makers' behaviour when making risk-based decisions with profound uncertainties, ultimately resulting in the development of improved response strategies.

1.INTRODUCTION

The construction industry is inherently exposed to a range of risks that can have significant implications for project success, such as increased costs, project delays, and quality deficiencies. These risks can stem from diverse sources, including regulatory changes, unforeseen site conditions, and disruptions in the supply chain (Al-Mhdawi et al. 2022a). Effectively managing construction risks is essential to ensure that projects are completed on time, within budget, and to the required quality standards (Al-Mhdawi et al. 2022b). A pivotal aspect of risk management is the successful implementation of effective risk response strategies. In the context of construction, risk response strategies refer to the measures that project managers and stakeholders take to mitigate the potential consequences of risks that may arise during the course of a construction project (Mubin and Mannan 2013). These strategies aim to ensure that projects are completed in a timely manner, within budget, and to the required quality standards. Risk response strategies have a critical role in the construction industry by reducing the impact of construction risks and enabling informed decision-making. These strategies also encourage transparency and open communication among project stakeholders, ensuring that everyone involved is aware of the risks and prepared to take necessary actions (Ahmadi-Javid et al. 2020). Establishing clear roles and responsibilities for risk management (RM) fosters accountability among project stakeholders, leading to effective RM and alignment towards a shared objective. Ultimately, the implementation of effective risk response strategies leads to improved project outcomes, including timely completion within budget and meeting required quality standards. To develop and implement risk response strategies, a systematic approach is essential. This entails identifying feasible risk response strategies for each risk factor, assessing the effectiveness and efficiency of each strategy, selecting and implementing the optimal strategy, and continually monitoring both the risk factors and the response strategies to ensure ongoing efficacy.

A number of scholarly works have proposed the employment of optimisation-based models for the purpose of selecting the optimal set of risk response strategies (see, e.g., Zhang 2016 and others). However, the practical implementation of these models can be challenging and resource-intensive, requiring substantial data and effort. Additionally, such models typically take into account only a limited set of criteria, such as time, cost, and quality, which may result in the selection of risk responses that are cost-effective but unfeasible from technological or practical perspectives. Moreover, optimisation-based models are recognised for their low degree of transparency, making it challenging for others to comprehend the decisions made during the selection process. To address these limitations, and to account for the inherent uncertainty in decision-making arising from a lack of information and/or knowledge, alternative approaches can be employed to develop more realistic, feasible, and practical risk responses. Thus, the present study aims to develop a Fuzzy-based optimisation model for the selection of the most suitable construction risk response strategies by considering the case study of the Iraqi construction industry.

2.METHODOLOGY

A two-step research methodology was used to collect and analyse data. Details on each step are provided in the following subsections.

Step One: Identification of construction risks, risk response strategies and their decision components

The present study employed Delphi technique to (1) identify the risks facing the construction industry in Iraq; (2) identify suitable response strategies for each risk factor; and (3) identify the decision components of risk response strategies. The Delphi technique is a valuable tool for identifying risks and selecting response strategies, as it gathers diverse expert perspectives without group dynamics (Al-Mhdawi 2022). Its anonymous participation allows for unbiased opinions, unlike methods such as interviews and focus groups that can be influenced by group dynamics and limited expert representation. The iterative process of Delphi, involving multiple rounds of discussion and feedback can refine opinions and identify emerging risks and their response strategies (Hsu and Sandford 2007). In Delphi technqiue, a sample size ranging from 8 to 30 participants is considered adequate for facilitating consensus (Ameyaw et al. 2016). It is important to note that, while larger sample sizes may provide additional information, there is a diminishing return in terms of the validity of the findings as the sample size increases (De Villiers et al. 2005). The quality of the output of a Delphi study is primarily dependent on the experts involved, and the success of the entire process is greatly influenced by their unbiased judgment (Albert et al. 2017). Accordingly, the present study established four criteria for the selection of experts, including (1) a minimum of 15 years of experience with a Bachelor of Science (B.Sc.) degree or 10 years of experience with a postgraduate degree; (2) current employment in relevant construction organizations during data collection; (3) involvement in construction management and contracted administration; and (4) registration as a professional. To this end, a multi-round Delphi technique was employed for the identification and filtration of construction risks, response strategies, and their decision components.

