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

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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

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 Fatihizadeh (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...
In order to assess the dam construction project, it is first necessary to define the parameters required for risk assessment in these projects.
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) [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 aij denotes elements of the decision matrix.

\[ n_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \]  

(1)

2. Weighted unscaled matrix (V) is obtained by multiplying the unscaled matrix (N) by diagonal matrix of weights (Wnorm) according to equation (2).

\[ V = N \times W_{norm} \times n \times n \]  

(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 (Wnorm) based on the following equations and algorithm and then multiply by the unscaled matrix.

Step 1: calculate Pi according to equation (3)

\[ P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \]  

(3)

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

\[ E_{j} = -K \sum_{i=1}^{m} [P_{ij} \ln P_{ij}] \]  

(4)

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

\[ K = \frac{1}{\ln(m)} \]  

(5)

Step 3: calculate uncertainty value dj by:

\[ d_{j} = 1 - E_{j} \]  

(6)

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

\[ W_{j} = \frac{d_{j}}{\sum_{i=1}^{n} d_{j}} \]  

(7)

Step 5: calculate the modified weights \( \hat{W}_{j} \) using equation (8).
where, \( \lambda_i \) 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.

\[
(V^+_i) \text{positive ideal solution} - \begin{bmatrix} \text{vector of the best values of each criterion in matrix } V \end{bmatrix}
\]

\[
(V^-_i) \text{negative ideal solution} - \begin{bmatrix} \text{vector of the worst values of each criterion in matrix } V \end{bmatrix}
\]

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.

4. 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).

\[
d^+_i = \sqrt{\sum_{j=1}^{n}(V_{ij} - V^+_i)^2}, \quad i = 1, 2, ..., m
\]

\[
d^-_i = \sqrt{\sum_{j=1}^{n}(V_{ij} - V^-_i)^2}, \quad i = 1, 2, ..., m
\]

5. The optimal option is the option that has the smaller distance to the positive ideal solution and the larger distance to the negative ideal solution and it will be a better option for selection.

\[
CL_i^* = \frac{d^-_i}{d^-_i + d^+_i}
\]

7. 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.

CONCLUSIONS AND DISCUSSIONS

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reservoir volume</th>
<th>Water supply</th>
<th>Flood containment</th>
<th>Economic</th>
<th>Job creation</th>
<th>Boundary water exit</th>
<th>Social</th>
<th>Security</th>
<th>Political</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarabodok</td>
<td>12</td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Qaderbad</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Jalgh</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Gezo</td>
<td>30</td>
<td>7</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Kaheer</td>
<td>60</td>
<td>8</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reservoir volume</th>
<th>Water supply</th>
<th>Flood containment</th>
<th>Economic</th>
<th>Job creation</th>
<th>Boundary water exit</th>
<th>Social</th>
<th>Security</th>
<th>Political</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarabodok</td>
<td>0.174</td>
<td>0.435</td>
<td>0.290</td>
<td>0.651</td>
<td>0.418</td>
<td>0.159</td>
<td>0.418</td>
<td>0.651</td>
<td>0.651</td>
</tr>
<tr>
<td>Qaderbad</td>
<td>0.044</td>
<td>0.290</td>
<td>0.145</td>
<td>0.507</td>
<td>0.209</td>
<td>0.318</td>
<td>0.209</td>
<td>0.244</td>
<td>0.244</td>
</tr>
<tr>
<td>Jalgh</td>
<td>0.145</td>
<td>0.363</td>
<td>0.363</td>
<td>0.434</td>
<td>0.279</td>
<td>0.398</td>
<td>0.279</td>
<td>0.407</td>
<td>0.407</td>
</tr>
<tr>
<td>Gezo</td>
<td>0.435</td>
<td>0.508</td>
<td>0.580</td>
<td>0.289</td>
<td>0.557</td>
<td>0.557</td>
<td>0.557</td>
<td>0.570</td>
<td>0.570</td>
</tr>
<tr>
<td>Kaheer</td>
<td>0.870</td>
<td>0.580</td>
<td>0.653</td>
<td>0.217</td>
<td>0.627</td>
<td>0.636</td>
<td>0.627</td>
<td>0.163</td>
<td>0.163</td>
</tr>
</tbody>
</table>
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\(_{xy}\))

<table>
<thead>
<tr>
<th></th>
<th>0.768</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.022</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>0</td>
<td>0</td>
<td>0.067</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.032</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.027</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.028</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.019</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.023</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.017</td>
</tr>
</tbody>
</table>

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)

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

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reservoir volume</th>
<th>Water supply</th>
<th>Flood containment</th>
<th>Economic</th>
<th>Job creation</th>
<th>Boundary water exit</th>
<th>Social</th>
<th>Security</th>
<th>Political</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.668</td>
<td>0.013</td>
<td>0.009</td>
<td>0.021</td>
<td>0.017</td>
<td>0.018</td>
<td>0.012</td>
<td>0.015</td>
<td>0.011</td>
</tr>
</tbody>
</table>

### Table 6: negative ideal vector

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reservoir volume</th>
<th>Water supply</th>
<th>Flood containment</th>
<th>Economic</th>
<th>Job creation</th>
<th>Boundary water exit</th>
<th>Social</th>
<th>Security</th>
<th>Political</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.033</td>
<td>0.006</td>
<td>0.041</td>
<td>0.007</td>
<td>0.006</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td>0.003</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>CL(_i)</th>
<th>0.164</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarabodok</td>
<td>CL(_2)</td>
<td>0.051</td>
</tr>
<tr>
<td>Qaderabad</td>
<td>CL(_1)</td>
<td>0.127</td>
</tr>
<tr>
<td>Jalgh</td>
<td>CL(_2)</td>
<td>0.473</td>
</tr>
<tr>
<td>Gezo</td>
<td>CL(_3)</td>
<td>0.944</td>
</tr>
<tr>
<td>Kaheer</td>
<td>CL(_3)</td>
<td>0.944</td>
</tr>
</tbody>
</table>

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.

### ACKNOWLEDGEMENT

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extremely contributed to introduction and prioritization of the parameters of dam construction projects.

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