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Designing a risk-based framework for prioritizing critical factors in drilling projects

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Abstract

Today, the increase in project costs and complexities on the one hand, and the escalation of risks in economic environments on the other hand, have led project managers to incorporate risk management into their project planning and control activities in order to reduce risk exposure and deviation from predetermined objectives. This study aims to present a comprehensive framework for addressing risks in drilling projects. In this research, a novel approach based on multi-criteria decision-making methods and mathematical programming is employed for the first time to analyze risk factors. The proposed approach consists of four main sections. In the first section, 26 common risks in drilling projects, categorized into 13 groups, were identified through a review of research and interviews with experts. In the second section, the best-worst weights related to the evaluation criteria for each risk were identified using the multi-criteria decision-making method. Subsequently, in the third section, critical risks were determined through the application of a new integrated approach based on FMEA (Failure Mode and Effects Analysis) and fuzzy GRA-VIKOR method. Finally, suitable strategies for addressing each risk were selected through the solution of a three-objective optimization mathematical model. The results obtained demonstrate the effectiveness of the proposed framework in addressing risk factors in the oil and gas drilling projects.

Keywords: risk management, drilling projects, Grey theory
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1 Introduction

Organizations are constantly seeking methods to increase efficiency, minimize costs based on their organizational strategy, and enhance their profits [6]. However, among the challenges that may incur significant losses and play a crucial role in escalating the costs of project-oriented organizations is the weak project management and delays occurring throughout its various stages. If a systematic approach can be established to identify the factors causing delays in project completion, and effective steps are taken to reduce or eliminate these factors, allocating resources

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according to strategic priorities can significantly mitigate these costs. Given that project-oriented companies view projects as a strategic option for planning, selecting the right projects on the one hand, and their proper and timely execution on the other hand, are of paramount importance [3]. One of the common issues and challenges in the implementation of drilling projects, especially in developing countries, is the occurrence of delays in the engineering, procurement, execution, and operation phases. In many instances, these delays reach a point where the economic justification of the project becomes questionable. To address existing delays, project managers need to understand the factors contributing to them and take action to mitigate these issues. Additionally, considering the technical requirements and support needs of each project, the impact of each delay factor in project implementation may vary. These factors are recognized by organizational managers in the form of project execution risks. In the field of drilling, identifying and analyzing risks is a fundamental aspect. Risk is a measurable component of uncertainty, with its likelihood of occurrence and the magnitude of its impact estimable and predictable. Risks can be described as deviations from the desired level, which can be either positive or, in most cases, negative. Therefore, risk analysis plays a crucial role in the selection of projects and construction activities [10].

On the other hand, risks in a project are events or conditions of uncertain occurrence that, when realized, can have both negative and positive impacts on project objectives. Each of these events or conditions has identifiable causes and discernible outcomes and consequences. The consequences of these events directly affect the time, cost, and quality of the project; therefore, identifying risks and determining the extent of their positive and negative impacts on project objectives is of particular importance. In recent years, extensive research has been conducted in the field of risk management for drilling projects. One of the most important of these projects involves the implementation of civil projects and massive structures. Drilling industry projects hold a significant and strategic position in the country's economy and security, with their importance growing in recent years. Unfortunately, due to the issues and challenges present in such projects, the evaluation of these projects has not been carried out as thoroughly as necessary. Consequently, in this research, the risks of drilling projects will be analyzed and assessed. Identifying the factors contributing to delays and examining the impact of each of these factors, once investigated and documented, can serve as a guide for future tasks and projects, providing a suitable roadmap for addressing challenges and obstacles in the implementation of upcoming projects. Therefore, the present research seeks to provide a framework for evaluating the risks of drilling projects. By examining, identifying, and analyzing these factors, appropriate solutions for the execution of these projects within the approved timeframe will be presented. In this regard, considering that, generally, in the process of implementing drilling projects in the country, delays have become commonplace due to numerous executive challenges and obstacles in various economic, technical, managerial, political, and environmental aspects, often left unaddressed during the project proposal and study phases. Thus, if the identification of delay-causing factors is undertaken, and the impact level of each of these factors is investigated, specified, and documented, it can serve as a guide for future tasks and projects, providing a suitable roadmap for addressing challenges and obstacles in the implementation of upcoming projects. The structure of the proposed approach includes five main sections.

In the first section, common risks in drilling projects are identified through a literature review, interviews with experts and specialists from the studied organization. Subsequently, for the content validity assessment of the identified risks and the selection and finalization of potential risks, the Laursen credibility assessment method is utilized. One of the advantages of this method is its consideration of both qualitative and quantitative indicators for evaluating factors (items). In the qualitative content review, researchers seek feedback from experts to make necessary adjustments to the tool. In the quantitative content validity assessment, two indices, Content Validity Ratio (CVR) and Content Validity Index (CVI), are employed. The approach is based on aggregating favorable scores for each factor (item). In the second section, the Best-Worst method of multi-criteria decision-making is utilized to calculate weights related to the performance evaluation indicators of each risk. This method addresses the shortcomings of pairwise comparison-based methods (such as Analytic Hierarchy Process and Network Analysis Process) by mitigating issues like inconsistency. Additionally, it significantly reduces the number of pairwise comparisons by only conducting reference comparisons.

Subsequently, in the third section, for ranking and determining critical risks in drilling projects, a new combined approach based on FMEA (Failure Mode and Effects Analysis) and GRA-VIKOR method is employed under an environment of uncertainty in information and utilizing Grey Theory. One of the advantages of the combined GRA-VIKOR method is its ability to optimize multiple responses using a compromise ranking approach for ranking options. In the fourth section, appropriate strategies for addressing each risk are chosen through mathematical modeling. As this section presents a linear multi-objective mathematical model, the Epsilon-Constrained Evolutionary approach is employed to achieve the best solution. Finally, in the fifth section, the results obtained from the proposed approach, along with practical recommendations for future research, are presented.

2 Literature review

Dary and Hamzei [7] employed the ANP technique to investigate risk management in the response phase. Through pairwise comparisons, the best strategy for the most critical risk in the development project of the North Azadegan Oil Field was selected. Baradaran Kazemzadeh and Sharif Mousavi [5] presented a fuzzy risk assessment methodology to determine the project's time risk and estimate deviations from the project scheduling plan. Hosseini et al. [13] used a system scoring method to evaluate the environmental risk of construction activities in the Shadat Oil Platform project. They examined the impact of various identified activities on environmental aspects (air pollution, water pollution, soil pollution, noise, waste, and human impact). Subsequently, using the scoring system (the product of the three factors of importance, effect, and occurrence sequence), they calculated the priority numbers for the risks of each activity. Finally, considering expert opinions, they provided managerial solutions to reduce the risks of activities. The priority numbers for the risks were then recalculated after corrective actions. Zahraei et al. [29] presented a fuzzy expert system-based risk analysis model for project management. Risk assessment was conducted as a case study from the perspectives of the client, consultant, contractor, and ultimately, considering all project stakeholders.

Malmasi et al. [19] examined environmental risks based on importance, intensity, and probability criteria using a Delphi questionnaire in dam construction projects. Subsequently, the mentioned risk criteria were weighted using the entropy method. In the next stage, they employed the ELECTRE method for ranking potential risks. The results indicate that, considering the selected risk indicators, the most significant risks arising from this project include, in order, soil quality reduction, river pollution in the Koomasi River, severe reduction of organic matter and nutrients in the downstream of the dam. Heyrani and Baghaei [12] utilized the Bow-tie method in conjunction with fuzzy logic to reduce uncertainty in the risk assessment of oil and gas pipeline lines. Initially, the influential factors on the safety of transmission lines were identified through the preparation of a specific checklist. Subsequently, using the mentioned method, the risk of the studied pipeline lines was assessed. The research findings showed that third-party injury factors, initial defects in materials, and pipeline construction with a probability of failure of 0.0484 have the highest importance percentage in the destruction of gas and oil transmission pipelines. Jalalvand and Mohammadizadeh [15] investigated risk management and assessed safety challenges, ranking them using the Analytic Hierarchy Process (AHP) method. The results, based on questionnaires distributed among consultants, contractors, and supervisory personnel involved in these projects, indicate that the non-use of safety equipment and personal protection, with a relative weight of 0.322, and the poor and inadequate performance of HSE teams, with a relative weight of 0.208, were the main identified issues. Xu et al. [28] introduced a new approach to developing a reliable risk assessment model based on data obtained from China. This approach provides an opportunity for industry stakeholders to conduct risk assessment in PPP projects using concrete evidence rather than subjective judgment.

