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The Risk Assessment of Dam Construction Projects Using Fuzzy TOPSIS (Case Study: Alavian Earth Dam)

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Abstract

One of the appropriate tools for conducting a successful project is the risk management during the implementation of the project. Dam construction projects are complex projects with high impact factors such as variable and uncertain conditions. To identify the risks of project, experts' experiences and comments including mind storm and consultation sessions were used. Risk analysis is a complex issue. Therefore, in this paper, the fuzzy multiple criteria decision making (FMCDM) technique was used to rank the risk which is a powerful and effective tool in solving complex problems under uncertain and implicit conditions. Due to the uncertainty in the language, fuzzy data were used for the quantitative analysis of the probability and severity of effects and the repetition of risks taken into account. The present research was conducted on Alavian dam in the northeast of Iran. Due to the result of the study, design mistakes' risk (R4) has the highest level of risk and earthquake, etc. has the lowest level of risk in Alavian dam project.

Key word: Risk Management; FMCDM; Uncertain Conditions; Dam Construction.

1. Introduction

Dam projects in the world are conducted with different objectives such as water supply, drinking water supply for agriculture, industry, flood control and energy supply as well as the potential energy supply to construct powerhouses. The high cost of dams' construction requires a correct and efficient management in such projects. (Rahimi, 2003; Cooke et al., 1992). Therefore, one of the main reasons of delaying and increasing costs of dam projects is the inadequate and weak management, especially the risk management. Risk ranking and assessment are the key section in risk management. (Ahangari et al. 2010) Because with ranking, the superiority of a risk over other risks is identified and therefore the main factors involved in the project can provide an appropriate planning for the allocation of existing resources to deal with any risk. A correct understanding of project risks will lead to a correct risk management. Risks collection and prioritization based on the occurrence probability and their impact on the project is very important and influential (Jozi & Seyfosadat, 2014). A large number of risks produced during the risk management process should be classified in such a way that they can be properly assessed and used as a principle in the powerful and effective management of the project. Considering numerous and inaccurate criteria, risk assessment is a multiple criteria decision making problem and because of uncertainty in language, it has a fuzzy nature. Therefore, to obtain the significance degree of each criterion, fuzzy multiple criteria decision making method can effectively analyze and rank the general impact of risk by combining the effect of criteria such as repeatability, occurrence possibility and degree of

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impressionability on the existing risks (Shayesteh et al., 2015; Ghashami, 2012; Harrald et al., 2004). This method is very effective and useful in the risk analysis projects with a complex planning under uncertain conditions.

In this research, to evaluate the risks of Alavian dam construction operations in the northwest of Iran, in addition to the design and collection of the project's risks and a set of indices for measuring risk, experts' opinions regarding the risk are used for evaluating and ranking based on the Fuzzy Technique for Order Performance by Similarity to Ideal Solution. For this purpose, the pseudo-code of Fuzzy TOPSIS algorithm is written in MATLAB software and the required analyses are accurately conducted for modeling.

2. Fuzzy Sets and Theory

In 1965, the theory of fuzzy set was offered by Professor Lotfi (1965). This theory is a powerful and flexible tool for modeling uncertainty and imprecisions existing in the reality. The first and most successful application of fuzzy logic was in the area of control. Mamdani (1974) for the first time used the fuzzy logic to control a simple steam engine (Ataei, 2010). The use of fuzzy logic in the area of control has created a new approach to the application of this theory and its spread in other sciences. In addition, studies of other researchers such as Kaufmann & Gupta (1988) and Zimmermann (1992) had a key role in developing the fuzzy logic. Other applications of this method include data analysis and parametric forecasting in geological engineering and geotechnics (Rad et al., 2014; Mikaeil., et. al 2013; Rad et al., 2012; Mikaeil., et. al 2011; Shanian & Savadogo, 2006), site selection and optimization of systems (Cheng et al , 2009; Ertuğrul & Tuş, 2007; Kahraman et al, 2003), evaluation and ranking of risk (Amigun et al., 2011; Wu, 2008;Au et al., 2007). Fuzzy logic widely uses linguistic variables in practical problems. Indeed, the existing rules and regulations in a system expressed in the form of statements and linguistic variables can be modeled in the form of fuzzy systems (Bojadziev & Bojadziev., 1995). Therefore, fuzzy systems are a very effective phenomenon in solving problems with uncertainty in the phenomena resulting from of human knowledge and weakness in identifying the complexity of a phenomenon. This issue is related to the definition of a membership function in fuzzy sets. Membership degree of different elements of a set is shown with the membership function. In fact, the membership function represents the amount of fuzziness of a fuzzy set. Exhibition of fuzzy numbers is done by the membership function. A fuzzy number may be introduced in the triangular or trapezoidal form. Fuzzy number A is shown according to Figure (1).

