CCC 2024 Proceedings of the Creative Construction Conference (2024)
Edited by: Miroslaw J. Skibniewski & Miklós Hajdu
https://doi.org/10.3311/CCC2024-097

ENHANCING RISK RESPONSE STRATEGY SELECTION IN OIL AND GAS CONSTRUCTION PROJECTS: A FUZZY-BASED OPTIMISATION APPROACH

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Abstract

Oil and Gas construction projects are faced with a multitude of risks and uncertainties that can profoundly impact project success, leading to cost overruns, schedule delays, and quality deficiencies. The effective implementation of risk management in this sector is vital to guaranteeing the successful execution and delivery of energy projects. Prior work has mainly focused on the risk identification and analysis phases of the risk management process. However, little attention has been given to the risk response phase and the selection of optimal response strategies. To fill this gap, this research seeks to develop a novel fuzzy-based optimisation model for selecting the most effective and efficient risk response strategy through the lens of Oil and Gas construction experts in Iraq. A mixed-method approach was implemented for data collection, analysis, and processing. This approach included: (1) a focus group session with 10 construction risk and safety experts in Iraq to identify the top five risks facing oil and gas construction projects in the country, outline three to four response strategies for each identified risk, and determine the key criteria for assessing the significance of these risks and for selecting the most appropriate response strategies; (2) a questionnaire survey administered to 100 construction experts to rank the significance of potential responses and their selection criteria based on a five-point Likert scale; (3) the application of fuzzy set theory to develop an optimisation model for risk response strategy selection. By providing a model for evaluating and selecting risk response strategies, decision-makers can gain deeper insights into the potential effectiveness of different approaches and their alignment with project objectives and constraints. This not only facilitates more informed decision-making but also enhances the overall risk governance framework within organisations operating in the Oil and Gas sector in Iraq.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2024.

Keywords: construction, fuzzy set theory, optimisation, risk, risk response selection.

1. Introduction

The oil and gas construction sector is faced with numerous uncertainties and complexities that pose significant risks to project execution, including volatile market prices, environmental considerations, and geopolitical factors [1, 2]. These risks can significantly impact project estimated timelines, costs, and the quality of construction, necessitating effective risk management practices to ensure project success [2].

The nature of these projects demands the implementation of effective risk response strategies to mitigate adverse effects and ensure project deliverables meet planned objectives [3, 4]. Risk response strategies, as highlighted by Mubin and Mannan [5], are vital measures enacted by risk managers to manage potential threats or opportunities throughout the project lifecycle. These strategies aim to minimise the impacts of identified risks, thereby ensuring that the project progresses within its defined constraints of time, budget, and quality standards [6]. The implementation of these strategies is pivotal, as it enables projects to navigate the myriad risks inherent in the oil and gas sector, fostering better decision-making, enhancing transparency, and promoting effective communication among stakeholders. It allows for better cost control through early identification and mitigation of potential risks, ensuring that budgets are allocated efficiently [7]. In addition, it aids in adhering to project schedules by proactively addressing risks as they arise, minimising delays. Moreover, it enhances quality assurance as risks to construction work are mitigated, reducing the likelihood of rework or defects [8].

Prior work and industry practices often place a disproportionate emphasis on the risk identification and analysis phases of the risk management process [9, 10, 11, 12]. While the identification and analysis (collectively known as assessment) of risks are undeniably critical for laying the groundwork for risk management, there exists a notable gap in literature and practice when it comes to the subsequent step: the selection of risk response strategies. Professional risk management standards and bodies extensively discuss potential risk responses—avoidance, acceptance, mitigation, sharing, or transfer—yet they fall short of providing concrete guidelines for choosing the most suitable strategy. These recommended responses are better described as broad themes rather than actionable strategies, each requiring specific, implementable actions tailored to address identified risks. The challenge of selecting optimal risk response strategies has not been adequately addressed by engineering practices and has been scarcely investigated in the risk management literature. In fact, the handful of research on risk response strategy selection via optimisation often faces practical challenges. These challenges include the need for extensive data and the difficulty of incorporating complex criteria like technological feasibility or practicality into decision-making processes [7]. Additionally, the transparency of these models is frequently questioned, complicating the understanding of decision-making rationales. To fill this gap, this research aims to develop a novel fuzzy-based optimisation model for selecting the optimal risk response strategy for oil and gas construction projects by surveying oil and gas construction experts in Iraq.

