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FUZZY MULTI CRITERIA DECISION MAKING MODEL FOR RISK FACTOR SELECTION IN CONSTRUCTION PROJECTS

BY

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Abstract. Risk factor selection is an important step in a successful risk management plan. There are many risk factors in a construction project and by an effective and systematic risk selection process the most critical risks can be distinguished to have more attention. In this paper through a comprehensive literature survey, most significant risk factors in a construction project are classified in a hierarchical structure. For an effective risk factor selection, a modified rational multi criteria decision making model (MCDM) is developed. This model is a consensus rule based model and has the optimization property of rational models. By applying fuzzy logic to this model, uncertainty factors in group decision making such as experts' influence weights, their preference and judgment for risk selection criteria will be assessed. Also an intelligent checking process to check the logical consistency of experts' preferences will be implemented during the decision making process. The solution inferred from this method is in the highest degree of acceptance of group members. Also consistency of individual preferences is checked by some inference rules. This is an efficient and effective approach to prioritize and select risks based on decisions made by group of experts in construction projects. The applicability of presented method is assessed through a case study.

Key words: multi criteria decision making; risk management; fuzzy set; construction management.

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1. Introduction

There are many risk factors in a construction project. These risk factors vary from one project to other depending on different conditions of a project. The first step to have an effective risk management plan is *risk classification*. Risk classification is an important step in the risk assessment process, as it attempts to structure the diverse risks that may affect a project. In this study through a comprehensive literature survey of different risk classification approaches, most effective risk factors in a construction project are classified by their source and effect on project objective. Although this classification is comprehensive but it is not restricted and depends on different situations of a project, some new factors can be added to this classification. To make the risk management plan as effective as possible, the most effective risk factors on project objectives should be prioritized and selected through group decision making. Group members consist of different experts in construction industry with variety in experience, knowledge and expertise. In this research we proposed a fuzzy multi-criteria group decision making solution which is based on the Hybrid Rational-Political model. The proposed model has ten steps within three stages. The rest of the paper is organized as follows. In the next section, a literature survey on different methods of risk classification with focus on construction project risks is introduced. This section ends with a suggested hierarchical risk factor classification in a construction project. Then in the subsequent section, the proposed methodology for risk factor prioritization and selection is defined. Applicability of proposed model is assessed through a case study in next section and final section concludes the article.

2. Risk Classification

A guide to the project management body of knowledge (PMBok, Version 2008) defines risk classification as a provider of a structure that ensures a comprehensive process of systematically identifying risks to a consistent level of detail and contributes to the effectiveness and quality of the identify risks process. Risk classification is an important step in the risk assessment process, as it attempts to structure the diverse risks that may affect a project. There are many approaches in literature for construction risk classification. Perry and Hayes (1985) give an extensive list of factors assembled from several sources, and classified in terms of risks retainable by contractors, consultants and clients. Abdou (1996) classified construction risks into three groups, *i.e.* construction finance, construction time and construction design. Shen (1997) identified eight major risks accounting for project delay and ranked them based on a questionnaire survey with industry practitioners. Tah and Carr (2000) classified project risks by using the hierarchical risk breakdown structure (HRBS) and

classified them into internal and external risks. Chapman (2001) grouped risks into four subsets: environment, industry, client and project. Shen (2001) categorized them into six groups in accordance with the nature of the risks, *i.e.* financial, legal, management, market, policy and political. Chen *et al.* (2004)