In their research, Fernández-Sánchez and Rodriguez-López [11] proposed a technical-scientific method as a suggested framework. The proposed methodology involves identifying various stability factors of a project through the use of risk management standards, suggesting stability as an opportunity. Nieto-Morote and Ruz-Vila [21] presented a risk assessment method based on fuzzy set theory, which serves as an effective tool to deal with subjective judgments. This method was utilized in the hierarchical analysis process for structuring a multitude of risks. Doloi et al. [9] examined key factors influencing delays in the construction industry in India. Through factor analysis and regression modeling, the most critical causes of delays were identified as follows: 1- Lack of commitment, 2- Inefficient management, 3- Weak coordination, 4- Incorrect planning, 5- Lack of transparency in the project scope, 6- Lack of communication, and 7- General contract. Tam and Shen [27] studied risk management by contractors to identify critical risks and risk response techniques in marine projects. Eighteen essential factors were identified through a distributed questionnaire, among which "lack of access to materials, plant, and labor" was found to have the greatest impact on the project's risk. Additionally, the most effective risk response technique was considered to be "relying on past experiences." Mousavi [20] proposed a multi-criteria decision-making method to respond to project risks in the oil and gas industry. This article introduced a new decision-making methodology in a fuzzy environment, using both decision tree and TOPSIS methods to evaluate and select the best solutions for project risks. Huang et al. [14] presented a new evaluation model to estimate the environmental impact of mining, called GEIAM. The evaluation framework in this model considers three groups of criteria, namely geographical risk, environmental risk, and resource damage risk.

The objective of the research by Zou and Sunindijo [30] was to understand project management team skills needed for the safe construction, implementation of safe activities, and the development of a healthy climate for risk in construction. The study also discusses individual project management skills, i.e., what project personnel need effectively for safety management activities. Abhishek and Kumar [1] investigated the scheduling issue of marine construction projects. The results of their research indicated a significant gap in the project management literature concerning marine projects. Additionally, they recommended conducting further technical studies to identify the consequences of delays in Indian marine projects. Adeleke et al. [2] conducted a study examining the role of external organizational factors in construction risk management in Nigerian construction companies. They utilized structural equation modeling to analyze the minimum squares. Koulinas et al. [16] evaluated and analyzed risks at construction sites using the fuzzy network analysis process in the construction sector in Greece. The results obtained indicate that the proposed framework can be a useful tool for decision-makers to estimate a limited contingency budget with the goal of achieving health and safety at the minimum cost.

The present research aims to evaluate the risks of drilling projects by combining the FMEA, BWM, GRA-VIKOR methods under the grey environment and epsilon-constraint. According to the conducted reviews in previous studies, risk management in drilling projects in Iran has received limited attention, focusing solely on identifying risk factors using statistical methods and questionnaires. However, this research not only identifies risk factors but also allocates strategies to address each risk through the presentation of a zero-one programming model, incorporating innovative aspects by combining MCDM methods. The combination of FMEA, BWM, GRA-VIKOR methods under the grey environment offers a novel solution for identifying and prioritizing project risk criteria and factors. Additionally, the use of the epsilon-constraint method to determine risk mitigation strategies allows the operator to tailor strategies based on their preferences for each objective, marking another significant innovation. Due to the complex and specific economic, political, environmental, and social conditions in the country and the susceptibility of drilling projects to these conditions, the epsilon-constraint method will provide a broad range of effective responses tailored to each objective, allowing the operator to prioritize and choose optimal solutions. After finding possible and effective solutions and presenting them to the user, the final choice will be made based on the user's direct decision and preferences or through decision-making methods. This represents a highly significant and practical innovation in the management of risk in the maritime industry, currently the most critical and impactful industry on the country's economy and policies.

3 Research methodology

Research is a systematic and scientific activity revolving around a topic, involving an examination of various aspects of that topic. In another definition, research is the process of knowledge generation. Researchers collect and process information using various tools and methods to analyze and interpret the data. One of the fundamental challenges for the success of a researcher, especially when selecting a topic and presenting research proposals, lies in the failure to choose information and a lack of awareness of systematic research methods. To obtain accurate results from research, it is essential to use an appropriate and topic-matched scientific research method to achieve desired results with lower costs, increased speed, and greater accuracy. The choice of research method depends on the goals, the nature of the research topic, and its execution capabilities. Generally, research methods can be classified based on two criteria: a) research goals and b) execution method. Accordingly, the present research is considered practical in terms of goals (as it involves implementing a model in a specific industry), and in terms of the execution method, it is exploratory and descriptive research. In this study, information is first collected from credible sources such as books and articles in the relevant field. Subsequently, this information (risks and their assessment criteria) is analyzed by industry experts. Initially, the importance (weights) of the relevant criteria for risk assessment are determined using the Multi-Criteria Decision Making (MCDM) method of Best-Worst. Later, a new integrated approach based on the FMEA method and the combined GRA-VIKOR method under the grey environment is used to rank and determine critical risks in drilling. Finally, suitable strategies for responding to each risk are selected through mathematical modeling. Therefore, the present research, in terms of execution method, is both library and field research (survey). A comprehensive examination of a managerial phenomenon requires an appropriate conceptual framework. A theoretical framework or conceptual model illustrates the theoretical relationships among the important variables under investigation. Thus, the theoretical framework of the research is presented in Figure 1 to enhance the understanding of the research stages and clarify the relationships among variables.

3.1 Lauche credibility assessment

Lawshe [18] suggested that each item or question is presented to a group of evaluators or judges, and they are asked whether the specific item is essential or beneficial for measuring the intended construct. According to Lawshe, if more than half of the evaluators or judges indicate that the item is essential or beneficial, that item is considered to have at least some content validity. The higher the success rate of evaluators or judges in identifying an item as essential or beneficial, the higher the level of content validity. Lawshe used the following formula (3.1) to measure content validity, referred to as the Content Validity Ratio (CVR):

$$CVR = \frac{\left(n_e - \frac{N}{2}\right)}{\frac{N}{2}} \tag{3.1}$$

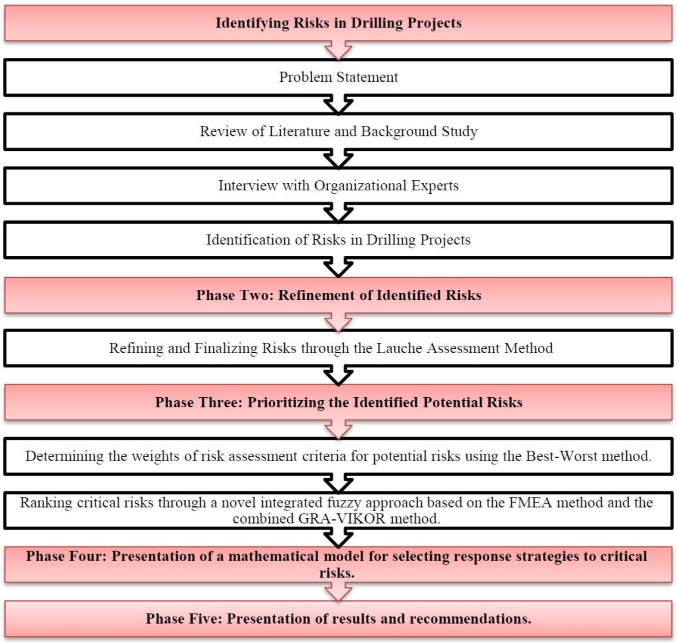

Figure 1: Research Theoretical Framework

in this formula: CVR is the Content Validity Ratio, n_e is the number of evaluators or judges indicating that the item is essential or beneficial, and N is the total number of evaluators or judges.

