



Project portfolio selection for construction using the fuzzy logic and TOPSIS method

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Abstract

The limitation of government resources, especially in the field of budget, for the development of infrastructure on the one hand and the possibility of defining multiple plans and projects on the other hand, makes the issue of prioritizing and choosing the best portfolio of feasible projects vital. The basic question is which projects should be done and how the projects will be managed. The model used to select the project portfolio should be realistic, capable, flexible, affordable and simple. It is natural that the correct choice of the prioritization model and the selection of projects with the help of economic and non-economic criteria can help in the development of infrastructures as quickly as possible and in achieving the goals. In this research, we are trying to prioritize projects by using the TOPSIS method and the innovative method of fuzzy group decision making. Among the main indicators identified in this research, we can mention financial indicators, technical indicators, risk indicators, environmental indicators and political-social indicators; Each of these indicators has sub-criteria. As a case study, we have rated four dam construction projects using this decision-making method. Sensitivity analysis of the ranking based on changing the weights of the sub-criteria showed that the ranking has high robustness. The results show that this method can be used to select projects of the same type in other project portfolios.

Keywords: Ranking of projects, Multi-criteria decision making, economic and non-economic criteria, fuzzy logic, TOPSIS.

Paper Type: Original Research

1. Introduction

We are always choosing in our daily life; There are things that can be done in different ways, and for these choices among different options, we do the evaluation process both consciously and unconsciously. After the evaluation, we rank the tasks and the priority of each of them is determined for us. To choose the best project(s), we must evaluate them and then rank them based on their priority; One of the sectors that drive economic growth is the infrastructure industry (Tian et al., 2023). Projects in this sector usually require large investments, these projects often include; public buildings, transportation infrastructure, defense procurement, dam construction, etc. (Volden and Andersen, 2018). In developing countries, governments usually do not have sufficient financial resources to implement all infrastructure projects. (Tian et al., 2023). Therefore, considering the many financial resources that are spent in the implementation of a project, choosing the most suitable project(s) according to the existing conditions is of great importance to the extent that a large part of the first process of the project life cycle processes or the initial processes to this discussion is allocated There are different criteria for choosing the most appropriate project(s) and by considering all these criteria we can make a worthy choice. Using approaches that only consider the financial aspect to evaluate and prioritize the portfolio of projects (especially in projects where information uncertainty is greater) may cause wrong choices and loss of opportunities and resources. The construction industry is important in the economic growth of countries. Given the need for high investment in the infrastructure project portfolio and encouraging more private sectors and governments to invest, the issue of selecting these projects is based on the involvement of various criteria, including multi-criteria decision-making issues, which can be used to help industry owners, policymakers, and planners in this sector to choose the best decision by using multi-criteria decision-making techniques. Therefore, in this study, with the aim of helping to select the construction project portfolio, the project evaluation criteria in this sector are first identified and the decision-making options, which are the projects, are ranked according to the importance of the evaluation criteria. Among the unique contributions of this research compared to other research are: Due to the fact that in the previous researches, the ranking of projects was based on a few criteria, most of which were financial and economic criteria, and less non-

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economic criteria were considered, in this research, we intend to take into account both of these criteria (economic factors and non-economic factors) we rank the projects. This paper is organized as follows: Section 2 introduces a review of the relevant Research background. The research methodology is explained in Section 3. Section 4 presents numerical examples of data analysis related to the identification of criteria and sub-criteria for Project portfolio selection for construction of the extracted and ranked. The discussion is presented in Section 5. Finally, a conclusion is included in Section 6.

2. Research background

Project portfolio selection is one of the most important decisions that achieve organizational goals (Costantino et al. 2015). Over the past few decades, numerous and diverse researches have been conducted in the field of project evaluation and selection, and various methods have been proposed for selecting the appropriate project (Jeng and Huang 2015; Relich and Pawlowski 2017; Wu et al. 2018). However, it is difficult to consider all the factors involved in project selection simultaneously and continuously, and project portfolio selection is a challenging task due to the influential aspects and different criteria (Pérez et al. 2018). Ock (1999) provided a framework for analyzing and investigating the mutual effects of non-financial aspects in the financial analysis model. Ye and Tiong (2000) used a new method called net present value at risk to evaluate investment in infrastructure projects. Their method works by considering risk factors and combining those factors with an evaluation method like net present value. Bonnafous and Jensen (2005) also ranked 17 highway projects using the economic criteria of internal rate of return and net present value to rank transportation projects. Gabriel et al. (2006) presented a multi-objective model for rating projects. Using the hierarchical analysis process, they ranked the previously implemented projects to improve the selection of future projects. In their research, the combination of the Monte Carlo method with the multi-objective optimization method was used in solving the problems of multiple objectives that have uncertainty. In their research, McCowan and Mohammad (2007) presented a decision support system for evaluating and comparing projects. They used fifteen cases, twelve of which were economic and three were non-economic. The limitation of their model was that their non-financial factors were limited to risks and opportunities. Arjrodi et al. (2009) also presented a model for prioritizing road construction projects in the country. Using multi-criteria decision-making and a combination of pyramid methods and hierarchical analysis, they prioritized the main road construction projects. Namdarzangheh et al. (2013) also conducted a study on choosing the most economical project by combining Delphi methods, dynamic ranking method and ideal planning method. In their research, they chose the best option considering economic aspects, profitability and existing limitations. Khalili Iraqi (2008) also used group decision-making to rank projects. Using the opinion of experts, they considered 12 indicators to rank the projects. 7 of these indicators were financial and 5 were qualitative and related to risk. It was in line with the selection of investment projects. Shahrjardi et al. (2015) prioritized 5 construction-handover investment projects using fuzzy TOPSIS method. In their research, they used 30 risk factors that affected the main factors of the project (time, cost, scope and quality). Innovative methods have taken part of the research in this field. In order to maximize the expected profit of the project, Asgaryan et al. (2017) presented an innovative genetic algorithm to select the appropriate project among several projects and used several small-scale examples to evaluate their method. In addition to the multi-criteria methods that a large number of researchers have used because of their comprehensibility and relative ease. Golmohammadi and Pajotan (2011) used meta-innovative methods to select projects. They used electromagnetic algorithm and genetic algorithm to select the project portfolio. In their presented model, criteria related to cost and risk and random income are used. Hashemizadeh and Ju (2019) studied project portfolio selection for construction contractors using an MCDM-GIS approach. They used a combined method of multi-criteria decision making (MCDM) and geographic information system (GIS) to select projects by examining a wide range of different criteria, including strategic, financial, and project specifications from the perspective of construction contractors. Nascimento et al. (2023) studied the selection of a portfolio of construction projects in the public sector using the TOPSIS method. Considering that public institutions have limited financial and personnel resources and high demand for project development, they used the technical and managerial perspectives of experts to identify quantitative and qualitative evaluation criteria for project selection and selected construction projects by integrating TOPSIS and a portfolio optimization process. Hejazi et al. (2023) studied the selection of a project portfolio to improve safety in the construction industry in fuzzy environments. They used decision-making techniques and a questionnaire design in a fuzzy environment to identify candidate locations and related strategies. They used an empirical Bayesian approach to estimate the expected frequency of accidents with the aim of selecting the optimal safety project considering economic indicators and the time value of money in uncertain conditions. The results of the optimization of the mathematical model of this study indicate that by modifying the two factors of the safety level and the uncertainty coefficient, several scenarios can be examined to reduce costs and reduce the number of construction projects. Anjamrooz et al. (2024) conducted a study to identify and evaluate the criteria for selecting a specific sustainability project for construction organizations from the customer's perspective. They reviewed the