2. Methods

A mixed-method approach was adopted in this research for data collection, analysis, and processing. The following subsections provide details on each of the adopted methods:

2.1. Focus Group Session

In this research, a focus group session was organised with 12 safety and risk management experts working in the oil and gas construction projects in Iraq to (1) identify the top five risks facing oil and gas construction projects in Iraq; (2) outline two to three responses strategies for each identified risk; and (3) determine the key criteria for assessing the significance of these risks and for selecting the most appropriate response strategies. The participants of the focus group session were selected based on their extensive experience in managing risks in oil and gas construction projects, each having more than 10 years of experience, and being members of the Iraqi Engineers Association. Subsequently, the outputs of the focus group were analysed using the manual content analysis method. This method involves examining the main facets and deriving valid inferences from both verbal and written communication messages, which can be done either quantitatively or qualitatively, as outlined by Krippendorff [13]. Through this analytical process, key factors and risk responses were identified, highlighted, and organised in a coherent manner.

2.2. Questionnaire Survey

The outputs of the focus group session were used to inform the development of a survey instrument aimed at collecting quantitative data. Participants in the focus group recommended the adoption of Failure Mode and Effects Analysis to evaluate the significance of identified risks, using probability (*p*), impact (*i*), and detection (*d*) as criteria. Additionally, the focus group outcomes identified four key criteria for assessing risk response strategies: Sustainability (*S*), Cost-Efficiency (*CE*), Resilience (*R*), and Innovation (*I*). Building on this, the purpose of the survey was to assess the perceived *p*, *i*, and *d* of each identified risk, as well as the assessment criteria associated with each response strategy (i.e., *S*, *CE*, *R*, *I*). The survey was distributed to 100 construction experts working in oil and gas construction projects in Iraq. It consisted of two sections. The first section asked questions about the participants' characteristics, such as working sector, educational background, and years of experience. In the second section, participants were asked to rate the risk and their response strategies assessment criteria using a five-point Likert scale ranging from "very low" (0.1) to "extremely high" (0.5). To ensure the reliability and validity of the survey responses, a Cronbach's alpha test was performed on the dataset. The results of the Cronbach's alpha test yielded a score of 0.78, exceeding the threshold of 0.75, which indicates a reliable and valid scale [14].

2.3. Fuzzy Set Theory

Fuzzy set theory was applied in this research to develop an optimisation model that processes the data from a questionnaire survey to select the optimal risk response strategy for oil and gas construction projects in Iraq. The model, developed using MATLAB® (V.2022a), was structured hierarchically and incorporated several inputs leading to a single final output. The model consisted of three Fuzzy controllers. The first controller processed three specific inputs (i.e., p, *I*, and *d*) —to produce a preliminary risk value (*prv*). The second controller utilised four inputs, representing the selection criteria for each response strategy related to each risk factor (i.e., *S*, *CE*, *R*, *I*) —to produce the quantified selection criteria for each strategy as its output. Finally, the third controller synthesised the outputs (crisp values) from the first two controllers to compute the final risk value (*frv*) for each response strategy. The efficacy of the response strategies corresponding to each risk factor was determined by the reduction in risk value from the initial value to the updated/final value. For example, if three response strategies were proposed for a single risk, with reductions in risk value of 18%, 21%, and 27% respectively, the third strategy—yielding a 27% reduction—would be identified as the most effective. This determination took into account the influence of the four selection criteria associated with the response strategies.

In total, 150 IF-THEN statements were employed in this model, which were established from previous fuzzy-based RM literature [8, 12, 15, 16, 17]. The developed model consists of 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 [12]. Mamdani's fuzzy inference system was used to evaluate the output variable, owing to its frequent use, intuitive nature, and suitability for subjective inputs [15]. Finally, the centroid of area method was employed in this research for defuzzification, due to its effectiveness in producing precise and balanced output values that represent the aggregated fuzzy input [17,18].