3.2 Best-worst method

The Best-Worst Method (BWM) is a recent multi-criteria decision-making technique proposed by Rezaei [25], relying on pairwise comparisons to determine the weights of options and relevant criteria. This method addresses the shortcomings of other methods based on pairwise comparisons (such as Analytic Hierarchy Process and Analytic Network Process), such as inconsistency. The Best-Worst Method significantly reduces the number of pairwise comparisons by only performing reference comparisons. Experts are only required to prioritize the best criterion over others and prioritize all criteria over the worst criterion. By eliminating secondary comparisons, this method proves to be much more efficient and faster than other available methods for determining weights in multi-criteria decision-making problems.

Definition 3.1. The comparison a_{ij} is defined as a reference comparison if i is the best element and/or j is the worst element.

Definition 3.2. The comparison a_{ij} is defined as a secondary comparison if neither i nor j is the best or worst element, and $a_{ij} \geq 1$.

The structure of the BWM method consists of the following steps:

Step 1: Determining the set of decision criteria. In this step, criteria are identified through a review of literature and expert opinions, forming $\{c_1, c_2, ..., c_n\}$.

Step 2: Identifying the best (e.g., maximum desirability, maximum importance) and worst (e.g., minimum desirability, minimum importance) criteria. If more than one criterion is considered as the best or worst, the selection is arbitrary.

Step 3: Prioritizing the best criterion relative to other criteria using values between 1 to 9 based on the linguistic scale presented in Table 1. The results of this vector are represented in equation (3.2):

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn}) \tag{3.2}$$

Such that a_{Bj} represents the priority of the selected best criterion B relative to each criterion j. It is clear that $a_{BB} = 1$.

Step 4: Similarly, using numbers between 1 to 9, the priority of all criteria relative to the selected worst criterion is calculated. The results of this vector are represented in equation:

$$A_w = (a_{1W}, a_{2W}, ..., a_{nW})^T \tag{3.3}$$

where a_{jW} represents the priority of each criterion j relative to the selected worst criterion W. It is clear that $a_{WW} = 1$.

Step 5: Optimal weights for all criteria, denoted as $(W_1^*, W_2^*, ..., W_n^*)$, are determined. The objective is to calculate the weights of the criteria in such a way that the maximum absolute difference for all j from the set $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$ is minimized. Based on this, the minimax model is formulated as equation (3.4):

$$\begin{aligned}
&\min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}\\
&S.t. \sum_j w_j = 1\\
&w_j \geq 0, \quad \text{for all } j
\end{aligned} \tag{3.4}$$

The problem (3.4) can be transformed into the model (3.5):

$$\begin{aligned}
&\min \xi\\
&S.t.\\
&\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \quad \text{for all } j\\
&\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \quad \text{for all } j\\
&\sum_j w_j = 1\\
&w_j \geq 0, \quad \text{for all } j
\end{aligned} \tag{3.5}$$

$$\begin{aligned}
&\min \xi^L\\
&S.t.\\
&|w_B - a_{Bj}w_j| \leq \xi^L, \quad \text{for all } j\\
&|w_j - a_{jW}w_W| \leq \xi^L, \quad \text{for all } j\\
&\sum_j w_j = 1\\
&w_j \geq 0, \quad \text{for all } j
\end{aligned} \tag{3.6}$$

The linear model above has a unique solution. Therefore, by solving model (3.5), optimal weights $(w_1^*, w_2^*, ..., w_n^*)$ are obtained. For this model, the value of ξ^{L*} directly indicates the compatibility of the conducted comparisons, and there is no need to use the compatibility index in equation (3.5). Generally, values close to zero for ξ^{L*} indicate a high level of compatibility [26].

3.3 Introduction to the combined fuzzy approach of GRA with VIKOR

In this section, the fundamental definitions of the VIKOR and GRA methods, as well as the new fuzzy combined method, GRA-VIKOR, are briefly introduced.

VIKOR Technique

The VIKOR method was first introduced by Opricovic [24]. It is a compromise ranking method and is often utilized in situations involving conflicting criteria. This method creates a compromise solution based on "closeness to the ideal solution and bilateral agreement through scores." Widely used by many researchers, this method ranks options extensively. Different options are denoted as $a_1, a_2, ..., a_m$. For option a_i, the competence of aspect j is represented by f_{ij}, where f_{ij} is equal to the performance value of aspect j for option a_i. In summary, the compromise ranking algorithm is reviewed as follows:

1. Determining the best value f_j^* and the worst value f_j^- for all criterion performances. The performance of criterion j for beneficial criteria is calculated using equation (3.7):

$$f_j^* = \max_i f_{ij}, \quad i = 1, 2, ..., m$$
$$f_j^- = \min_i f_{ij}, \quad i = 1, 2, ..., m \tag{3.7}$$

2. Calculating the values of S_i and R_i for $i = 1, 2, ..., m$ using equation (3.8).

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij})/(f_j^* - f_j^-)$$
$$R_i = \max \left[w_j (f_j^* - f_{ij})/(f_j^* - f_j^-) \right] \tag{3.8}$$

3. Calculating the values of Q_i for $i = 1, 2, ..., m$, which is defined based on equation (3.9).

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*} \right] + (1 - v) \left[\frac{R_i - R^*}{R^- - R^*} \right] \tag{3.9}$$

So that $S^- = \max_i S_i$, $S^* = \min_i S_i$ and $R^- = \max_i R_i$, $R^* = \min_i R_i$, and the parameter v is the reference weight. v is introduced as the weight of the maximum group satisfaction, while $(1 - v)$ is the weight of individual regret.

3.4 Grey Relational Analysis (GRA)

Grey Relational Analysis (GRA) was first proposed by Deng [8]. The theory of grey systems is an algorithm that analyzes the non-linear relationships among the elements of a system concerning a reference element. It is capable of being used in multi-criteria decision-making problems. The notable feature of this approach is its ability to identify both qualitative and quantitative relationships among complex factors in a system. The approach measures the degree of association between two options using a distance metric [17]. The following concepts, along with the calculation process for the GRA model, are briefly reviewed.

For an MCDM problem, if $X = \{x_0, x_1, x_2, ..., x_i, ..., x_m\}$ is a set of sequences (options), where x_0 represents the reference series and x_i is a comparative series. If x_{0j} and x_{ij} are the relative values at the point/factor j, $j = 1, 2, ..., n$ for x_0 and x_i, then the grey relational coefficient $\gamma(x_{0j}, x_{ij})$ between these options at point j is calculated using Equation (3.10):

$$\gamma(x_{0j}, x_{ij}) = \frac{\min_i \min_j \Delta_{ij} + \xi \max_i \max_j \Delta_{ij}}{\Delta_{ij} + \xi \max_i \max_j \Delta_{ij}} \tag{3.10}$$

where $\Delta_{ij} = |x_{0j} - x_{ij}|$ and ξ is the compensation coefficient with $\xi = [0, 1]$, $i \in I = \{1, 2, ..., i, ..., m\}$, $j \in J = \{1, 2, ..., j, ..., n\}$. After obtaining all the coefficients of grey relationships, the grey relational degree $\gamma(x_{0j}, x_{ij})$ between x_0 and x_i at point j is calculated using Equation (3.11):

$$\gamma(x_{0j}, x_{ij}) = \sum_{j=1}^{n} w_j \gamma(x_{0j}, x_{ij}), \qquad \sum_{j=1}^{n} w_j = 1 \tag{3.11}$$

where w_j represents the weight of point/attribute j

3.5 Mathematical model for risk response

The mathematical model for responding to risks in an organization assumes the existence of a set of strategies for responding to critical risks. In general, implementing each of these solutions incurs costs for the organization. Due to budget constraints, it is only possible to implement a portion of them. Additionally, the response time to each of the risks varies due to their critical nature. Reducing costs and response time, as well as maximizing the quality, are the main objectives of the problem. The aim of this research is to allocate response strategies to critical risks in the organization in a way that achieves the specified goals.

