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Research Article

RISK ASSESSMENT OF DAM CONSTRUCTION PROJECTS USING DELPHI METHOD AND MULTI-CRITERIA DECISION MAKING TECHNIQUES (TOPSIS) AND SHANNON ENTROPY MODELS

FARZAD FADAIE[1], MEHDI AZHDARY MOGHADDAM[2], MOHAMMAD REZA SHAHRAKI[3]*

[1] Nikbakht Faculty of Engineering, Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran.
[2] Nikbakht Faculty of Engineering, Department of Civil Engineering, University of Sistan and Baluchestan, Zahedan, Iran.
[3] Nikbakht Faculty of Engineering, Department of Industrial Engineering, University of Sistan and Baluchestan, Zahedan, Iran.

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ABSTRACT

One of the factors which can lead to economically cost-effective project is effective risk management and its factors. Dam construction projects spending considerable time and cost and complex spatial conditions are more risky than other construction projects. This study determines the importance of risks and their ranking in dam construction projects and then prioritizes various projects based on risks using Delphi and TOPSIS. In order to assess the risk of projects, it is necessary to first identify and prioritize risk parameters in the projects and then determine the rank of risk factors by TOPSIS and calculate their effect on the projects. The results of this study show that the least risky project can be selected and run by prioritizing the criteria, calculating relative weight of each criterion and assessing the risk parameters.

Keywords: Dam construction, Assessment, Risk, TOPSIS, Management

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INTRODUCTION

The American Risk and Insurance Association has defined risk as uncertainty about outcome of an incident which has two or more probabilities [1]. In engineering economics, risk relates to a situation in which a financial process is not behaving as predicted [2]. In addition, the risks are divided into general risks and project-related risks which are significantly used in various risk modeling [3].
Considering the shortage of water resources in Iran and the need for optimal use of surface water for drinking, agriculture, industry and the importance of electricity generation through hydroelectric power plants, major investments have been made in dam construction [4]. Therefore, defining the parameters used in risk assessment will vary depending on the project and its environment. To determine the risk parameters, in-depth knowledge of the organization and project, the market in which the organization operates, legal, social, political and cultural context of that organization, as well as correct information about strategic and operational objectives of the organization are required [5].
To assess risk of dam construction projects, this study first defines the risk parameters for these projects and then prioritize the determined parameters considered as indicators based on the Delphi method, which is the collection of expert opinions [6]. In the next step, TOPSIS is used to assess five dams by defined and prioritized parameters [7]. The results of calculations based on TOPSIS will identify the least risky projects for implementation.

PROBLEM STATEMENT

Dam construction projects, because of strategic importance of water supply, are very important and costly projects for any nation. Due to limitation of development budgets and obligations arising from implementation of dam construction projects, risk of these projects are studied to identify, prioritize and assess the risks. In fact, prioritizing and implementing these projects according to risk studies will lead to optimal utilization of limited financial resources and higher productivity. Incorrect selection of dam construction projects for implementation, considering their risk parameters, will cause loss of capital and resources, as well as failure to achieve the defined goals of the project.
In the form of programs developed for the water sector, water supply projects in cities and villages, flood control, prevention of exit of boundary waters, supply of drinking, agricultural and industrial water, etc. are defined as major goals of dam construction [5]. In order to achieve these goals, precise and cohesive planning is required, which is done by defining a variety of projects and sub-projects. This study tends to assess risk of dam construction projects to make economic savings, make optimal use of resources, increase productivity, and have more effective results.
In the following, the third section reviews the studies conducted in this regard. The fourth section introduces the project and parameters used. The fifth section presents a brief description of the method used and results of calculations. The last section discusses the method and the results and draws conclusions.

LITERATURE REVIEW

Considering that the success of project-based companies is considerably dependent on risk assessment and management, risk assessment in projects has been dramatically improved with different methodologies in the recent decades [8]. Successful risk assessment and management requires identifying risk and constructing a risk model for assessing its magnitude [9]; some of the relevant studies are described here.
By identifying the sources of risk and uncertainty in dam construction projects and assessing these resources, Shoul and Fathizadeh (2009) determined the most important and most effective sources in the project. For assessment, factor analysis technique (AHP) was used. The results of this assessment for five dam construction projects in order to determine the importance of various sources of risk indicated that 35 risk sub-factors can be grouped into four distinct risk factors. The specific measurement instrument showed that 9 critical risk factors were subjected to reliable, constructive, and differential validation tests [4].
To develop a comprehensive model for assessing critical factors in executive performance of the Taleghan project, Rajabi et al first

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reviewed the valid references in this field and determined the critical factors. By defining "determining the critical factors in success of the Taleghan Dam and Power Plant" as target level, placed the factors associated with each of these groups in the next levels according to executive conditions of the dam and power plant project. To avoid increasing the number of factors, the related factors were integrated. In this study, three criteria of golden triangle (cost, time and quality) were considered as success factors of the project. The data obtained from the questionnaires was analyzed and assessed using the Expert Choice and Excel software and integrated by hierarchical analysis of experts' opinions [10].