literature and identified 16 criteria, categorized them based on the three pillars of environmental, social, and economic sustainability, and then weighted and ranked them. In this study, the Analytic Hierarchy Process (ANP) method was used to weight the sustainability selection criteria. The results of this study indicate that the environmental group has the highest weight. Ghanbari et al. (2024) have presented a framework for optimal selection of a portfolio of construction projects along with risk analysis for a construction holding company in Iraq. They used a multi-objective genetic algorithm to optimize the portfolio selection process. In this study, 13 projects were selected for implementation after examining 34 candidate projects.

2.1 MCDM techniques

From a general point of view, multi-criteria decision-making models can be divided into the following two main categories:

1. Multi Objective Decision Making (MODM)
2. Multi Attribute Decision Making (MADM)

In multi-objective decision-making models, the best evaluated option should be selected based on system limitations, different objectives, and the desired value of the decision-maker for these objectives. In multi-indicator decision-making models, we are faced with a number of pre-defined decision-making options, each of which satisfies a level of the desired characteristics of the decision-maker. Now the decision maker should choose the best option based on the amount and type of available information from options and criteria.

In order to select and rank projects, considering that the amount of information from decision-making options is limited and each of the decision-making indicators has a different weight to each other, there are various decision-making methods such as weighted simple sum, hierarchical analysis process, elimination selection in translation to reality and TOPSIS. which have been used in previous researches.

2.2 Distinctive aspects of study

By reviewing the previous researches, it can be seen that there are several problems in the previous models presented for the selection and ranking of projects as follows:

- I. Failure to simultaneously consider economic and non-economic factors in the ranking of projects is seen in most of the previous researches. In a few researches where these factors have been considered together, risk factors have been used instead of non-economic factors and other non-economic factors have been ignored.
- II. b. Unlike previous researches, in this research, a group of Fifteen experts was used for decision-making, which leads to an increase in the accuracy of decision-making.
- III. J. Many of the methods that have been carried out in recent researches have complexity and difficulties in terms of implementation. In this research, the method of doing work is simpler and more understandable than most previous methods.

3. Methodology

This research is an applied research based on the results it has for contractors, customers and policymakers in the construction industry and is of the constructivist type in terms of its research philosophy, which seeks to create concepts in a specific field, especially in identifying the evaluation criteria for project selection. The objectives of the research are descriptive-analytical. The data collection methods in this research are partly in the form of a library that reviews the literature on the subject and partly in the form of a survey of experts. A case study of the construction industry and dam construction projects is considered for the research. The research implementation process: First, by studying the literature on the subject in the field of construction project selection, effective criteria in project selection are extracted and based on past studies and survey of experts, evaluation criteria are identified and ranked using the TOPSIS method in a fuzzy environment. The method of selecting experts in this research is non-probability, non-random and purposeful, and people who have at least five years of professional work experience in the field of construction project implementation and at least a relevant bachelor's degree in terms of knowledge were used.

3.1 Establishing fuzzy numbers

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets have been introduced by Zadeh (1965) as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition an element either belongs or does not belong to the set (Sun, 2010). It is possible to use different fuzzy numbers according to the situation. Trapezoidal fuzzy numbers can be defined as a trapezoidal $\tilde{A} = (a1, a2, a3, a4)$. A trapezoidal fuzzy number M is shown in Figure. 1 (Xiao et al, 2012).

