A Fuzzy Decision-Making Methodology for Risk Response Planning in Large-Scale Projects

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Abstract

Risk response planning is one of the main phases in the project risk management and has major impacts on the success of a large-scale project. Since projects are unique, and risks are dynamic through the life of the projects, it is necessary to formulate responses of the important risks. The conventional approaches tend to be less effective in dealing with the impreciseness of risk response planning. This paper presents a new decision-making methodology in a fuzzy environment to evaluate and select the appropriate responses for project risks. To this end, two fuzzy well-known decision-making techniques, namely, decision tree and TOPSIS (technique for order preference by similarity to ideal solution), are extended based on multiple selected criteria, simplifying parameterized metric distance and fuzzy similarity measure. Finally, a case study in an oil and gas project in Iran is provided to show the suitability of the proposed fuzzy methodology in large-scale practical situations.

Keywords: Risk Response Planning, Fuzzy Sets, Decision Tree, Modified TOPSIS, Large-Scale Projects.

1. Introduction

Risk management is a main part of the decision-making process in large-scale projects. It is concerned with understanding the project and making an appropriate decision in this regard for future [24]. Because of the various existing factors, such as planning and design complexity, presence of different groups (e.g., project owner, consultants and contractors), required resources (e.g., materials, equipment and funds), the economic and political environment and regulations, large-scale projects are exposed to uncertain environments [14].

A risk within a project is an uncertain event that can influence its objectives including time, cost, quality, and scope. Project risk management is defined as the processes including identifying, analyzing, responding, and monitoring to uncertainty throughout the project life cycle. Risk response planning is one of the major phases in the project risk management that has critical impacts on the success of a project. In this phase, options and actions are extended to reduce threats and to enhance opportunities to the project objectives [23]. In fact, the project team in the risk response planning is asked to assign responsibilities to people and groups close to the risk event. This phase often contains the following strategies and actions [4]:

- *Avoidance*: The project plan is altered by the project team in order to eliminate the risk or to protect the project objectives from its impact. The team may manage this activity by changing scope of work, adding time, or adding required resources to avoid identified risks.
- *Transference*: The project team transfers the financial influence of an identified risk by contracting out some aspects of the work. Transference often considers the risk reduction if the contractor can take steps to alleviate the identified risk and does so.
- *Mitigation*: The project team makes attempts to reduce the probability or consequences of a risk event to an acceptable threshold before the risk occurs. They achieve this by using many different means that are specific to both the project and the risk.

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- *Acceptance*: The project team makes a decision to accept certain risks. Then, the project plan is not altered to handle a risk, or identify any response action other than agreeing to address the risk if and when it occurs.

Risk response planning in large-scale projects needs to be more specific, structured and professional. Since projects are unique, and risks are dynamic through the life of the project, it is necessary to formulate responses of the risks that are suitable. The information gained from the project risk identification and assessment phases provide an understanding of their likely impact on the project if they are realized appropriately. Consequently, a proper response can be selected [24].

In the previous studies, there are limited attempts that have focused on the risk response planning phase within large-scale projects. Baker et al. [2] investigated the choice and application of the most commonly used techniques for the risk response planning within oil and gas industry and compared them with the use of those selected by construction industry. They concluded that risk reduction as a response to evaluated risks is commonly used for large-scale projects. Ben-David and Raz [3] proposed the development of a decision-support model for risk response planning in software development of electronic devices. Their model let the risk reduction efforts to be allocated with mathematical optimization technique. Piny [22] built the response planning chart for treats and opportunities which is divided in six areas to define the overall strategy for each risk.

Young [27] proposed a conceptual framework for risk response planning on projects. Pan and Chen [21] presented an economic optimization model based on the model proposed by Ben-David and Raz [6] for selecting risk reduction actions in CMMI-based software projects with an example taken from a Chinese software industry. Fan et al. [8] provided a conceptual framework that defines the relationship between risk-handling strategy and relevant project characteristics, and describes the quantitative relationships among all variables. Aaltonen and Sivonen [1] identified and regarded five different types of response strategies through an empirical analysis of four cases in emerging markets in global projects.

The review of related literature indicates that risk response planning in large-scale projects has not received sufficient attention from researchers unlike other phases of the project risk management, such as risk identification and risk assessment. Moreover, in the previous researches, a single criterion (cost) was regarded for the evaluation and selection of project risk responses. In fact, they focused on the project objective based on the cost factor, and other objectives, such as time, quality and scope, were not considered in the risk response planning phase. Also, secondary risks were not focused properly. This may stem from the selection of preliminary responses for each important project risk. On the other hand, lack of information, uncertain project environment and uniqueness in large-scale projects lead to benefiting from fuzzy set theory in the risk response planning phase. To the best of our knowledge, no fuzzy decision-making approach was found regarding the risk response planning of the large-scale projects.

Decision-making process often involves the experts' subjective judgments and preferences regarding qualitative/quantitative criteria in the large-scale projects. This problem usually results in imprecise and indefinite data being present, which makes the decision-making process complex and challenging. The decision-making process often occurs in a fuzzy environment where the information available is imprecise and uncertain [6-15]. In the last few years, numerous researches have attempted to handle this uncertainty, imprecision, and subjectivity by means of the fuzzy set theory, as fuzzy set theory might provide the flexibility needed to represent the imprecision or vague information resulting from lack of knowledge or information [16, 20]. Therefore, the application of fuzzy set theory to decision-making process has been introduced as an effective approach [10,11]. Furthermore, when a factor is ambiguous, vague and incomplete data available, experts simply utilize linguistic variables such as ‘‘low’’, ‘‘medium’’, ‘‘fairly high’’. But, in many cases it is virtually inapplicable for experts to directly determine the scale of a vague factor. In fact, it is natural to apply linguistic expressions to estimate project risks.

The purpose of this paper is to present a new decision-making methodology in a fuzzy environment in order to overcome the above-mentioned difficulties. Two well-known techniques are developed to evaluate and select the responses of project risks in the phase of risk response planning for large-scale projects, particularly oil and gas projects. A fuzzy decision tree is constructed to help the experts or decision makers (DMs) to measure the important project risks with respect to multiple criteria and use a graphic approach for evaluations through the sequential decision making. Then, a fuzzy technique for order preference by similarity to ideal solution (TOPSIS) technique is extended based on an effective distance and similarity measure in order to process uncertain risk data and to conduct a more comprehensive assessment. Notably, this technique is chosen for the selection of project risk responses because of its stability and ease of use with subjective and objective information. Furthermore, an application in constructing a gas refinery plant in Iran is shown to highlight proposed fuzzy decision-making methodology and demonstrate its applicability. Proposed procedure is well suited for evaluating the ambiguous of risk responses involved in oil and gas industry. This methodology considers multiple criteria including time, cost, quality and scope, unlike previous researches only focusing on the cost criterion. Also, it deals with the secondary risks that may happen after selecting the first responses for each important risk within the project in order to assess precisely through sequential decision-making in the phase of the risk response planning.