3. Results and Discussion

3.1. Characteristics of Survey Participants and Adequacy of Response Rate

A hundred online questionnaires were distributed among professionals working in oil and gas construction projects in Iraq, targeting roles such as project managers, risk managers, safety managers, and consultants. Out of these, 83 responses were collected. Further analysis revealed that 68 of these responses were sufficiently complete and appropriate for in-depth analysis. Data review showed that 65% of the respondents are employed in the public sector, with the remaining 35% in the private sector. Additionally, the findings showed that about 18% of the participants have 1 to 5 years of experience, 42% have 6 to 15 years, 28% have 16 to 25 years, and 12% boast more than 25 years of experience. It was also noted that a significant majority of the participants, 91%, hold a bachelor's degree, while 9% have a master's degree. The relevance and adequacy of the data from these 68 participants were assessed against prior studies. Prior work has established guidelines for minimum sample sizes and acceptable response rates for surveys in construction research. Marsden [19] recommended a sample size ranging from 30 to 50 respondents, while Converse and Presser [20] broadened this recommendation to between 25 and 75 respondents. As for survey response rates, Fellows and Liu [21], along with Hwang et al. [22], have found that a typical response rate in construction research surveys lies between 25% and 35%. The 68% response rate achieved in this research surpasses the standard minimum sample size and response rate benchmarks for empirical studies in the construction field, thereby suggesting that the data collected is both sufficient and valid for this study.

3.2. Developed Fuzzy-based Optimisation Model

The architecture of the proposed response strategies selection model comprises three Fuzzy controllers, as shown in Fig 1. The identified risk factors and their corresponding response strategies are presented in Table 1. The mean values of *p*, *i*, *d*, *S*, *CE*, *R*, and *I* corresponding to each risk factor and response strategy were utilised as inputs to the model and are illustrated in columns 2 through 9 of Table 2. These inputs were subjected to fuzzification using triangular membership functions, followed by conditional processing using 150 IF-THEN rules, and control using a Mamdani-type inference system. The process was concluded with defuzzification through the application of the center of area method. The final result, represented by *frv*, was generated for each of the risk response strategies, as shown in column 11 of Table 2. As described in the research methods, the efficacy of the risk response strategies was measured in terms of their reduction in risk value. Table 2 reveals that the highest reduction in risk value for Risk 1 was recorded for Response 2 (30%), which was deemed the most suitable response strategy in light of its assessment criteria. The most suitable response strategy for Risk 2 was found to be Response 1, with a 38.89% reduction in risk value. Response 2 was identified as the most suitable response strategy for Risk 3, exhibiting a 31% reduction in risk value. Response 1 was determined to be the most suitable response strategy for Risk 4, with a risk reduction percentage of 22.21%. Finally, the highest reduction in risk value for Risk 5 was recorded for Response 2, with a 34.38% reduction in risk value.