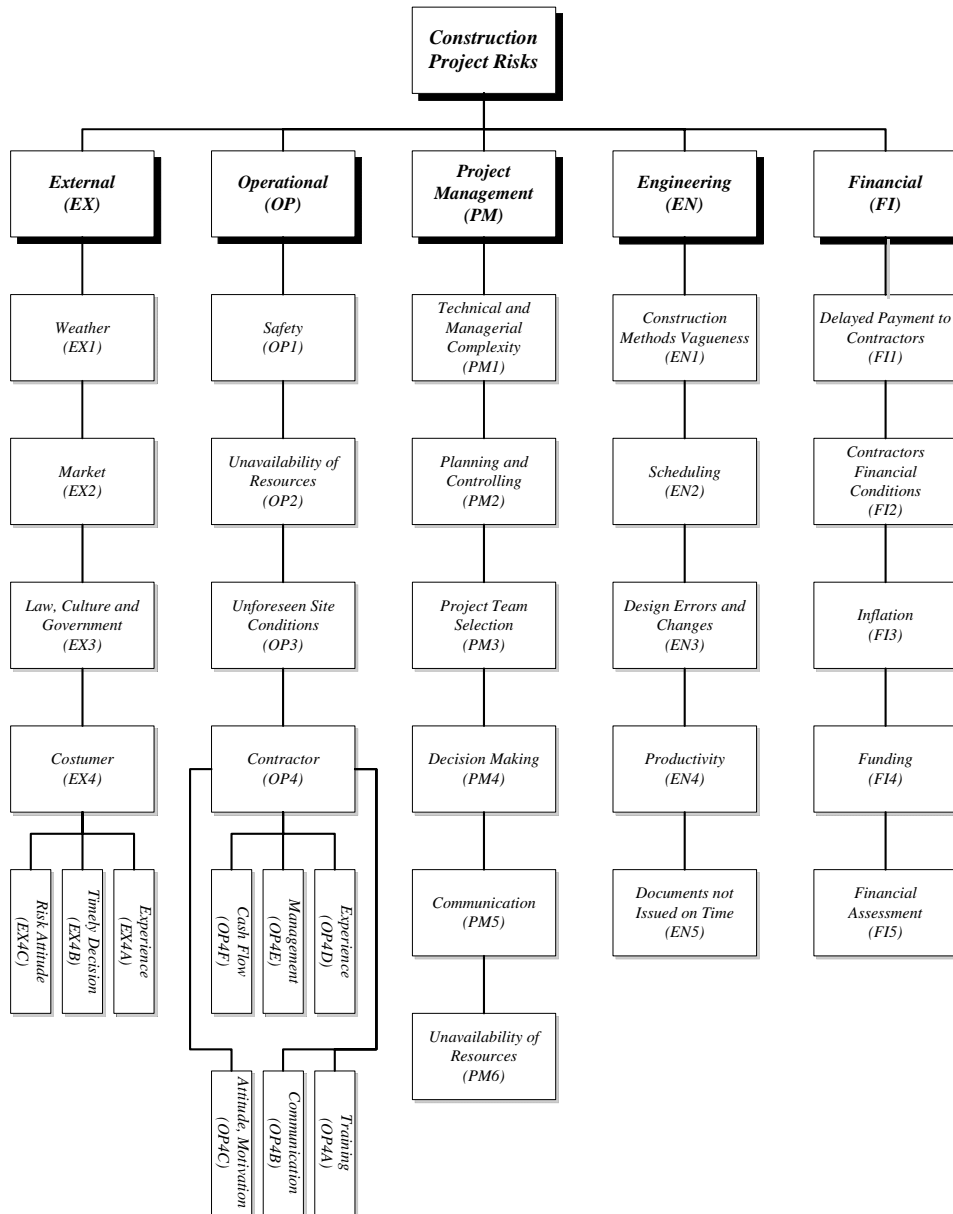


Fig. 1 – Construction risk classification.

proposed 15 risks concern with project cost and divided them into three groups: resource factors, management factors and parent factors. Assaf and Al-Hejji (2006) mentioned the risk factors as the delay factors in construction projects. Dikmen *et al.* (2007) used influence diagrams to define the factors which have influence on project risks. Zeng *et al.* (2007) classified risk factors as human, site, material and equipment factors. Based on the above literature review, we propose the risk classification represented in Fig. 1.

3. Risk Factor Prioritization and Selection

After classifying the inherent risks in construction projects, it is very important to select and prioritize the risk items in order to have an efficient risk management plan. Since we have a finite number of criteria and infinite number of feasible alternatives, the multiple criteria decision making model should be utilized. The main factors that taken into consideration in mentioned model are decision makers influence weights, their preferences for risk factor selection and the criteria for assessing risks. Group members consist of different experts in construction industry with variety in experience, knowledge and expertise. Experts with higher degree of competence should be assigned higher weights. Experts may not know or consider all the relevant information for a decision problem. To conquer this subject, an uncertainty factor named preference of every decision maker and related belief matrices are considered.

To apply this model, risk factor classification, projects requirements and objectives should be determined. Experts select the risk factors and then rank them to select N of them. Risk assessment and ranking criteria will be nominated by group members and finally T criteria will be used. To incorporate human inconsistency in decisions, it is suggested that all group members cooperate in group aggregation process to ensure that the disparate individuals come to share the same decision objectives. Any individual role in a decision process, a preference for alternatives, and a judgment for assessment criteria are often expressed by linguistic terms as normal, more important. To deal with these uncertain and vague terms, crisp mathematical approaches cannot be applied. To handle these uncertainties, inaccurate and vague linguistic terms, the fuzzy logic is applied. The theory of fuzzy sets provides a framework and offers a calculus to address these fuzzy statements.

3.1. Methodology

Let $P = \{P_1, P_2, \dots, P_n\}, n \geq 2$, be a given number of experts in the decision making group to prioritize and select risks from classified risk factors. The proposed model has ten steps within three stages namely

Stage 1: Risk factor, assessment criteria and experts` influence weights determination.

Step 1: By proposing classified risks in a group, every expert may have one or several possible risk factor selection. Through discussions and summarizations, $S = \{S_1, S_2, \dots, S_m\}, m \geq 2$, is selected from alternative pool as final risk factors (alternatives) for prioritization.

Step 2: A criterion pool is constructed in this step and every members' assessment criteria is put into this pool. Each expert can propose his own assessment criteria for ranking and assessing the risk factors in this pool. Top T criteria, $C = \{C_1, C_2, \dots, C_t\}$, are chosen as assessment criteria for risk selection problem.

