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ORIGINAL ARTICLE

Design a new intelligence expert decision making using game theory and fuzzy AHP to risk management in design, construction, and operation of tunnel projects (case studies: Resalat tunnel)

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Abstract One of the traditional methods on managing risk is taken using engineering decisions taken during the project development. In this paper, we propose a new method for risk assessment of a tunnel project where there are three main parameters called taskmaster, adviser, and contractor. The proposed model of this paper is built based on interactive framework of a game theory where, in making decision, each player considers other possible risks choices. We implement three-person cooperative game theory combined with an interactive decision structural model of fuzzy analytical hierarchy process to perform a balance between actions and suitable cooperative strategy for each player. The results reveal that collaboration strategies give the highest outcome for the three players. It also recommends owner managers, design managers, and contractor managers to make collaboration in undertaking innovation while the operator managers need to let an independent organization clearly identify the appropriate risk mitigation measures to be implemented in a timely manner.

Keywords Risk management · Tunnel project · Cooperative game theory · Fuzzy AHP

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1 Introduction

Most of the real-world decision problems occur in a complex environment where conflicting systems of logic, uncertain, and imprecise knowledge need to be considered. To face such complexity, preference modeling needs the use of specific tools, techniques, and concepts to reveal the available information with the appropriate granularity [1, 2]. There are many cases such as choice of alignment or selection of construction methods where the risk management becomes vital in the early stages of a project [3]. The purpose of this paper is to present guidelines for managers to prepare and implement a comprehensive tunnel risk management system. There are four managers for our system called owner managers, designer managers, contractor managers, and operator managers. For the purpose of this paper, "risk management" is the overall term which includes risk identification, risk assessment, risk analysis, risk elimination, and risk mitigation and control. Tunneling and underground construction works impose risks on all parties involved as well as on those not directly involved in the project. The nature of tunnel projects normally involves significant amount risks such as large-scale accidents which create catastrophic incidents. Due to the inherent uncertainties, including ground and groundwater conditions, there might be significant cost overrun and delay risks as well as environmental risks. Furthermore, for tunnels in urban areas there is a risk of damage to people and their properties or even historical buildings. Finally, there is a social risk that the tunneling project may give rise to public protests affecting the course of the project [4].

The primary focus of this paper is on the assessing the different risk factors involved in a project taken by the various players of taskmaster, adviser, and contractor to organize tunnel project. A comprehensive risk analysis is accomplished based on an interactive framework. A previous survey is also conducted to determine various kinds of risk factors which were previously involved in risk assessment. The assessment is often divided in two parts. The first phase is the evaluation phase that comprises the steps under which various alternatives of the problem are evaluated through the pre-determined criteria. Based on the literature, this step is mostly dependent on experts and their expertise to quantitatively and/or qualitatively evaluate each alternative under each criterion. The result of this phase normally consists of a number of strategic plans and the best strategy for each player is chosen. The second phase is to determine the highest total outcome for all participants as a group obtained from a cooperative game. In a cooperative game, the agents can communicate with each other and take actions after they reach an agreement. The cooperative solution is difficult to implement unless the agents can communicate with each other and the game is repeated many times [5].

In this paper, we first determine the key parameters affecting the Resalat tunnel project. Then, we determine the priority of each particular item using fuzzy analytical hierarchy process (FAHP). In the next step, we find the relationship among various players. We use decision maker's opinions to study the effects of different strategies and good combinations of these factors are determined. The rest of this article is organized as follows. In the following section, the case study is presented. In Section 3, we provide an introduction to risk management and risks in case, the cooperative game theory and utilizing fuzzy AHP concept to deal with the uncertainty of risks. In Section 4, the issues related to design of a fuzzy expert system by using combine cooperative game theory and fuzzy AHP are investigated. Section 5 describes the implementation of the whole system, in one of the biggest tunnel project in Iran and the experimental results. Finally, we discuss the new ideas and summarize the contribution of our paper.

In order to derive a framework for this paper, the following major assumptions are adopted:

- ✓ The proposed method of this paper considers a multidimensional choice proportion to structure of the project.
- ✓ We select suitable strategies for each player and analyze them.
- ✓ Combined dynamic and static strategies are used.
- ✓ All players are rational.
- ✓ All risk factors are selected proportion to the nature of this project.
- ✓ The AHP method used for the proposed method of this paper is based on decision makers' (DM) opinions.