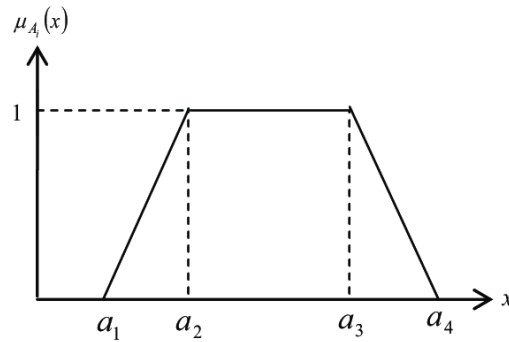


Figure 1. Trapezoidal membership function

the membership function $\mu_{\bar{A}}(x)$ as follows:

$$\mu_{\bar{A}}(x) = \begin{cases} 0, & x < a_1. \\ \frac{x-a_1}{a_2-a_1}, & a_1 \leq x \leq a_2. \\ 1, & a_2 \leq x \leq a_3. \\ \frac{x-a_4}{a_3-a_4}, & a_3 \leq x \leq a_4. \\ 0, & x > a_4. \end{cases} \quad (1)$$

3.2 Linguistic Variables

Linguistic variables take on values defined in its term set: it's set of linguistic terms. Linguistic terms are subjective categories for the linguistic variable. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language (Banadkouki MZ, Lotfi, 2021). This paper used linguistic variables to express reasonably a situation that is difficult to define. Table 1 shows Linguistic variables for the rating alternatives and corresponding Trapezoidal Fuzzy Numbers (Singh and Tiang, 2005).

Table 1. Fuzzy numbers corresponding to linguistic expressions

The corresponding trapezoidal fuzzy number	Linguistic titles introduced by Singh and Tiang		
(0.8,0.9,1.0,1.0)	Very High	VH	very high
(0.6,0.7,0.8,0.9)	High	H	high
(0.5,0.6,0.7,0.8)	Medium High	MH	Relatively much
(0.4,0.5,0.5,0.6)	Medium	M	medium
(0.2,0.3,0.4,0.5)	Medium Low	ML	Relatively less
(0.1,0.2,0.3,0.4)	Low	L	less
(0.0,0.0,0.1,0.2)	Very Low	VL	very little

According to Figure 1, the trapezoidal fuzzy number A is as follows:

- a1 Lower bound
- a2 and a3 Middle bound
- a4 High bound

3.3 The fuzzy TOPSIS method

TOPSIS is a widely used MADM technique because of its simple and programmable nature (Tavakkoli et al., 2011). TOPSIS, developed by Hwang and Yoon (1981) is used to obtain ranking scores and rank the alternatives accordingly (Sen & Yang, 2012). The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang & Elhag, 2006). In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, under many conditions crisp data are inadequate to model real-life decision problems. Therefore, the fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional

TOPSIS (Aghajani-Delavar et al., 2015). This method is particularly suitable for solving the group decision-making problem under fuzzy environment. The algorithm of this method can be described as follows (Banadkouki, 2023):

Step 1: Determine the weighting of evaluation criteria (This research employs entropy to find the fuzzy preference weight).

Step 2: Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

$$\tilde{D} = \begin{matrix} & C_1 & C_1 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} & i=1,2,\dots,m; j=1,2,\dots,n; & \tilde{x}_{ij} = \frac{\sum \tilde{x}_{ij}^{(k)}}{k} \end{matrix} \quad (2)$$

Where \tilde{x}_{ij}^k is the performance rating of alternative A_i with respect to criterion C_j evaluated by k th expert, and $\tilde{x}_{ij}^{(k)} = (a_{ij}^{(k)} \cdot b_{ij}^{(k)} \cdot c_{ij}^{(k)} \cdot d_{ij}^{(k)})$.

Step 3: Normalize the fuzzy-decision matrix. The normalized fuzzy-decision matrix denoted by \tilde{R} is shown as following formula:

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad i = 1.2. \dots m; j = 1.2. \dots n \quad (3)$$

Then, the normalization process can be performed by following formula:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{d_j^+} \cdot \frac{b_{ij}}{d_j^+} \cdot \frac{c_{ij}}{d_j^+} \cdot \frac{d_{ij}}{d_j^+} \right); d_j^+ = \max_i \{d_{ij} | i = 1.2. \dots m\} \quad \text{for benefit criteria} \quad (4)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{d_{ij}^-} \cdot \frac{a_j^-}{c_{ij}^-} \cdot \frac{a_j^-}{b_{ij}^-} \cdot \frac{a_j^-}{a_{ij}^-} \right); a_j^- = \min \{a_{ij} | i = 1.2. \dots m\} \quad \text{for cost criteria} \quad (5)$$

The normalized \tilde{r}_{ij} is still trapezoidal fuzzy numbers. The weighted fuzzy normalized decision matrix is shown as following matrix \tilde{V} :

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1.2. \dots m; j = 1.2. \dots n \quad \text{Where } \tilde{v}_{ij} = \tilde{x}_{ij} * w_i \quad (6)$$

Step 4: Identify positive ideal (A^+) and negative ideal (A^-) solutions. The fuzzy positive-ideal solution (FPIS, A^+) and the fuzzy negative-ideal solution (FNIS, A^-) are shown in the following equations:

$$A^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_i^+\} = \left\{ \left(\max_j v_{ij} \mid i \in I' \right) \times \left(\min_j v_{ij} \mid i \in I'' \right) \right\}, i = 1.2. \dots n \quad (7)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_i^-\} = \left\{ \left(\min_j v_{ij} \mid i \in I' \right) \times \left(\max_j v_{ij} \mid i \in I'' \right) \right\}, i = 1.2. \dots n \quad (8)$$

Where I' is associated with benefit criteria and I'' is associated with cost criteria.