For modeling the problem, as with other mathematical models, certain assumptions are made:

- The number of identified critical risks in the organization is defined and limited.

- The number of response strategies to risks is specified and limited.
- The cost of implementing each strategy for each risk is different and known.
- The response time to each risk is different and known.
- The qualitative level of each strategy for each risk is different and known.

Sets:

i: Set of critical risks, $i = \{1, 2, ..., m\}$

j: Set of response strategies, $j = \{1, 2, ..., n\}$

Parameters:

C_{ij}: Cost of implementing strategy j for critical risk i

T_{ij}: Response time of strategy j for critical risk i

Q_{ij}: Qualitative level of strategy j for critical risk i

BD: Available budget

TN: Available time duration

TP_i: Maximum allowable number of strategies to be assigned to each risk

Decision Variables:

x_{ij}: Equals 1 if strategy j is assigned to critical risk i, and 0 otherwise.

Mathematical Model:

$$\min Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} x_{ij} \tag{3.12}$$

$$\min Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} T_{ij} x_{ij} \tag{3.13}$$

$$\max Z_3 = \sum_{i=1}^{m} \sum_{j=1}^{n} Q_{ij} x_{ij} \tag{3.14}$$

s.t.

$$\sum_{j=1}^{n} x_{ij} \leq TP_i, \qquad \forall i \tag{3.15}$$

$$\sum_{j=1}^{n} x_{ij} \geq 1, \qquad \forall i \tag{3.16}$$

$$x_{ij} \in \{0, 1\}, \qquad \forall i, j \tag{3.17}$$

The presented model has three objective functions explained below. The first objective function (3.12) aims to minimize the cost of implementing risk response strategies. The second objective function (3.13) seeks to minimize the response time of strategies to risks. The third objective function (3.14) aims to maximize the quality level of strategies for risks. The model also includes four constraints. Equation (3.15) ensures that the number of strategies assigned to each risk does not exceed the maximum allowable limit. Constraint (3.16) ensures that each risk is assigned at least one strategy. Finally, constraint (3.17) determines the type of variables used in the problem.

4 Findings

This study generally consists of qualitative and quantitative parts. The following are the basic steps of the study:

Table 1: The initial list of identified risk factors based on the organization's HSE documents

The type of operation/activity/service	**Identified risks**	**Outcomes**
Storing, receiving, and distributing the goods needed by the workshop	Manual loading and unloading	Fractures, injuries, and neuromuscular involvement
Dyeing	Spilling dangerous solutions on the body's skin	Death, burns, and injuries
	Fire	Burns, skin damage
	Respiratory complications caused by dyeing in a closed environment	Damage to the respiratory system
Construction of drilling terminals	Unfavorable ergonomic conditions	Diseases caused by ergonomic factors (back pain, early fatigue caused by work, etc.)
	Harmful psychological factors	Excessive fatigue, intolerance of problems, job dissatisfaction, headache, spine pain, and insomnia
	Noise	auditory system
	Vibrations	Causing the vibration white finger (VWF)
	Radiation	Diseases caused by radiation
Installing rotary equipment	Unexpected startup	Damage to employees in the form of injury, fracture, and amputation
Sandblasting	Working at height	Fractures, injuries, and deaths
	Scattering of dust particles and copper fragments	Damage to the respiratory system and eyes
General activities	H2S gas emission	Death and stoppage of operation
	Burning with molten bitumen during insulation	Skin burns
Oxyacetylene welding	Acetylene tank explosion	Death and injury
Gouging	Electrocution and electric shock	Burns and death
	Inhalation of toxic fumes and vapors	Damage to the respiratory system
Crane operation testing	The sudden fall of the crane and the load on the person during Load and Deflection tests	Death and stoppage of operation
Scaffolding	Scaffolding collapse	Severe brain tissue damage and chest rib fractures
	Falls from height	Severe head injury and death
A hydro test to check the health of the weld lines in the tanks	Bursting pipelines and tanks	Fractures, injuries, and deaths
Flushing pipelines	The risk of working with hydrazine	Vision problems, skin burns, gastrointestinal damage, explosions, fires, and death
External activities affecting the health of employees, equipment, and operational processes	Development and transfer of fire from the neighboring contractors to the workshop	Death, stoppage of operations, and damage to equipment
	The spread of infectious diseases from neighboring contractors due to using common facilities	Spread of diseases and stoppage of operations
	The risk of collision of machinery with visitors and trainees	Injury and death
	The risk of parts falling on visitors and trainees	Injury and death

4.1 Identifying the risks of drilling projects

The risks of various projects in different industries have been studied by many researchers. In the following, the risk factors of drilling projects were identified according to Table 1 through holding meetings and interviews with the relevant officials and brainstorming methods. So, the basic model of the study is as follows:

The mentioned risks were the basis of the study work and refined by experts.

4.2 Validation of risks of drilling projects

At this stage, the risks of drilling projects were first identified through a literature review and face-to-face interviews with experts in the studied organization. These factors were then screened using the Lawshe validity test. For this purpose, questionnaires were designed and provided to an expert committee who were asked to determine the most effective factors. This stage consists of three main parts as follows:

- A list of 26 risks of offshore construction projects and an interview schedule were first prepared based on the Lawshe validity test.
- 40 experts were then interviewed and asked to express their agreement or disagreement with each component.
- Finally, expert opinions were entered in Lawshe validity questionnaires and the CVR of each component was obtained.

Table 2 shows the results of the Lawshe validity test.

Table 2: Validation of risks of drilling projects

Row	**Identified risks**	**N**	n_e	**CVR**	**Threshold**
1	Manual unloading and loading	40	30	0.5	0.29
2	Spilling dangerous solutions on the body's skin	40	38	0.9	0.29
3	Fire	40	32	0.6	0.29
4	Respiratory complications caused by dyeing in a closed environment	40	35	0.75	0.29
5	Unfavorable ergonomic conditions	40	13	-0.35	0.29
6	Harmful psychological factors	40	5	-0.75	0.29
7	Noise	40	10	-0.5	0.29
8	Vibrations	40	32	0.6	0.29
9	Radiation	40	30	0.5	0.29
10	Unexpected startup	40	12	-0.4	0.29
11	Working at height	40	36	0.8	0.29
12	Scattering of dust particles and copper fragments	40	32	0.6	0.29
13	H2S gas emission	40	35	0.75	0.29
14	Burning with molten bitumen during insulation	40	27	0.35	0.29
15	Acetylene tank explosion	40	30	0.5	0.29
16	Electrocution and electric shock	40	32	0.6	0.29
17	Inhalation of toxic fumes and vapors	40	27	0.35	0.29
18	The sudden fall of the crane and the load on the person during Load and Deflection tests	40	34	0.7	0.29
19	Scaffolding collapse	40	27	0.35	0.29
20	Falls from height	40	31	0.55	0.29
21	Bursting pipelines and tanks	40	38	0.9	0.29
22	The risk of working with hydrazine	40	32	0.6	0.29
23	Development and transfer of fire from the neighboring contractors to the workshop	40	31	0.55	0.29
24	The spread of infectious diseases from neighboring contractors due to using common facilities	40	12	-0.4	0.29
25	The risk of collision of machinery with visitors and trainees	40	12	-0.4	0.29
26	The risk of parts falling on visitors and trainees	40	14	-0.3	0.29

The CVR of the factors was calculated using Equation (3.1). According to Table 2, the minimum validity value to accept the factors is 0.29 because there were 40 evaluators. If the CVR value is higher than 0.29 according to expert opinions, the factor is acceptable. Otherwise, it is not acceptable. Table 3 shows the potential risks of drilling projects.