2 Problem definition

The Resalat tunnel is one of the most important projects in Iran. The construction of this project was completed in about 9 years from 1997 to 2006. Resalat tunnel is a part of Resalat highway which runs east–west through the northern part of Tehran in Iran. This is a dual tunnel with approximately 15 m width and 950 m length (Fig. 1) [6].

2.1 Strategic options and determinant factors for the Resalat Tunnel

Tunneling and underground construction works impose risks on all parties considered as well as on those not directly involved in the project [7]. Due to the inherent uncertainties, including ground and groundwater conditions, there is a chance of having significant cost overrun and delay risks as well as environmental risks [8, 9].

The use of risk management from the early stages of a project, where major decisions such as choice of alignment and selection of construction methods can be influenced, is essential. The following are the basic steps on assessing the risk management in the early stages of project management [10–12]:

- ➢ Phase 1: tendering and contract negotiation
- ➢ Phase 2: construction phase
- ➢ Phase 3: strategic risk management
- ➢ Phase 4: strategic options in case

Fig. 1 Picture of Resalat tunnel

2.1.1 Risk management during preparation of tender documents

In the planning of the tender evaluation process, construction risk aspects need to be considered very carefully. We also need to choose the quantitative risk assessment techniques to evaluate the individual tenders [13, 14]. The necessary inputs to the tender documents resulting from the qualitative risk assessment are as follows:

- Identifying the necessary requirements to the construction methods which are related to the risk to the third party buildings
- Provision of the necessary requirements to the contractor's construction risk management
- Request for information to be included by the tenders as basic for the tender evaluation:
  - ✓ Envisaged risk reduction measures
  - ✓ Plan for the construction risk assessment work
  - ✓ Information on the tender's capabilities in risk assessment work along with their past experiences

Another basic step for the quantification of the risk involved in the projects proposed in the individual tenders, a quantitative risk assessment of the project outline is carried out using the framework provided by the qualitative risk assessment. The quantification process begins with a review of the hazards in the light of the final tender documents. The likelihoods and consequences are quantified using some experts' judgment. A risk model is constructed using a Monte Carlo simulation technique. Only the cost over-runs and the delays are quantified, and the delays are assessed as extensions to the expected critical path. The cost consequences of delays are finally detected using a unit price per week extension.

2.1.2 Risk management during selection of contractor

The system adopted for the assessments of the bids is the same as the assessment of the project outline. Expert judgment drawn from the project team and the staff of collaborating organizations is used to evaluate the deviations in both likelihood and consequences for each identified hazard when compared to the project outline. The resulting total risks are then quantified using the Monte Carlo simulator. Therefore, all tenders are evaluated on a consistent basic. In parallel with this quantification, a qualitative assessment of the risk of damage to third party is carried out. At each stage of the evaluation, the risk assessment is able to provide a most likely risk cost which could be taken into account in the overall evaluation of the tender together with the tender price, the "upgrade cost" estimate and the estimated "other costs". The "upgrade cost" represents the costs considered necessary to upgrade the tender to the quality required and other cost items such as additional operation and maintenance costs, compared to the project outline. Care need to be taken to ensure that technical reservations are not double counted in both the risk and the upgrade costs. The results of the assessments are passed to the decision makers in tabulation form and as plots, e.g., Fig. 2. Where the total estimated risk cost of each tender (T1–T6) is shown and compared to the risk costs of the project outline.

The final selected tender (T1) shows a level of risk approximately equal to that of the project outline. Interestingly, the successful tender is also the lowest bid price, but the effective difference between T1, T2, and T3 in bid price is so small that it is difficult to justify the selection of any one of the three without a risk cost estimate. T3 is excluded first; T2 is excluded after receipt of the final bid and a revision of the risk shown that the risk costs are larger for T2 than for T1. Risk clauses in contract the information could be obtained through the risk assessments based on the negotiations with the tenders in the last stages of the tender evaluation. The most significant aspects are:

- ✓ TBM design and operation
- ✓ Procedures and measures to be used in prevention of damage to third party property
- ✓ Procedures for the contractor's construction risk management work.

2.1.3 Strategic risk management for the Resalat axis

This type of risk management covers the assessment of threats and opportunities including their causes, which have a potential long-term influence on planning and execution of the new construction of the new connections as a total.