Taking into account the various risks in dam construction projects, Shamsai and Razmara presented the advantages of integrating risk management and value engineering techniques. In this study, value engineering and risk management were presented as two integral parts; by integrating risk management and value engineering, a strategy was presented to prevent the occurrence of risks as much as possible. Finally, time periods and costs of these projects can be reduced considerably by minimizing their effects [11].

Velayati et al noted the importance of flood risk management in rural planning by identifying flood risk factors in the Kardeh basin and presented a model for flood risk management for this basin. In this study, the risk of flooding in the basin was modeled using three statistical models including probability distribution functions, regression model and time series ARIMA model. The results of testing the obtained models showed that probability distribution functions were not able to model the basin flood risk; the regression model also did not provide acceptable solutions because it did not follow a general trend. Finally, the ARIMA time series models of different orders were tested. ARIMA (1,2,3) model provided the best statistical fit, which is also applicable to basins [12].

Chinichian developed a new fuzzy rating model in project risk management process. The proposed model is based on expert qualitative data, discrete fuzzy sets, discrete-ranking theorem and hierarchical ranking process (AHP). Using the proposed model and PMBOK standard, the risks identified for a dam project in Zanjan province were prioritized [13].

Using the ANP technique as one of the multi-criteria decision-making techniques, Dorri and Hamzei chose a strategy among several risk-related response strategies. In this study, the main risk of the project was first determined by a questionnaire. Then, response strategies were determined for the most critical risk; eventually, the decision-making model was developed by using other studies and nominal group technique. Through pairwise comparisons, the best strategy was selected for the most important risk in the North Azadegan field development project [14].

Zare and Ahmadi Naseri evaluated practical projects using Fuzzy AHP. While referring to defects of traditional evaluation, this study addressed how fuzzy AHP was used to evaluate the practical projects and compared practical projects with each other and relative to various existing criteria [15]. Najafi and Karimipour investigated the risk of implementation of production projects using a suitable forecasting model. Using fuzzy AHP and performing pairwise comparisons, effective priorities in factors and categorization of various factors in risk level of production projects were investigated and ultimately, risk forecasting was estimated based on significant factors [16].

Kazemzadeh and Mousavi examined time risk of development projects based on fuzzy risk assessment (FAHP) by developing a risk-taking model. By presenting a methodology, time risk of the project was estimated in the implementation phase and modeling of risks of each activity separately provided more accuracy of the model and more comprehensive picture of overall risk model of the project; as a result, risk assessment process was formulated. The proposed model can be generalized to other organizations based on the defined risks [17].

Jahantigh evaluated the feasibility of construction of an underground dam using the analytical hierarchy process (AHP). In this study, the effective criteria for locating the dam were identified and the best location of the dam was suggested using the AHP method and making pairwise comparisons between the criteria [18]. Baloi and Price modelled the risk factors which affect the cost performance of development projects using AHP; the result was a major classification for the risks inherent in development projects [9]. Linkov et al conducted a risk assessment using multivariate decision making analysis methods and developed a model for risk assessments [19].

Dikmen et al used fuzzy risk assessment to determine cost risk rate in development projects. Considering the uncertainty in cost risk rate, fuzzy AHP was used to determine this rate in development projects, which has resulted in evaluation of the effects of factors such as price fluctuations, financial repayments and other costs on poor performance of projects [3]. Taroun et al. evaluated and modeled the risk in development projects. This study examined the history of risk assessments and methodologies used in them and ultimately considered risk cost assessment as the most important factor in a variety of assessment methods [20].

For presenting a model for locating sales and after sales service centers of Talia Company, Momeni et al conducted a study to identify effective factors through library studies and interviews with experts in Talia. The effective factors included criteria and constraints. The former consisted of marketing and customer orientation criteria, and the latter was related to financial and investment and geographical constraints. Considering the presence of criteria and constraints, the integration of two TOPSIS (pairwise comparisons for weighting criteria) and zero and one planning were used for the first and second factors, respectively. Finally, six sales and after sales services were selected among these options [21].