4.3 Determining the weights of evaluation indicators

As described in the third section, indicators are needed based on which the criteria "risk severity", "risk probability of occurrence", "risk identification", "time", "cost", and "quality" are analyzed to evaluate the potential risks identified based on the combined GRA-VIKOR method under the fuzzy environment. The best-worst multi-criteria decision-making method was used to determine the weight and importance of each indicator. For this purpose, questionnaires were designed and provided to an expert committee who were asked to determine the most effective factors. The general steps of this method are explained below. The most important (best) and least important (worst) indicators are first determined by distributing and collecting the questionnaires. The criteria were valued based on the opinions of an expert committee in the field of drilling projects. The best criterion identified by each respondent is the most important criterion affecting the evaluation of risks, and the worst criterion identified by each respondent is the least important criterion based on expert opinions. The best and worst criteria identified by the experts are given in Table 4.

In the following, the other criteria are prioritized over the best criteria through the distribution of questionnaires of the best-worst method among the respondents (experts). It is worth mentioning that the best criterion is chosen

Table 3: The potential risks of drilling projects

Row	The type of operation/activity/service	Identified potential risks	Code
1	Storing, receiving, and distributing the goods needed by the workshop	Manual loading and unloading	R_1
2	Dyeing	Spilling dangerous solutions on the body's skin	R_2
3		Fire	R_3
4		Respiratory complications caused by dyeing in a closed environment	R_4
5	Construction	Vibrations	R_5
6		Radiation	R_6
7	Sandblasting	Working at height	R_7
8		Scattering of dust particles and copper fragments	R_8
9	General activities	H2S gas emission	R_9
10		Burning with molten bitumen during insulation	R_{10}
11	Oxyacetylene welding	Acetylene tank explosion	R_{11}
12	Gouging	Electrocution and electric shock	R_{12}
13		Inhalation of toxic fumes and vapors	R_{13}
14	Crane function testing	The sudden fall of the crane and the load on the person during Load and Deflection tests	R_{14}
15	Scaffolding	Scaffolding collapse	R_{15}
16		Falls from height	R_{16}
17	A hydro test to check the health of the weld lines in the tanks	Bursting pipelines and tanks	R_{17}
18	Flushing pipelines	The risk of working with hydrazine	R_{18}
19	External activities affecting the health of employees, equipment, and operational processes	Development and transfer of fire from the neighboring contractors to the workshop	R_{19}

Table 4: The best and worst criteria identified by the experts

Criterion (indicator)	Best	Worst
Severity	1, 5, 8	–
Probability of occurrence	3, 7	6, 10
Identification	9	1, 4, 5
Time	2, 10	8
Cost	4, 6	–
Quality	–	2, 3, 7, 9

Table 5: The pairwise vectors of the best criterion-other criteria

Experts	the best criterion	The other criteria					
		Severity	Probability of occurrence	Identification	Time	Cost	Quality
1	Severity	1	3	9	2	4	2
2	Time	4	2	3	1	2	8
3	Probability of occurrence	2	1	4	2	2	9
4	Cost	2	3	8	4	1	2
5	Severity	2	2	9	3	2	2
6	Cost	2	8	2	4	1	2
7	Probability of occurrence	2	1	2	2	3	8
8	Severity	1	3	3	9	2	5
9	Identification	3	4	1	2	3	9
10	Time	2	8	3	1	4	2

optionally if more than one criterion is chosen as the best according to the experts. Table 5 shows the pairwise vectors of the best criterion-other criteria.

Similarly, the other criteria are prioritized over the worst criteria through the distribution of questionnaires of the best-worst method among the respondents (experts). It is worth mentioning that the best criterion is chosen optionally if more than one criterion is chosen as the worst according to the experts. Table 6 shows the pairwise vectors of the best criterion-other criteria.

Finally, the results of the compatibility coefficient of pairwise comparisons and the weights of the indicators affecting the evaluation of potential risks of drilling projects were determined by solving the linear model of the best-worst method (Equation (3.7)) for 10 respondents (experts) using GAMS version 24.3 software and CPLEX solver. These weights are the average weights obtained for each indicator in a single weight vector shown in Table 7.

In the table above, ξ^{L^*} indicates the compatibility of pairwise comparisons. According to the table, the comparisons

Table 6: The pairwise vectors of the worst criterion-other criteria

Experts	1	2	3	4	5	6	7	8	9	10
	The worst criterion									
The other criteria	Identification	Quality	Quality	Identification	Identification	Cost	Quality	Time	Quality	Probability of occurrence
Severity	9	2	2	2	9	2	2	9	2	4
Probability of occurrence	2	3	9	4	2	8	8	3	3	1
Identification	1	2	3	1	1	3	2	2	9	2
Time	2	8	5	2	2	4	3	1	4	8
Cost	3	3	2	8	4	1	5	4	2	4
Quality	4	1	1	5	3	2	1	3	1	3

Table 7: The weights of the indicators affecting the evaluation of potential risks of drilling projects

Criterion	Experts (respondents)										Final weight
	1	2	3	4	5	6	7	8	9	10	
Severity	0.356	0.100	0.148	0.151	0.326	0.149	0.139	0.400	0.121	0.205	0.210
Probability of occurrence	0.138	0.175	0.352	0.137	0.137	0.043	0.353	0.146	0.106	0.038	0.163
Identification	0.046	0.125	0.102	0.048	0.042	0.191	0.145	0.121	0.394	0.128	0.134
Time	0.149	0.375	0.205	0.103	0.126	0.106	0.185	0.042	0.212	0.359	0.186
Cost	0.103	0.175	0.148	0.356	0.189	0.362	0.139	0.204	0.121	0.103	0.190
Quality	0.207	0.050	0.045	0.205	0.179	0.149	0.040	0.088	0.045	0.167	0.118
ξ^{L^*}	0.056	0.025	0.057	0.055	0.053	0.064	0.064	0.038	0.030	0.051	0.049

are highly compatible because their value is 0.049 and this value is close to zero. Furthermore, the indicators "risk severity" and "cost" are more important and weighted than other indicators, respectively.

4.4 Determining critical risks

The weights of the indicators for evaluating the potential risks of drilling projects were determined in the previous stages. As stated earlier, the weaknesses of the traditional FMEA model that obtains the PRN number, led to the development of the FMEA model in this study and taking a fundamental by combining the GRA-VIKOR model under the fuzzy environment to solve this problem. To this end, the indicators probability of occurrence, severity, and identification were evaluated for the identified risks. These numbers are no longer multiplied together to obtain PRN, but they are applied together with the evaluation numbers of three other indicators, i.e. time, cost, and quality, as inputs to the GRA-VIKOR model under the fuzzy environment, and potential risks are prioritized after analysis. Finally, critical risks are determined to allocate response strategies to them. In this section, the functional characteristics of each risk can be measured by converting verbal variables into quantitative values and using the fuzzy GRA-VIKOR combined technique. For this purpose, 19 risks identified based on the indicators "severity", "probability of occurrence", "identification", "time", "cost", and "quality" are done by distributing and collecting questionnaires for ranking potential risks and implementing the proposed ranking method step by step as follows.