Step 5: Calculate the distance of each alternative from A^+ and A^- using the following equations:

$$D_j^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_i^+) \quad j = 1.2. \dots m \quad (9)$$

$$D_j^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_i^-) \quad j = 1.2. \dots m \quad (10)$$

Step 6: Calculate similarities to ideal solution.

$$CC_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad j = 1.2. \dots m \quad (11)$$

Step 7: Rank preference order. Choose an alternative with maximum CC_j^* or rank alternatives according to CC_j^* in descending order.

Wang and Cheng (2007) provide four reasons for using the TOPSIS method:

- The TOPSIS method is a logical and understandable method.
- It has simple calculation processes.
- This format allows tracking the best options for each criterion in a simple mathematical format.
- Importance weights are included in comparative methods.

In addition to the above, the reasons for using the TOPSIS method for prioritizing projects in this article are as follows:

In this study, a large number of criteria have been used to increase the accuracy of project prioritization (30 criteria). For this reason, we should use one of the decision-making methods that does not have a limit on the number of criteria and options. The TOPSIS method is one of the methods in which we can use a large number of criteria and

options according to our problem. In the TOPSIS method, we can prioritize decision-making options using quantitative and qualitative criteria as well as positive and negative criteria. In this research, we intend to choose the best project from the project portfolio by using the TOPSIS method, which is one of the multi-criteria decision-making methods. The proposed method includes two general parts. In the first part, we will identify the criteria and the method of determining the weight of the criteria with the help of fuzzy logic, and then we will rank the case projects using the obtained data and using the TOPSIS method.

4. Numerical Examples

As mentioned in the previous part, in this research, we try to prioritize projects with the TOPSIS method and of course with the help of fuzzy logic. In general, the rating criteria of projects can be divided into economic and non-economic categories or financial and non-financial categories. Economic criteria and factors refer to all environmental conditions (internal or external of the project) that have a direct effect on the amount of profit or the cost of project implementation. Environmental factors affecting projects are divided into external and internal two categories. Environmental factors may have a positive or negative effect on the outcome of the project. In the ranking process of projects, environmental factors are considered as input. In the PMBak Project Management Knowledge Scope Guidebook (PMBOK® Guide, 2013), some environmental factors are introduced as follows: organizational structure, culture and processes, industrial or government standards (regulations, product standards, quality standards, etc.), existing infrastructure facilities, available human resources, market conditions, political situation, access to information. Non-economic criteria have a wider range than economic criteria and are different for different projects. Some of the non-economic criteria can include technical criteria, risks, opportunities, political, social, environmental conditions, etc. Many non-economic criteria have an indirect effect on economic criteria and profit and loss ratios. In the ranking of projects, some non-economic factors can be given more attention or ignored according to their impact on the project. In this research, economic and non-economic criteria are first identified by reviewing the subject literature and using the opinions of experts. Considering the variety of decision-making criteria and the large number of these criteria, I will use some of them that were more important in this evaluation according to the opinion of experts. It should be noted that the experts in this research included a group of professors from the Faculty of Civil Engineering (Seven from each) as well as a number of experienced project workers (Eight).

Step 1: Introducing Dam Projects in Iran

Dam projects in the world are among the largest, most critical, and most extensive infrastructure projects. Due to their large dimensions and complexity, as well as their technical, environmental, and economic structures, dam projects have numerous risks. Identifying each of these factors facilitates the selection of the right project and increases the likelihood of the project succeeding. These projects not only help manage water resources and provide energy, but also control floods, store water, and prevent natural disasters. However, the design and implementation of dam projects presents many challenges that require expertise and great care in selection and implementation. The volume of investment in dam projects is very large, so it is very important to pay attention to the economic benefits of these projects. In this study, 4 projects were hypothetically considered in 4 geographical locations in Iran to show the impact of the selection criteria for dam projects. The presented method will be used to rank these 4 projects.

Step 2: Identifying the evaluation criteria for selection of the project

After a comprehensive review of the literature as well as numerous meetings with the project's expert team, the criteria affecting project selection were identified and categorized into five groups; Environmental, Political and social, Technical and operational, Risk and Financial. The approach of these indicators is economic and non-economic. An economic criterion including 5 financial indicators and 4 non-economic criteria were selected, which includes a total of 25 non-financial indicators. In Table 1, we see economic and non-economic criteria and sub-criteria. In ranking projects, many indicators change according to the type and nature of projects. Table 2 shows the general classification and the complete list of indicators that are used to evaluate and rank dam construction projects.

Table 2: Evaluation and rating indicators of dam construction projects

Indicators	Code	Criteria
Environmental	C1	E1- Environmental effects caused by the implementation of the project
	C2	E2- Geographical and climatic conditions of the project location
	C3	E3- Reducing the use of natural resources
	C4	E4- recycling
	C5	E5- Preservation of the natural beauty caused by the structure of the dam and reservoir lake
Political and social	C6	P1- Legal requirements
	C7	P2- Social and political conditions of the region
	C8	P3- Reducing political dependence on neighboring countries or provinces
	C9	P4- Strategic importance of the project
	C10	P5- Employment of local unemployed workers
	C11	P6- Percentage increase in crops and livestock
	C12	P7- Maintaining and providing recreational facilities
	C13	P8- The status of ownership of the natural resources of the region such as land, water, minerals and forests
Technical and operational	C14	T1- Availability of the required technology
	C15	T2- Technical problems and complexities of the project
	C16	T3- Conditions of the contractor company (financial-technical-similar works-equipment, etc.)
	C17	T4- The duration of the project
	C18	T5- Ease of implementation, maintenance
	C19	T6- Compliance with the necessary quality criteria and standards
Risk	C20	R1- The ratio of opportunity to risk
	C21	R2- Government support in the face of risk
	C22	R3- Risk of increasing construction time
	C23	R4- Rework risk
	C24	R5- Project insurance cost
	C25	R6- Damages caused by dam dewatering
Financial	C26	F1-IRR (Internal Rate of Return)
	C27	F2- NPV (Net Present Value)
	C28	F3- Benefit-cost ratio
	C29	F4- The number of years of capital return
	C30	F5- Availability of financial resources for project implementation

Step 3: Weighting of ranking indicators selection of the project

After identifying the evaluation indicators and rating of the projects, each of the indicators is weighted using descriptive expressions and language which are described below and using the opinions of Fifteen experts.