Alam Tabriz and Bagherzade Azar suggested a fuzzy network analysis model to support the supplier selection process in strategic situations. In the beginning, the supplier assessment problem was formulated by integrating multi-criteria decision-making process and five-step link process using fuzzy network analysis process. Then, the modified TOPSIS was used to rank suppliers according to their overall function. The newly developed network analysis process is used to calculate the relative weights of multiple evaluation criteria derived from nominal group technique with interdependence of criteria. As a result of empirical research, the suggested method for ranking suppliers, considering their overall function and taking into account the dependence of criteria, is a practical model [22].

Considering the strengths of balanced scorecard model in evaluating strategic performance, Mehregan and Dehghan Nayeri used its integration with TOPSIS technique to evaluate and rank a number of top management schools of Tehran Province. The present study used the TOPSIS compensatory model to summarize the results of BSC model. The results of this study not only can be used for planning improvement of management schools and other schools and they are effective in developing BSC model in the academic sector, but also they provide a proper integration of these two techniques to summarize the results of evaluating different scenarios of the BSC model [23].

Aliakbar Esfahani et al study on evaluation model for the implementation of hospital information system in public hospitals and using multi-criteria-decision-making (MCDM) approaches [24]. Surahman et al study on Selection of the best supply chain strategy with using fuzzy based decision model [25].

Norazliani et al study on Assessment of Flood Risk Analysis in Selangor. To conclude, authorities must work vigorously towards an efficient flood risk management and effective flood safety measures. The establishments of flood forecasting and warning system are crucial in minimising the flood losses [26].

This study tends to develop a risk assessment model for implementing dam construction projects by TOPSIS to prioritize and implement dam construction projects based on different risks.

MATERIALS AND METHODS

In order to assess the dam construction project, it is first necessary to define the parameters required for risk assessment in these projects.

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There are many risk parameters of dam construction projects which are used as criteria for assessment; therefore, more specific and important criteria which are involved in assessment should be determined depending on the type of assessment. The criteria defined in this study tend to determine and assess the risk of dam construction projects, considering the "Dam Construction Detection Service List", Iran Water Resources Management Company [5].

Delphi method is used to select and prioritize required criteria. The Delphi method primarily tends to discover creative and reliable ideas or provide the right information for decision making. The Delphi method is a structured process for collecting and classifying the knowledge available to a group of experts through distribution of questionnaires among experts and the controlled feedback of responses and comments received. The Delphi technique is based on the fact that the expert opinion in each scientific field is the rightest opinion about the future prediction; contrary to survey methodologies, validity of the Delphi method depends on scientific reputation of experts participating in the study, rather than the number of participants in the study. Participants in the Delphi research include 5 to 20 people [27].

After collecting and categorizing expert opinions about criteria of dam construction projects by Delphi, the result was selection of 9 criteria and 4 sub-criteria for risk assessment in dam construction projects.

The criteria and sub-criteria used with the priority determined are as follows:

1. Volume of the reservoir which is determined by the amount of water stored behind the dam
2. Water supply, including uses of stored water
   - 2.1. Drinking, showing the volume of water consumed to supply drinking water to inhabitants of the area
   - 2.2. Agriculture, showing the amount of water consumed for the area under cultivation
   - 2.3. Industry, showing the volume of water consumed for industries in the region
   - 2.4. Environmental, determining the priority of water supply according to regional conditions
3. Flood containment, showing that how dam construction can be effective in controlling these floods considering climatic conditions and possibility of seasonal precipitation that will cause flood
4. Economic ($\frac{B}{C}$), which is the rate of profitability of the dam constructed to its implementation costs. The amount of profit and cost calculated will be based on agricultural sector data, meaning that profitability of agricultural product sales from the cultivated area will be calculated in relation to costs of dam construction and the amount of water delivered to the agricultural sector.
5. Job creation determines how much jobs will be created for the region by constructing a dam (agriculture, industry, etc.)
6. Exit of boundary waters, showing how much the dam will prevent the flow of water from border rivers
7. Social, indicating how much dam construction will be effective on welfare and preventing the migration of people in the region
8. Security, determining whether dam construction in the region, considering the social parameter which prevents migration, particularly in the border regions, will provide security for the inhabitants
9. Politics, showing the positive attitude of people towards the government

Once the project parameters were determined and prioritized by Delphi method, TOPSIS was selected to identify the least risky dam construction project.