The rest of this paper is organized as follows. The proposed decision-making methodology is elaborated in a fuzzy environment in Section 2. Section 3 explains the details of the methodology through a real application case in a gas refinery plant in Iran. In Section 4, the discussion of results is given. Finally, some concluding remarks are provided in the last section.

2. The Proposed Methodology

In this section, a new decision-making methodology with fuzzy numbers is designed. It deals with subjective and objective information, expressed in linguistic terms or numerical values simultaneously. The proposed methodology is developed for handling the evaluation and selection of risk responses with respect to multiple criteria under uncertainty. This methodology allows individual experts or DMs to make judgments in a conventional manner. Individual judgments are aggregated as a group judgment to reflect the inherent imprecision involved by using triangular fuzzy numbers. The proposed methodology contains the two extended and well-known techniques explained below.

2.1. Fuzzy Decision Tree

A fuzzy decision tree technique is introduced with multiple criteria for the risk response evaluation problem based on Kahraman approach [13]. This technique is a graphical representation of the logical structure of the decision-making problem in terms of the sequence of decisions to be made and outcomes of uncertain events. Also, it offers a mechanism to decompose a large and complex problem into a sequence of small and essential components. The proposed decision tree clarifies the responses provided by the experts or DMs, and presents a framework to deal with project risk in a fuzzy environment. The proposed technique helps the experts to structure the risk response evaluation problem characterized by a sequence of one or more decisions and event outcomes with respect to multiple criteria. For instance, a judgment about the outcome of a risk response in the engineering phase of the project life-cycle can affect the experts' decision to handle the risk and lead to new risks for the construction phase.

A decision tree can be regarded as a classifier in the form of a tree structure, where each node is either:

- A leaf node that indicates the value of the target attribute (e.g., risk response)
- A decision node that specifies some tests to be carried out on a single attribute-value, with one branch and sub-tree for each possible outcome of the test.

When a decision is influenced by outcomes of one or more uncertain events, the experts must anticipate what those outcomes might be as part of the process of assessment with the imprecision or vague information. For this purpose, a useful technique is presented for structuring the risk response evaluation problem under uncertainty, called a fuzzy decision tree, which is helpful for representing ill-defined structures in decision analysis for the phase of the risk response planning. In this paper, we extend the above-mentioned fuzzy decision tree by considering multiple criteria (not a single criterion) for solving the problem of risk response planning.

2.2. Fuzzy TOPSIS Technique

A fuzzy TOPSIS technique is extended to solve multi-criteria decision making (MCDM) problem under fuzzy environment in a systematic process. This paper aims to rank and select from a set of risk responses and to determine a compromise solution for the decision-making problem with conflicting criteria, including time, cost and quality, which can helps the DMs to reach a final solution. A simplified parameterized metric distance method proposed by Wang et al. [26] is applied to calculate the distance between fuzzy numbers through the proposed MCDM technique to measure fuzzy similarity. This method is an effective and simple way to calculate the distance between two fuzzy numbers.

We briefly describe a simplified parameterized metric distance in a fuzzy environment [5, 26]. The fuzzy number can be denoted using [*a*, *b*, *c*, *d*; 1], and the membership function $f_{\tilde{A}}$ of the fuzzy number $\tilde{A} = [a, b, c, d; 1]$ can be expressed as

$$f_{\tilde{A}} = \begin{cases} f_{\tilde{A}}^{L}(x), & a \le x \le b, \\ 1, & b \le x \le c, \\ f_{\tilde{A}}^{R}(x), & c \le x \le d, \\ 0, & \text{otherwise}, \end{cases} \tag{1}$$

Where $f_{\tilde{A}}^{L} : [a,b] \to [0,1]$ and $f_{\tilde{A}}^{R} : [c,d] \to [0,1]$. since $f_{\tilde{A}}^{L} : [a,b] \to [0,1]$ is continuous and strictly increasing, the inverse function of $f_{\tilde{A}}^{L}$ exists. Similarly, $f_{\tilde{A}}^{R} : [c,d] \to [0,1]$ is continuous and strictly decreasing, the inverse function of $f_{\tilde{A}}^{R}$ also exists.

Simplifying parameterized metric distance: The simplified method can be described as follows [21]:

Let $\tilde{A}$ denote a triangular fuzzy number, $\tilde{A} = (a, b, c)$, and write Eq. (2) in parameterized form:

$$\tilde{f}_{\tilde{A}} = \begin{cases} \dfrac{x-a}{b-a}, & a \le x \le b, \\ 1, & x = b, \\ \dfrac{c-x}{c-b}, & b \le x \le c, \end{cases} \tag{2}$$

Then, the inverse functions of $f_{\check{A}}^{L}$ and $f_{\check{A}}^{R}$ are

$$g_{\tilde{A}}^{L} = a + (b-a)y \quad (3)$$

$$g_{\tilde{A}}^{R} = c + (b-c)y \quad (4)$$

Let two triangular fuzzy numbers be $\check{A} = (a, b, c)$ $\check{B} = (d, e, f)$ and $D(\widetilde{A}, \widetilde{B})$ can be simplified as Eq. (5) via the *p*-norm metric method:

$$D(\widetilde{A}, \widetilde{B}) = [\int_0^1 [(a+(b-a)y)-(d+(b-d)y)]^p dy + \int_0^1 [(c+(b-c)y)-(f+(e-f)y)]^p dy]^{1/p} \quad (5)$$

- When p = 1, Eq. (5) can be simplified as Eq. (6):

$$D(\widetilde{A}, \widetilde{B}) = |(a+b+c)-(d+e+f)| + \left|\frac{d-a}{2} + \frac{f-c}{2}\right| \quad (6)$$

- When p = 2, Eq. (5) can be simplified as Eq. (7):

$$D(\widetilde{A}, \widetilde{B}) = [(d-a)^2 + \frac{[(e-d)-(b-a)]^2}{3} + (d-a)[(e-d)-(b-a)] + (f-c)^2 + \frac{[(e-f)-(b-c)]^2}{3} + (f-c)[(e-f)-(b-c)]^{1/2} \quad (7)$$

Definition. Fuzzy similarity measure based on the distance can be defined as follows [23]:

$$S(\widetilde{A}, \widetilde{B}) = \frac{1}{1 + D(\widetilde{A}, \widetilde{B})} \quad (8)$$

The proposed fuzzy TOPSIS technique utilizes Eqs. (6) and (8) to calculate the similarity measure and the distance between each point and ideal solutions by using the metric distance method.

It is worth mentioning that the above two well-known techniques are extended and selected in this paper due to their stability and ease of use with both subjective and objective information as well as wide applications in engineering and management fields [13,15,17].