In fact, weighing and evaluating the relative importance of indicators is one of the most important and difficult decision-making steps that can create significant uncertainty in the decision-making process. In most cases, decision makers cannot provide exact values for the weight of indicators. This issue may be due to the existence of some ambiguities and contradictions in the decision-making process, or the lack of knowledge and limited decision-making ability in processing information, and even the existence of time pressure in the decision-making process (Mianabadi & Afshar, 2012). In general, there are three methods for estimating the relative weight of indicators, which are:

- Assessing the weight of indicators using objective information
- Evaluating the weight of indicators using the subjective preferences of decision makers
- Assessing the weight of indicators using a combination of the above two methods

To carry out this stage of the research, any expert can put a mark in front of each of them and under each of the language expressions that will be converted into trapezoidal fuzzy numbers in the next stage according to the relative importance of the indicators. Fuzzy numbers related to these language expressions are given in the table 1.

After collecting experts' opinions about each index, in order to be able to compare these opinions with each other, we convert the fuzzy numbers into definite numbers using aggregation operators. To de-fuzzify these fuzzy numbers, we use the center of surface (COA) method as follows. (Shaheen et al., 2007) For the trapezoidal fuzzy number, $\tilde{A} = (a_1, a_2, a_3, a_4)$:

$$EV_{\text{Trapezoidal}} = \frac{a_1 + 2(a_2 + a_3) + a_4}{6} \tag{12}$$

In Table 3, we see the indicators and their final evaluation.

Table 3: The weight of the indicators used in the ranking of dam construction projects

Code	weight	Rank	Code	weight	Rank
C1	0.03148	20	C16	0.03675	7
C2	0.03124	23	C17	0.03974	4
C3	0.03423	11	C18	0.03163	19
C4	0.03148	21	C19	0.03384	12
C5	0.03187	18	C20	0.02479	30
C6	0.02676	29	C21	0.03289	14
C7	0.03132	22	C22	0.03628	8
C8	0.02872	27	C23	0.03494	10
C9	0.03226	16	C24	0.03714	6
C10	0.02912	26	C25	0.03840	5
C11	0.04068	2	C26	0.03360	13
C12	0.03226	17	C27	0.02951	25
C13	0.03030	24	C28	0.03242	15
C14	0.04068	3	C29	0.02872	28
C15	0.03580	9	C30	0.04116	1

We use the obtained weights in the next step and in the TOPSIS decision making method.

Step 4: Creating the decision matrix

To evaluate the project selection criteria in the dam construction industry, as mentioned earlier, the opinions of 14 experts were obtained based on the verbal expressions in Table 1.

After completing the initial decision matrices by all experts and converting the verbal expressions into trapezoidal fuzzy numbers and calculating their average values, the final decision matrix was determined. Table 4 shows the decision matrix.

Step 5: Normalizing the fuzzy decision matrix

The fuzzy decision matrix presented in Step 4 (Table 4) is normalized using Eq. 4 and 5.

Step 6: Creating weighted normal fuzzy decision matrix

The weights of the criteria obtained by Step 3 (Table 3) and the normalized fuzzy decision matrix were converted into a weighted normalized fuzzy decision matrix, using Eq. 6. Table 5 shows this matrix.

Step 7: Calculating the distance of each alternative from fuzzy positive ideal strategy (FPIS) and fuzzy negative ideal Projects (FNIS)

The distances of each alternative, A^+ and A^- , were obtained from the set of positive and negative ideal Projects through Eqs. 7 and 8.

Table 4. Fuzzy decision matrix

Alternatives	Criteria																							
	C1				C2				C3				C4				C5				C6			
Dam1	0.24	0.3	0.4	0.5	0.34	0.42	0.46	0.56	0.6	0.7	0.8	0.86	0.18	0.28	0.38	0.48	0.58	0.68	0.78	0.88	0.66	0.76	0.86	0.92
Dam2	0.66	0.76	0.86	0.92	0.52	0.62	0.7	0.8	0.66	0.76	0.86	0.92	0.26	0.36	0.46	0.56	0.46	0.56	0.66	0.76	0.46	0.56	0.62	0.72
Dam3	0.48	0.58	0.68	0.78	0.36	0.46	0.48	0.58	0.58	0.68	0.78	0.86	0	0	0.1	0.2	0.64	0.74	0.84	0.92	0.46	0.56	0.66	0.76
Dam4	0.52	0.62	0.72	0.8	0.52	0.62	0.66	0.74	0.58	0.68	0.78	0.88	0.22	0.32	0.38	0.48	0.44	0.54	0.64	0.74	0.64	0.74	0.84	0.92