Step 1. Forming the decision matrix: The fuzzy decision matrix is formed as in Table 8 by applying Equation (3.14) according to the number of criteria, the number of alternatives, and the evaluation of all alternatives for different criteria.

Step 2. Descaling the decision matrix: The initial fuzzy decision matrix should be converted to a comparable scale to ensure consistency between the evaluation criteria. So, the normalized fuzzy decision matrix is obtained as in Table 9 by applying Equation (3.16).

Although the indicators time, cost, and intensity are of the type of cost, all the indicators are considered to be of the type of benefit since their score in the questionnaire is given based on their importance, not based on their measurement unit.

Step 3. Calculating the reference series of positive and negative ideal solutions: Two reference series of positive ideal solutions A^+ and negative ideal solutions A^- are defined by applying Equations (3.16) and (3.17) as shown in Table 10 after calculating the normalized values of different criteria.

Step 4. Calculating the coefficient of the fuzzy gray relation: The positive and negative ideal solutions are the reference series, and each alternative is the comparing series. The coefficient of the fuzzy gray relation of each alternative compared to the positive ideal solution is calculated in as in Table 11. It is worth mentioning that the parameter ξ, which is introduced as the elimination coefficient, is considered 0.5.

Table 8: The alternative-criterion matrix for the evaluation values of potential risks

	Severity			Probability of occurrence			Identification			Time			Cost			Quality		
R_1	2.62	5.04	7.30	1.34	6.12	8.64	2.52	5.72	9.41	3.01	5.86	8.28	2.76	6.45	7.63	2.60	5.90	8.08
R_2	2.55	5.86	8.38	1.91	6.36	8.44	1.32	5.04	7.41	2.60	5.14	7.37	3.86	5.18	7.41	1.61	5.93	8.94
R_3	1.98	5.17	9.48	1.02	5.11	8.97	4.18	5.43	7.12	1.25	6.26	9.30	4.48	5.05	7.93	4.27	6.34	9.40
R_4	2.71	6.00	7.97	1.16	6.24	7.65	1.23	5.34	7.95	1.66	5.09	7.34	1.27	5.50	8.85	3.08	5.07	9.09
R_5	3.08	5.34	8.39	3.72	5.63	7.02	2.13	6.15	9.38	2.09	6.07	9.48	1.82	5.33	7.07	3.87	5.99	7.16
R_6	4.11	5.36	7.24	2.46	5.60	8.68	1.14	5.11	9.49	2.08	5.04	8.05	3.23	5.44	9.40	4.10	6.46	7.04
R_7	1.67	5.66	9.47	2.29	5.78	9.08	2.70	5.52	7.06	1.06	5.70	8.68	3.04	5.88	8.59	2.93	6.36	8.61
R_8	2.27	5.79	7.78	1.76	5.04	8.63	3.96	5.46	7.04	2.44	5.39	7.47	2.35	5.58	8.97	3.18	5.11	8.35
R_9	2.87	6.45	7.78	1.98	5.01	9.27	1.15	6.46	7.09	4.22	6.40	7.75	4.12	6.31	7.28	4.42	5.58	7.32
R_{10}	3.32	5.31	7.00	1.13	5.72	7.83	3.35	5.12	8.52	4.47	6.22	8.10	2.35	6.08	7.24	2.83	5.75	9.00
R_{11}	2.80	5.88	7.56	4.26	5.90	8.40	3.91	6.06	9.17	3.78	5.41	8.43	1.76	6.42	7.02	4.25	5.43	8.62
R_{12}	3.45	6.40	7.86	1.80	5.90	8.63	3.98	5.97	7.73	3.10	5.07	7.59	3.42	5.95	7.55	4.23	6.49	7.67
R_{13}	3.95	6.45	7.57	3.24	5.81	7.72	3.20	6.40	7.73	2.71	5.56	9.39	3.34	5.56	7.58	2.44	5.43	8.73
R_{14}	3.40	5.70	9.41	1.48	5.67	7.96	1.06	5.88	7.47	2.46	6.10	7.96	3.98	6.29	9.33	3.31	5.79	8.67
R_{15}	2.37	6.32	7.09	3.48	5.30	8.37	1.30	5.92	9.36	2.32	5.95	8.02	4.30	5.38	9.14	1.21	5.15	7.52
R_{16}	1.24	5.07	8.45	2.99	5.67	9.02	2.90	5.53	9.46	1.34	5.38	8.92	1.82	6.02	7.44	4.31	5.44	9.04
R_{17}	1.67	6.04	7.20	4.49	6.09	7.49	3.55	5.72	9.42	4.14	5.54	7.48	3.60	5.82	8.84	2.87	5.81	7.27
R_{18}	2.24	5.94	8.46	4.40	5.20	9.12	4.29	5.25	7.32	1.96	5.24	8.12	1.84	5.47	7.78	1.24	5.46	9.42
R_{19}	2.90	5.58	7.72	3.39	5.14	7.74	2.35	5.42	7.87	3.80	5.30	7.12	3.48	6.45	9.18	4.28	6.18	9.29

Table 9: The unscaled alternative-criterion fuzzy matrix

	Severity			Probability of occurrence			Identification			Time			Cost			Quality		
R_1	0.28	0.53	0.77	0.14	0.66	0.93	0.27	0.60	0.99	0.32	0.62	0.87	0.29	0.69	0.81	0.28	0.63	0.86
R_2	0.27	0.62	0.88	0.21	0.69	0.91	0.14	0.53	0.78	0.27	0.54	0.78	0.41	0.55	0.79	0.17	0.63	0.95
R_3	0.21	0.55	1.00	0.11	0.55	0.97	0.44	0.57	0.75	0.13	0.66	0.98	0.48	0.54	0.84	0.45	0.67	1.00
R_4	0.29	0.63	0.84	0.13	0.67	0.83	0.13	0.56	0.84	0.18	0.54	0.77	0.14	0.59	0.94	0.33	0.54	0.96
R_5	0.32	0.56	0.89	0.40	0.61	0.76	0.22	0.65	0.99	0.22	0.64	1.00	0.19	0.57	0.75	0.41	0.64	0.76
R_6	0.43	0.57	0.76	0.27	0.60	0.94	0.12	0.54	1.00	0.22	0.53	0.85	0.34	0.58	1.00	0.44	0.69	0.75
R_7	0.18	0.60	1.00	0.25	0.62	0.98	0.28	0.58	0.74	0.11	0.60	0.92	0.32	0.63	0.91	0.31	0.68	0.91
R_8	0.24	0.61	0.82	0.19	0.54	0.93	0.42	0.58	0.74	0.26	0.57	0.79	0.25	0.59	0.95	0.34	0.54	0.89
R_9	0.30	0.68	0.82	0.21	0.54	1.00	0.12	0.68	0.75	0.45	0.68	0.82	0.44	0.67	0.77	0.47	0.59	0.78
R_{10}	0.35	0.56	0.74	0.12	0.62	0.84	0.35	0.54	0.90	0.47	0.66	0.85	0.25	0.65	0.77	0.30	0.61	0.96
R_{11}	0.30	0.62	0.80	0.46	0.64	0.91	0.41	0.64	0.97	0.40	0.57	0.89	0.19	0.68	0.75	0.45	0.58	0.92
R_{12}	0.36	0.68	0.83	0.19	0.64	0.93	0.42	0.63	0.81	0.33	0.53	0.80	0.36	0.63	0.80	0.45	0.69	0.81
R_{13}	0.42	0.68	0.80	0.35	0.63	0.83	0.34	0.67	0.81	0.29	0.59	0.99	0.36	0.59	0.81	0.26	0.58	0.93
R_{14}	0.36	0.60	0.99	0.16	0.61	0.86	0.11	0.62	0.79	0.26	0.64	0.84	0.42	0.67	0.99	0.35	0.61	0.92
R_{15}	0.25	0.67	0.75	0.38	0.57	0.90	0.14	0.62	0.99	0.24	0.63	0.85	0.46	0.57	0.97	0.13	0.55	0.80
R_{16}	0.13	0.53	0.89	0.32	0.61	0.97	0.31	0.58	1.00	0.14	0.57	0.94	0.19	0.64	0.79	0.46	0.58	0.96
R_{17}	0.18	0.64	0.76	0.48	0.66	0.81	0.37	0.60	0.99	0.44	0.58	0.79	0.38	0.62	0.94	0.30	0.62	0.77
R_{18}	0.24	0.63	0.89	0.47	0.56	0.98	0.45	0.55	0.77	0.21	0.55	0.86	0.20	0.58	0.83	0.13	0.58	1.00
R_{19}	0.31	0.59	0.81	0.37	0.55	0.83	0.25	0.57	0.83	0.40	0.56	0.75	0.37	0.69	0.98	0.45	0.66	0.99