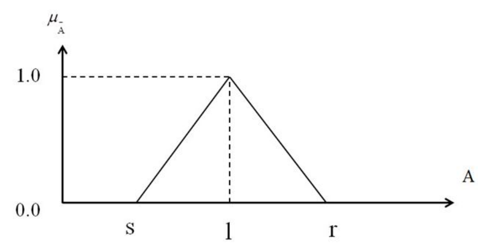

Figure1. A triangular fuzzy number (A)

A tilde on number A indicates the fuzziness of that number. Each triangular fuzzy number is defined by three real numbers, such as A = (s, l, r) which its membership function is based on Eq (1).

$$\mu_M(x) = \begin{cases} 0 & x < 0 \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0 & x > c \end{cases} \tag{1}$$

3. Fuzzy Technique for Order Performance by Similarity to Ideal Solution (FTOPSIS)

In general, multiple criteria decision making methods (MCDM) are divided into two general categories of compensatory and non-compensatory and from among existing methods, only compensatory methods can be used in the ranking of risks problem because in the ranking of project risks' problems, various factors influence each other. Besides, The FTOPSIS algorithm is one of the most effective compensatory methods in the analysis and ranking of risks. In fact, in addition to quantitative measures, we face qualitative and linguistic criteria. In Fuzzy technique for order performance by similarity to ideal solution, the fuzzy numbers' linguistic variables are introduced and it is done by assigning them to the decision making matrix or criteria or both of them. (Koorehpzan Dezfuli., 2008)

In a comparative study, Linkov et al. (2006) showed the superiority of multiple criteria decision making methods (MCDM) over risk assessment methods in terms of ranking different options of project and confirmed it. They tried to consider the shareholders opinion in ranking different options using these decision making methods. Some other researchers used MADM methods in combination with other methods such as fuzzy, etc. for prioritization of options and risk assessment. Other applications of this method include the risk assessment of bridge projects, logistics services and fuzzy group multiple criteria problems (Fouladgar et al., 2011; Sayadi et al., 2009; Wang & Lee, 2008; Wang & Elhag, 2006; Boutni & Rizzi., 2006).

Chen and Hwang (1992) can be introduced as researchers who have developed relations in this area. They introduced a multiple criteria decision making method with title: Fuzzy technique for order performance by similarity to ideal solution (FTOPSIS) with (n) criteria and (m) options in 8 steps as follows:

3.1. Step 1 Decision Matrix

Decision matrix is formed to form below matrix: $\tilde{A} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{1j} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{i1} & \tilde{x}_{i2} & \tilde{x}_{ij} \end{bmatrix}$

In the decision matrix x_{ij} = (s, l, r), the performance of ith option is in relation to jth criterion for fuzzy triangular numbers, where (i = 1, 2, 3... N) And (j = 1, 2, 3… n). Linguistic variables and their corresponding triangular fuzzy numbers for ranking options and evaluating criteria are shown in Tables (1) and (2).

Table 2. Linguistic variables to assess the criteria significance

Corresponding fuzzy number	Linguistic variable
(0, 0, 0.1)	Very Low Preferred(VLP)
(0, 0.1, 0.3)	Low Preferred (LP)
(0.1, 0.3, 0.5)	Medium-Low Preferred (MLP)
(0.3, 0.5, 0.7)	Indifferent (IND)
(0.5, 0.7, 0.9)	Medium-High Preferred (MVP)
(0.7, 0.9, 1)	High Preferred (HP)
(0.9, 1, 1)	Very High Preferred (VHP)

Table 1. Linguistic variables to rank alternatives

Corresponding fuzzy number	Linguistic variable
(0, 0, 1)	Very Low (VL)
(0, 1, 3)	Low (L)
(1, 3, 5)	Medium-Low (ML)
(3, 5, 7)	Medium (M)
(5, 7, 9)	Medium-High (MH)
(7, 9, 10)	High (H)
(9, 10, 10)	Very High (VH)