2.3. Steps of the Proposed Methodology

In a decision-making process, it is often difficult for the experts or DMs to estimate a precise performance rating for an alternative with respect to criteria and the weights of criteria. The main advantage of using a fuzzy approach is to assign the relative importance of the criteria by linguistic variables or fuzzy numbers instead of precise numbers. In this section, steps of the proposed fuzzy decision-making methodology are elaborated. This methodology is designed in five main steps as illustrated in Fig 1.

To take advantage of the proposed methodology productively, these steps should be iterated in specific time intervals through the project life cycle. Furthermore, documentation of the methodology results and compiling lessons learned are provided for future applications.

Step 1: Establish a risk response planning team in a large-scale project.

Step 2: Gather project risk data for the phase of the risk response planning.

Step 2-1: Project risk response problem is defined for developing the project risk responses.

Step 2-2: Project risks are collected by using historical information and documents regarding project risk identification and assessment phases [24 -27].

Step 2-3: Reponses of the project risks are obtained by using group decision techniques, such as Brainstorming, Delphi and nominal group technique (NGT).

Step 2-4: A list of potential responses is provided for each important risk.

Step 3: Execute the proposed fuzzy decision tree based on multiple criteria for the evaluation of risk responses through sequential decision-making process.

Step 3-1: According to fuzzy decision tree technique, the decision-making problem is defined based on multiple selected criteria.

Step 3-2: Criteria for the evaluation responses of project risks are determined.

Step 3-3: Fuzzy decision tree is structured based on the selected criteria.

Step 3-4: Probability of occurrence is provided for each risk response with respect to each criterion.

Step 3-5: The outcome is estimated for each risk response with respect to each criterion. It is worth mentioning that experts' judgments can be expressed by "around" term for the outcome and then converted into triangular fuzzy numbers.

Step 3-6: Fuzzy expected value (EV) method is conducted for each node (each risk response) with respect to each criterion when all outcomes and subsequent decisions are quantified.

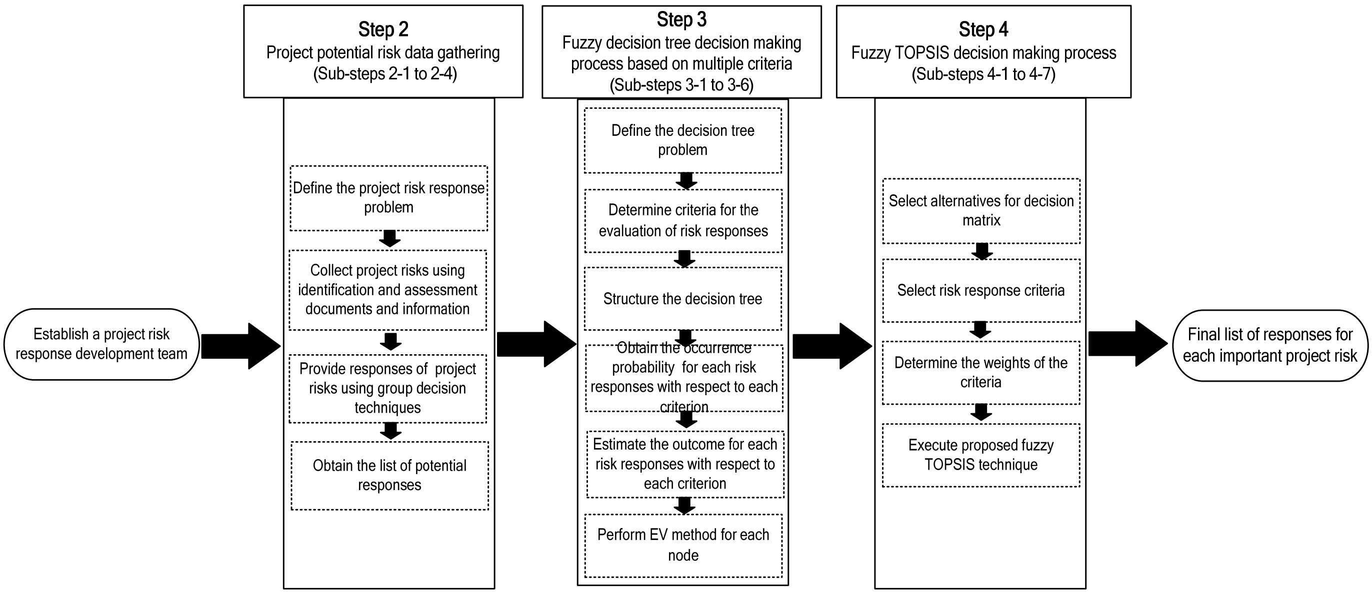

Fig. 1. Fuzzy decision-making methodology for risk response planning in large-scale projects

Step 4: Apply proposed fuzzy TOPSIS decision-making process, which is based on simplifying parameterized metric distance and fuzzy similarity measure for the selection of project risk responses.

Step 4-1: Choose the linguistic ratings or fuzzy numbers $(\tilde{x}_{ij}, i = 1,2,..,m,\ j = 1,2,\dots,n)$ for alternatives (risk responses) with respect to criteria (time, cost, quality and scope), and the appropriate linguistic variables or fuzzy numbers $(\tilde{w}_j,\ j = 1,2,\dots,n)$ for the weight of the criteria. The fuzzy linguistic rating ($\tilde{x}_{ij}$) preserves the property that the ranges of normalized triangular fuzzy numbers belong to [0, 1]. Then, the vector normalization is used to calculated $\tilde{r}_{ij}$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{e_j^*}, \frac{b_{ij}}{e_j^*}, \frac{c_{ij}}{e_j^*}\right), \tag{9}$$

$i = 1,2,\dots,m : j = 1,2,\dots,n$

where

$$e_j^* = \sqrt{\sum_{i=1}^{m} b_{ij}^2}\ .$$

Step 4-2: Construct the weighted normalized fuzzy decision matrix. The weighted normalized value $\tilde{V}$ is calculated by Eq. (10).

$$\tilde{V} = \tilde{r}_{ij} \times \tilde{w}_j \tag{10}$$

Step 4-3: Identify the set of positive ideal solution (PIS) and negative ideal solution (PIS). The fuzzy PIS (A^+) and the fuzzy NIS (A^-) are shown as Eqs. (11) and (12):

$$\begin{aligned} A^+ &= (\tilde{v}_1, \tilde{v}_2, \dots, \tilde{v}_n) \\ &= \{(\max_i \tilde{v}_{ij} \mid i = 1,2,\dots,m),\ j = 1,2,\dots,n\} \end{aligned} \tag{11}$$

$$\begin{aligned} A^- &= (\tilde{v}_1, \tilde{v}_2, \dots, \tilde{v}_n) \\ &= \{(\min_i \tilde{v}_{ij} \mid i = 1,2,\dots,m),\ j = 1,2,\dots,n\} \end{aligned} \tag{12}$$

Step 4-4: Calculate the distance of each alternative from (A^+) and (A^-) by using Eqs. (13) and (14).