For the purpose of validating each round of the Delphi technique, Kendall's coefficient of concordance was employed. Kendall's coefficient of concordance is a statistical measure of the strength of the degree of agreement between a set of rankings. It is commonly used to assess the consistency of rankings among a group of experts. In this research, we tested two hypotheses to ascertain whether or not there is a correlation between the rankings of the experts: the null hypothesis (H0), which states that the rankings of the experts are independent of each other, and the alternative hypothesis (H1), which posits that the expert rankings are correlated. For a significance level of α, the null hypothesis (H0) would be rejected if p is less than or equal to α. In contrast, if the p-value is greater than α, the null hypothesis (H0) would not be rejected, and the alternative hypothesis (H1) would be supported.

Step two: The development of a Fuzzy-based Optimisation Model for Response Strategies Selection

In the second step of this study, a Fuzzy-based Optimisation Model was developed to identify the optimal risk response strategy for construction projects in Iraq. The model was developed using MATLAB® (V.2014b) and was structured hierarchically with several inputs and one output. Seven input values, ranging from 0.1 (very low) to 0.5 (very high), were provided by construction experts in Iraq. The model consisted of two Fuzzy controllers and one Fuzzy sub-system. The first controller had two inputs, namely, risk probability and impact, and 25 IF-THEN conditional statements, with one output - the initial risk weight. The second controller had five inputs representing the decision components for each response strategy corresponding to each risk factor, and one output - quantified response strategy characteristics. The Fuzzy sub-system had inputs consisting of the crisp values of the two controllers and was governed by 25 IF-THEN conditional statements, yielding one output - the updated risk weight. The efficacy of the response strategies corresponding to each risk factor was determined by the reduction in risk weight from the initial weight to the updated weight. For example, if there are three response strategies corresponding to one risk and the reduction in risk weight for the first response strategy is 15%, for the second strategy is 17%, and for the third strategy is 23%, then the third response strategy would be the most appropriate for responding to this specific risk factor, taking into consideration the influence of the five response strategy decision components. The IF-THEN statements for the entire model were established from previous Fuzzy-based RM literature (see e.g., Al-Mhdawi 2022; Al-Mhdawi et al.

2022c; Al-Mhdawi et al. 2023 and others). Our research model comprises three processes: fuzzification, Fuzzy inference system, and defuzzification. Triangular membership functions were chosen for fuzzification as they are simple, effective, and easy to define and calculate input ranges. Mamdani's Fuzzy inference system was used to evaluate the output variable, owing to its frequent use, intuitive nature, and suitability for subjective inputs. Finally, we employed the commonly used centroid of area method for defuzzification, which reflects the expert viewpoint.

Following the identification of the risk factors, response strategies, decision components, and the development of the model, we conducted a questionnaire survey to evaluate the probability and impact of each risk, and the decision components associated with each response strategy. The participants in the survey were asked to rate the probability and impact of each risk, as well as the decision components for each risk response strategy, using a five-point Likert scale ranging from "very low" (0.1) to "extremely high" (0.5). The survey was administered to 100 construction experts working in Iraq. In order to ascertain the reliability and validity of the responses collected through the multi-point scale, a Cronbach's alpha test was performed. Statistically, a value of 0.75 or higher is considered an indication of a reliable and valid scale. Thus, the reliability of the scales used as inputs for the Fuzzy model was tested and the results indicated that the scales used in the questionnaire survey were reliable and valid with a Cronbach's alpha test score of 0.83.

3. RESULTS AND ANALYSIS

Delphi Participants

A total of 13 experts participated in the study, comprising of eight project managers, three construction contractors, and two RM academics. 11 of the experts were employed in the private sector and two in the public sector. Out of the 13 participants, three held PhD degrees, while the rest held BSc degrees. Furthermore, all of the participants possessed a minimum of 17 years of engineering management experience.

Delphi Rounds

This research utilised a three-round Delphi technique to identify and filter construction risks, response strategies, and decision components. The subsequent sub-sections provide a detailed description of each round.

Delphi Technique: Round 1

The 13 participants in the Delphi technique were allotted 45 minutes to identify the key construction risks, key response strategies for each risk factor, and key decision components for risk response strategies. An initial list comprising of 9 risks, 27 response strategies, and 8 decision components were identified during this round. It is noteworthy that the Delphi technique facilitator instructed the participants to only identify a succinct list of risks, owing to the considerations pertaining to the scope and depth of this conference paper. The application of Kendall's coefficient of concordance was not deemed necessary for the initial round, as its primary function is to identify pertinent factors for further elaboration.