3.2. Step 2. Determine the Weight Matrix Criteria

The weight matrix criteria are determined on the basis of Eq (2) where the relation of each component w_j (weight of each criterion) is $w_j = (w_{j1}, w_{j2}, w_{j3})$ if fuzzy triangular numbers are used.

$$W = [w_1, w_2, ...w_n] \tag{2}$$

3.3. Step 3. Normalization of the Fuzzy Decision Matrix

Normalization of the fuzzy decision matrix considering fuzzy triangular numbers for decision matrix elements is computed for positive and negative criteria, based on the Eqs (3) and (4), respectively.

$$r = [\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}] \tag{3}$$

$$r = [\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}] \tag{4}$$

$$c_j^* = \max_i c_{ij}$$

$$a_j^- = \min_i a_{ij}$$

Then, the normalized fuzzy decision matrix R is formed according to equation (5) for (m) criterion and (n) options.

$$R = [r_{ij}]_{m\times n} \qquad \begin{array}{l} i=1, 2, 3,\dots, m \\ j=1, 2, 3, \dots, n \end{array} \tag{5}$$

3.4. Step 4. Forming Weighted Fuzzy Decision Matrix

In order to determine the weighted fuzzy decision matrix based on Eq (6), the significance factor relating to each criterion is multiplied by the normalized weighted matrix.

$$v_{ij} = r_{ij}.w_j \tag{6}$$

Where in Eq (6), wi indicates the importance factor of each criterion. Then, the weighted decision matrix is formed according to Equation (7).

$$V = [v_{ij}]_{m\times n} \tag{7}$$

3.5. Step 5: Determine Fuzzy Positive Ideal Solution (FPIS, A*) and Fuzzy Negative Ideal Solution (FPIS, A^-)

Fuzzy positive ideal solution and fuzzy negative ideal solution are calculated according to equations (8) and (9).

$$A^* = \left(v_1^*, v_2^*, \dots, v_n^*\right) \tag{8}$$

$$A' = \left(v_1^-, v_2^-, \dots, v_n^-\right) \tag{9}$$

Where, vj* and vj- are the best and worst values of i criterion from among all options, respectively and are obtained according to equations (10) and (11).

$$A^* = \{v_1^*, v_2^*, v_3^*, \dots\dots, v_n^*\} \tag{10}$$

$$A^- = \{v_1^-, v_2^-, v_3^-, \dots\dots, v_n^-\} \tag{11}$$

3.6. Step 6. Calculate the Distance from Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution

According to relations (12) and (13), the distance of each option is obtained from the fuzzy positive ideal solution and fuzzy negative ideal solution.

$$S_i^* = \sum_{j=1}^{n} d\left(v_{ij}, v_j^*\right), \; j = 1, 2, \dots, m \tag{12}$$

$$S_t^- = \sum_{j=1}^{n} d\left(v_{tj}, v_j^-\right), \; j = 1, 2, \dots, m \tag{13}$$

In above relations, (D) is the distance between two fuzzy numbers which its value for triangular fuzzy numbers is obtained from Eq. (14).

$$d_v(A_1, A_2) = \sqrt{\frac{1}{3}\left[(s_1 - s_2)^2 + (l_1 - l_2)^2 + (r_1 - r_2)^2\right]} \tag{14}$$

3.7. Step 7. Determined Closeness Coefficient (CC)

The closeness coefficient calculation is obtained according to relation (15) and based on the distance from fuzzy positive ideal solution and fuzzy negative ideal solution for each option.

$$CC_1 = \frac{S_i^*}{S_i^* + S_i^-} \; i = 1, 2, \dots, m \tag{15}$$

3.8. Step 8. Ranking the Options

In the final step, the rank of options is prioritized based on their closeness coefficient.

4. Alavian Dam

Alavian dam has been constructed on Sufi Chai River in a 3.5 km-distance in the northwest of Maragheh city in

Iran (Fig (2)). The purpose of this dam construction is to collect and control the surface flow of Sufi Chai River, supply the drinking water in Maragheh city, as well the water for irrigation and agriculture of Maragheh plains and its surrounding gardens and supply of the hydroelectric energy production. Alavian dam is a soil dam with a central clay core. Technical specifications of the dam include: the dam height from bedrock is 80 meters, dam crest length and height are 935 m and 10 m, respectively and total volume of dam body is 4.8 million per cubic meters. The dam crest elevation is 1572 meters above sea level and normal water level of the reservoir is 1568 meters above sea level. The volume of water at normal level is 60 million per cubic meters and the useful volume of water is 57 million per cubic meters. The controlled volume of water is approximately 123 million per cubic meters per year (Mahab Ghodss, 1990) (Fig (3)).