In the latest project progress report of the management published twice a year, the supervising authorities and political organizations, the threats and opportunities are

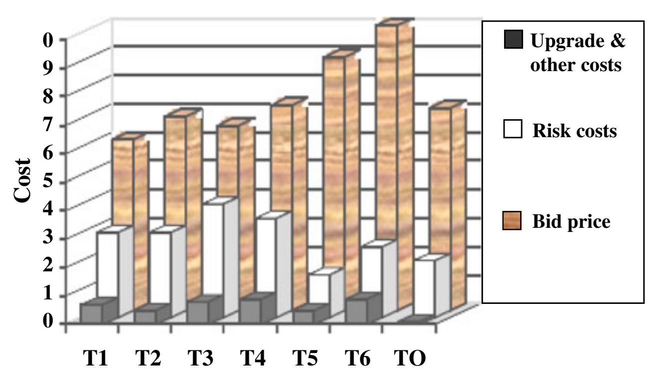


Fig. 2 Risk costs and tender price for six tenders and the project outline, PO, first evaluation of the tenders

listed in Fig. 3 [15, 16]. Particularly, the report identifies two "mega"-threats and a "mega"-opportunity, each of them showing a high probability of occurrence and a great extent of impact. In order to prevent the occurrence of the identified threats and seize the recognized opportunities, comprehensive measures are proposed, mainly on a superior management level (Table 1).

Based on the risk analysis which is carried out by the project owner at the beginning of the construction planning for the Resalat tunnel, the following crucial project requirements are identified in the context of the operational risk management:

- Functionality (safety of load-bearing structures, practical capability)
- Costs (cost minimization, supplementary charges by contractors, etc.)
- Construction scheduling, environmental impact
- Work safety
- Project organization of all involved parties (process management, implementation of contractual agreements, CQM)

The following summarizes the necessary definitions,

✓ Risk $R=P\times E$: value after implementation of planned measures from contracts, project and CQM, i.e., remaining risk potential. Where P and E are the probability of occurrence and the extent of damage/benefit, respectively.
✓ Threats: reduced damage potential (residual damage)
✓ Opportunities: seized opportunities (supplementary benefit).

A summary of all these items are given in the Table 2 [17].

The sum of all accidents is calculated by multiplying each category with its respective fraction of total traffic. Note that collisions are expected to be 95% of all traffic accidents.

2.1.4 Strategic options in Resalat tunnel

In order to avoid being trapped to a high-complicated model, strategic options are limited to three.

Taskmaster For taskmaster the issue is "What level of control risks." It corresponds to the taskmaster's responsibility to the society. The extreme choice of that issue in this case are [11, 16]:

1. Fully control it
2. Let an independent organization do it
3. No control at all

The first and the third items are the extreme choices of the level of control. Alternatively, one may let independent organization manage risks. Note that in some cases it might not be implemented completely. For instance, the constitution states that taskmaster must fully control all researches that may hurt public interest, or may cause big disasters.

Adviser For our case study, the adviser is given choices to:

1. Envisaged risk reduction measures
2. Collaborate with other institutions
3. Disregard risks

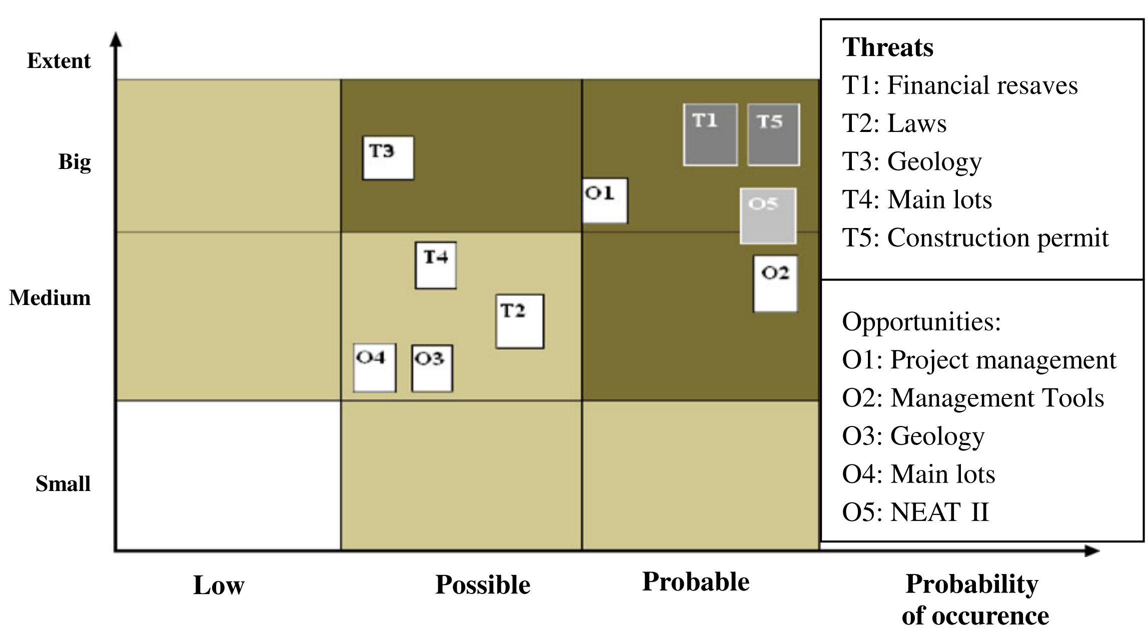


Fig. 3 Risk situation in the overall project as of December 31, 2005

Table 1 Applied valuation matrixes

	1	2	3
Probability of occurrence (*P*)	Low (not expected)	Possible (cannot be excluded)	Probable (occurrence assumed)
Extent of damage/benefit (*E*)			
Costs	Low (melow CHF 1 Mio.)	Medium (CHF 1–10 Mio.)	High (over CHF 10 Mio.)
Schedule	Low (below12 months)	Medium (12–18 months)	High (over 15 months)

Idea of collaboration actually emerges from attempting to reduce risks sharing with other firms or with the public sectors. Likewise, transfer of risks may be prohibited in some industries since the taskmaster may wish to protect domestic industry.

Contractor For contractor, the study provides choices for academicians as follows:

1. Initiate to reduce risks
2. Collaborate with other institution (joint research)
3. Do research for an outside company or institution with the initiative coming from the company/institution

There is arguing toward the first and the third choices. Collaboration research is another option where the results are expected to give benefits toward contractor. Thus, the research goal and the methodology can be determined together in such a way that the two parties' objectives can be fulfilled proportionally.

2.1.5 Determinant factors in Resalat tunnel

Before selecting any alternatives normally the decision maker weights first the impact.

Taskmaster In choosing alternative to reduce risks, taskmaster most likely considers three potential impacts: cost, political image, and risk performance. Cost is considered since taskmaster planning is limited by budget. All taskmaster expenditure must be transparent and accountable, so spending that budget must be careful so that each activity include reduce risks must be considered accurately.

Adviser Considering that most adviser focus their objectives on profitability and competitiveness, the study observes three determinant factors: cost, technology advancement, and risks. Reducing cost is substantial factor to push marketable price, where the lower marketable price the higher competitive advantages.

Contractor There are three criteria of knowledge advancement, cost, and risks which area pplied for contractor. Unlike adviser, the contractor's focuses on technology development is usually nonprofit and tend to be an ideal objective. The factor of cost is included with the reason that, in many cases contractors are so reliant on subsidy coming from taskmaster or foundations, so to attract the sponsor; cost must be pressed as lower as possible.

3 Background of the expert system, game theory and the fuzzy AHP

In this section, we explain the basic concepts of expert decision in fuzzy approach, game theory, and in final fuzzy AHP.

3.1 Fuzzy expert decision system

The fuzzy decision system has become as one of the most popular methods for decision making for the past few decades [18, 19]. Expert system can also be considered as one of the well-known branches of artificial intelligence from commercial point of view [20, 21]. Intelligence expert decision making is an expert system that uses fuzzy logic

Table 2 Summary of accident frequencies

	All	Passenger vehicle fire	Heavy vehicle fire	Dangerous goods accident	Collisions
Accident rate per million vehicle km	1.008	0.0453	0.092	0.199	0.960
Yearly frequency	7.23	0.324	0.038	0.00302	6.86
Average return period (years)	0.138	3.09	26.1	331	0.146
Probability of an outcome given an accident has occurred	100%	4.48%	0.529%	0.0418%	94.9%
Frequency of all vehicle fire per year	0.36	0.02	0.12	1.1	0.21
Average return period for vehicle fire (years)	2.8	1.87	2.15	2.13	2.4

