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# A Fuzzy Group Decision Making Approach to Construction Project Risk Management

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## KEYWORDS

Construction industry,
Group decision making,
Fuzzy sets,
Multi-criteria decision making,
Risk management

## ABSTRACT

*Implementation of the risk management concepts into construction practice may enhance the performance of project by taking appropriate response actions against identified risks. This research proposes a multi-criteria group decision making approach for the evaluation of different alternative response scenarios. To take into account the uncertainties inherent in evaluation process, fuzzy logic is integrated into the evaluation process.*

*To evaluate alternative response scenarios, first the collective group weight of each criterion is calculated considering opinions of a group consisted of five experts. As each expert has its own ideas, attitudes, knowledge and personalities, different experts will give their preferences in different ways. Fuzzy preference relations are used to unify the opinions of different experts. After computation of collective weights, the best alternative response scenario is selected by the use of proposed fuzzy group decision making methodology which aggregates opinions of different experts.*

*To evaluate the performance of the proposed methodology, it is implemented in a real project and the best alternative responses scenario is selected for one of the identified risks.*



## 1. Introduction

Many construction projects have not yet secured good project goal achievement. Such failure could be realized in terms of severe project delay, cost overrun and poor quality [1]. The presence of risks and uncertainties might be responsible for such a failure. Thus, there is a considerable need to incorporate the risk management concepts into construction practice in order to enhance the performance of project.

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The idea that risk management should be an important part of project management is currently widely recognized by the leading project management institutions [2]. Different levels of risk management have been proposed by the researchers and organizations since 1990. Al-Bahar and Crandall [3], the U.K. Ministry of Defense [4], Wideman [5], and the U.S. Department of Transportation [6] are among those suggesting the use of a process with four phases. These phases include risk identification, risk analysis, risk response planning, and control.

Feylizadeha et. al. [7] used a fuzzy neural network model to determine the EAC (estimate at completion) cost of the project. The proposed approach considers both qualitative and quantitative factors affecting the EAC prediction. Abdelgawad and Fayek [8] extended

the application of failure mode and effect analysis (FMEA) to risk management in the construction industry. They used fuzzy logic and fuzzy analytical hierarchy process (AHP) for the risk analysis. Liu et. al. [9] highlighted the differences between enterprise risk management (ERM) and project risk management (PRM).

Creedy et. al. [10] addressed the problem of why highway projects overrun their predicted costs. It identified the owner risk variables that contribute to significant cost overruns. Molenaar [11] modelled the risk events in the construction cost estimation as individual components. The risk analysis was performed using Monte Carlo simulation approach. Jannadi and Almishari [12] used expected value technique to perform the risk analysis phase for individual risk. Touran [13] used a probabilistic model for the calculation of project cost contingency by considering the expected number of changes and the average cost of change.

Although there are several researches in the area of risk management, almost all of them only concentrate on the risk analysis phase. The risk response planning phase is not discussed in the previous works and the selection of the most appropriate risk response action is mainly performed by personal judgment and there is no systematic approach to select the optimum response against the identified risks [14].

This research proposes a methodology for the evaluation of different alternative response scenarios based on their impacts on the project objectives in terms of project cost, project duration and project quality. The proposed approach is a fuzzy multi-criteria group decision making approach. To evaluate alternative response scenarios, first the collective group weight of each criterion is calculated considering opinions of a group consisted of five experts. As each expert has its own ideas, attitudes, knowledge, and personalities, different experts will give their preferences in different ways. Fuzzy preference relations are used to unify the opinions of different experts. After computation of collective weights, the best alternative response scenario is selected by the use of proposed integrated fuzzy multi-criteria group decision making methodology.

To evaluate the performance of the proposed methodology, it is implemented in a real project and the best alternative responses scenario is selected for one of the most important identified risks.

## 2. Concept of Fuzzy Sets Theory

Fuzzy set theory introduced by Zadeh [15], is used increasingly for uncertainty assessment in situations where little deterministic data are available. The use of fuzzy sets theory allows the user to include the imprecision, arising from the lack of available information or randomness of a future situation. Using fuzzy set theory in practical problems would make the models more consistent with reality. The central concept of fuzzy sets theory is the membership function which represents the degree to which a member belongs to a set as represented by the following equation:

$$\tilde{A} = \left\{ (x, \mu_{\tilde{A}}(x)) \middle| x \in X \right\} \quad (1)$$

Where, $\mu_{\tilde{A}}(x)$ is called the membership function of $x$ in $\tilde{A}$ that maps $x$ to the membership space $M$.