Step 3: To consider the experience, knowledge and expertise of each expert, an influence weight is described and assigned to every expert. These influence weights are described by linguistic term $\tilde{v}_k, (k = 1, 2, \dots, n)$. These weights can be determined through discussions in group or assigned by the leader of decision making group. These weights are assigned before or at the beginning of decision process. Table 1 shows related linguistic terms of decision makers. These linguistic terms and related membership functions are shown in Fig. 2. Triangular fuzzy numbers are used to map the linguistic terms to their corresponding fuzzy numbers. Table 2 presents a suggestive construction expert board to deal with risk selection in construction projects.

Table 1
Linguistic Terms for Describing Weights of Decision Makers

Linguistic terms	Membership functions	Fuzzy numbers	Supporting intervals	Abbreviation
Normal	$5x$	$(0,0.2,0.4)$	$0 \leq x \leq 0.2$	c1
	$2-5x$		$0.2 \leq x \leq 0.4$	
Important	$5x-1$	$(0.2,0.4,0.6)$	$0.2 \leq x \leq 0.4$	c2
	$3-5x$		$0.4 \leq x \leq 0.6$	
More Important	$5x-2$	$(0.4,0.6,0.8)$	$0.4 \leq x \leq 0.6$	c3
	$4-5x$		$0.6 \leq x \leq 0.8$	
Most Important	$5x-3$	$(0.6,0.8,1)$	$0.6 \leq x \leq 0.8$	c4
	$5-5x$		$0.8 \leq x \leq 1$	

Table 2
Suggestive Construction Expert Board in Decision Group

Experts	Linguistic terms	Abbreviation
Construction Manager	Most Important	c4
Senior Execution Engineer	More Important	c3
Senior Design Engineer	More Important	c3
Site Engineer with 15 Years Experience	Important	c2
Expert Presented By Client	Normal	c1

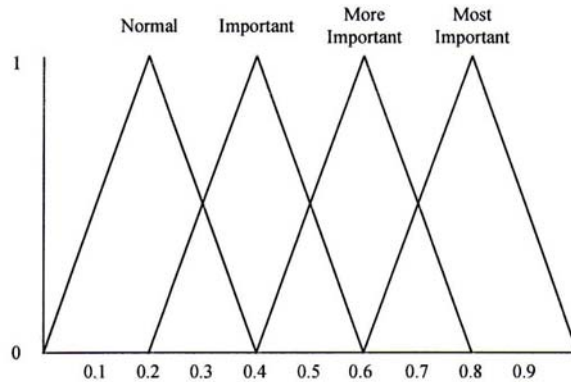


Fig. 2 – Membership functions of decision makers weights.

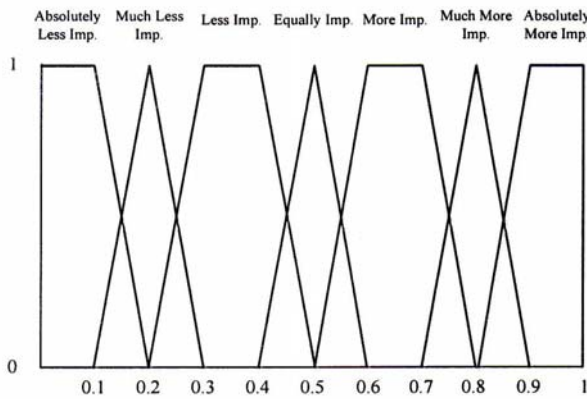


Fig. 3 – Membership functions of assessment criteria comparison.

Stage 2: Expert preference generation.

In this step each expert by using a pair-wise comparison expresses his opinion about outcomes of step 2. At first, a pair-wise comparison matrix $E = [\tilde{e}_{ij}^k]_{t \times t}$ is established. Every member of this matrix represents the quantified judgments on pairs of assessment criteria, C_i and C_j , ($i, j = 1, 2, \dots, t, i \neq j$). The linguistic terms and corresponding membership values which will be used for the comparison of the assessment criteria are described in Table 3 and Fig. 3. By utilizing the political model in this hybrid system, there is no obligation for experts to compare all the outcomes. Where ever the experts do not know or cannot compare the relative importance of assessment criteria C_i and C_j a '*' sign will be placed in pair-wise comparison matrix. By using following linguistic inference rules, the inconsistency of each pair-wise comparison matrix $E = [\tilde{e}_{ij}^k]_{t \times t}$, is corrected:

Table 3
Linguistic Terms for the Comparison of Assessment Criteria

Linguistic Terms	Membership Functions	Fuzzy Numbers	Supporting Intervals	Abbreviation
Absolutely Less Important	0	(0,0,0.1,0.2)	$x=0$	a1
	1		$0 \leq x \leq 0.1$	
	2-10x		$0.1 \leq x \leq 0.2$	
Much Less Important	10x-1	(0.1,0.2,0.2,0.3)	$0.1 \leq x \leq 0.2$	a2
	3-10x		$0.2 \leq x \leq 0.3$	
Less Important	10x-2	(0.2,0.3,0.4,0.5)	$0.2 \leq x \leq 0.3$	a3
	1		$0.3 \leq x \leq 0.4$	
Equally Important	5-10x	(0.4,0.5,0.5,0.6)	$0.4 \leq x \leq 0.5$	a4
	10x-4		$0.5 \leq x \leq 0.6$	
More Important	6-10x	(0.5,0.6,0.7,0.8)	$0.5 \leq x \leq 0.6$	a5
	10x-5		$0.6 \leq x \leq 0.7$	
Much More Important	1	(0.7,0.8,0.8,0.9)	$0.7 \leq x \leq 0.8$	a6
	8-10x		$0.7 \leq x \leq 0.8$	
Absolutely More Important	10x-7	(0.8,0.9,1,1)	$0.8 \leq x \leq 0.9$	a7
	9-10x		$0.8 \leq x \leq 0.9$	
	10x-8		$0.9 \leq x \leq 1$	
	1		$0.9 \leq x \leq 1$	
	0		$x=1$	

Rule 1: Positive-Transitive rule

If $\tilde{e}_{ij}^k = a_s$, ($s = 4, 5, 6, 7$), and $\tilde{e}_{jm}^k = a_t$, ($t = 4, 5, 6, 7$), then $\tilde{e}_{im}^k = a_{\max(s,t)}$.

Rule 2: Negative-Transitive rule

If $\tilde{e}_{ij}^k = a_s$, ($s = 3, 2, 1$), and $\tilde{e}_{jm}^k = a_t$, ($t = 3, 2, 1$), then $\tilde{e}_{im}^k = a_{\min(s,t)}$.

Rule 3: De-In-Uncertainty rule

If $\tilde{e}_{ij}^k = a_s$, ($s = 4, 5, 6, 7$), and $\tilde{e}_{jm}^k = a_t$, ($t = 3, 2, 1$) or '*',
then $\tilde{e}_{im}^k = a_i$ for any $t \leq i \leq s$ or '*'.

Rule 4: In-De-Uncertainty rule

If $\tilde{e}_{ij}^k = a_s$, ($s = 3, 2, 1$), or '*', and $\tilde{e}_{jm}^k = a_t$, ($t = 4, 5, 6, 7$),
then $\tilde{e}_{im}^k = a_i$ for any $s \leq i \leq t$ or '*'.

After calculating the comparison matrix $E = [\tilde{e}_{ij}^k]_{t \times t}$ by using the geometric mean of each row, consistent weights w_i^k , ($i = 1, 2, \dots, t$), for every risk selection criterion is calculated. It results that fuzzy numbers are

normalized and described as $\tilde{w}_i^k = \frac{w_i^k}{\sum_{i=1}^t w_i^k}$, ($i = 1, 2, \dots, t$; $k = 1, 2, \dots, n$),

$\tilde{w}_i^k \in F_T^*(R)$.

Step 5: To express the possibility of selecting a risk factor by experts, a belief level is introduced. The belief level b_{ij}^k , ($i = 1, 2, \dots, t$, $j = 1, 2, \dots, m$, $k = 1, 2, \dots, n$) belongs to a set of linguistic terms that contain various degrees of preferences required by decision makers. Where ever an expert do not know or cannot give a belief level a ‘**’ sign is used in belief matrix. The linguistic terms for preference belief levels of alternatives are described in Table 4.

Table 4
Linguistic Terms for Preference Belief Levels for Alternatives

Linguistic terms	Membership functions	Fuzzy numbers	Supporting intervals	Abbreviation
Lowest	0	(0,0,0.1,0.2)	$x=0$	b1
	1		$0 \leq x \leq 0.1$	
	$2-10x$		$0.1 \leq x \leq 0.2$	
Very Low	$10x-1$	(0.1,0.2,0.2,0.3)	$0.1 \leq x \leq 0.2$	b2
	$3-10x$		$0.2 \leq x \leq 0.3$	
Low	$10x-2$	(0.2,0.3,0.4,0.5)	$0.2 \leq x \leq 0.3$	b3
	1		$0.3 \leq x \leq 0.4$	
	$5-10x$		$0.4 \leq x \leq 0.5$	
Medium	$10x-4$	(0.4,0.5,0.5,0.6)	$0.4 \leq x \leq 0.5$	b4
	$6-10x$		$0.5 \leq x \leq 0.6$	
High	$10x-5$	(0.5,0.6,0.7,0.8)	$0.5 \leq x \leq 0.6$	b5
	1		$0.6 \leq x \leq 0.7$	
	$8-10x$		$0.7 \leq x \leq 0.8$	
Very High	$10x-7$	(0.7,0.8,0.8,0.9)	$0.7 \leq x \leq 0.8$	b6
	$9-10x$		$0.8 \leq x \leq 0.9$	
Highest	$10x-8$	(0.8,0.9,1,1)	$0.8 \leq x \leq 0.9$	b7
	1		$0.9 \leq x \leq 1$	
	0		$x=1$	

Step 6: By applying the normalized weights resulted from step 4 into belief level matrix (b_{ij}^k) , ($k = 1, 2, \dots, n$), and aggregate the results, belief vectors $\bar{b}_j^k = \tilde{w}_{j_1}^k * b_{j_1}^k + \tilde{w}_{j_2}^k * b_{j_2}^k + \dots + \tilde{w}_{j_s}^k * b_{j_s}^k$, where $b_{j_i}^k$, ($i = 1, 2, \dots, s$), is not ‘**’, are obtained.