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) \quad,\ i = 1,2,\dots,m \tag{13}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \quad,\ i = 1,2,\dots,m \tag{14}$$

Step 4-5: The degree of similarity between each alternative fuzzy PIS (A^+) and fuzzy NIS (A^-) as S^+ and S^-, can be currently calculated using Eq. (8).

Step 4-6: Calculate similarities to the ideal solution. This step solves the similarities to an ideal solution by Eq. (15):

$$CC_i = \frac{S_i^+}{S_i^+ + S_i^-} \tag{15}$$

Step 4-7: Rank preference order. Choose an alternative with minimum CC_i or rank alternatives according to CC_i in ascending order.

Step 5: Prepare the final list of responses for each important risk. Then, select the best response.

3. Case Study in Oil and Gas Industry

The purpose of the case study is to illustrate the application of the proposed fuzzy decision-making methodology presented in Section 2. Experiences obtained from this case study of oil and gas industry, located in the South Pars Gas Field, have been utilized as input in the process of developing the proposed methodology introduced in this paper. The description of the gas refinery plant is briefly presented in this section.

3.1. Project Definition

Gas refinery plant is utilized to purify the raw natural gas extracted from underground gas fields and brought up to the surface by gas wells. The processed natural gas, used as fuel by residential, commercial and industrial consumers, is almost pure methane. When processed and purified into finished by-products, these are collectively referred to natural gas liquids (NGL). The raw natural gas must be purified to meet the quality standards specified by the major pipeline transmission and distribution companies. Those quality standards vary from pipeline to pipeline and are usually a function of a pipeline system's design and the markets that it serves. For this purpose, a large-scale refinery plant in Iran is selected for this study. The objectives of developing this refinery plant are as follows:

- Daily production of 50 MMSCFD (Million Metric Standard Cubic Feet per Day) of natural gas
- Daily production of 80,000 bl (barrel) of gas condensate
- Annual production of 1 million tons of ethane
- Annual production of 1.05 million tons of liquid gas, butane and propane
- Daily production of 400 tons of sulfur

Gas refinery plant construction project breaks down into two main parts; onshore and offshore facilities based on Fig 2, the scope of work for each part is described as follows.

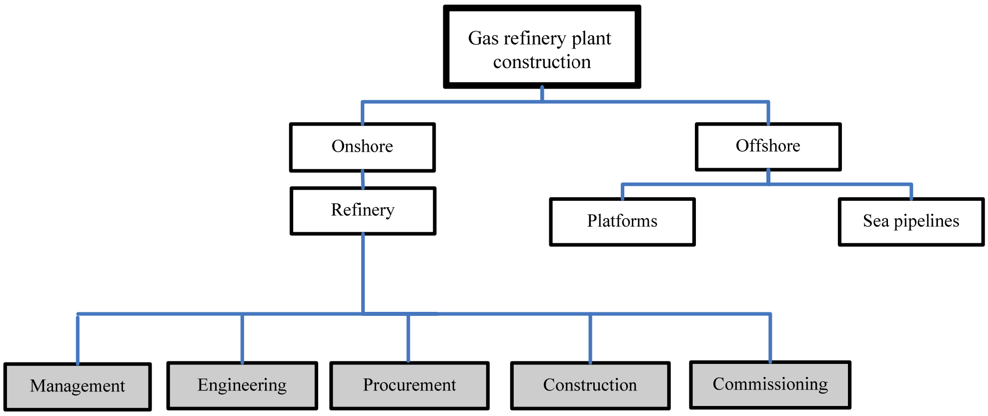

Fig. 2. Work breakdown structure for the gas refinery plant

3.1.1. Offshore Facilities

- Two offshore gas production platforms with 24 gas wells, some 105 kilometers from the main land
- Two 32" submarine pipelines for transferring gas to the onshore refinery
- Two 4.5" pipelines for transferring glycol

3.1.2. Onshore Facilities

- Gas and condensate receiving and separation unit
- Gas condensate stabilization unit
- Gas sweetening and dehydration unit
- Natural gas, ethane, propane and butane cooling and separation unit
- Gas compression unit for being transferred
- Sulfur recovery and granulation unit
- Mono Ethylene Glycol (MEG) recovery unit

3.2. MEPCC contract

The contract type of above-mentioned project is MEPCC (management, engineering, procurement, construction and commissioning). In this contract, the MEPCC contractor agrees to deliver the keys of a commissioned plant to the owner for an agreed period of time. The MEPCC way of executing a project is gaining importance worldwide. But, it is also a way that needs good understanding, by the MEPCC, for a profitable contract execution. The MEPCC contract, especially in global context, needs thorough understanding. The MEPCC must be informed of the various factors that will impact the process of work, the results and success or failure of the contract, in global arena. The MEPCC must have data and expertise in all the required fields.

In this paper, the risk response planning from general contractor's (GC) perspective is considered. GC receives work packages from the owner and delivers them to subcontractors by bidding and contracting. This contractor is in charge of monitoring the planning, engineering, designing and constructing phases. Moreover, the installation, leadership and the payment of the subcontractors are burdened by GC. Work breakdown structure (WBS) for selected project is offered in Figure 2.

3.3. Implementation

The proposed fuzzy decision-making methodology is implemented for the gas refinery plant. For this purpose, a decision committee of experts is formed. The team establishment step is needed to consider the organizational and project environment in which the risk response planning is taking place and to specify the main vision, goals, objectives and outcomes required. To set the whole together, objectives play an indispensable part of empowering the risk response planning team. The main goal of the team is to mitigate the project risks to find their priorities for further measures. Project size, budget, location, available resources and unique aspects of the project are some factors that influence the selection of the project risk team. Having considered above-mentioned explanations, the appropriate team for the phase of the risk response planning is established in this study. The list of the experts is provided in the process of project risk management below:

- Project manager and project team
- Project sponsors and site representatives
- Discipline engineers (e.g., civil, electrical, mechanical, and piping engineers)
- Experts with specific knowledge in particular areas of concern
- Commercial specialists
- Health, safety and environment (HSE) specialists
- Experienced people in similar field of the project
- Stakeholders
- A consulting team outside the project

In Step 1, we organized the project risk management team for each activity in the phase of risk response planning. Defining the purpose of the risk response planning is an essential step in the proposed decision-making methodology, since this largely determines other factors in the development of the methodology. This includes the selection of what is to be evaluated, the criteria for ranking, and the appropriate participants. To gather the project risk data, we utilized historical information, project records and documents regarding risk identification and assessment for this project risks in step 2. Thus, important risks are recognized for the phase of the risk response planning in the project as follows:

- International relations (R_1)
- Design failures (R_2)
- Delay in paying and receiving project's invoices (R_3)
- Change in construction scope of work (R_4)
- HSE matters (R_5)

Then, for better understanding of potential risk responses, some other techniques based on group decision techniques [24-27] are focused considerably in the gas refinery plant project. These main techniques are Brainstorming, Delphi, and NGT. Therefore, risk data are offered based on the above-mentioned resources and risk data collection techniques. A risk response list may contain assessed risks, root causes of identified risks, potential responses, a list of risks requiring response in the near term, a list of risks for additional analysis and response, and trends in qualitative analysis results. Finally, in step 2, the list of responses is obtained for project important risks.