## 3. Selection of Optimum Response Against the Identified Risks

Prior to the discussion of optimum risk response selection process, it is necessary to introduce alternative risk response methods. Risk response is an action taken to avoid risks, to reduce the occurring probability of risks, or to mitigate losses arising from risks. Risk handling methods are classified into four categories, including risk avoidance, risk transfer, risk mitigation, and risk acceptance.

**Risk avoidance** means the rejection or change of an alternative to remove some hidden risk. For example, if a construction method is contingent on rain, the contractor could avoid schedule delay by adopting another construction method that will not be influenced by rain.

**Risk transfer** means the switch of risk responsibility between contracting parties in a project. Contractors usually use three risk transfer methods to offload risk responsibilities. They are as follows:

- Insurance
- Subcontracting.
- Claims to the owner for financial losses or schedule delay.

**Risk mitigation** denotes reduction of the occurring probability or the expected losses of some potential risk by either reducing the probability or the impacts of a risk event.

**Risk acceptance** includes two conditions i.e., (1) Unplanned risk retention, where the manager does not take any action for some risk; and (2) Planned risk retention, where the manager decides to take no action for some risk after cautious evaluation [16].

The risk handling strategies may involve one or a combination of multiple approaches mentioned herein. To handle risks appropriately, managers need to realize the contents and effects of all alternative response actions before making decisions.

The objective of the study presented in this paper is to provide different construction parties, with a decision making mechanism that will aid them in the selection of best alternative response scenario to the identified risks which allow them to make intelligent and

economical decisions based on the proposed reliable fuzzy methodology.

### 3.1. Selection of Evaluation Criteria

Each potential risk may have a negative impact on project objectives in terms of project delay, cost overrun and poor quality. Selection criteria are directly linked with project objectives, both tangible, including time and cost and intangible i.e., quality.

Implementation of alternative response scenarios may decrease the negative impacts of risks. However, the implementation of alternative response scenarios will impose additional expenses on the project, Therefore, after implementation of alternative response scenarios, the value of different project performance objectives is determined as the deduction of two aforementioned terms.

Finally the selection factors that are relevant to the decision making problem are selected as below:

1. Project duration
2. Project cost
3. Project quality

### 3.2. Computation of Collected Weights of Criteria

In this section the aggregated weights of different criteria is calculated. For calculation of the group weight of each criterion, decision makers should evaluate relative importance of criteria. Since each expert has its own ideas, attitudes, motivations, and personalities, they will give their preferences in different ways. Herrera-Viedma et al [17] states that group members may express their opinions as 1) preference ordering, 2) utility values, 3) fuzzy preference relations and 4) multiplicative preference relations. These opinions can be converted into the various representations using appropriate transformations [18]. In this paper, fuzzy preference relations are used to unify opinions. Fuzzy relationships in the evaluation are used to incorporate the uncertainties in the decision opined by a particular decision maker. In addition, decision making becomes difficult when the available information is incomplete or imprecise [19], [20]. In these assessments, preference orderings of alternatives are represented by $O_s^i$, which defines preference ordering evaluation given by $DM_i$ to alternative $x_s$. Fuzzy preference relation is expressed by $k_{sm}^i$, where $k_{sm}{}^i \subset X * X$ with membership function $\mu_{ki} : X \times X \to [0,1]$, and $\mu_{ki}(x_s, x_m) = k_{sm}^i$, where $X = \{x_1, ..., x_n\}$ is a finite set of alternatives.

Value of $k_{sm}^i$ defines a ratio of the fuzzy preference intensity of alternative $x_s$ to $x_m$. Multiplicative preference relations are represented as $A^i$ where $A^i \subset X * X$, $A^i = a_{sm}^i$ and $a_{sm}^i$ is a ratio of the fuzzy preference intensity of alternative $x_s$ to $x_m$ given by $DM^i$ where is scaled in a 1 to 9 scale. Utility function is shown as $U^i$ where $DM^i$ explains his/her preferences on alternatives as utility values. Utility value of alternative $x_s$ given by $DM^i$ is presented by $u_s^i \in [0,1]$.