Step 7: At this step, normalized weight of decision maker is calculated namely

$$\tilde{v}_k^* = \frac{\tilde{v}_k}{\sum_{i=1}^n v_{i_0}^R}, \quad (k=1, 2, \dots, n).$$

S t e p 8: By applying the normalized weight obtained from previous step and belief vectors obtained from step 6, a weighted normalized fuzzy decision matrix is constructed

$$(\tilde{r}_1, \tilde{r}_2, \dots, \tilde{r}_m) = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \begin{pmatrix} \bar{b}_1^1 & \bar{b}_2^1 & \dots & \bar{b}_m^1 \\ \bar{b}_1^2 & \bar{b}_2^2 & \dots & \bar{b}_m^2 \\ \vdots & \vdots & \ddots & \vdots \\ \bar{b}_1^n & \bar{b}_2^n & \dots & \bar{b}_m^n \end{pmatrix}, \text{ where } \tilde{r}_j = \sum_{k=1}^n \tilde{v}_k^* \bar{b}_j^k.$$

S t e p 9: The ideal solution is assessed and the distance between alternatives (risk factor) and the ideal solution will be calculated. Alternative (risk factor) with the least distance is assumed to be the highest priority risk factor selected by group decision.

Suppose elements in decision matrix defined as $\tilde{r}_m = (r_m^L, r_m^M, r_m^R)$ and the ideal alternative is named $A^* = [\tilde{x}_j^*]: \tilde{b}_j^* = (x_j^{*L}, x_j^{*M}, x_j^{*R})$. The distance between every alternative in decision matrix and ideal alternative is calculated as follow:

$$d_i = d_{(\tilde{r}_m, A^*)} = \sqrt{\frac{1}{3} \sum_{j=1}^m \left[(r_m^L - x_j^{*L})^2 + (r_m^M - x_j^{*M})^2 + (r_m^R - x_j^{*R})^2 \right]}.$$

Assume that decision matrix is a set of pairs (r_K, r_L) , that r_K is preferred to r_L . This implies that risk factor K has more effect on project objectives than risk factor L and distance (d_i) between risk factor K to ideal set of alternatives (risk items) is less than risk factor L , ($d_L \geq d_K$). As we stated before, experts may have no or incomplete information about assessment criteria; so we the human errors in prediction should be considered. This error (d^-) and the amount of incredibility (error) in pair-wise comparison of alternatives (B) to find the negative ideal solution is defined as bellow:

$$d_{K,L}^- = \begin{cases} d_K - d_L, & d_K > d_L, \\ 0, & d_K \leq d_L; \end{cases}$$

$$d_{K,L}^- = \max \{0, d_K - d_L\};$$

$$B = \sum_{(K,L) \in \tilde{r}_m} d_{K,L}^-.$$

To obtain the positive ideal solution, a new value, called *credibility judgment degree*, is defined between two risk factors, K and L ,

$$d_{K,L}^+ = \begin{cases} d_L - d_K, & d_L > d_K, \\ 0, & d_L \leq d_K; \end{cases}$$

$$d_{K,L}^+ = \max \{0, d_L - d_K\};$$

$$G = \sum_{(K,L) \in \tilde{r}_m} d_{K,L}^+.$$

To obtain the final ideal solution, credibility degree should be maximized while incredibility (error) degree should be minimized. Amount of this difference (h) and P should be defined by decision makers ($G - B \geq h$). The membership function of this ideal solution is

$$\mu_{(G-B)} = \frac{(G-B) - (h-P)}{P} = \frac{\sum_{(K,L) \in \tilde{r}_m} (d_L - d_K) - (h-P)}{P}.$$

In the field of risk selection in construction projects, h can be the defined as the least effect of a risk item in project objective and amount of P can be described as the highest effect of a risk item. The membership function of $G - B$ is shown on Fig. 4.

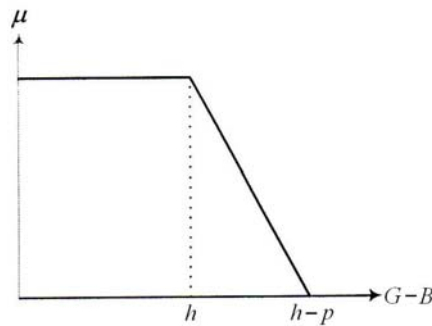


Fig. 4 – Membership function of $G - B$.

The distance (d_i) of alternatives (risk factors) with ideal solution ($G - B$) is calculated. The risk factor with the least distance is selected as the

highest priority factor to be considered and other factors will be ranked in ascending order.