TOPSIS model was proposed by Huang and Yoon in 1981. This model is one of the best multi-criteria decision-making models and is used extensively. In this method, m options are assessed by n criteria. This technique is based on the fact that the selected option should have the least distance with positive ideal solution (best possible state) and the greatest distance with negative ideal solution (worst possible state) [7].

The underlying facts of this method are as follows:

a) Desirability of each criterion should be uniformly incremental (or decreasing), thus the best available value of a criterion represents its ideal and the worst value of it will indicate the negative ideal for it.

b) Distance of an option from a positive or negative ideal may be calculated as the Euclidean distance (second power) or as the sum of absolute magnitude of the linear intervals (known as block intervals), which depends on the exchange rate and the substitution between the criteria [28].

Problem solving by TOPSIS requires six steps:

1. Quantization and unscaling of the decision matrix (N), for which norm unscaling is used as shown in equation (1), where a_{ij} denotes elements of the decision matrix.

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (1)$$

2. Weighted unscaled matrix (V) is obtained by multiplying the unscaled matrix (N) by diagonal matrix of weights (W_{nxn}), according to equation (2).

$$V = N \times W_{nxn} \quad (2)$$

Note that the weights of criteria should be calculated to calculate the weighted unscaled matrix. To do this, the Shannon entropy technique (or any other method) is used to derive the weights of criteria (W_{nxn}) based on the following equations and algorithm and then multiply by the unscaled matrix.

Step 1: calculate P_{ij} according to equation (3)

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (3)$$

Step 2: calculate entropy value E_j according to equation (4)

$$E_j = -K \sum_{i=1}^{m} [P_{ij} \ln P_{ij}] \quad (4)$$

where, K value is derived from equation (5) and m is the number of options.

$$K = \frac{1}{\ln(m)} \quad (5)$$

Step 3: calculate uncertainty value d_j by:

$$d_j = 1 - E_j \quad (6)$$

Step 4: calculate weights W_j according to equation (7).

$$W_j = \frac{d_j}{\sum_{i=1}^{n} d_j} \quad (7)$$

Step 5: calculate the modified weights $\acute{W}_j$ using equation (8).

$$W'_j = \frac{\lambda_j W_j}{\sum_{i=1}^{n} \lambda_j W_j} \quad (8)$$

where, λ_j are judgemental weights; if these weights are not present, step 5 is not done and the weights obtained in step 4 are used. Now, the square matrix W_{nxn}, whose main diagonal is the weights of the criteria, is multiplied by the unscaled matrix (N).

3. Positive and negative ideal solutions which are obtained by equations (9) and (10) are determined.

4.

$$(V_j^+) positive\ ideal\ solution - [vector\ of\ the\ best\ values\ of\ each\ criterion\ in\ matrix\ V] \quad (9)$$

$$(V_j^-) negative\ ideal\ solution - [vector\ of\ the\ worst\ values\ of\ each\ criterion\ in\ matrix\ V] \quad (10)$$

The best values are the largest values for positive criteria and the smallest values for negative criteria. The worst values are the smallest values for positive criteria and the largest values for negative criteria.

5. The distance from each option to positive and negative ideals is obtained, the equations of which are as follows based on calculation of Euclidian distance of each option from positive ideal (11) and negative ideal (12).

6.

$$d_j^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \quad ,i = 1,2,\dots,m \quad (11)$$

$$d_j^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \quad ,i = 1,2,\dots,m \quad (12)$$

7. Relative closeness of an option to ideal solution (CL*) is determined by:

$$CL_i^* = \frac{d_j^-}{d_j^- + d_j^+} \quad (13)$$

8. The options are ranked based on CL values; the larger the CL value, the option will be closer to the positive ideal solution and farther than the negative ideal solution and it will be a better option for selection.

CONCLUSIONS AND DISCUSSIONS

Considering the determined parameters and their prioritization based on Delphi method, decision matrix is shown in Table 1.

Table 1: decision matrix

Criteria	Reservoir volume	Water supply	Flood containment	Economic	Job creation	Boundary water exit	Social	Security	Political
Sarabodok	12	6	4	9	6	2	6	8	8
Qaderabad	3	4	2	7	3	4	3	3	3
Jalgh	10	5	5	6	4	5	4	5	5
Gezo	30	7	8	4	8	7	8	7	7
Kaheer	60	8	9	3	9	8	9	2	2

According to the algorithm, decision matrix is unscaled by using norm method, as shown in Table 2.