Alternatives	Criteria																							
	C7				C8				C9				C10				C11				C12			
Dam1	0.62	0.72	0.82	0.9	0.52	0.62	0.72	0.82	0.7	0.8	0.9	0.94	0.58	0.68	0.78	0.88	0.8	0.9	1	1	0.6	0.7	0.8	0.9
Dam2	0.6	0.7	0.8	0.9	0.36	0.46	0.54	0.64	0.6	0.7	0.8	0.9	0.34	0.44	0.52	0.62	0.6	0.7	0.8	0.9	0.46	0.56	0.62	0.72
Dam3	0.56	0.66	0.74	0.84	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.6	0.7	0.78	0.86	0.76	0.86	0.96	0.98	0.7	0.8	0.9	0.94
Dam4	0.5	0.6	0.7	0.8	0.38	0.48	0.54	0.64	0.76	0.86	0.96	0.98	0.52	0.62	0.72	0.82	0.62	0.72	0.82	0.9	0.54	0.64	0.72	0.82

Alternatives	Criteria																							
	C13				C14				C15				C16				C17				C18			
Dam1	0.58	0.68	0.78	0.88	0.48	0.58	0.66	0.76	0.6	0.7	0.8	0.9	0.48	0.58	0.66	0.76	0.72	0.82	0.9	0.92	0.6	0.7	0.8	0.9
Dam2	0.5	0.6	0.7	0.8	0.4	0.5	0.5	0.6	0.46	0.56	0.62	0.72	0.5	0.6	0.7	0.8	0.64	0.74	0.84	0.92	0.5	0.6	0.7	0.8
Dam3	0.7	0.8	0.9	0.94	0.6	0.7	0.8	0.9	0.62	0.72	0.82	0.88	0.58	0.68	0.78	0.88	0.8	0.9	1	1	0.8	0.9	1	1
Dam4	0.5	0.6	0.7	0.8	0.58	0.68	0.78	0.88	0.5	0.6	0.7	0.8	0.36	0.46	0.48	0.58	0.64	0.74	0.84	0.92	0.52	0.62	0.72	0.82

Alternatives	Criteria																							
	C19				C20				C21				C22				C23				C24			
Dam1	0.6	0.7	0.8	0.9	0.2	0.3	0.4	0.5	0.1	0.12	0.22	0.32	0.1	0.2	0.3	0.4	0.54	0.64	0.72	0.82	0.5	0.6	0.7	0.8
Dam2	0.52	0.62	0.72	0.82	0.44	0.54	0.58	0.68	0.44	0.54	0.64	0.74	0.6	0.7	0.8	0.9	0.48	0.58	0.66	0.76	0.6	0.7	0.8	0.9
Dam3	0.66	0.76	0.86	0.92	0.42	0.52	0.54	0.64	0.6	0.7	0.8	0.9	0.6	0.7	0.8	0.9	0.5	0.6	0.66	0.76	0.5	0.6	0.7	0.8
Dam4	0.52	0.62	0.72	0.82	0.46	0.56	0.62	0.72	0.6	0.7	0.8	0.9	0.52	0.62	0.72	0.82	0.32	0.42	0.52	0.62	0.28	0.38	0.48	0.58

Alternatives	Criteria																							
	C25				C26				C27				C28				C29				C30			
Dam1	0.48	0.58	0.66	0.76	0.68	0.78	0.88	0.94	0.58	0.68	0.78	0.88	0.74	0.84	0.94	0.96	0.8	0.9	1	1	0.62	0.72	0.82	0.9
Dam2	0.2	0.3	0.4	0.5	0.24	0.34	0.42	0.52	0.42	0.52	0.54	0.64	0.5	0.6	0.7	0.8	0.68	0.78	0.88	0.94	0.64	0.74	0.84	0.88
Dam3	0.38	0.48	0.52	0.62	0.76	0.86	0.96	0.98	0.76	0.86	0.96	0.98	0.72	0.82	0.92	0.96	0.58	0.68	0.78	0.88	0.68	0.78	0.86	0.9
Dam4	0.48	0.58	0.64	0.74	0.56	0.66	0.74	0.84	0.48	0.58	0.66	0.76	0.56	0.66	0.76	0.86	0.64	0.74	0.84	0.92	0.56	0.66	0.76	0.84