In Step 3, we utilized the proposed decision tree technique based on multiple criteria for the risk response evaluation. This evaluation is structured by using a decision tree diagram describing a situation under fuzzy consideration and the implications of each of the available alternatives (risk responses) with respect to four selected criteria (i.e. time, cost, quality and scope). It incorporates the impacts of criteria for each risk response, the probability of each possible scenario, and the outcome of each alternative logical path. In the studied project, objective information obtained by the professional experts deals with uncertain numerical values. Then, the proposed decision tree is solved by using fuzzy EV method for each alternative, when all outcomes and subsequent decisions are quantified for each the important risks in the phase of the risk response planning. In Appendix A, the results of the first important risk (R_1) and its responses are explained and depicted in Figure A-1 to Figure A-4 based on the four selected criteria, respectively.

In Step 4, we conduct the proposed TOPSIS technique in a fuzzy environment for the risk response selection and ranking. The weights of four criteria provided by the experts by using the Geometric mean are given as follows.

$$\tilde{w} = (0.\tilde{8}7, 0.\tilde{9}2, 0.\tilde{7}2, 0.\tilde{7}5)^T$$

In Appendix B, normalized decision matrixes are presented for the ranking of responses for each important risk in the project based on Sub-step 4-1 (Eq. (9)). Then, computational results of proposed fuzzy TOPSIS are provided for five important project risks in Table 1 to Table 5, respectively. For this purpose, first, the weighted normalized values are calculated by Eq. (10) (Sub-step 4-2); second, the fuzzy PIS (A^+) and fuzzy NIS (A^-) are given by Eqs. (11) and (12) (Sub-step 4-3); third, the distance of each alternative from (A^+) and (A^-) by using Eqs. (13) and (14) according to the metric distance method (Sub-step 4-4); fourth, the degree of each alternative from fuzzy PIS (A^+) and fuzzy NIS (A^-) as S^+ and S^-, is computed by Eq. (8) on the basis of fuzzy similarity measure (Sub-step 4-5). Finally, in the last column of these Tables, similarities to ideal solutions are computed, and the ranking of the risk responses is obtained according to fuzzy decision-making methodology (Sub-step 4-6).

The final list is offered according to Step 5 and the best alternative (response) is then selected for each important risk in the gas refinery plant project.

4. Discussion

The results obtained from the proposed fuzzy decision-making methodology agree with the decision to select the responses for the important risks, which was undertaken in the previous projects in oil and gas industry. The proposed methodology quantifies the priority of each response that provides the expert or DM with the needed insights on the available responses for each risk. Hence, the appropriate responses for the five important risks in the gas refinery plant are selected as follows:

Table 1
Evaluation of responses for international relations risk (R_1)

Risk		Risk responses		S_i^+	S_i^-	CC_i	Rank
Risk ID	Description	Response ID	Description				
R_1	International relations	Res. 1	Establishment of project office in European countries	0.133	0.399	0.251	5
		Res. 2	Change of procurement from European countries to China or Ukraine	0.128	0.458	0.218	4
		Res. 3	Establishment of consortium with east Asian countries	0.115	0.770	0.130	1
		Res. 4	Purchasing from black markets	0.115	0.753	0.133	2
		Res. 5	Risk acceptance response	0.115	0.746	0.134	3

Table 2
Evaluation of responses for design failures risk (R2)

Risk		Risk responses		S_i^+	S_i^-	CC_i	Rank
Risk ID	Description	Response ID	Description				
R_2	Design failures	Res. 1	Contracting with licensor and third party authorities	0.135	0.384	0.260	6
		Res. 2	Acquiring experts	0.123	0.528	0.189	5
		Res. 3	Contracting with renown companies	0.116	0.712	0.140	3
		Res. 4	Belief of international standards	0.115	0.782	0.128	2
		Res. 5	Study of contract requirements	0.113	0.849	0.118	1
		Res. 6	Risk acceptance response	0.118	0.651	0.154	4

Table 3
Evaluation of responses for delay in paying and receiving project's invoices risk (R3)

Risk		Risk responses		S_i^+	S_i^-	CC_i	Rank
Risk ID	Description	Response ID	Description				
R_3	Delay in paying and receiving project's invoices	Res. 1	Taking advantage of strong financiers	0.141	0.342	0.292	4
		Res. 2	Earned value management system and cost control	0.114	0.787	0.127	2
		Res. 3	Invoicing procedure	0.113	0.873	0.114	1
		Res. 4	Risk acceptance response	0.116	0.722	0.139	3

Table 4
Evaluation of responses for change in construction scope of work risk (R4)

Risk		Risk responses		S_i^+	S_i^-	CC_i	Rank
Risk ID	Description	Response ID	Description				
R_4	Change in construction scope of work	Res. 1	Claim management system	0.139	0.359	0.279	5
		Res. 2	Preparing project quality plan	0.115	0.771	0.130	1
		Res. 3	Preparing project change order plan	0.115	0.759	0.132	2
		Res. 4	Preparing project execution plan	0.116	0.728	0.137	3
		Res. 5	Risk acceptance response	0.119	0.618	0.162	4

Table 5
Evaluation of responses for HSE matters risk (R5)

Risk		Risk responses		S_i^+	S_i^-	CC_i	Rank
Risk ID	Description	Response ID	Description				
R_5	HSE matters	Res. 1	Preparing health, safety and environmental (HSE) plan	0.116	0.705	0.142	1
		Res. 2	Training all personnel with HSE plan	0.122	0.548	0.182	4
		Res. 3	Fire extinguishing system	0.121	0.576	0.173	3
		Res. 4	First aid system (SOS)	0.119	0.617	0.162	2
		Res. 5	Preparing Green environment	0.123	0.540	0.185	5
		Res. 6	Risk acceptance response	0.126	0.478	0.209	6

- International relations (R_1): Establishment of consortium with east Asian countries
- Design failures (R_2): Study of contract requirements
- Delay in paying and receiving project's invoice (R_3): Invoicing procedure
- Change in construction scope of work (R_4): Preparing project quality plan
- HSE matters (R_5): Preparing HSE plan