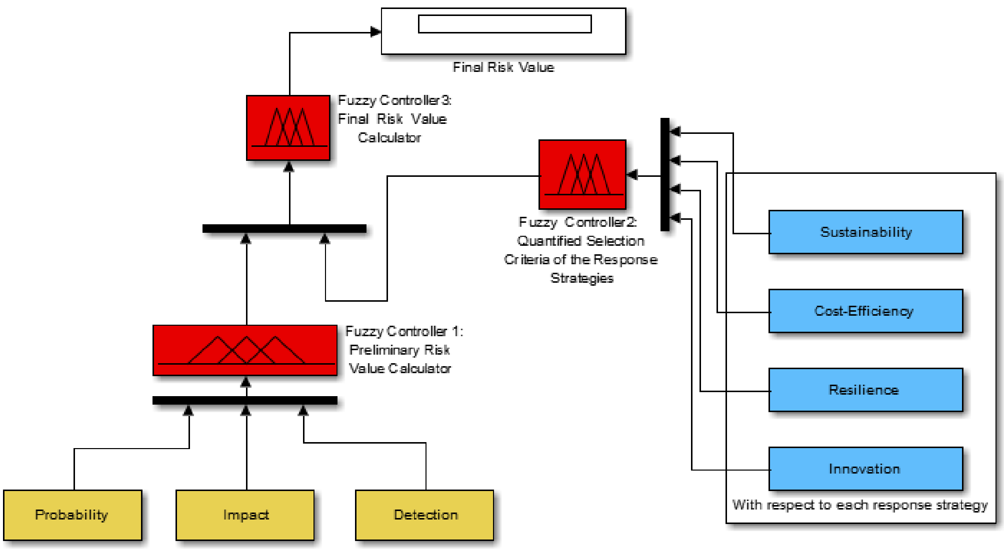

Fig. 1. Architecture of the developed risk response optimisation model

Table 1. Identified risks and their response strategies

Risks	Potential response strategies
Risk 1: Labour shortages	Response 1: Invest in recruitment and training programs to build a reliable workforce
	Response 2: Foster relationships with local labour unions and training institutions to ensure a steady supply of skilled workers

	Response 3: Explore automation and modern construction techniques that can reduce the labour dependency of certain project tasks
Risk 2: Unforeseen site conditions	Response 1: Perform detailed site investigations and geotechnical surveys prior to construction
	Response 2: Include flexible clauses in contracts to accommodate changes due to unforeseen site conditions
Risk 3: Stakeholder misalignment	Response 1: Regular stakeholder meetings to ensure all parties are aligned with the project goals
	Response 2: Utilise transparent communication platforms to share updates and critical information
	Response 3: Implement conflict resolution strategies to manage and resolve disputes quickly
Risk 4: Inadequate documentation and record-keeping	Response 1: Implement a digital document management system to keep records secure and accessible.
	Response 2: Train staff in the importance of proper documentation and provide guidelines on how to maintain records
Risk 5: Equipment malfunction or failure	Response 1: Implement a regular maintenance and inspection schedule for all equipment
	Response 2: Keep critical spare parts in stock to minimise downtime in case of equipment failure
	Response 3: Train operators in the basics of troubleshooting and repairs to address issues quickly

Table 2. Analysis outputs of risk assessment and strategy selection under fuzzy environment

Risk	Risk analysis				*S*	*CE*	*R*	*I*	Response strategy	*frv*	Risk Reduction (%)
Factor	*p*	*i*	*d*	*prv*							
Risk 1	0.4	0.3	0.3	0.036	0.42	0.37	0.24	0.33	Response 1	0.031	13.89
	0.5	0.5	0.2	0.050	0.31	0.43	0.28	0.45	Response 2	0.035	30.00
	0.3	0.4	0.3	0.036	0.35	0.32	0.33	0.49	Response 3	0.027	25.00
Risk 2	0.3	0.2	0.3	0.018	0.41	0.46	0.28	0.38	Response 1	0.011	38.89
	0.2	0.4	0.5	0.040	0.31	0.25	0.25	0.21	Response 2	0.038	5.00
Risk 3	0.4	0.5	0.4	0.080	0.24	0.45	0.39	0.43	Response 1	0.062	22.50
	0.2	0.4	0.5	0.040	0.32	0.28	0.40	0.39	Response 2	0.029	31.00
	0.5	0.2	0.4	0.040	0.48	0.22	0.26	0.25	Response 3	0.034	15.00
Risk 4	0.3	0.3	0.1	0.009	0.19	0.34	0.47	0.40	Response 1	0.007	22.21
	0.4	0.5	0.2	0.040	0.31	0.35	0.38	0.22	Response 2	0.032	20.00
Risk 5	0.2	0.4	0.3	0.024	0.18	0.32	0.28	0.30	Response 1	0.021	12.50
	0.4	0.4	0.2	0.032	0.42	0.37	0.28	0.47	Response 2	0.021	34.38
	0.5	0.3	0.4	0.060	0.39	0.41	0.34	0.29	Response 3	0.046	23.33