4. Case Study

To illustrate the application of proposed fuzzy multi-criteria group decision making model in construction risk selection, we applied this model to a typical construction project as a case study.

Suppose a group of experts to identify inherent risk in a construction project consisting of three experts, $P1$, $P2$ and $P3$. To avoid complexity of manual computations, it is assumed that experts have same influence weights. Their weights, preference for risk factor selection and judgments for proposed assessment criteria are described in Tables 1, 3 and 4. The risk selection process by using proposed method is described as follow:

S t a g e 1: Alternatives, assessment criteria and influence weights generation.

S t e p 1: to initiate the selection process, involved risks in project should be classified. Each expert proposes one or more risk factor for project risk selection. Final alternative risk, S , is determined by merging similar risk factors

$$S = \{S_1, S_2, S_3, S_4\},$$

where S_1 – Safety, S_2 – Scheduling, S_3 – Unavailability of resources, S_4 – weather.

S t e p 2: The experts should assess these risk factors with regard to magnitude and effect on project objectives by proposing an assessment criteria. In this case study we put emphasis on project duration and assess risk factors based on their impact on project duration. By merging overlapped criteria, five assessment criteria, C_1 , C_2 , C_3 , C_4 and C_5 , are obtained.

C_1 : Effect of new safety plans on project duration.

C_2 : The impact of changing operations` scheduling on project delivery.

C_3 : Change operations from non-critical to critical due to unavailability of resources.

C_4 : Consequence of undesired weather condition on project delays with regard to project location.

C_5 : Impact of risk factor on costumer.

S t e p 3: to avoid the complexity, we assume that all experts have same influence weights as ‘normal’.

S t a g e 2: Individual preferences generation.

S t e p 4: Five assessment criteria obtained from previous step are being judged by using pair-wise comparison. At this step, every expert should present his individual judgment for assessment criteria. Resulted pair-wise comparison matrices are calculated namely

$$E^1 = E^2 = E^3 = \begin{pmatrix} EI & EI & * & * & EI \\ EI & EI & * & EI & * \\ * & * & EI & * & * \\ * & EI & * & EI & EI \\ EI & * & * & EI & EI \end{pmatrix} = \begin{pmatrix} a_4 & a_4 & * & * & a_4 \\ a_4 & a_4 & * & a_4 & * \\ * & * & a_4 & * & * \\ * & a_4 & * & a_4 & a_4 \\ a_4 & * & * & a_4 & a_4 \end{pmatrix}.$$

To correct the inconsistency of each pair-wise comparison matrix, the positive-transitive, De-In and In-De uncertainty rules are applied. Finalized pair-wise comparison matrices to express the possibility of selecting a risk factor, under certain criteria, is

$$E^1 = E^2 = E^3 = \begin{pmatrix} EI & EI & * & EI & EI \\ EI & EI & * & EI & * \\ * & * & EI & * & * \\ EI & EI & * & EI & EI \\ EI & * & * & EI & EI \end{pmatrix} = \begin{pmatrix} a_4 & a_4 & * & a_4 & a_4 \\ a_4 & a_4 & * & a_4 & * \\ * & * & a_4 & * & * \\ a_4 & a_4 & * & a_4 & a_4 \\ a_4 & * & * & a_4 & a_4 \end{pmatrix}.$$

Normalized pair-wise comparison matrix and consistent weight for every assessment criteria are calculated by computing the geometric mean of every row

$$\begin{pmatrix} w_1^1 \\ w_2^1 \\ w_3^1 \\ w_4^1 \\ w_5^1 \end{pmatrix} = \begin{pmatrix} w_1^2 \\ w_2^2 \\ w_3^2 \\ w_4^2 \\ w_5^2 \end{pmatrix} = \begin{pmatrix} w_1^3 \\ w_2^3 \\ w_3^3 \\ w_4^3 \\ w_5^3 \end{pmatrix} = \begin{pmatrix} \sqrt[4]{a_4^4} \\ \sqrt[3]{a_4^3} \\ a_4 \\ \sqrt[4]{a_4^4} \\ \sqrt[3]{a_4^3} \end{pmatrix} = \begin{pmatrix} a_4 \\ a_4 \\ a_4 \\ a_4 \\ a_4 \end{pmatrix} = \begin{pmatrix} [10x-4, 6-10x] \\ [10x-4, 6-10x] \\ [10x-4, 6-10x] \\ [10x-4, 6-10x] \\ [10x-4, 6-10x] \end{pmatrix},$$

$$\sum_{i=1}^5 w_{i_0}^{1R} = \sum_{i=1}^5 w_{i_0}^{2R} = \sum_{i=1}^5 w_{i_0}^{3R} = 3,$$

$$\begin{pmatrix} \tilde{w}_1^1 \\ \tilde{w}_2^1 \\ \tilde{w}_3^1 \\ \tilde{w}_4^1 \\ \tilde{w}_5^1 \end{pmatrix} = \begin{pmatrix} \tilde{w}_1^2 \\ \tilde{w}_2^2 \\ \tilde{w}_3^2 \\ \tilde{w}_4^2 \\ \tilde{w}_5^2 \end{pmatrix} = \begin{pmatrix} \tilde{w}_1^3 \\ \tilde{w}_2^3 \\ \tilde{w}_3^3 \\ \tilde{w}_4^3 \\ \tilde{w}_5^3 \end{pmatrix} = \frac{1}{3} \begin{pmatrix} a_4 \\ a_4 \\ a_4 \\ a_4 \\ a_4 \end{pmatrix}.$$