Figure 2. The Alavian dam [33]

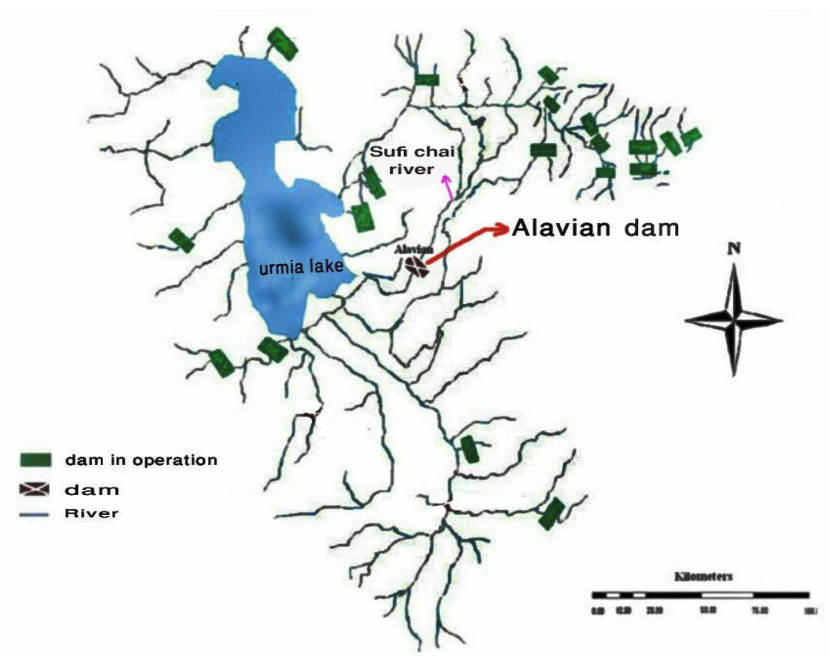

Figure 3. Location of the Alavian dam (Mahab Ghodss,1990)

In this research, based on the conducted studies, a substantial number of risks was identified which may be faced during the implementation of dam projects. Then, based on experts' opinions and various consultation sessions with experts who were present during Alavian dam project, number of risks that may occur in this project will be selected and shown in Table (3).

Table 3. Sorts and title of Alavian dam project risks

Risk Sorts	Title of Risk	Number of Risk
Environmental Risks	Environmental pollution	R_1
	Slope Instability	R_2
Accidents and Failure Risks	Machineries Failure	R_3
Technical Risks	Design Mistakes	R_4
	Inexperience Contractor	R_5
Natural Hazards Risk	Earthquake, etc.	R6
Dam Settlement	Soil Settlement	R7
Leak Risks	Seepage of Body	R8
	Seepage of Foundation	R9
Project Estimations (PE)	Construction Delays	R10
	Price Changes	R11

5. Step 8. Ranking the /options

In this study, by collecting the opinions of experts in the field of implementation and management of the dam project as well as former studies and researches, the main risks in Alavian dam were evaluated. Initially, more than 15 risks in this project were chosen on the basis of data collection and consultation. According to experts, 7 risk sorts were selected but with 11 risks titles (Table (3)). Also, 3 factors affecting risk in the project are as follows: repeat chance, occurrence possibility, and efficacy. Thus, the hierarchical structure of the Alavian dam project risk assessment with 11 risks and 3 criteria is shown in the hierarchy chart according to Fig (4).