4. Conclusion

This research aims to select the optimal risk response strategy for oil and gas construction projects under fuzzy environment. A mixed-method approach was adopted for data collection, analysis, and processing, including a focus group session, questionnaire surveys, and fuzzy set theory. The developed model operates by initially analysing each risk factor's significance through Failure Mode and Effects Analysis, which provides a preliminary risk value. It then evaluates the efficacy of response strategies for each risk factor, assessing their sustainability, cost-efficiency, resilience, and innovation. Finally, the model selects the strategy that achieves the greatest reduction in the preliminary risk value. The selection is based on calculating the percentage reduction from the preliminary to the final risk value generated by the model. The strategy resulting in the greatest reduction is considered the most appropriate for addressing the specific risk factor. The key conclusions of this research can be summarised as follows:

1. Prior work has primarily focused on risk identification and analysis, with minimal attention given to the selection and implementation of appropriate risk response strategies.
2. The application of Failure Mode and Effects Analysis in this research provided a structured approach for analysing the significance level of key risks facing the successful delivery and implementation of oil and gas construction projects.
3. The application of fuzzy set theory effectively addresses the uncertainties and imprecisions often introduced by human bias and conflicts in priorities during risk assessments and the selection of response strategies. The incorporation of fuzzy logic allows these processes to model the complexities of human reasoning, enabling a more detailed interpretation of risk levels and decision-making criteria. This, in turn, facilitates a structured assessment and optimisation mechanism, enhancing the reliability and effectiveness of the strategies implemented.
4. The incorporation of the four assessment criteria for risk response strategies in the developed model allows for a comprehensive evaluation of each strategy, ensuring that the selected responses are not only effective in mitigating risks but also support broader goals such as sustainability (environmental and practices), financial efficiency, operational resilience, and innovative practice enhancement.

4.1. Research Implications

This research makes two significant contributions to the field of risk management in the energy sector. Firstly, it identifies and validates the key criteria (i.e., S, CE, R, I) for evaluating risk response strategies, derived from focus group session with construction risk and safety experts in Iraq. The integration of these criteria into the risk response process establishes a detailed framework that not only aligns with the operational and strategic imperatives of the sector but also promotes the adoption of strategies that are sustainable, cost-effective, resilient, and innovative. This enhances the precision and relevance of risk management practices, improving project management efficacy and efficiency in this high-stakes sector. Secondly, the development of a fuzzy-based optimisation model employs fuzzy set theory to process subjective assessments of risk, incorporating a fuzzy inference system with IF-THEN rules that mimic complex decision-making processes. This methodological innovation significantly enhances the simulation of risk-taking attitudes among decision-makers, allowing for the quantification and integration of expert judgment. Consequently, it enables the selection of the most effective risk response strategies, improving decision-making under uncertainty, effectively aiding in risk mitigation, and ensuring strategic alignment with project demands.

4.2. Limitations and Future Work

The research employed Failure Mode and Effects Analysis to analyse the level of significance of the identified oil and gas construction risks based on three criteria: probability, impact, and detection. To enhance the comprehensiveness of this model, additional dimensions such as the focused impact on time, cost, and quality could be considered. Furthermore, the study identified four key criteria for assessing the appropriateness of response strategies for each risk factor. Incorporating additional assessment criteria could further refine the precision of the developed optimisation model.

4.3. Recommendations for Construction Practitioners

1. Implement the developed fuzzy-based response strategies on various case studies and at different stages of the project life cycle and analyse their impact on project success and related indicators.

2. It is necessary to select the right set of effective and efficient tools and techniques that will assist with the identification and analysis of preliminary risk value or weight. Failure to use the appropriate tools

and techniques could result in ambiguity during the very initial steps of the risk management process, potentially negatively affecting the resources of the construction firm.

3. Construction firms engaged in oil and gas projects should adhere to recognised risk management standards and guidelines, such as ISO:31000 and PMBOK guidelines, throughout the planning, design, implementation, delivery, and maintenance phases. In line with this, they should involve all crucial stakeholders in the risk management process and set up a risk management information and reporting system for each project.

4. Governmental bodies like the Iraqi Engineers Association should provide training, education, and awareness to project managers and contractors on managing key risks in critical infrastructure projects. This effort is crucial for enhancing a sector that significantly impacts the economy of energy-importing countries like Iraq.

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