Before aggregating DMs' assessments, the opinions should be unified into fuzzy preference relationship by an appropriate transformation function. A common transformation function between the various preferences is presented below [18]:

$$K_{sm}^i = \frac{(u_s^i)^2}{(u_s^i)^2 + (u_m^i)^2} \tag{2}$$

$$K_{sm}^i = \frac{1}{2}(1 + \frac{o_m^i - o_s^i}{n-1}) \tag{3}$$

$$K_{sm}^i = \frac{1}{2}(1 + \log_9 a_{sm}^i) \tag{4}$$

OWA operator is used to aggregate unified opinions. OWA operator was introduced in 1988 by Yager [21], [22], [23]. An OWA operator is an aggregation operator with an associated vector of weights $\sum_{i=1}^{n} w_i = 1, w \in [0,1]^n$ such that:

$$F_w(x) = \sum_{i=1}^{n} w_i . b_i \quad , \quad \mathrm{x} \in \mathrm{I}^{\mathrm{n}} \tag{5}$$

with $b_i$ denoting the $i$th largest element in $x_1; \ldots; x_n$.

The most important characteristic of OWA operator is that it may produce many solutions based on decision maker's objective characteristics. In the other word, OWA operator considers decision maker's subjective characteristics to estimate collective value; whereas, other aggregation operators have not this important characteristic. An important problem in using OWA aggregation operator is how to obtain the associated weighting vector. There are two approaches to calculate the weighting vector w. In the first approach, the weighting vector is calculated using sample data as the function of the values to be aggregated. In the second approach, however, the weighting vector w is calculated using linguistic quantifiers. In this approach that was introduced by Yager, the weighting vector is calculated as follow [22], [24]:

$$w_i = Q(\frac{i}{n}) - Q(\frac{i-1}{n}) \quad , \quad i = 1, ..., n \tag{6}$$

Q is a fuzzy linguistic quantifier that represents the concept of fuzzy majority, is calculated as:

$$Q(r) = \begin{cases} 0 & \text{if : } r < a \\ \frac{r-a}{b-a} & \text{if : } b \le r \le a \\ 1 & \text{if : } r > b \end{cases} \tag{7}$$

The most common linguistic fuzzy quantifiers used are "most", "at least half", and "as many as possible".

Their ranges are given as (.3, .8), (0, .5) and (.5, 1), respectively [20]. Five considered DMs represented their views on the various criteria including project duration, project cost and project quality in four different ways. The first DM presented his view in the form of utility functions, the second DM remarked his view in preference ordering of the alternatives, the third DM proposed his view in multiplicative preference relation on a scale of 1 to 9 and the fourth DM expressed his view in fuzzy preference relation, and the fifth DM presented his views in utility function, as follows:

$$DM^1\ [.5\ ,\ .6\ ,.25]$$

$$DM^2\ [1\ ,\ 2\ ,\ 3]$$

$$DM^5\ [.5\ ,\ .5\ ,\ .3]$$

$$DM^3\begin{bmatrix} & 1 & 2 & 3 \\ 1 & 1 & 2 & 5 \\ 2 & 1/2 & 1 & 4 \\ 3 & 1/5 & 1/4 & 1 \end{bmatrix},\ DM^4\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .55 & .7 \\ 2 & .45 & .5 & .65 \\ 3 & .3 & .35 & .5 \end{bmatrix}$$

The various forms of presented opinions are transformed into fuzzy preference relation using the previously defined transformation functions.

$$DM^1\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .41 & .8 \\ 2 & .59 & .5 & .85 \\ 3 & .2 & .15 & .5 \end{bmatrix},\ DM^2\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .75 & 1 \\ 2 & .25 & .5 & .75 \\ 3 & 0 & .25 & .5 \end{bmatrix},\ DM^3\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .66 & .87 \\ 2 & .34 & .5 & .82 \\ 3 & .13 & .18 & .5 \end{bmatrix}$$

$$DM^4\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .55 & .7 \\ 2 & .45 & .5 & .65 \\ 3 & .3 & .35 & .5 \end{bmatrix},\ DM^5\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .5 & .74 \\ 2 & .5 & .5 & .74 \\ 3 & .26 & .26 & .5 \end{bmatrix}$$

Transformed and uniformed values in previous step are aggregated using OWA operator and aggregation weights in the aggregation step that resulted from quantifier "most" with the domain (.3, .8) are (0, 0.2, 0.4, 0.4, 0). The resulted collective fuzzy preference opinion is:

$$\text{Collective solution}=\begin{bmatrix} & 1 & 2 & 3 \\ 1 & .5 & .552 & .79 \\ 2 & .416 & .5 & .76 \\ 3 & .184 & .224 & .5 \end{bmatrix}$$

For calculation of final aggregated weight of each criterion, the values of collective solution must be aggregated together.