Table 10: Reference series of ideal positive and negative solutions

A^+	0.43	0.68	1.00	0.48	0.69	1.00	0.45	0.68	1.00	0.47	0.68	1.00	0.48	0.69	1.00	0.47	0.69	1.00
A^-	0.21	0.53	0.77	0.11	0.55	0.76	0.13	0.53	0.75	0.13	0.54	0.77	0.14	0.54	0.75	0.17	0.54	0.76

Table 11: The coefficient of fuzzy gray relation of each alternative compared to the positive ideal solution

Alternative-criterion matrix	Severity	Probability of occurrence	Identification	Time	Cost	Quality
R_1	0.17	0.11	0.09	0.10	0.09	0.12
R_2	0.10	0.09	0.21	0.17	0.14	0.12
R_3	0.12	0.17	0.12	0.10	0.11	0.01
R_4	0.10	0.14	0.18	0.20	0.15	0.12
R_5	0.11	0.12	0.08	0.08	0.19	0.10
R_6	0.12	0.11	0.15	0.17	0.09	0.07
R_7	0.11	0.10	0.16	0.15	0.09	0.07
R_8	0.13	0.16	0.13	0.16	0.11	0.13
R_9	0.08	0.14	0.15	0.05	0.07	0.10
R_{10}	0.15	0.16	0.12	0.05	0.13	0.09
R_{11}	0.12	0.05	0.04	0.10	0.14	0.08
R_{12}	0.06	0.11	0.08	0.16	0.10	0.05
R_{13}	0.05	0.11	0.08	0.09	0.13	0.13
R_{14}	0.06	0.15	0.17	0.11	0.02	0.09
R_{15}	0.12	0.11	0.11	0.12	0.07	0.21
R_{16}	0.18	0.08	0.09	0.15	0.15	0.07
R_{17}	0.15	0.06	0.06	0.11	0.07	0.13
R_{18}	0.10	0.07	0.12	0.16	0.17	0.14
R_{19}	0.12	0.14	0.15	0.14	0.03	0.02

Accordingly, the coefficient of the fuzzy gray relation of each alternative compared to the negative ideal solution is calculated as in Table 12.

Table 12: The coefficient of fuzzy gray relation of each alternative compared to the negative ideal solution

Alternative-criterion matrix	Severity	Probability of occurrence	Identification	Time	Cost	Quality
R_1	0.88	0.50	0.45	0.48	0.45	0.53
R_2	0.55	0.45	0.94	0.74	0.56	0.53
R_3	0.63	0.67	0.52	0.48	0.49	0.34
R_4	0.55	0.57	0.75	0.93	0.60	0.54
R_5	0.59	0.51	0.42	0.45	0.80	0.49
R_6	0.60	0.49	0.63	0.75	0.44	0.43
R_7	0.57	0.45	0.63	0.63	0.44	0.42
R_8	0.64	0.64	0.54	0.68	0.50	0.59
R_9	0.49	0.57	0.60	0.40	0.41	0.50
R_{10}	0.73	0.65	0.52	0.39	0.55	0.47
R_{11}	0.60	0.38	0.37	0.48	0.56	0.45
R_{12}	0.46	0.50	0.43	0.67	0.47	0.40
R_{13}	0.44	0.47	0.43	0.47	0.52	0.56
R_{14}	0.45	0.61	0.69	0.51	0.34	0.46
R_{15}	0.60	0.48	0.50	0.54	0.41	1.00
R_{16}	0.92	0.43	0.44	0.65	0.58	0.43
R_{17}	0.73	0.40	0.40	0.50	0.41	0.59
R_{18}	0.56	0.41	0.52	0.70	0.66	0.60
R_{19}	0.63	0.56	0.61	0.60	0.35	0.36

Step 5. Calculating S_i, R_i, and Q_i values: In this section, the values of S_i representing the distance of alternative i from the positive ideal solution, R_i representing the distance of alternative i from the negative ideal solution, and Q_i of each alternative (risk) are calculated as in Table 13. It should be noted that the parameter v, which is introduced as a weight for the maximum group utility strategy, is considered 0.5.

Table 13: The values of S, R, and Q for each alternative (risk)

	S	**R**	**Q**
R_1	0.539	0.185	0.744
R_2	0.499	0.138	0.618
R_3	0.574	0.131	0.341
R_4	0.472	0.173	0.895
R_5	0.542	0.151	0.550
R_6	0.531	0.139	0.520
R_7	0.551	0.119	0.347
R_8	0.486	0.135	0.647
R_9	0.604	0.102	0.088
R_{10}	0.545	0.153	0.548
R_{11}	0.613	0.125	0.182
R_{12}	0.596	0.124	0.230
R_{13}	0.596	0.100	0.100
R_{14}	0.627	0.100	0.000
R_{15}	0.543	0.125	0.410
R_{16}	0.523	0.193	0.835
R_{17}	0.593	0.152	0.393
R_{18}	0.517	0.130	0.518
R_{19}	0.607	0.132	0.237
$S^- = 0.472$		$R^- = 0.193$	
$S^* = 0.627$		$R^* = 0.100$	

Step 6. Ranking the alternatives based on the values of S_i, R_i, and Q_i: The alternatives are ranked according to the values of S_i, R_i, and Q_i, with the alternative with the lowest value of S_i, R_i, and Q_i ranked first. In this way, R_{14} (the sudden fall of the crane and the load on the person during the Load and Deflection tests) is ranked first because it has the lowest Q value and also guarantees the pair of conditions of the GRA-VIKOR fuzzy hybrid method as shown in Table 14 ($Q(R_9) - Q(R_{14}) \geq 1.18$).

The results were provided to an expert committee to select critical risks in drilling projects. They selected the items whose Q was less than 0.5 as critical risks for allocating a response strategy to them after reviewing the prioritization of risks and implicitly confirming the results. The final prioritization of the studied risks can be seen in Table 15.