We discussed the results of the proposed methodology with the professional experts in some common meetings. The results of our methodology proved more appealing in comparison with traditional approaches based on experts' judgments. For instance, results of the proposed methodology for R_1 show that establishment of consortium with east Asian countries ranked first among responses to mitigate the international relations risk in the gas refinery plant. When we discussed this response with the experts, they expressed that this response in the studied project in Iran has higher priority. In fact, the experts confirmed the methodology results in risk management process of the project. Moreover, the uncertainty factor in the proposed decision-making process is much lower and the precision is much higher considering its advantages in oil and gas industry. In addition, the methodology results according to the gathered data from the studied project are compared to the decision-making approach proposed by Mojtahedi et al. [17]. The technique is based on the group TOPSIS as a well-known group decision-making approach under multiple criteria. The performance rating of alternatives versus the selected criteria within the contents of the project are described through linguistic terms and then are converted to numerical numbers. For details, readers can refer to [17]. For this purpose, we utilize the weights of criteria obtained in our case study to provide the same conditions for the decision-making process. Then, the same ranks of responses for each important risk are obtained as illustrated in Table 6. In comparison with the approach presented in [17], the proposed fuzzy methodology, although the computational process is somewhat higher than the previous approach, has the main advantages discussed below due to the steps of fuzzy decision tree technique. The benefits of the proposed methodology through the phase of the risk response planning can be summarized as follows:

- Providing a new decision-making framework in a fuzzy environment, unlike the previous researches, by considering insufficient information and uncertain project environment in oil and gas industry.
- Considering multiple criteria for evaluations based on the project objectives, including time, quality and scope, for the phase of the risk response planning besides the cost criterion existing in the literature.
- Focusing on the issue of secondary risks, which may happen after selecting responses for the preliminary risk (see Appendix A for R_1) in order to assess more precise through the sequential decision making.
- Introducing a fuzzy decision tree based on multiple criteria to cope with fuzzy presentation and evaluation of responses for each important risk of the project.
- Proposing an extended version of fuzzy TOPSIS technique based on the effective simplified parameterized metric distance and fuzzy similarity measure in order to process uncertain risk data and to select the best response for each important risk of the project.

5. Concluding Remarks

Combining new effective criteria in an appraisal study and synthesizing them to evaluate and select the appropriate responses in the phase of risk response planning is one of the contributions of this paper. Moreover, a professional expert team from different executive areas related to oil and gas projects was brought together to assess the criteria, namely, time, cost, quality and scope, and alternatives (i.e., risk responses), which

Table 6
Comparison results for important risks in the phase of the risk response planning

Risk ID	Response ID	Proposed methodology		Decision-making approach [26]	
		CC_i	Ranking	Relative closeness	Ranking
R_1	Res. 1	0.251	5	0.201	5
	Res. 2	0.218	4	0.150	4
	Res. 3	0.130	1	0.025	1
	Res. 4	0.133	2	0.034	3
	Res. 5	0.134	3	0.030	2
R_2	Res. 1	0.260	6	0.223	6
	Res. 2	0.189	5	0.101	5
	Res. 3	0.140	3	0.040	4
	Res. 4	0.128	2	0.029	2
	Res. 5	0.118	1	0.021	1
	Res. 6	0.154	4	0.032	3
R_3	Res. 1	0.292	4	0.247	4
	Res. 2	0.127	2	0.025	2
	Res. 3	0.114	1	0.018	1
	Res. 4	0.139	3	0.032	3
R_4	Res. 1	0.279	5	0.245	5
	Res. 2	0.130	1	0.025	1
	Res. 3	0.132	2	0.029	2
	Res. 4	0.137	3	0.032	3
	Res. 5	0.162	4	0.055	4
R_5	Res. 1	0.142	1	0.067	1
	Res. 2	0.182	4	0.135	4
	Res. 3	0.173	3	0.116	3
	Res. 4	0.162	2	0.082	2
	Res. 5	0.185	5	0.158	5
	Res. 6	0.209	6	0.149	6

may affect the success of large-scale projects. Although the extended fuzzy TOPSIS, which is based on a simplified parameterized metric distance method and fuzzy similarity measure for ranking the responses for each important risk, has already been demonstrated effective, it is not a sufficient decision-making approach in the risk response phase. Furthermore, this paper introduced a fuzzy decision tree technique based on multiple selected criteria. This technique is a graphical means of structuring a decision-making situation where the imprecision or vague information can be characterized by fuzzy numbers for risk responses of the project. The proposed fuzzy decision tree clarifies the risk responses provided by the experts in terms of the sequence of decisions to be made and outcomes of uncertain events. The fuzzy decision tree is particularly compatible with risks and responses that have a natural sequence in time. Notably, the issue of secondary risks is focused that may happen after selecting responses for the preliminary risk in order to assess more precise through sequential decision-making. Moreover, instead of giving precise numbers as the rating values, studying the situation by using fuzzy numbers, can provide more accuracy in large-scale projects for real-life decisions compared to the conventional approaches. The proposed methodology embeds and solves the ambiguity and imprecision of the decision-making process by the experts fundamentally. Furthermore, a case study involving an Iranian gas refinery plant was presented to illustrate the utilization of the fuzzy methodology. The results demonstrated the effectiveness of the methodology that can assist the project manager and professional experts to identify and evaluate the project risk responses better. Although this methodology has dealt with the evaluation of risk responses in oil and gas projects, it can be applied to other large-scale projects in construction industry through the group decision-making process.

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7. Appendix

A. Fuzzy decision tree based on multiple criteria for the evaluation of responses for international relations risk (R_1).

As depicted in Figure A-1, the fuzzy decision tree for the first important risk (R_1) is shown. For example, in the third level of R_1, the probability and outcome of the third responses (RRRes.1) are 0.75 and 80, respectively. The multiplication of these values is 60, which can be expressed by fuzzy value (around 60). According to [20], we have

Around $60 = 60 \pm 6\alpha$.

Then, left and right representations of the triangular fuzzy number (RRRes.1) are obtained.