Fuzzy linguistic quantifier "as many as possible" with domain (.5, 1) is utilized. Hence, corresponding weight vector with this operator is W= (0, .33, .67) and collective weight of each criterion is: $DM^G = [.517\quad .443\quad .197]$. Before assigning these values to weights, they should be normalized. The normalized weight vector is: $DM^G = [.447\quad .383\quad .17]$.

### 3.3. Selection of the Optimum Response Scenario Using the Proposed Fuzzy Multi-Criteria Group Decision Making Approach

The structure of the proposed fuzzy multi-criteria decision making approach is depicted in Fig. 1. The proposed fuzzy multi-criteria decision making approach was adapted from the model developed by Lee, Y. et al. [25] for dredged material management.

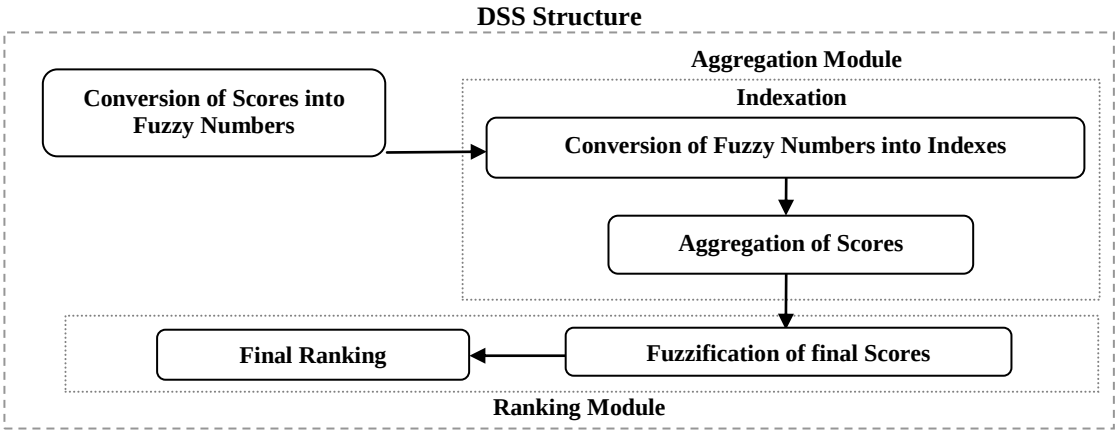


**Fig. 1. The structure of the proposed fuzzy multi-criteria group decision making approach [adopted from 25 and 26]**

The model comprises three main sectors. At first assigned scores are converted into the fuzzy set. Thereafter scores for each alternative system would be aggregated at aggregation module. Finally alternative response scenarios are ranked based on the acquired final scores at aggregation module, which are fuzzy numbers. If $Z_i(x)$ is assumed as a fuzzy value for ith alternative, its membership function will be $\mu[Z_i(x)]$ as denoted in Fig. 2 with a trapezoid membership function. Membership degree for each value would be assigned based on the expert's judgment.

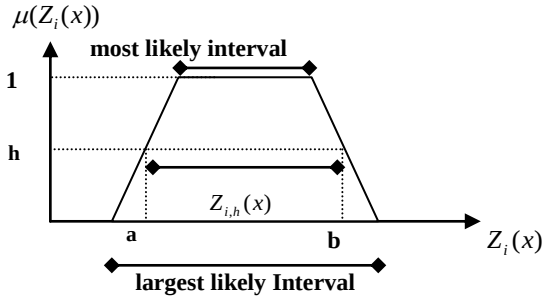


**Fig. 2. Fuzzy score of $x^{th}$ alternative against $i^{th}$ criterion**

As it is shown in Fig.2, $Z_{i,h}(x)$ is an interval in which membership degrees are higher than h. This interval, which has been assigned based on h likely interval, is a sub-set of the fuzzy set and has been introduced based on level-cut concept. One of these intervals $Z_{i,1}(x)$ is the most likely interval, where the membership degrees are one. Moreover $Z_{i,0}(x)$ is largest likely interval and if any of $Z_i(x)$ fall out of this interval its membership degree would be zero.