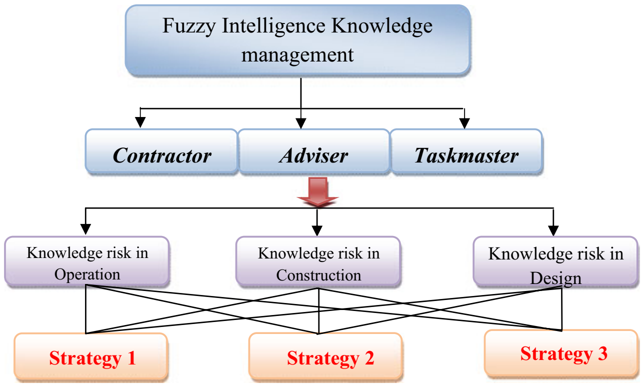


Fig. 4 The model of intelligence knowledge management (fuzzy rule-base expert system)

and rule base. It can be seen as special rule-based systems that use fuzzy logic in its knowledge base by combine game theory and fuzzy MCDM to define rules to design intelligence knowledge management.

The architecture of the system is shown in Fig. 4.

3.2 Game theory

Game theory is often described as a branch of applied mathematics and economics which studies situations where multiple players make decisions in an attempt to maximize their returns. Generally, the publication of the Theory of Games and Economic Behavior by Morgenstern and Von Neumann in 1944 symbolizes the foundation of game theory system [22]. The modern game theory developed from 1950s to 1960s, and in 1970s the modern game theory became popular economic theory [22]. The primary basic concept of game theory includes: player, action, strategy, information, income, equilibrium. Player can be individual or groups such as manufacturer, government, and nation. The basic model of formal game theory [23]:$(\delta_1, \delta_2)$are the actions of player1 and player2; P is the pay-off function of every player in different strategy association. Set is the set of players' strategies. If $(\overline{\delta_1}, \overline{\delta_2})$ satisfied the following:

$$\begin{cases} P^1\left(\overline{\delta_1}, \overline{\delta_2}\right) = \max_{\delta_1 \in S^1} P^1(\delta_1, \delta_2) \\ P^2\left(\overline{\delta_1}, \overline{\delta_2}\right) = \max_{\delta_2 \in S^2} P^2(\delta_1, \delta_2) \end{cases} \tag{1}$$

Then strategy set $(\overline{\delta_1}, \overline{\delta_2})$ is equilibrium. For game set$\left(\overline{\delta_1}, \overline{\delta_2}\right) \in V$, if there is no strategy set (δ_1, δ_2) satisfying the following at the same time:

$$\begin{cases} P^1\left(\overline{\delta_1}, \overline{\delta_2}\right) < P^1(\delta_1, \delta_2) \\ P^2\left(\overline{\delta_1}, \overline{\delta_2}\right) < P^2(\delta_1, \delta_2) \end{cases} \tag{2}$$

Then it is called Pareto optimality.

3.3 Fuzzy AHP

The analytic hierarchy process was devised by Saaty [24]. It is a useful approach to solve complex decision problems. It prioritizes the relative importance of a list of criteria (critical factors and sub-factors) through pairwise comparisons amongst the factors by relevant experts using a nine-point scale [25].

Buckley incorporated the fuzzy theory into the AHP, called the fuzzy analytic hierarchy process. It generalizes the calculation of the consistent ratio into a fuzzy matrix [25]. The procedure of FAHP for determining the evaluation weights are explained as follows [26, 27]:

Step 1: Construct fuzzy pairwise comparison matrices. Through expert questionnaires, each expert is asked to assign linguistic terms by triangular fuzzy numbers (TFNs) to the pairwise comparisons among all criteria in the dimensions of a hierarchy system. The result of the comparisons is constructed as fuzzy pairwise comparison matrices$(\widetilde{A})$.

Step 2: Examine the consistency of the fuzzy pairwise comparison matrices. According to the research of Buckley, it proves that if $\mathrm{A} = [a_{ij}]$is a positive reciprocal matrix then $\widetilde{\mathrm{A}} = [\widetilde{a_{ij}}]$is a fuzzy positive reciprocal matrix. That is, if the result of the comparisons of $\mathrm{A} = [a_{ij}]$ is consistent, then it can imply that the result of the comparisons of $\widetilde{\mathrm{A}} = [\widetilde{a_{ij}}]$ is also consistent. Therefore, this research employs this method to validate the questionnaire [25].