S t e p 5: To express the possibility of selecting a risk factor (S_i) under criterion (C_j), three belief level matrices are obtained by group members

$$\begin{pmatrix} b_{11}^1 & b_{12}^1 & b_{13}^1 & b_{14}^1 & b_{15}^1 \\ b_{21}^1 & b_{22}^1 & b_{23}^1 & b_{24}^1 & b_{25}^1 \\ b_{31}^1 & b_{32}^1 & b_{33}^1 & b_{34}^1 & b_{35}^1 \\ b_{41}^1 & b_{42}^1 & b_{43}^1 & b_{44}^1 & b_{45}^1 \end{pmatrix} = \begin{pmatrix} M & VL & ** & ** & ** \\ VH & M & ** & ** & ** \\ ** & ** & M & VL & ** \\ ** & VL & ** & ** & M \end{pmatrix} = \begin{pmatrix} b_4 & b_1 & ** & ** & ** \\ b_7 & b_4 & ** & ** & ** \\ ** & ** & b_4 & b_1 & ** \\ ** & b_1 & ** & ** & b_4 \end{pmatrix},$$

$$\begin{pmatrix} b_{11}^2 & b_{12}^2 & b_{13}^2 & b_{14}^2 & b_{15}^2 \\ b_{21}^2 & b_{22}^2 & b_{23}^2 & b_{24}^2 & b_{25}^2 \\ b_{31}^2 & b_{32}^2 & b_{33}^2 & b_{34}^2 & b_{35}^2 \\ b_{41}^2 & b_{42}^2 & b_{43}^2 & b_{44}^2 & b_{45}^2 \end{pmatrix} = \begin{pmatrix} M & VL & ** & ** & ** \\ VH & ** & M & ** & ** \\ ** & ** & VL & M & ** \\ ** & M & ** & ** & VL \end{pmatrix} = \begin{pmatrix} b_4 & b_1 & ** & ** & ** \\ b_7 & ** & b_4 & ** & ** \\ ** & ** & b_1 & b_4 & ** \\ ** & b_4 & ** & ** & b_1 \end{pmatrix},$$

$$\begin{pmatrix} b_{11}^3 & b_{12}^3 & b_{13}^3 & b_{14}^3 & b_{15}^3 \\ b_{21}^3 & b_{22}^3 & b_{23}^3 & b_{24}^3 & b_{25}^3 \\ b_{31}^3 & b_{32}^3 & b_{33}^3 & b_{34}^3 & b_{35}^3 \\ b_{41}^3 & b_{42}^3 & b_{43}^3 & b_{44}^3 & b_{45}^3 \end{pmatrix} = \begin{pmatrix} VL & M & ** & ** & ** \\ M & ** & VH & ** & ** \\ ** & ** & M & VL & ** \\ ** & M & ** & ** & VL \end{pmatrix} = \begin{pmatrix} b_1 & b_4 & ** & ** & ** \\ b_4 & ** & b_7 & ** & ** \\ ** & ** & b_4 & b_1 & ** \\ ** & b_4 & ** & ** & b_1 \end{pmatrix}.$$

S t e p 6: By applying the results obtained from step 4 to belief level matrix, three belief vectors are obtained as follow:

$$\bar{b}_1^1 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_2^1 = \frac{1}{3}(a_4^2 + a_4a_7), \bar{b}_3^1 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_4^1 = \frac{1}{3}(a_4^2 + a_4a_1),$$

$$\bar{b}_1^2 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_2^2 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_3^2 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_4^2 = \frac{1}{3}(a_4^2 + a_4a_1),$$

$$\bar{b}_1^3 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_2^3 = \frac{1}{3}(a_4^2 + a_4a_7), \bar{b}_3^3 = \frac{1}{3}(a_4^2 + a_4a_1), \bar{b}_4^3 = \frac{1}{3}(a_4^2 + a_4a_1).$$

S t a g e 3: Group aggregation.