**Conversion of Scores Into Indexes:**

Since different criteria, with different characteristics and units, are going to be integrated; $Z_{i,h}(x)$ as score assigned to each response scenario regarding every criterion should be converted into an index. This index is in fact a ratio and is comparable for variety of criteria. Subsequently final decision would be made based on aggregation of opinions considering all criteria. For that reason, considering (BES $Z_i$) and (WOR $Z_i$) respectively as best and worst values $Z_{i,h}(x)$ could be converted into $S_{i,h}(x)$ index as follows:

1. If BES $Z_i$ > WOR $Z_i$ then:

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \geq BESZ_i \\ \dfrac{\left(Z_{i,h}(x) - WORZ_i\right)}{\left(BESZ_i - WORZ_i\right)} & WORZ_i < Z_{i,h}(x) < BESZ_i \\ 0 & Z_{i,h}(x) \leq WORZ_i \end{cases} \quad (8)$$

2. If WOR $Z_i$ >BES $Z_i$ then:

$$S_{i,h}(x) = \begin{cases} 1 & Z_{i,h}(x) \leq BESZ_i \\ \dfrac{\left(Z_{i,h}(x) - WORZ_i\right)}{\left(BESZ_i - WORZ_i\right)} & BESZ_i < Z_{i,h}(x) < WORZ_i \\ 0 & Z_{i,h}(x) \geq WORZ_i \end{cases} \quad (9)$$

Consequently $Z_{i,h}(x)$ as a fuzzy function is converted to $S_{i,h}(x)$ and related trapezoid diagram is transformed to the following diagrams (Fig.3). Two conditions have been considered above, due to the reason that usually characteristics are assessed in two directions. That is, regarding some criteria like Quality, getting greater score is equal to being more appropriate, so first equation would be assigned to these types of criteria. In contrast concerning some criteria like time or cost, getting greater score means less acceptability, therefore second equation would be assigned for these types of criteria. Subsequently impact of the scoring direction is crossed out and results from all criteria could be summed up.

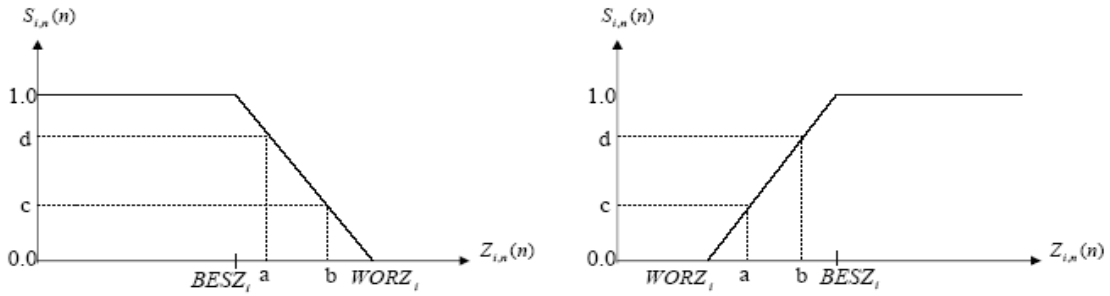


**Fig. 3. Transferring fuzzy values to index value**

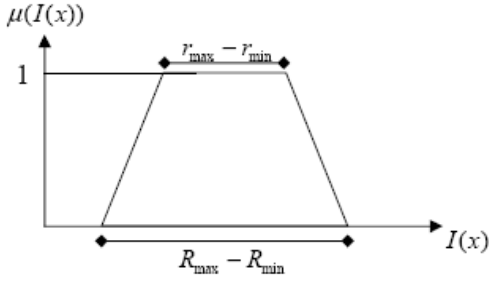


**Fig. 4. Membership function of the final score regarding each alternative [adopted from 25 and 26]**

**Aggregation of Scores of Each Alternative Response Scenario:**

For summing up all the scores and obtaining final score concerning each response scenario following equation could be exploited:

$$I_h(x) = \left\{ \sum_{i=1}^{n} W_i \left(S_{i,h}(x)\right) P \right\}^{\frac{1}{p}} \quad (10)$$

Where n= the number of criteria; $S_{i,h}$ = Index for ith criterion with h level of acceptance; $w_i$ = Related

weight of each criterion $\left(\left(\sum w_i = 1\right)\right)$; P= balancing factor and $I_h(x)$ = Final index for each criterion with h level of acceptance. The balancing factor P $(P \geq 1)$ is a factor which shows importance of deviation magnitude between a criterion value and the best criterion for that value and would be proposed for a group of criteria. Therefore if P=1 then all deviations will get equal weight, and if P=2 each deviation will get weight in proportion to its scale. In general $P \geq 3$ would be used for limiting criteria [26]. Furthermore if each criterion comprises other criteria, this equation could be extended for lower levels and then final result would be reached by adding up results of each level. Consequently evaluation process could be followed up in different levels so as to obtain final score regarding each alternative [25].