Step 3: Compute the fuzzy geometric mean for each criterion. The geometric technique is used to calculate the geometric mean $(\widetilde{r_i})$of the fuzzy comparison values of criterion i to each criterion, as shown in Eq. 3, where $(\widetilde{a_{ij}})$is a fuzzy value of the pairwise comparison of criterion i to criterion n[25].

$$\widetilde{r_i} = [\widetilde{a_{i1}} \otimes \widetilde{a_{i2}} \otimes \cdots \widetilde{a_{in}}]^{\frac{1}{n}} \tag{3}$$

Step 4: Compute the fuzzy weights by normalization. The fuzzy weight of the ith criterion$(\widetilde{w_i})$, can be derived as Eq. 4, where $(\widetilde{w_i})$is denoted as $\widetilde{w_i} = (L_{w_i}, M_{w_i}, U_{w_i})$by a TFN and $(L_{w_i}, M_{w_i}, U_{w_i})$ represent the lower, middle, and upper values of the fuzzy weight of the ith criterion:

$$\widetilde{w_i} = \widetilde{r_i} \otimes [\widetilde{a_{i1}} \oplus \widetilde{a_{i2}} \oplus \cdots \widetilde{a_{in}}]^{-1} \tag{4}$$

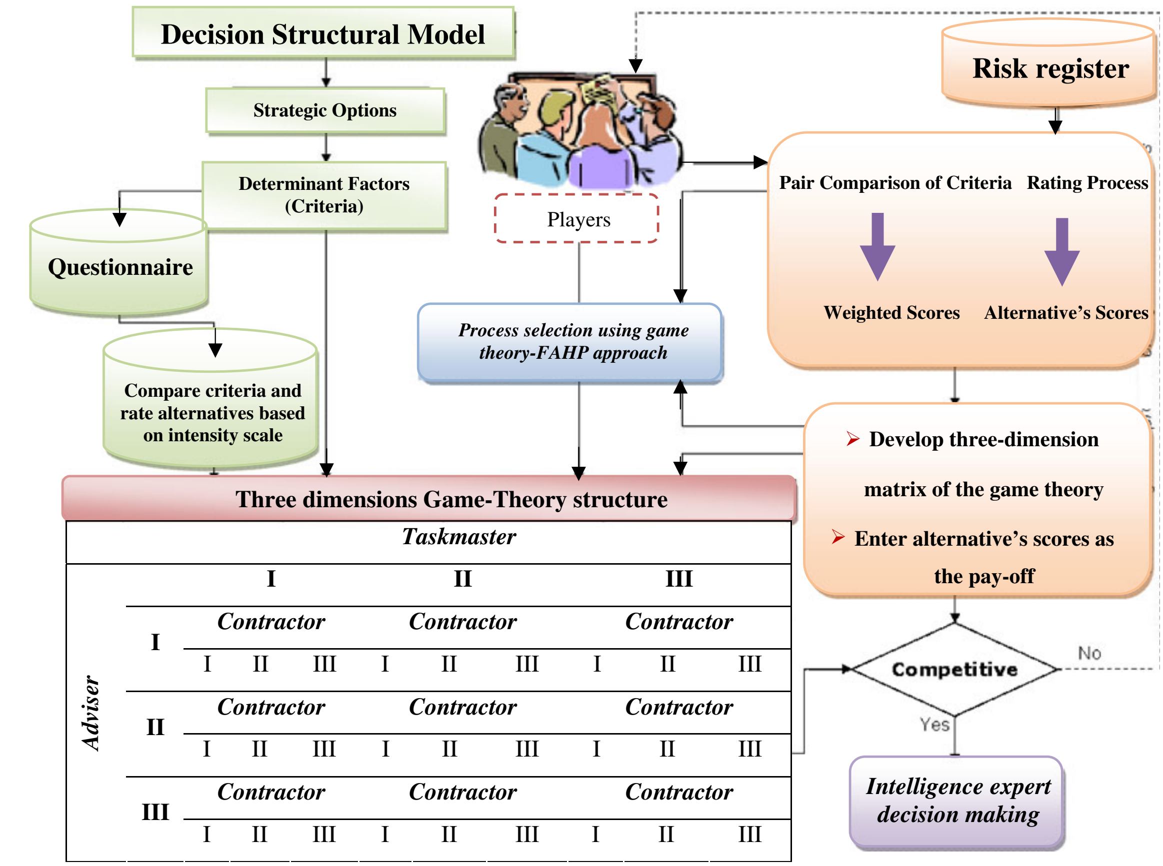


Fig. 5 The proposed architecture for the fuzzy decision-making system in risk management by using combined game theory and fuzzy AHP

4 Methodologies

In this study, the concept of game theory is used combined with fuzzy analytical hierarchy process. Game theory has been widely accepted as the best tool for interactive decision making, while FAHP on the other hand has been accepted also as the best tool in interpreting qualitative decisions into quantitative scores, which is the basic requirement for game theory. Game theory is used to simulate interactively each possible combination of alternative decisions selected by the three players. In this paper, that prioritized ranking is considered as the pay-off of the game theory which can be translated as "how much (level of preference) of the decision maker (player) will get when he or she chooses that particular risk other player's decision".