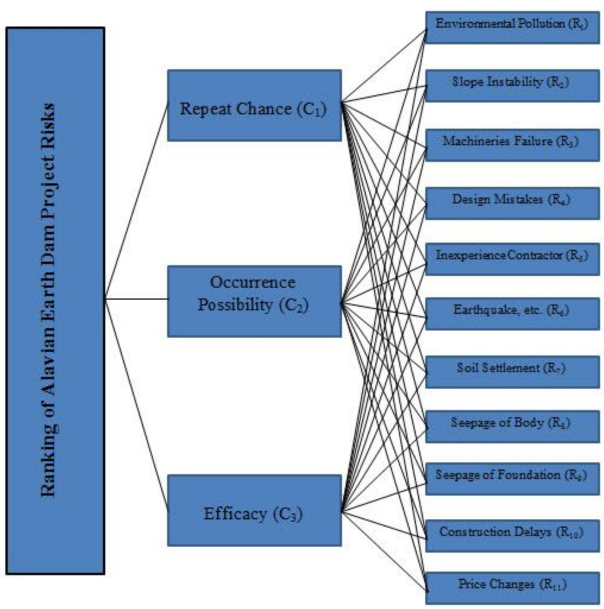

Figure4. Hierarchical structure of Alavian dam project risks

Using Tables (1) and (2) and experiences, expertise and data collected, the weight vector and decision matrix will be formed according to Tables (4) and (5).

Table 4. Vector of criteria weight

Criteria	C_1	C_2	C_3
Criterion Weight	(0.3,0.63,1)	(0.5,0.9,1)	(0.3,0.8,1)

Table 5. Matrix of Fuzzy Decision

	C_1	C_2	C_3
R_1	(1,5.67,10)	(1,4.33,7)	(3,5.67,9)
R_2	(3,5.67,9)	(3,7.67,10)	(1,5,10)
R_3	(1,4.33,7)	(3,6.33,9)	(1,7.67,10)
R_4	(1,3,5)	(1,5.67,9)	(1,3.67,10)
R_5	(1,3.67,7)	(3,5.67,9)	(1,4.33,7)
R_6	(7,9.67,10)	(7,9.33,10)	(5,8.33,10)
R_7	(5,9,10)	(1,4.33,9)	(1,7,10)
R_8	(5,8,10)	(5,8.33,10)	(3,6.33,9)
R_9	(3,6.33,9)	(5,7.67,10)	(1,5.33,10)
R_{10}	(1,5,10)	(1,7.67,10)	(5,7.67,10)
R_{11}	(1,4.33,9)	(1,7,10)	(3, 7.67,10)

After determining the weight vector criteria and decision matrix, the pseudo-code of FTOPSIS algorithm is written in MATLAB analysis. 3 Criteria considered in the risks review have a negative aspect. Therefore, normalization of the weighted fuzzy decision matrix is calculated on the basis of Eqs (2) and (4) (Table (6)).

Table 6. Normalized Matrix of Fuzzy Decision

	C_1	C_2	C_3
R_1	(0.03,0.111,1)	(0.072,0.208,1)	(0.033,0.141,0.333)
R_2	(0.033,0.111,0.333)	(0.05,0.117,0.333)	(0.03,0.16,1)
R_3	(0.043,0.146,1)	(0.055,0.142,0.333)	(0.03,0.104,1)
R_4	(0.06,0.21,1)	(0.055,0.15,1)	(0.043,0.218,1)
R_5	(0.043,0.171,1)	(0.055,0.15,0.333)	(0.043,0.185,1)
R_6	(0.03,0.065,0.143)	(0.05,0.096,0.143)	(0.03,0.096,0.2)
R_7	(0.03,0.07,0.2)	(0.055,0.208,1)	(0.03,0.114,1)
R_8	(0.03,0.079,0.2)	(0.05,0.108,0.2)	(0.033,0.126,0.333)
R_9	(0.033,0.1,0.333)	(0.05,0.117,0.2)	(0.03,0.15,1)
R_{10}	(0.03,0.126,1)	(0.05,0.117,1)	(0.03,0.104,0.2)
R_{11}	(0.03,0.146,1)	(0.05,0.129,1)	(0.03,0.104,0.333)

In the next step, the fuzzy positive ideal solution A* and fuzzy negative ideal solution A- ideas are obtained based on Eqs (7) to (9) in Table (6).

$$A^{*} = \{(1,1,1),(1,1,1),(1,1,1)\}$$

$$A^{-} = \{(0.03,0.03,0.03),(0.05,0.05,0.05),(0.03,0.03,0.03)\}$$

Based on Eqs (11) to (14) for each of the risks discussed, distance from fuzzy positive ideal solution, fuzzy negative ideal solution and closeness coefficient are provided in Table (7).