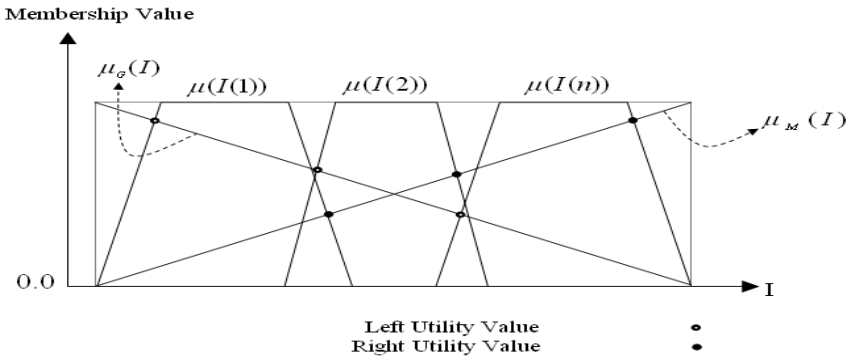


**Fig. 5. final idea's score functions with related utility functions [adopted from 25 and 26]**

**Preparing Proposed Alternative Response Scenarios for Ranking:**

After acquiring final index for each alternative, membership function of a fuzzy set $\mu[I_i(n)]$ will be figured out utilizing equation (6). The membership function is a piecewise linear function, in which $I(x)$ is member of the fuzzy set associated with final score of the $x$ th alternative. This could be performed by calculating $I_{h=0}(x)$, and $I_{h=1}(x)$ whose levels of acceptance are zero and one respectively.

$$\mu[I(x)] = \begin{cases} 1 & r_{\min} \leq I(x) \leq r_{\max} \\ \dfrac{I_{(x)} - R_{\min}}{r_{\min} - R_{\min}} & R_{\min} \leq I(x) < r_{\min} \\ \dfrac{I_{(x)} - R_{\max}}{r_{\max} - R_{\max}} & r_{\max} < I(x) \leq R_{\max} \\ 0 & otherwise \end{cases} \quad (11)$$

$r_{\max}$ and $r_{\min}$ = lowest and highest value of $I_{h=1}(x)$ for final index respectively

$R_{\max}$ and $R_{\min}$ = lowest and highest value of $I_{h=0}(x)$ for final index respectively

$I_{h=0}(x)$ and $I_{h=1}(x)$ are resulted from $Z_{i,h=0}(x)$ and $Z_{i,h=1}(x)$ correspondingly.

If n alternative response scenarios have been considered for ranking, there will be n fuzzy sets as $\left|I_{(n)} \mid n = 1,2,....,n\right|$ whose membership functions will be resulted from equation (11).

**Final Ranking of Alternative Response Scenarios:**

Since the values which are assigned to each alternative response scenario are fuzzy, their ranking could not to be done by conventional straightforward ranking methods. Therefore, a fuzzy ranking method is required to fulfill the objective. According to Chen and Hwang opinion, variety of the ranking methods which are proposed for fuzzy MCDM's, can be categorized into four groups [27]:

1. Utilizing preferences ratio, by applying techniques such as degree of optimality, hamming distance, α-cut and comparison function.
2. Fuzzy mean and spread by applying probability distribution.
3. Fuzzy scoring which involves techniques such as proportional optimal, left right scores, centroid index and area management.
4. Utilizing linguistic expression.