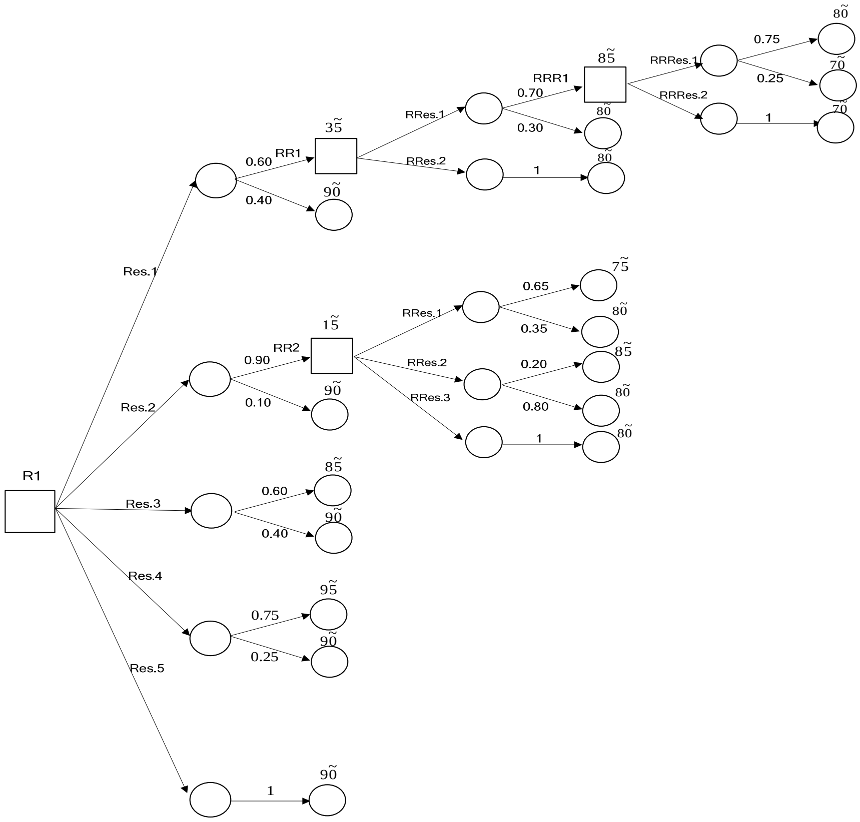

Fig. A-1. Fuzzy decision tree for R_1 with respect to time criterion

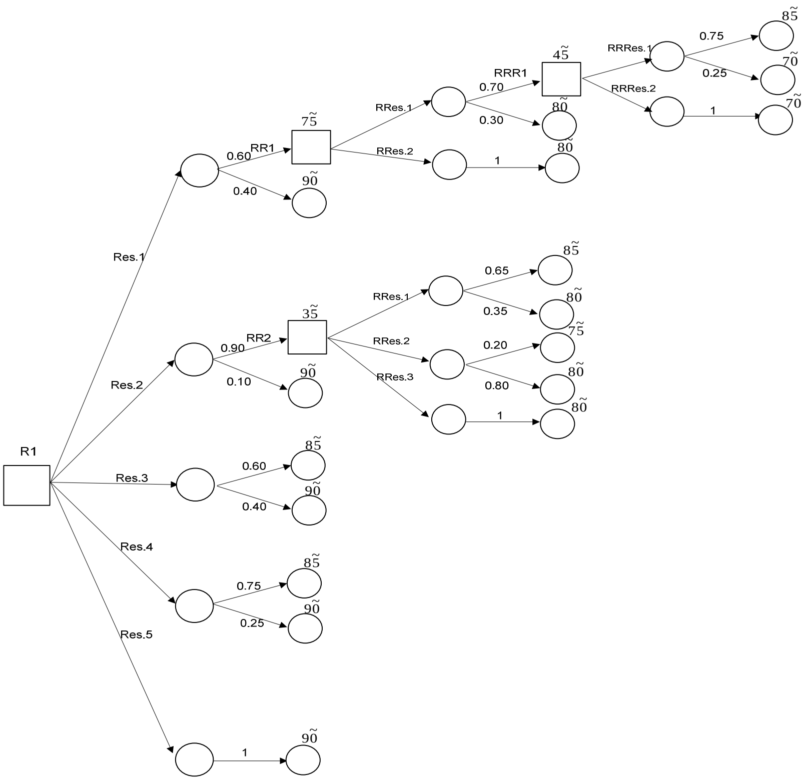

Fig. A-2. Fuzzy decision tree for R_1 with respect to cost criterion

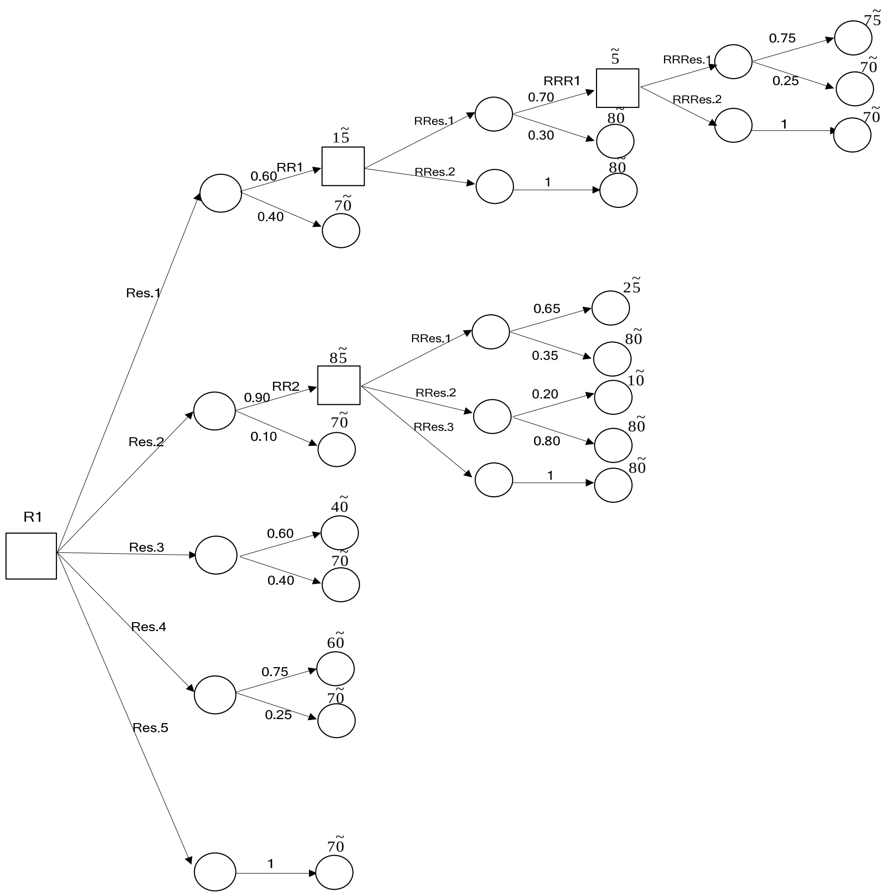

Fig. A-3. Fuzzy decision tree for R_1 with respect to quality criterion

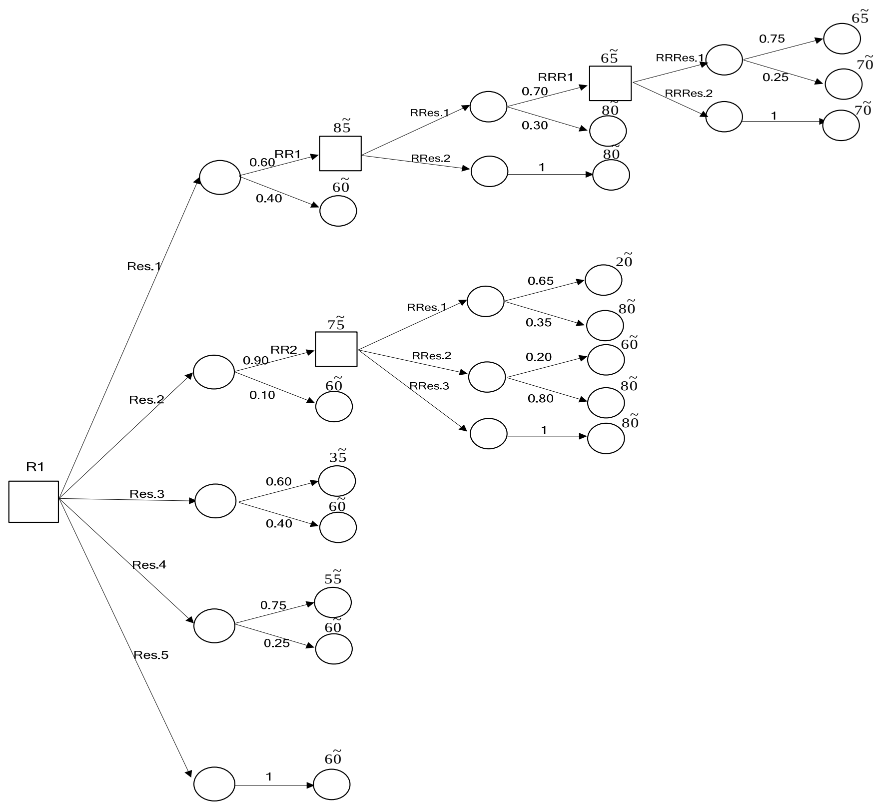

Fig. A-4. Fuzzy decision tree for R_1 with respect to scope criterion

B. Normalized decision matrixes through fuzzy TOPSIS technique for the ranking of responses for important risks.

Table B-1

Normalized decision matrix of responses for R_1

Criteria / Alternatives	Time criterion	Cost criterion	Quality criterion	Scope criterion
Res. 1	(0.694, 0.771, 0.848)	(0.678,0.753, 0.829)	(0.630, 0.700, 0.770)	(0.705, 0.783, 0.862)
Res. 2	(0.491, 0.545, 0.600)	(0.521, 0.579, 0.637)	(0.598, 0.665, 0.731)	(0.529, 0.587, 0.646)
Res. 3	(0.164, 0.182, 0.201)	(0.160, 0.178, 0.196)	(0.114, 0.126, 0.139)	(0.088, 0.098, 0.107)
Res. 4	(0.177, 0.197, 0.216)	(0.159, 0.177, 0.194)	(0.137, 0.152, 0.167)	(0.110, 0.122, 0.134)
Res. 5	(0.170, 0.189, 0.208)	(0.166, 0.184, 0.203)	(0.153, 0.170, 0.187)	(0.117, 0.130, 0.143)

Table B-2

Normalized decision matrix for the ranking of responses for R2

Criteria / Alternatives	Time criterion	Cost criterion	Quality criterion	Scope criterion
Res. 1	(0.731, 0.812, 0.893)	(0.730, 0.811, 0.892)	(0.689, 0.765, 0.842)	(0.734, 0.816, 0.898)
Res. 2	(0.318, 0.353, 0.388)	(0.400, 0.444, 0.488)	(0.485, 0.539, 0.593)	(0.427, 0.474, 0.522)
Res. 3	(0.266, 0.296, 0.325)	(0.218, 0.242, 0.266)	(0.104, 0.116, 0.128)	(0.112, 0.124, 0.137)
Res. 4	(0.159, 0.177, 0.194)	(0.119, 0.133, 0.146)	(0.092, 0.102, 0.113)	(0.126, 0.140, 0.154)
Res. 5	(0.057, 0.063, 0.069)	(0.035, 0.039, 0.043)	(0.187, 0.208, 0.229)	(0.061, 0.068, 0.075)
Res. 6	(0.276, 0.306, 0.337)	(0.234, 0.260, 0.285)	(0.215, 0.239, 0.263)	(0.238, 0.264, 0.290)