$$S_i^{*} = \sum_{j=1}^{n} d(v_{ij}, v_j^{*})$$

$$S_{11}^{*} = \sqrt{\frac{1}{3}\left[(0.03-1)^2 + (0.111-1)^2 + (1-1)^2\right]} = 0.92$$

$$S_{12}^{*} = \sqrt{\frac{1}{3}\left[(0.072-1)^2 + (0.208-1)^2 + (1-1)^2\right]} = 0.704$$

$$S_{13}^{*} = \sqrt{\frac{1}{3}\left[(0.033-1)^2 + (0.141-1)^2 + (0.333-1)^2\right]} = 0.84$$

$$S_i^{-} = \sum_{j=1}^{n} d(v_{ij}, v_j^{-})$$

$$S_{11}^{-} = \sqrt{\frac{1}{3}\left[(0.03-0.03)^2 + (0.111-0.03)^2 + (1-0.03)^2\right]} = 0.562$$

$$S_{12}^{-} = \sqrt{\frac{1}{3}\left[(0.072-0.05)^2 + (0.208-0.05)^2 + (1-0.05)^2\right]} = 0.556$$

$$S_{13}^{-} = \sqrt{\frac{1}{3}\left[(0.033-0.03)^2 + (0.141-0.03)^2 + (0.333-0.03)^2\right]} = 0.186$$

$$S_1^{*} = 0.92 + 0.704 + 0.84 = 2.464$$

$$S_1^{-} = 0.562 + 0.556 + 0.186 = 1.304$$

$$CC_1 = \frac{1.304}{2.464 + 1.304} = 0.529$$

Table 7. Distance between each alternative and (S^{*}_{i}, S^{-}_{i}) and closeness coefficient

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}
Distance of Fuzzy Positive Ideal Solution	2.464	2.434	2.335	2.157	2.286	2.721	2.374	2.628	2.479	2.394	2.339
Distance of Fuzzy Negative Ideal Solution	1.304	0.914	1.294	1.693	1.306	0.233	1.219	0.379	0.839	1.22	1.294
Closeness Coefficient	0.346	0.273	0.357	0.44	0.364	0.079	0.34	0.126	0.253	0.338	0.356

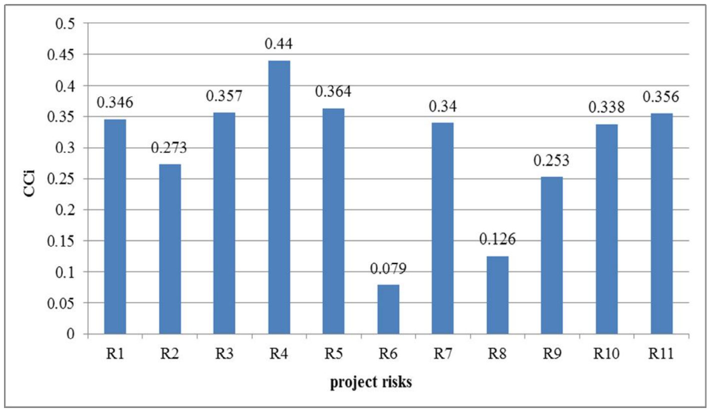

Figure 5. Ranking of Alavian dam project risks by Fuzzy Topsis

In Figure (5), the closeness coefficient for each of the Alavian dam project's risks is shown based on the FTopsis algorithm. The results showed a significant difference in scores of the design mistakes' risk (R4) with a rating of 0.44 and earthquake, etc. (R6) with the value of 0.079. Also, there is a mild reduction in scores R5, R3, R11, R1, R10, R7. Finally, after performing calculations, ranking of Alavian dam project risks based on Fuzzy Topsis is as follows: (R4> R5> R3> R11> R1> R7> R10> R2> R9> R8> R6)

6. Conclusion

Dam construction projects are traditionally classified in terms of dealing with unknown and less predictable issues (especially in the implementation phase) and are considered as one of the most risky construction projects. Thus, taking into account the nature of the risk and its full compliance with fuzzy concepts in this paper to rank the risk of Alavian Dam in northwest of Iran, fuzzy multiple criteria decision making techniques have been used. In this study, after consultation with experts and data collection, 11 risks of dam construction projects and 3 criteria of risks, including repeat chance (C1), occurrence possibility (C2) and efficacy (C3) were considered in ranking. In the analysis conducted by the FTopsis algorithm, the design mistakes' risk (R4) and earthquake, etc. (R6) obtained the highest and lowest ranks in the risks ranking of Alavian dam projects, respectively.

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