The method chosen for this purpose is developed by Chen [28] through applying minimizing and maximizing sets [28]. The maximizing set M is a fuzzy subset with membership function of $\mu_M$, defined as follows:

$$\mu_M(I) = \begin{cases} \left(I - I_{\min}\right) / \left(I_{\max} - I_{\min}\right) & I_{\min} \leq I \leq I_{\max} \\ 0 & otherwise \end{cases} \quad (12)$$

$$I_{\min} = \min\ (\min\ \ I_{h=0}(x)) \quad \text{for x} = 1, \ldots.., \text{n} \quad (13)$$

$$I_{\max} = \max\ (\max\ \ I_{h=0}(x)) \quad \text{for x} = 1, \ldots.., \text{n} \quad (14)$$

Therefore right utility value $U_R(x)$ for $x$ th alternative would be determined as:

$$U_R(x) = \max\left(\min\ \left(\mu_M(I(x))\ ,\ \mu(I(x))\right)\right. \quad (15)$$

In the same way minimizing set G is also introduced as a fuzzy subset with membership function of $\mu_G$:

$$\mu_G(I)=\begin{cases}(I-I_{max})/(I_{min}-I_{max}) & I_{min}\le I\le I_{max}\\ 0 & otherwise\end{cases} \quad (16)$$

And then left utility value $U_L(x)$ for alternative system x would be determined as follows:

$$U_L(x)=\max(\min\ (\mu_G(L)\ ,\ \mu(I(x))) \quad (17)$$

Consequently total utility or ranking value for proposal x is:

$$U_{(x)}=\frac{(U_R(x)+1-U_L(x))}{2} \quad (18)$$

The alternative with best total utility value would be presented as the best option, thus all alternatives would be sorted based on their total utility values.

## 4. Model Application

The proposed fuzzy group decision making approach can be used for the selection of optimum response against the identified risks. To evaluate the performance of the proposed methodology it has been implemented in a sample real project.

This project is related to the execution of a large massive concrete foundation of a high rise building. This project involves 2500 cubic meter of concreting and its duration has been estimated as 5 months. The total cost of the project, including both direct and indirect costs, has been estimated as 200000 dollars. Facing to inclement weather risk is one of the most important risks identified for this project. The proposed fuzzy group decision making approach is implemented to select the most effective alternative response scenario against this risk. In this project case example, it is expected that inclement weather risk will be occurred during the 3rd and 4th months.

The occurrence of this risk would have negative impacts on the construction productivity and may lead to project cost overrun, project delay and poor quality. The alternative response scenarios which have been identified for this risk are explained below briefly.

Risk avoidance:

The first alternative response scenario which may be implemented against the inclement weather risk is to avoid it by change in project schedule. It means that the execution plan of the project is changed in a manner that the concreting work is postponed to the 5th month to avoid the negative impacts of the risk.

**Risk Acceptance:**

The second alternative response scenario which may be implemented against inclement weather risk is its acceptance, where the manager does not take any action against this risk.

**Risk Mtigation:**

In the 3rd alternative response scenario, the potential expected losses caused by the inclement weather risk are reduced. To reduce the schedule delay caused by this risk, the overtime policy is implemented during the 3rd and 4th months.

**Risk Transfer:**

Finally in the last alternative response scenario, the potential losses arising from inclement weather risk are transferred through subcontracting or insurance. A group consisting of five experts was considered to carry out the case study, through application of the proposed model.

A spread sheet program is also provided in order to help risk analysis team during the selection process. Brief outcomes of the assessment performed by the proposed fuzzy group decision making approach are presented in table 1. As shown in table1, using the proposed fuzzy group decision making approach, it is concluded that the risk avoidance is the best alternative response scenario. It should be emphasized that this evaluation was made based on the proposed case and in different situations the outcome of the assessment could vary depending on the actual requirements and restraints. It is believed that the proposed fuzzy group decision making approach provides a powerful tool for the selection of optimum response scenario against the identified risks.

**Tab. 1. Scoring and final results**

| Response Scenario | interval | Project Cost | Project Duration | Project Quality | left utility value | right utility value | total utility value |
|---|---|---|---|---|---|---|---|
| Acceptance | most likely interval | 75-84 | 65-79 | 40-61 | 0.468 | 0.701 | 0.616 |
| | least likely interval | 78-80 | 66-72 | 50-55 | | | |
| Avoid | most likely interval | 52-67 | 82-95 | 74-83 | 0.335 | 0.83 | 0.747 |
| | least likely interval | 57-60 | 88-91 | 80-82 | | | |
| Mitigate | most likely interval | 80-97 | 57-65 | 52-71 | 0.5 | 0.698 | 0.599 |
| | least likely interval | 81-92 | 60-64 | 61-70 | | | |
| Transfer | most likely interval | 64-72 | 63-72 | 48-57 | 0.53 | 0.573 | 0.521 |
| | least likely interval | 68-69 | 68-69 | 52-55 | | | |

## 5. Sensitivity Analysis

In OWA method, risk level of DMs is accounted in an explicit manner. At this decision-making problem, sensitivity analysis is carried out considering the change in the DMs' optimism degree or their risk level and its impact on weighting coefficients and final ranks of alternatives. For sensitivity Analysis, another equation was used to calculate the function Q to find the order weights of OWA operator. The equation $Q(r) = r^{\alpha}, \alpha \geq 0$ having many applications in calculation of membership function of a quantifier can be used in which α is optimistic coefficient of DM.