Each player in this study has three options of strategies reduce risks. Each strategy is mutually exclusive, meaning only one of them can be chosen. Therefore, there are 27 possibilities of interaction (3×3×3). These interactions are arranged in three-dimension box (Fig. 5). Each unique interaction is placed in one box where each box consists of three number reflecting the outcome (or usually called pay-off) of each player when we choose any strategy. The research's stages are illustrated in Fig. 5. Respondents filled a questionnaire to express their opinions and preferences. Three kinds of question have guided them in comparing criteria used to select strategy of risks reduce, and in rating the strategic alternatives against an intensity scale. The fuzzy AHP structure is created and applied. These tools are used for weighting the strategies in each sector.

5 Experimental results

In this section, example is provided. The proposed fuzzy AHP method is applied to solve this problem, and the computational procedure is summarized as follows:

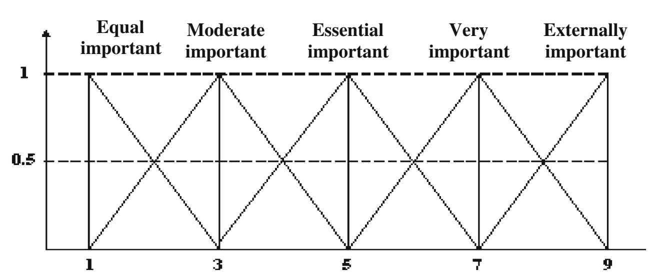


Fig. 6 Membership functions of linguistic variables

Table 3 Membership functions of the linguistic scale

Linguistic scales	$TFN(\widetilde{a}_{ij})$		
Extremely important	7	9	9
Very important	5	7	9
Essentially important	3	5	7
Moderate important	1	3	5
Equally important	1	1	1

Step 1: The research uses the linguistic variables in Fig. 6 and Table 3, for each criterion. We use triangular fuzzy numbers to express the importance of each criterion. The linguistic terms range from "Equally important" to "Extremely important" [28, 29].

Step 2: Each DM may rate each criterion's weight with respect to linguistic term. The aggregated fuzzy rating and fuzzy weight of each criterion is shown in Fig. 7. (Population to be studied is composed of three groups of strategies by use of three experts).

Step 3: Besides the subjective weights, we apply this method to calculate the objective weight for each criterion. According to Fig. 5, we derive its crisp projection for each criterion. That means one expert may apply his/her own expertise to judge "How much (level of preference) of the decision maker (player) will get when he or she chooses that particular risk other player's decision". (Population to be studied is composed of three group of respondent: taskmaster, adviser, and contractor. A total of 150 questionnaire (50 for each group) have been distributed, but only 100 (67%) of them are returned). Figure 8 illustrates a game where taskmaster n is appointed as the first mover, adviser as the follower, and contractor is assumed to have moved with the first choice.