Delphi Technique: Round 2

During the second round, participants were allocated 45 minutes to complete handouts during a virtual session. These handouts required them to determine, assess, and rank 75% of the 9 risks, 75% of the 27 risk response strategies, and 75% of the 8 decision components that were randomly listed. After the first round, the top 7 risks, the top 20 strategies and the top 6 decision components were identified. Results indicated that each of the 7 risks, the 20 strategies and the 6 decision components received at least one ranking, suggesting that each strategy had some degree of importance. Following a further 45-minute group discussion, participants compared their rankings with the preliminary data. The validity of the second-round results was assessed using Kendall's coefficient of concordance. The coefficient was found to be 0.71, with a corresponding p-value of 0.000. At α value of 0.05, the null hypothesis (H0) was rejected, as the p-value of 0.000 was less than 0.05. This indicated that the rankings of the Delphi technique participants were related to each other. The arithmetic mean was subsequently used to determine the weights of the 20 strategies and the 11 decision components.

Delphi Technique: Round 3

In the third round, participants summarised their findings, identified effective strategies, and selected appropriate decision components with the aim of reducing the number of risk factors, response strategies, and decision components by 25%. The research team collected and analysed the results, presented them to the participants, and conducted a group discussion to determine the rankings. The coefficient was 0.78, with a corresponding p-value of 0.000. At an α value of 0.05, the null hypothesis (H0) was rejected because the p-value of 0.000 was less than 0.05. Therefore, this round was considered valid as the rankings were related.

Identified risks, potential response strategies, and decision components for response strategies

The identified risks and their potential response strategies are presented in column 1 and 11 of Table 1. The identified key decision components for risk response strategies are as follows:

1. Effectiveness. Effectiveness refers to the ability of the risk response strategy to reduce or eliminate the risk.
2. Feasibility. Feasibility refers to the practicality of implementing the risk response strategy given the resources, time, and budget constraints of the project.
3. Acceptability. Acceptability refers to the degree to which the risk response strategy is acceptable to all stakeholders, including the project team, client, and other interested parties.
4. Sustainability. Sustainability refers to the long-term viability of the risk response strategy.
5. Flexibility. Flexibility refers to the ability of the risk response strategy to adapt to changes in the project environment or unforeseen events.

Profile of Survey Respondents

Out of the 100 distributed surveys, 77 were returned and 69 were complete and considered for analysis. The latter is equivalent to a response rate of 69%, which is considered high compared to previous relevant studies (see e.g., Yates 2014 and others). The distribution of respondents between the public and private sectors was as follows: private sector 78% and public sector 22%. The survey respondents had different construction roles in the Iraqi construction industry, including project managers (43%), contractors (24%), consultants (18%), and safety engineers (15%). The distribution of the respondents' range of experience was as follows: 1-5 years, 8%; 6-15 years; 13%; 16-25 years, 47%; and over 25 years; 32%. Thus, the collected responses represent a diverse range of specialties, educational backgrounds, and experiences, making it a reliable representation of the Iraqi construction industry.

Optimisation under Fuzzy environment

According to Step Two of the Research Methodology, the architecture of the proposed response strategies selection model is comprised of two Fuzzy controllers and one Fuzzy sub-system, as depicted in Figure 1. The first controller utilises the risk probability (p) and impact (i) as inputs, and generates the initial risk weight (irw) as its output. The second Fuzzy controller takes the five decision components for each risk response strategy (*f1, f2, f3, f4,* and *f5*) as inputs, and produces the quantified decision components as its output. Finally, the Fuzzy sub-system utilises the initial risk weight (*irw*) and the quantified decision components as inputs, and outputs the updated risk weight (*urw*). The mean values of the *p, i, f1, f2, f3, f4,* and *f5*, collected from subject matter experts, were utilised as inputs and are illustrated in columns 2 through 9 of Table 1. These inputs were subjected to fuzzification using triangular membership functions, followed by conditional processing using IF-THEN rules and control using a Mamdani-type inference system. The process was concluded with defuzzification through the application of the centre of area method. The ultimate result, represented by risk weight reduction (*rwr)*, was generated for each of the risk response strategies, as illustrated in Table 2. As described in the research methodology, the efficacy of the risk response strategies was measured in terms of their reduction in risk weight. Table 2 reveals that the highest reduction in risk weight for R1 was recorded for the response strategy R1B (46.6%), which was deemed the most suitable response strategy in light of its effectiveness, feasibility, acceptability, sustainability, and flexibility. The most suitable response strategy for R2 was found to be R2A, with a 40% reduction in risk weight. R3A was identified as the most suitable response strategy for R3, exhibiting a 50% reduction in risk weight. R4C was determined to be the most suitable response strategy for R4, with a risk weight reduction of 40%. Finally, the highest reduction in risk weight for R5 was recorded for the response strategy R5B, with a 35% reduction.