Table 14: Ranking the alternatives based on the values of S, R, and Q

Risk	S	Ranking	R	Ranking	Q	Ranking
R_1	0.539	7	0.185	18	0.744	17
R_2	0.499	3	0.138	12	0.618	15
R_3	0.574	12	0.131	9	0.341	7
R_4	0.472	1	0.173	17	0.895	19
R_5	0.542	8	0.151	14	0.550	14
R_6	0.531	6	0.139	13	0.520	12
R_7	0.551	11	0.119	4	0.347	8
R_8	0.486	2	0.135	11	0.647	16
R_9	0.604	16	0.102	3	0.088	2
R_{10}	0.545	10	0.153	16	0.548	13
R_{11}	0.613	18	0.125	6	0.182	4
R_{12}	0.596	15	0.124	5	0.230	5
R_{13}	0.596	14	0.100	2	0.100	3
R_{14}	**0.627**	**19**	**0.100**	**1**	**0.000**	**1**
R_{15}	0.543	9	0.125	7	0.410	10
R_{16}	0.523	5	0.193	19	0.835	18
R_{17}	0.593	13	0.152	15	0.393	9
R_{18}	0.517	4	0.130	8	0.518	11
R_{19}	0.607	17	0.132	10	0.237	6

Table 15: The critical risks of drilling projects

Row	**Identified critical risk**	**Q**	**Ranking**	**Code**
1	The sudden fall of the crane and the load on the person during Load and Deflection tests	0.000	1	R_{14}
2	H2S gas emission	0.088	2	R_9
3	Inhalation of toxic fumes and vapors	0.100	3	R_{13}
4	Acetylene tank explosion	0.182	4	R_{11}
5	Electrocution and electric shock	0.230	5	R_{12}
6	Development and transfer of fire from the neighboring contractors to the workshop	0.237	6	R_{19}
7	Fire	0.341	7	R_3
8	Working at height	0.347	8	R_7
9	Bursting pipelines and tanks	0.393	9	R_{17}
10	Scaffolding collapse	0.410	10	R_{15}

4.5 Solving the mathematical model of strategy selection

The model was solved in 66.96 seconds using GAMS optimization software and the CPLEX solver. The allocation of each strategy to each risk was then determined, the results of which are given in the tables below. A total of 18 points on the Pareto front were created after solving the model. Table 16 shows the values of the objective functions (cost, time, and quality) for each point.

Table 16: Pareto points created by solving the model

Point	1	2	3	4	5	6	7	8	9	10
Cost	100	101	103	124	136	101	102	148	103	104
Time	48	44	39	27	24	48	43	24	43	39
Quality	4.32	4.40	4.92	5.62	5.13	4.62	4.84	5.13	5.14	5.23
Point	11	<u>12</u>	13	14	15	16	17	18	–	–
Cost	107	<u>108</u>	137	111	113	114	125	139	–	–
Time	40	<u>36</u>	24	33	31	33	27	24	–	–
Quality	5.48	<u>5.57</u>	5.44	5.69	5.66	5.96	5.92	5.91	–	–

The Pareto front obtained from the three objective functions is shown in Figures 2 to 4. The best point is point 12 from the point of view of the management after presenting the results to the experts and according to the values obtained for the objective functions. At this point, $Z_1 = 108, Z_2 = 36$, and $Z_3 = 5.57$. The Pareto front created based on the objective functions of time and cost can be seen in Figure 2.

In the following, how to allocate strategies to each risk according to Table 17 is shown by opening point 12 (redpoint) from the Pareto front created.

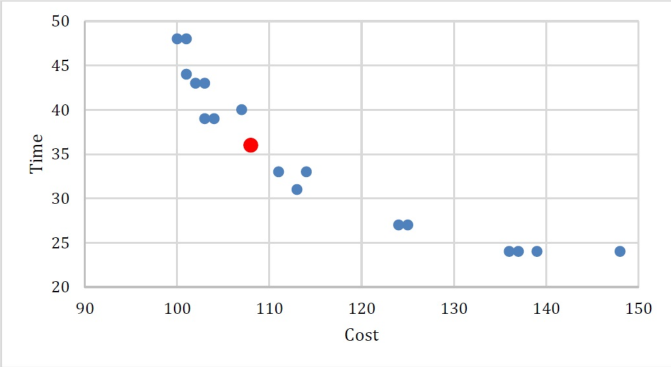

Figure 2: The Pareto front created based on the objective functions of time and cost

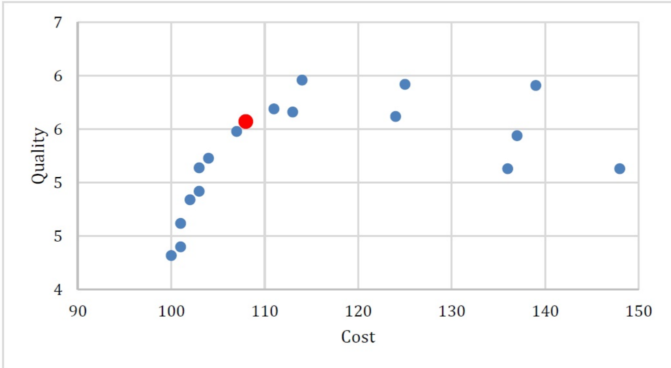

Figure 3: The Pareto front created based on the objective functions of quality and cost

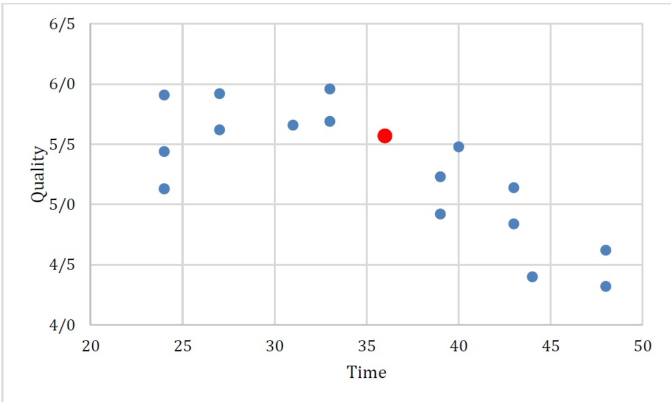

Figure 4: The Pareto front created based on the objective functions of quality and time

5 Conclusions and recommendations for future studies

Risk management is one of the project management phases. Since the oil industry operates in the form of construction projects, this study used the project management standard (PMBOK) for risk management. 26 risks and opportunities (potential and actual) were identified and placed in 13 general categories to develop and implement a risk management system in drilling projects. The calculations concerning their evaluation and ranking were then performed. In the following, a team of selected members and senior managers was formed and the team members proposed solutions according to their field of activities to develop the proposed solutions. The index of important risks was then calculated after applying the solutions. The results confirm the efficiency of the proposed approach to dealing with risk. The general review of important risks and proposed solutions confirms that most drilling projects lack a mature and professional management and execution system, and most of the problems are caused by this deficiency. Accordingly, the proposed solutions are mainly about the development of guidelines, procedures, and job

Table 17: How to allocate strategies to each risk

Risk	Strategy								Risk	Strategy							
R1	x_1	x_2	x_3	x_4	x_5	x_6	x_7 ■	x_8	**R6**	o_1	o_2	o_3 ■	-	-	-	-	-
R2	y_1 ■	y_2	y_3	y_4	y_5	y_6	-	-	**R7**	p_1	p_2	p_3 ■	p_4	p_5	-	-	-
R3	z_1	z_2	z_3	z_4 ■	z_5	-	-	-	**R8**	q_1	q_2	q_3	q_4 ■	-	-	-	-
R4	m_1	m_2	m_3 ■	m_4	m_5	-	-	-	**R9**	r_1	r_2 ■	r_3	-	-	-	-	-
R5	n_1	n_2	n_3 ■	-	-	-	-	-	**R10**	s_1	s_2 ■	s_3	s_4	s_5	s_6	-	-

descriptions and determining the scope of authority. According to the findings, future studies are recommended to use a combination of interviews and questionnaires in all stages to examine all aspects of the problem more completely and to prevent experts from giving conservative answers because usually more useful information can be obtained during the interview process due to two-way communication. It should be noted that this method was used only in the risk response section of this study.

While we have not yet moved beyond the age of cyberspace and social media [22], the revolutionary development of artificial intelligence brings AI applications to the core of every aspect of our lives [4]. Whether we consider this as the empowerment of modern societies with powerful technologies or label it as a 'technological overload' [23], we must examine the use of all these technologies for the future of professional management in different fields. Future studies should also delve deeper into the application of evolving technologies in risk management.

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