Table B-3

Normalized decision matrix for the ranking of responses for R3

Criteria / Alternatives	Time criterion	Cost criterion	Quality criterion	Scope criterion
Res. 1	(0.863, 0.959, 1)	(0.881, 0.979, 1)	(0.851, 0.946, 1)	(0.866, 0.962, 1)
Res. 2	(0.118, 0.131, 0.144)	(0.109, 0.122, 0.134)	(0.077, 0.086, 0.094)	(0.183, 0.204, 0.224)
Res. 3	(0.034, 0.038, 0.042)	(0.026, 0.029, 0.032)	(0.061, 0.067, 0.074)	(0.154, 0.171, 0.188)
Res. 4	(0.225, 0.250, 0.275)	(0.145, 0.161, 0.177)	(0.276, 0.307, 0.337)	(0.050, 0.055, 0.061)

Table B-4

Normalized decision matrix for the ranking of responses for R4

Criteria / Alternatives	Time criterion	Cost criterion	Quality criterion	Scope criterion
Res. 1	(0.804, 0.894, 0.983)	(0.773, 0.859, 0.944)	(0.844, 0.938, 1)	(0.807, 0.897, 0.987)
Res. 2	(0.184, 0.205, 0.225)	(0.192, 0.213, 0.235)	(0.061, 0.067, 0.074)	(0.072, 0.080, 0.089)
Res. 3	(0.219, 0.243, 0.267)	(0.202, 0.224, 0.246)	(0.066, 0.073, 0.080)	(0.055, 0.061, 0.067)
Res. 4	(0.207, 0.230, 0.253)	(0.245, 0.272, 0.300)	(0.084, 0.093, 0.103)	(0.108, 0.120, 0.132)
Res. 5	(0.195, 0.217, 0.239)	(0.274, 0.305, 0.335)	(0.287, 0.319, 0.351)	(0.372, 0.413, 0.455)

Table B-4

Normalized decision matrix for the ranking of responses for R5

Criteria / Alternatives	Time criterion	Cost criterion	Quality criterion	Scope criterion
Res. 1	(0.120, 0.133, 0.146)	(0.139, 0.155, 0.170)	(0.200, 0.222, 0.244)	(0.316, 0.352, 0.387)
Res. 2	(0.516, 0.573, 0.630)	(0.399, 0.443, 0.487)	(0.154, 0.172, 0.189)	(0.375, 0.417, 0.459)
Res. 3	(0.378, 0.420, 0.462)	(0.377, 0.419, 0.461)	(0.193, 0.214, 0.236)	(0.350, 0.388, 0.427)
Res. 4	(0.265, 0.294, 0.324)	(0.279, 0.310, 0.341)	(0.200, 0.222, 0.244)	(0.371, 0.412, 0.453)
Res. 5	(0.461, 0.512, 0.563)	(0.443, 0.492, 0.541)	(0.270, 0.300, 0.330)	(0.324, 0.360, 0.396)
Res. 6	(0.323, 0.359, 0.395)	(0.465, 0.516, 0.568)	(0.772, 0.858, 0.944)	(0.452, 0.502, 0.553)