Table 1: Fuzzy optimisation outputs

Risks	*p*	*i*	*irw*	*f1*	*f2*	*f2*	*f3*	*f4*	*f5*	Response Strategy	*urw*
R1. Inconsistency between the contract documents	0.3	0.5	0.15	0.35	0.27	0.42	0.46	0.26	0.39	**R1A.** Contract with external contract management office.	0.09
				0.42	0.45	0.33	0.46	0.23	0.48	**R1B.** Establish internal committees to review and verify the contract documents.	0.08
				0.44	0.25	0.24	0.38	0.31	0.37	**R1C.** Conduct a thorough study and review of contract documents by the owner and contractor.	0.11
R2. Change in the specifications and quality of materials specified in the contract documents	0.2	0.5	0.1	0.45	0.36	0.48	0.49	0.5	0.42	**R2A.** Avoid using untested or non-compliant materials and equipment and ensure that they are readily available in the market.	0.06
				0.25	0.18	0.29	0.31	0.28	0.37	**R2B.** Develop and implement an emergency plan.	0.09
				0.32	0.37	0.25	0.39	0.41	0.45	**R2C.** Obtain current reference standard specifications and follow any updates as necessary.	0.08
R3. Design change	0.2	0.4	0.08	0.42	0.41	0.39	0.38	0.37	0.35	**R3A.** Conducting a simulation of the project to ensure the safety and appropriateness of the design for the project, identifying any problems with the design in order to make modifications before the contract is awarded.	0.04
				0.35	0.30	0.32	0.29	0.27	0.21	**R3B.** Agreement between the contractor and the employer on a specific amount in exchange for the contractor bearing all claims that result from risks of changes in designs.	0.05
				0.22	0.2	0.17	0.15	0.12	0.1	**R3C.** Contract with external design office	0.07

Table 1: Continued

Risks	*p*	*i*	*irw*	*f1*	*f2*	*f2*	*f3*	*f4*	*f5*	Response Strategy	*urw*
R4. Inaccurate estimates in the quantities table	0.3	0.5	0.15	0.27	0.29	0.22	0.40	0.31	0.37	**R4A.** Establish specialised committees to review and verify the quantities table.	0.10
				0.18	0.36	0.22	0.24	0.26	0.28	**R4B.** Contract with an external specialized quantity surveying office.	0.13
				0.34	0.45	0.38	0.39	0.41	0.43	**R4C.** Verify all design maps, specifications, and the quantities table for completeness and clarity before starting work.	0.09
R5. Deficiency in the plans and specifications.	0.4	0.5	0.2	0.37	0.31	0.33	0.30	0.29	0.27	**R5A.** Contract with external contract management office.	0.15
				0.43	0.46	0.47	0.38	0.36	0.39	**R5B.** Establish specialised internal committees to review and verify the contract documents.	0.13
				0.28	0.26	0.24	0.22	0.13	0.18	**R5C.** Utilise design-build contracts	0.16