S t e p 7: The normalized weight of decision makers are

$$v_1 = v_2 = v_3 = c_1,$$

$$\sum_{i=1}^3 v_{i_0}^R = 1.2,$$

$$v_1^* = v_2^* = v_3^* = \frac{1}{1.2} a_4.$$

S t e p 8: By applying obtained results from steps 6 and 7, weighted and normalized fuzzy decision vector is constructed

$$\begin{aligned}\tilde{r}_1 &= v_1^* \bar{b}_1^1 + v_2^* \bar{b}_1^2 + v_3^* \bar{b}_1^3 = \frac{1}{1.2} a_4^2 (a_4 + a_1) = \frac{1}{1.2} [(10x-4)^2, (6-10x)^2] [(10x-4), (8-20x)], \\ \tilde{r}_2 &= v_1^* \bar{b}_2^1 + v_2^* \bar{b}_2^2 + v_3^* \bar{b}_2^3 = \frac{1}{1.2} a_4^2 (a_4 + a_7) = \frac{1}{1.2} [(10x-4)^2, (6-10x)^2] [(20x-12), (6-10x)], \\ \tilde{r}_3 &= v_1^* \bar{b}_3^1 + v_2^* \bar{b}_3^2 + v_3^* \bar{b}_3^3 = \frac{1}{1.2} a_4^2 (a_4 + a_1) = \frac{1}{1.2} [(10x-4)^2, (6-10x)^2] [(10x-4), (8-20x)], \\ \tilde{r}_4 &= v_1^* \bar{b}_4^1 + v_2^* \bar{b}_4^2 + v_3^* \bar{b}_4^3 = \frac{1}{1.2} a_4^2 (a_4 + a_1) = \frac{1}{1.2} [(10x-4)^2, (6-10x)^2] [(10x-4), (8-20x)].\end{aligned}$$

S t e p 9: To reach the ideal solution it is assumed that the ideal risk factor has minimum 0.25 and maximum 0.75 effect on project duration. The distances between obtained decision vector item for each risk factor and ideal risk factor are depicted below:

$$\begin{aligned}d_{s_1} &= 0.1536, \text{ (safety)}, \\ d_{s_2} &= 0.0695, \text{ (scheduling)}, \\ d_{s_3} &= 0.0725, \text{ (unavailability of resources)}, \\ d_{s_4} &= 0.1536, \text{ (weather)}.\end{aligned}$$

4.1. Discussion of Results

By considering relative Euclidean distance, it is concluded that ‘scheduling’ risk factor has the most effect on project duration and ‘unavailability of resources’, ‘safety’ and ‘weather’ are on next order. Another conclusion that can be obtained from these results is the criticality and dependency of “scheduling” and “unavailability of resources”. As can be seen, “Unavailability of resources” has a closer distance to the most critical risk factor than “safety” and “weather” which shows a dependency between “unavailability of resources” and “scheduling”. Due to the dependency of these two risk factors, improving them should be done simultaneously. Otherwise improving one risk factor may lead to criticality of other.

Considering the obtained results of this case study, project manager or decision maker should consider factors and operations that may cause “scheduling” to be critical on project objective. For instance, he may re-arrange the float times or make revisions on critical paths. Also he may take into consideration the share activities that overlap the “unavailability of resources”.

5. Conclusion

In this paper we introduced a comprehensive hierarchical risk classification for construction projects through an extensive literature review and experiences in different projects. The main matter in an effective risk management plan is managing the most effective risks which have the maximum effect on project objectives. Due to lack of information and limited time, all the risk factors in a project cannot be considered for assessment. So a comprehensive risk selection mechanism should be developed to prioritize the inherent risks. In this study we developed this mechanism through a fuzzy multi criteria decision making model which is based on group decision making. Presented method has both advantages of a self optimization and no limitation for experts. Case studies have shown reasonable results by utilizing this method. As shown in case study results, not only prioritized risk factors can be selected by proposed method but also the interdependency of risk factors can be identified by comparing the relative distance of risk factors to each other. This option gives the decision makers a guide map of managing relative risk factors otherwise improving one factor will make others be critical. Several methods presented to solve above MCDM (Multiple Criteria Making) problems. Some of them are based on ideal alternative in the decision maker's opinion such as TOPSIS and ELECTRE. In the cases where ideal alternative and weight of criteria are not available for decision maker, aforesaid methods are not applicable. One of the shortcomings of this method is the tedious calculations of matrices. This can be improved by programming the calculations using spreadsheet or other programming solutions. Also in this study to simplify the fuzzy sets, we utilized the triangular fuzzy membership functions that may not be suitable for complex systems. Further studies can be conducted in developing the programming solution for this model and utilizing other membership functions for complex problems.

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MODEL FUZZY PENTRU SELECȚIA FACTORILOR DE RISC ÎN PROIECTELE DE CONSTRUCȚII

(Rezumat)

Selecția factorilor de risc este un pas important în elaborarea unui plan eficient de gestionare a riscurilor. Într-un proiect de construcție sunt implicați mai mulți factori de risc iar pentru un proces eficient de selecție trebuie identificați factorii de risc critici. Pentru o selecție eficientă a factorilor de risc este dezvoltat un model modificat de analiză decizională multicriterială (multiple criteria making – MCDM). Acest model este un model de regulă pe bază de consens și are proprietatea de optimizare a modelelor raționale. Prin aplicarea logicii fuzzy pentru acest model, sunt evaluați factorii de incertitudine în luarea deciziilor de grup. De asemenea, un proces inteligent de control, pentru a verifica coerența logică a preferințelor, se aplică în timpul procesului de luare a deciziilor. Aplicabilitatea metodei prezentate este evaluată printr-un studiu de caz.