Table 5. Weighted normalized fuzzy decision matrix

Alter-natives	Criteria																							
	C1				C2				C3				C4				C5				C6			
Dam1	0.008	0.010	0.014	0.017	0.013	0.016	0.018	0.022	0.022	0.026	0.030	0.032	0.010	0.016	0.021	0.027	0.020	0.024	0.027	0.030	0.019	0.022	0.025	0.027
Dam2	0.023	0.026	0.029	0.031	0.020	0.024	0.027	0.031	0.025	0.028	0.032	0.034	0.015	0.020	0.026	0.031	0.016	0.019	0.023	0.026	0.013	0.016	0.018	0.021
Dam3	0.016	0.020	0.023	0.027	0.014	0.018	0.019	0.023	0.022	0.025	0.029	0.032	0.000	0.000	0.006	0.011	0.022	0.026	0.029	0.032	0.013	0.016	0.019	0.022
Dam4	0.018	0.021	0.025	0.027	0.020	0.024	0.026	0.029	0.022	0.025	0.029	0.033	0.012	0.018	0.021	0.027	0.015	0.019	0.022	0.026	0.019	0.022	0.024	0.027
Alterna-tives	Criteria																							
	C7				C8				C9				C10				C11				C12			
Dam1	0.022	0.025	0.029	0.031	0.018	0.022	0.025	0.029	0.023	0.026	0.030	0.031	0.019	0.022	0.026	0.029	0.033	0.037	0.041	0.041	0.021	0.024	0.027	0.031
Dam2	0.021	0.024	0.028	0.031	0.013	0.016	0.019	0.022	0.020	0.023	0.026	0.030	0.011	0.015	0.017	0.021	0.024	0.028	0.033	0.037	0.016	0.019	0.021	0.025
Dam3	0.019	0.023	0.026	0.029	0.004	0.007	0.011	0.014	0.016	0.020	0.023	0.026	0.020	0.023	0.026	0.028	0.031	0.035	0.039	0.040	0.024	0.027	0.031	0.032
Dam4	0.017	0.021	0.024	0.028	0.013	0.017	0.019	0.022	0.025	0.028	0.032	0.032	0.017	0.021	0.024	0.027	0.025	0.029	0.033	0.037	0.019	0.022	0.025	0.028
Alterna-tives	Criteria																							
	C13				C14				C15				C16				C17				C18			
Dam1	0.019	0.022	0.025	0.028	0.022	0.026	0.030	0.034	0.024	0.028	0.032	0.036	0.020	0.024	0.028	0.032	0.029	0.033	0.036	0.037	0.019	0.022	0.025	0.028
Dam2	0.016	0.019	0.023	0.026	0.018	0.023	0.023	0.027	0.018	0.022	0.025	0.029	0.021	0.025	0.029	0.033	0.025	0.029	0.033	0.037	0.016	0.019	0.022	0.025
Dam3	0.023	0.026	0.029	0.030	0.027	0.032	0.036	0.041	0.025	0.029	0.033	0.035	0.024	0.028	0.033	0.037	0.032	0.036	0.040	0.040	0.025	0.028	0.032	0.032
Dam4	0.016	0.019	0.023	0.026	0.026	0.031	0.035	0.040	0.020	0.024	0.028	0.032	0.015	0.019	0.020	0.024	0.025	0.029	0.033	0.037	0.016	0.020	0.023	0.026
Alterna-tives	Criteria																							
	C19				C20				C21				C22				C23				C24			
Dam1	0.022	0.026	0.029	0.033	0.010	0.012	0.017	0.025	0.010	0.015	0.027	0.033	0.009	0.012	0.018	0.036	0.014	0.016	0.017	0.021	0.013	0.015	0.017	0.021
Dam2	0.019	0.023	0.026	0.030	0.007	0.009	0.009	0.011	0.004	0.005	0.006	0.007	0.004	0.005	0.005	0.006	0.015	0.017	0.019	0.023	0.012	0.013	0.015	0.017
Dam3	0.024	0.028	0.032	0.034	0.008	0.009	0.010	0.012	0.004	0.004	0.005	0.005	0.004	0.005	0.005	0.006	0.015	0.017	0.019	0.022	0.013	0.015	0.017	0.021
Dam4	0.019	0.023	0.026	0.030	0.007	0.008	0.009	0.011	0.004	0.004	0.005	0.005	0.004	0.005	0.006	0.007	0.018	0.022	0.027	0.035	0.018	0.022	0.027	0.037
Alterna-tives	Criteria																							
	C25				C26				C27				C28				C29				C30			
Dam1	0.010	0.012	0.013	0.016	0.023	0.027	0.030	0.032	0.017	0.020	0.023	0.026	0.025	0.028	0.032	0.032	0.023	0.026	0.029	0.029	0.028	0.033	0.037	0.041
Dam2	0.015	0.019	0.026	0.038	0.008	0.012	0.014	0.018	0.013	0.016	0.016	0.019	0.017	0.020	0.024	0.027	0.020	0.022	0.025	0.027	0.029	0.034	0.038	0.040
Dam3	0.012	0.015	0.016	0.020	0.026	0.029	0.033	0.034	0.023	0.026	0.029	0.030	0.024	0.028	0.031	0.032	0.017	0.020	0.022	0.025	0.031	0.036	0.039	0.041
Dam4	0.010	0.012	0.013	0.016	0.019	0.023	0.025	0.029	0.014	0.017	0.020	0.023	0.019	0.022	0.026	0.029	0.018	0.021	0.024	0.026	0.026	0.030	0.035	0.038

Step 8: Determining the closeness coefficient index (CC_j, relative degree-distance) and the desire of the alternatives to reach the ideal levels in each criterion

The closeness coefficients are shown by CC_j, as the final index of ranking and evaluating the alternatives, calculated based on Eq. 11, whose results are displayed in Table 6 along with the distance between the positive and negative ideals.

Table 7. Distance values, closeness coefficients, and ranking of the strategies

Alternatives	d+	d-	CC _j	Rank
Dam1	29.2756	0.7380	0.0246	1
Dam2	29.3634	0.6467	0.0215	4
Dam3	29.3100	0.6991	0.0233	2
Dam4	29.3354	0.6744	0.0225	3

As shown in Table 6, dam construction projects have been ranked according to the evaluation criteria. Accordingly, Dam Project 1 ranks first, Dam Project 3 ranks second, Dam Project 4 ranks third, and Dam Project 2 ranks fourth.

Step 9: Sensitivity analysis

In this section, a sensitivity analysis is performed to examine the stability and robustness of the ranking of dam construction projects. The most famous method of sensitivity analysis is the change in the weight of the criteria for evaluating solutions (Ci) (Li et al., 2013). For this purpose, the weights of the C30 and C11 criteria, which have the highest weight among the thirty criteria, are selected for change. The weight of each selected evaluation criterion is increased and decreased in three steps ($\pm 5\%$, $\pm 10\%$, $\pm 15\%$) and the results obtained are compared with the ranking performed. For this purpose, the change in the weight of the criteria is proportional to the weight of each criterion and is adjusted with the weight of the remaining criteria so that the total weight is kept equal to 1 (Chauhan et al., 2017). Table 8 and Table 9 show the ranking of the options based on the change in the weight of the C30 and C11 criteria.