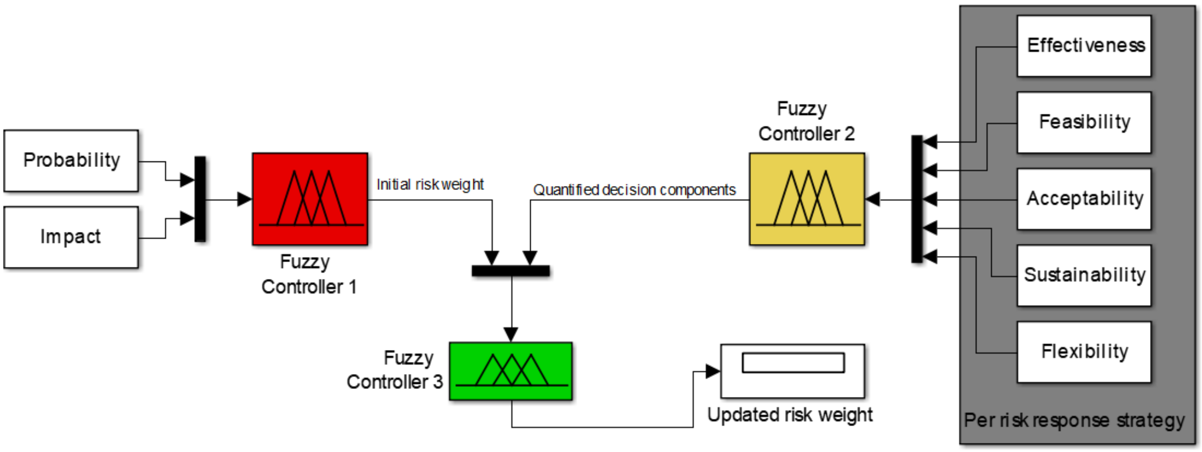

Figure 1: The developed Fuzzy-based optimisation model

Table 2: Risk weight reduction for each response strategy

Risks	**Response Strategy**	***Risk weight reduction***	***Rank***
R1	R1A	40%	2
	R1B	46.6%	1
	R1C	26.7%	3
R2	R2A	40%	1
	R2B	10%	3
	R2C	20%	2
R3	R3A	50%	1
	R3B	37.5%	2
	R3C	12.5%	3
R4	R4A	33.33%	2
	R4B	13.33%	3
	R4C	40%	1
R5	R5A	25%	2
	R5B	35%	1
	R5C	20%	3

4.CONCLUSIONS

This paper aimed to develop a Fuzzy-based optimisation model to select suitable construction risk response strategies, with a focus on Iraq as a case study. To achieve this, a three-round Delphi technique was conducted with 13 construction experts in Iraq to identify prevalent risks, appropriate response strategies, and decision components of risk response strategies. Subsequently, a Fuzzy-based optimisation model was developed to determine optimal response strategies. Finally, a survey was administered to 69 participants to assess the probability and impact of each risk and evaluate decision components of each risk response strategy using a five-point Likert scale ranging from 0.1 ("very low") to 0.5 ("extremely high").

The contributions of this paper are twofold: first, the appropriate criteria for evaluating risk response strategies were identified by experts; second, a Fuzzy-based optimisation model was developed to simulate risk-taking attitudes. These contributions hold meaningful implications for stakeholders and decision-makers charged with evaluating the effectiveness of risk mitigation strategies, and by leveraging these, decision-makers may be empowered to make informed choices, thus improving the quality of their response strategies. Additionally, it can aid in gaining a deeper understanding of the behaviour of decision-makers when making risk-based decisions under deep uncertainties, ultimately resulting in the development of better response strategies.

Despite its contributions, the study has several limitations. First, the study considers only five decision responses for the selection of risk response strategies. In order to enhance the model, further factors such as risk culture, RM policies, RM training, and continuous risk monitoring should be considered when selecting the optimal risk response strategy. Second, the study predominantly relies on expert judgment through questionnaire surveys. Finally, the evaluation of risks and response strategies did not encompass the perspectives of all stakeholder groups.

Our study also affords several promising avenues for future research. For instance, the proposed Fuzzy-based optimisation model could be further refined and extended to incorporate additional risk response strategies, as well as a broader range of decision-making criteria. This would facilitate a more comprehensive evaluation of risk response strategies and allow for more informed decision-making under varying circumstances. Another area of interest may be through the investigation of the impact of cultural, organisational, and contextual factors on the selection and effectiveness of risk response strategies. In this vein, by examining the role of these factors in shaping risk management practices, researchers may identify potential barriers to effective risk management and propose targeted interventions to improve overall project outcomes. Lastly, future research may prioritise the involvement of a wider range of stakeholders in the risk management process. For example, by engaging with diverse stakeholder groups and considering their unique perspectives and priorities, such as architects and suppliers, future research could gain valuable insights into the practical challenges and opportunities associated with implementing risk response strategies.

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