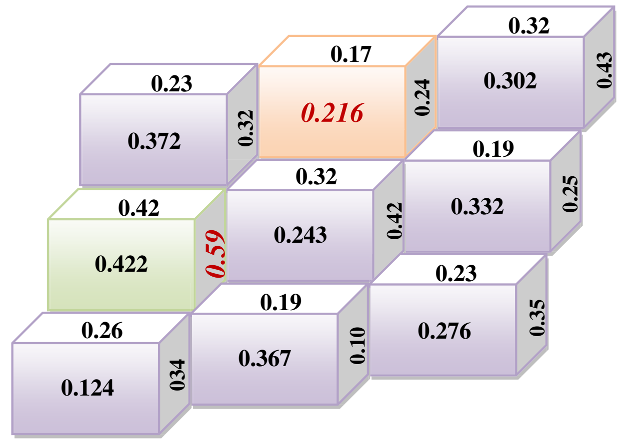
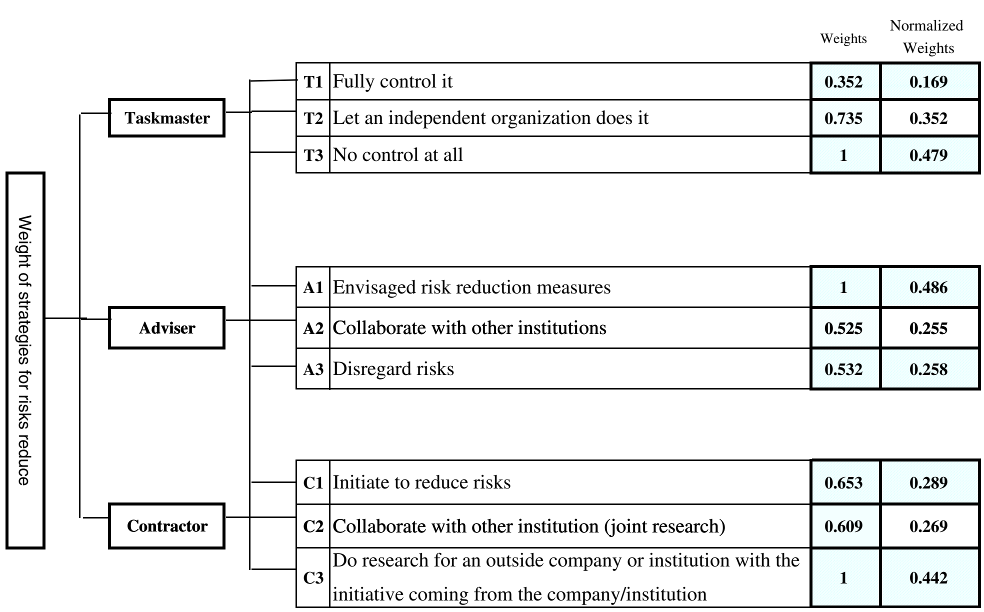


Fig. 8 Three-dimension game theory

Step 4: We calculate each alternative's and determine the best alternative. The results are shown in Fig. 8.

The study observes two possible results: 'ideal choice,' (sometimes called 'reasonable outcome') obtained from non-cooperative game and 'stylized outcome,' the highest total outcome for all participants as a group obtained from a cooperative game. Non-cooperative game applies minmax criterion method which means the first mover

Fig. 7 Hierarchical framework of strategies to risks reduce in tunnel project



will minimize his/her maximum losses whenever the resulting choice of strategy cannot be exploited by the other participant to improve his position. Cooperative game that may bring higher pay-off to all players is observed as well, reminding that players may do that, particularly when one of them has ability or interest to initiate it. For instance, Fig. 8, shows that strategy 2 for taskmaster, 1 for adviser, and 2 for contractor is the stylized outcome, while strategy 1 for taskmaster, 2 for adviser, and 2 for contractor is the ideal choice.

6 Discussion and implications

Most of the organizations need to develop suitable strategies in order to evaluate their outputs. There are also many limitations on the resources such as time or cost which leads us to merge different strategies to cope with these limitations. In this paper, we first determine the key parameters affecting the Resalat tunnel project. Then, we determine the priority of each particular item using FAHP. In the next step, we find the relationship among various players. We use decision maker's opinions to study the effects of different strategies and good combinations of these factors are determined. The primary purpose of this methodology is to setup a database to find the best strategy when we face a chaos. Therefore, when we face a chaotic situation, we could choose a suitable strategy.

The following summarize the details of our proposed method,

1. Use an intelligence knowledge-based strategy to choose the best combinations of various strategies
2. Use FAHP to assign suitable weights for all strategies
3. Flexible the choices when a chaotic situation happens
4. Setup a database to guide all managers in different situations

7 Conclusion

We have presented a new fuzzy game theory method for risk assessment of a tunnel project. The risk assessment plays an important role for tunnel projects especially when they are built inside the city where many civilian are involved with the consequences of the project. The proposed method of this paper has presented a combined fuzzy AHP and game theory to assess and evaluate different risk factors in tunnel project. One of the advantages of FAHP is its ability to translate qualitative considerations into quantitative results. The results of our study indicate that the best alternative to minimize the risk is to use independent organization to be involved in project. Situation for this paper was coincidental, although the effects of other situations are beyond the scope of this paper.

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