If α >1, it indicates pessimism or risk-averse decision-maker. If α=1, it means decision-maker is neutral. Finally, α<1, represents optimistic or risk-prone decision-maker. The order weights of OWA operator depend on the manager's optimism/pessimism view on the risk. If the DM has an optimistic view then larger weights will be assigned to the first ranks in the OWA operator and therefore the model will have larger outputs. Based on this perception, Yager (1988) has defined the optimism degree θ in the following way:

$$\theta = \int_0^1 Q(r)dr = \frac{1}{1+\alpha} \tag{19}$$

Transformed and uniformed values of DMs in section 3.2 are aggregated using OWA operator with regard to different optimism degree (α=0.01, 0.1, o.5, 1, 2, 20). For calculation of final aggregated weights of criteria, the calculated collective fuzzy preference opinions are aggregated using fuzzy linguistic quantifier "most" with domain (.3, .8) and corresponding weight vector W= (.067, .663, .27). The final normalized weight vector of criteria is shown in Table 2.

**Tab. 2. Sensitivity analysis for the normalized weights of criteria at different risk levels**

| Criteria | Risk Prone | | | Neutral | Risk Aversion | |
|---|---|---|---|---|---|---|
| | α=0.01 | α=0. 1 | α=0.5 | α=1 | α=2 | α=20 |
| w1 | 0.439 | 0.431 | 0.436 | 0.436 | 0.443 | 0.486 |
| w2 | 0.344 | 0.359 | 0.366 | 0.38 | 0.393 | 0.395 |
| w3 | 0.217 | 0.21 | 0.198 | 0.184 | 0.164 | 0.119 |

It can be clearly seen that by increasing α and decreasing optimism degree or risk level of DMs, the relative weights of the first and second attribute is increased. In contrast, the relative weight of third criterion is declined in similar situation.

In table 3 the results of the sensitivity analysis carried out for the scoring and final results is presented at different risk levels.

**Tab. 3. Sensitivity analysis for the scoring and final results at different risk levels**

| Response Scenario | Risk Prone | | | Neutral | Risk Aversion | |
|---|---|---|---|---|---|---|
| | α=0.01 | α=0. 1 | α=0.5 | α=1 | α=2 | α=20 |
| Acceptance | 0.608 | 0.608 | 0.611 | 0.613 | 0.617 | 0.627 |
| Avoid | 0.745 | 0.748 | 0.747 | 0.749 | 0.749 | 0.740 |
| Mitigate | 0.598 | 0.596 | 0.597 | 0.597 | 0.598 | 0.606 |
| Transfer | 0.515 | 0.516 | 0.518 | 0.519 | 0.522 | 0.527 |

## 6. Conclusions and Remarks

In this study a fuzzy group decision making approach is exerted to perform construction project risk management which assist different project parties to select the optimum response against identified risks. The model is well suited for situations where criteria have varying degree of importance as well as uncertain values. Since the risk response planning should be performed at the earlier stages of the project and taking account of more indefiniteness existed in those stages, introducing fuzzy sets theory could benefit decision makers to make more tangible and realistic evaluation. In the proposed methodology, first the group weight of each criterion is calculated. As each expert has its own ideas, attitudes and personalities, different experts will give their preferences in different ways. The fuzzy preference relations have been used to unify these opinions for calculation of the collective weights of each criterion. The best alternative response scenario is then selected by the use of the proposed fuzzy group decision making methodology. It should be taken into account that in spite of superficial complexity, the model is rather practical and straightforward and could be utilized in order to achieve more reliable assessment of the alternative response scenarios. More simplification, however, could encourage risk

management teams to more utilize it. The proposed model was implemented in a real project. The alternative response scenarios against one of the most important identified risks, i.e., inclement weather risk were identified. The outcome of the case study indicated that the risk management team has selected the risk avoidance as the best alternative response scenario. It is believed that the proposed fuzzy group decision making approach provides a powerful tool for the selection of optimum response scenario against the identified risks.

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