Table 2: the unscaled matrix (N)

Criteria	Reservoir volume	Water supply	Flood containment	Economic	Job creation	Boundary water exit	Social	Security	Political
Sarabodok	0.174	0.435	0.290	0.651	0.418	0.159	0.418	0.651	0.651
Qaderabad	0.044	0.290	0.145	0.507	0.209	0.318	0.209	0.244	0.244
Jalgh	0.145	0.363	0.363	0.434	0.279	0.398	0.279	0.407	0.407
Gezo	0.435	0.508	0.580	0.289	0.557	0.557	0.557	0.570	0.570
Kaheer	0.870	0.580	0.653	0.217	0.627	0.636	0.627	0.163	0.163

Using the Shannon Entropy Technique, weight of parameters is obtained and the matrix is shown in Table 3.

Table 3: square matrix of weights of criteria (W_{nxn})

0.768	0	0	0	0	0	0	0	0
0	0.022	0	0	0	0	0	0	0
0	0	0.064	0	0	0	0	0	0
0	0	0	0.032	0	0	0	0	0
0	0	0	0	0.027	0	0	0	0
0	0	0	0	0	0.028	0	0	0
0	0	0	0	0	0	0.019	0	0
0	0	0	0	0	0	0	0.023	0
0	0	0	0	0	0	0	0	0.017

By matrix multiplication of Table 2 by Table 3, the weighted unscaled matrix (V) is obtained as Table 4.

Table 4: the weighted unscaled matrix (V)

Criteria	Reservoir volume	Water supply	Flood containment	Economic	Job creation	Boundary water exit	Social	Security	Political
Sarabodok	0.134	0.010	0.018	0.021	0.011	0.004	0.008	0.015	0.011
Qaderabad	0.033	0.006	0.009	0.016	0.006	0.009	0.004	0.006	0.004
Jalgh	0.111	0.008	0.023	0.014	0.008	0.011	0.005	0.009	0.007
Gezo	0.334	0.011	0.037	0.009	0.015	0.016	0.011	0.013	0.010
Kaheer	0.668	0.013	0.041	0.007	0.017	0.018	0.012	0.004	0.003

Now, positive and negative ideals are obtained for each criterion based on Table 4, resulting in Table 5 and 6.

Table 5: positive ideal vector

Criteria	Reservoir volume	Water supply	Flood containment	Economic	Job creation	Boundary water exit	Social	Security	Political
V_j^+	0.668	0.013	0.009	0.021	0.017	0.018	0.012	0.015	0.011

Table 6: negative ideal vector

Criteria	Reservoir volume	Water supply	Flood containment	Economic	Job creation	Boundary water exit	Social	Security	Political
V_j^-	0.033	0.006	0.041	0.007	0.006	0.004	0.004	0.004	0.003

According to Table 4, 5 and 6, equations (11), (12) and (13) calculate values of relative closeness of options to ideal solution and the results are presented in Table 7.

Table 7: values of relative closeness of options to ideal solution

Sarabodok	CL_1^*	0.164
Qaderabad	CL_2^*	**0.051**
Jalgh	CL_3^*	**0.127**
Gezo	CL_4^*	**0.473**
Kaheer	CL_5^*	**0.944**

Considering that the larger values of CL will be better; based on CL values in Table 7, prioritization of the least risky dam construction project for five dams will be as follows:

Kaheer urban dam > Gezo Dam > Sarabodok Dam > Jalgh Dam > Qaderabad Dam

According to the results, the urban dam Kaheer with the least risk and the highest priority is the best option for achieving the highest economic savings and optimal use of resources.

CONCLUSION

Using the TOPSIS methodology, risk assessment of the parameters of dam construction projects was investigated for the five studied dams. This method can be used for more parameters and dams, and even for other projects, and will provide useful results for important decisions. Finally, it can be claimed that risk assessment of each project, considering its effective factors, increases the ability to deal with risk and significantly reduces the risk effects on the project. Therefore, different organizations with different projects and specific criteria can use this model and use the results obtained to make the best decision. It should be noted that the results achieved with this methodology are fully consistent with the results obtained with AHP methodology by the same authors. For future studies, fuzzy AHP methodology, tabu search, neural networks, or other multi-criteria decision-making methods can be used considering the uncertainty of project parameters and the results can be compared with the results of this study.

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