Table 8. Weight sensitivity of C30 on ranking.

Alternatives	Weight level						
	-15%	-10%	-5%	Original	+5%	+10%	+15%
	Ranking (Closeness coefficient)						
Dam1	1 (0.0300)	1 (0.0275)	1 (0.0249)	1 (0.0246)	1 (0.0248)	1 (0.0250)	1 (0.0252)
Dam2	4 (0.0265)	4 (0.0241)	4 (0.0217)	4 (0.0215)	4 (0.0219)	4 (0.0223)	4 (0.0227)
Dam3	2 (0.0286)	2 (0.0260)	2 (0.0235)	2 (0.0233)	2 (0.0237)	2 (0.0240)	2 (0.0244)
Dam4	3 (0.0274)	3 (0.0251)	3 (0.0227)	3 (0.0225)	3 (0.0227)	3 (0.0229)	3 (0.0231)

Table 9. Weight sensitivity of C11 on ranking.

Alternatives	Weight level						
	-15%	-10%	-5%	Original	+5%	+10%	+15%
	Ranking (Closeness coefficient)						
Dam1	1 (0.0302)	1 (0.0275)	1 (0.0248)	1 (0.0246)	1 (0.0249)	1 (0.0252)	1 (0.0256)
Dam2	4 (0.0263)	4 (0.0241)	4 (0.0218)	4 (0.0215)	4 (0.0217)	4 (0.0219)	4 (0.0221)
Dam3	2 (0.0286)	2 (0.0260)	2 (0.0235)	2 (0.0233)	2 (0.0236)	2 (0.0240)	2 (0.0243)
Dam4	3 (0.0274)	3 (0.0251)	3 (0.0228)	3 (0.0225)	3 (0.0226)	3 (0.0228)	3 (0.0230)

Table 8 and Table 9 show the ranking of dams based on the change in the weight of criteria C30 and C11. The results of these tables show that the ranking is completely the same with the change in the weight of the indicators and there is no change in the ranking of the options. Therefore, the ranking of the dam construction industry is not sensitive to the weight of the criteria.

5. Discussion

The findings of this study can be compared with the results of previous research in terms of evaluation criteria for the selection of construction and infrastructure projects. Ock (1999) used non-financial aspects in highway projects in his study, which used 4 groups of non-financial criteria in this study. Ye and Tiong (2000) used the net present value index to evaluate investments in infrastructure projects, which was used in the group of financial indicators for project selection. Also, Bonnafous and Jensen (2005) used the internal rate of return and net present value

criteria to select transportation projects, which are also seen in this study for project selection. McCowan and Mohamed (2007) used economic and non-economic criteria in their study to evaluate projects, which is also present in this study. Namdarzangheh et al. (2013) evaluated the economic aspect of projects, which is considered as an evaluation criterion in this study. Khalili-Iraqi (2008) also used financial and risk criteria to rank projects, which is discussed in this study. Shahrjerdi et al. (2015) used risk criteria to select construction investment projects, which is also present in this study. Golmohammadi and Pejoutan (2011) used criteria related to cost, risk, and income, which are also considered in this study. Hashemizadeh and Ju (2019) used various criteria such as strategic and financial characteristics to select a construction project portfolio, which in this study has also been considered in the evaluation of projects. Nascimento et al. (2023) identified evaluation criteria for selecting a set of construction projects from a technical and managerial perspective. In this study, one of the groupings of criteria is technical and operational aspects. In their study, Anjamrooz et al. (2024) examined the criteria for selecting a construction project based on the three pillars of environmental, social, and economic sustainability, which were taken into account in the classification of criteria in this study. Another aspect of comparing this study with other related studies in this field is the use of research methodology. In this study, MADM methods were used to select dam construction projects, which were also used in studies by Gabriel, Kumar and Gabriel et al. (2006), McCowan and Mohamed (2007), Arjrodi et al. (2009), Khalili Iraq (2008), Hashemizadeh and Ju (2019), Nascimento et al. (2023), Hejazi et al. (2023) and Anjamrooz et al. (2024) to select and evaluate infrastructure projects.

6. Conclusion

In this research, taking into account various economic and non-economic factors to rank the projects, the preferred option has been selected from among the projects. In this study, economic and non-economic criteria were first identified using experts' opinions and literature review. Among the identified criteria, the most important ones were used to rank the dam construction projects. These criteria were categorized into 5 main groups including financial indicators, technical indicators, risk indicators, environmental indicators and political-social indicators, each of these indicators has a number of sub-criteria. In this research, the group decision-making method and metallic logic were used to determine the weight of the criteria. Due to the use of linguistic expressions and fuzzy logic, it is possible to examine quantitative and qualitative factors to determine the exact weight of criteria and sub-criteria. Considering that 30 sub-criteria were weighted in this research, it is obvious that the weight of some of them is very low, but we have used all of them to increase the accuracy of decision-making and we have not omitted any of them. Compared to other researches that have been done in the field of ranking projects, it can be seen that the use of extensive criteria and sub-criteria can lead to the improvement of decision-making and increase the accuracy of decision-making. According to the results obtained from the output of the TOPSIS program on the Excel software, four dam construction projects were prioritized and these results can be used in planning to select the project portfolio. The results of the sensitivity analysis of the project selection evaluation criteria show that the ranks obtained from the fuzzy TOPSIS method are not affected by changing the weight of the criteria. It is suggested to use this method in future studies to rank different projects. Researchers can benefit from different criteria according to the type of projects. It is also suggested to use other weighting methods to improve the results.

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