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ORIGINAL PAPER

Application of fuzzy BWM-CoCoSo to time–cost–environmental impact trade-off construction project scheduling problem

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Abstract
The economic growth and the development of construction industry in several countries have had detrimental impacts on environment and natural ecosystems. Therefore, environmental impact assessment studies of construction projects have received more attention from governments and organizations. In other words, minimizing environmental impacts have been taken into consideration along with other common project goals. This study aims to identify and evaluate the environmental impacts of construction projects and ultimately determine the most favorable implementation modes of activities so that each project activity is executed with the least possible cost, duration, and environmental effects. The environmental consequences of projects are identified in three biological, physicochemical, and socioeconomic environments. Also, the positive and negative environmental impacts are assessed using the Leopold matrix method. Then, the importance weights of the project objectives including cost, time, negative environmental impacts, and positive environmental impacts are calculated using the fuzzy BWM method. Finally, the various modes of executing each activity are prioritized and ranked by using the fuzzy CoCoSo technique regarding the weighted objectives. The activity execution mode with the highest ranking indicates the best possible implementation mode of that given activity according to cost, time and positive environmental impacts as well as negative environmental impacts. The proposed method is implemented in a remote rural water supply construction project for efficiency evaluation. This study directs project managers to identify and assess the environmental consequences and impacts of construction projects in addition to considering the other two common project objectives.

Keywords Project scheduling · Time–cost trade-off · Environmental impacts · Fuzzy CoCoSo · Fuzzy BWM · Case study

Introduction

Along with the emergence of the concept of sustainable development, environment has been known as the fundamental pillar of continuous growth. Therefore, the tendency of global concerns toward the environmental issues is of extreme importance. Construction projects are generally being implemented around the world to satisfy a set of requirements and needs; consequently, the primary target of project managers is to propel and direct projects in order to meet a set of predefined project objectives. Several goals are specified for different construction projects. The most significant project objectives are to accomplish the project within the minimum cost and duration (Baptiste and Demassey 2004). The project scheduling problem of balancing the primary factors of cost and time, known as time–cost trade-off problem (TCTP), dates back to 1961. TCTP deals with implementing projects in minimum duration considering numerous implementation modes for any activity (Kelley 1961). In this study, the environmental consequences and impacts of construction projects in addition to the common project objectives of cost and time have been addressed. Also, in order to tackle the ambiguity and vagueness of verbal variables associated with the experts' opinions, the Fuzzy set theory is applied. The objectives of the present research can be stated as follows:

(1) The environmental consequences and impacts of different implementation modes of activities are analyzed

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and evaluated in terms of three socioeconomic, biological and physicochemical aspects.

(2) The environmental effects of project activities are classified into negative and positive impacts.

(3) Given that the importance of project objectives (cost, time, negative and positive environmental consequences) is dissimilar in various projects, the project goals and objectives are weighted using fuzzy BWM method.

(4) In addition to the primary project factors of time and cost, the environmental effects are considered for ranking the implementation modes of activities.

(5) The CoCoSo method is employed to order and rank the various execution modes of each project activity.

The research questions are also as follows:

(1) What are the environmental impacts of a construction project?

(2) How are the environmental impacts of a given construction project evaluated?

(3) Which of the several execution modes should be selected for each project activity to mitigate the environmental consequences of the entire project together with decreasing project cost and duration?

The contribution of this study is threefold: (1) taking the three socioeconomic, biological and physicochemical aspects, (2) evaluating both negative and positive environmental consequences and impacts of project activities, and (3) weighting the primary project objectives (time, cost, negative, and positive environmental effects).

This paper is organized as follows. The literature review is expressed in the following section. "Materials and methods" explains with the research methodology. In "Results and discussions", the proposed model is implemented in a real case study. Finally, "Conclusion" concludes the paper.

Literature review

Time–cost trade-off problems

Project scheduling is a topic that has been widely discussed in the construction industry. Initially, researchers sought to determine the start times of activities to complete projects in the minimum make-span. Afterward, other goals and objectives besides time became important for project practitioners. A project activity can be executed in several modes, each of which has different duration and cost. Hence, TCTP has been raised by project practitioners to find out the best combination of execution modes of project activities in order to minimize the project make-span (Tran 2020).

Eshtehardian et al. (2009) combined the fuzzy sets theory and the metaheuristic Genetic Algorithm (GA) to deal with TCTP, and the findings indicated the capability of their method in creating different optimal solutions. In addition, Zhang and Thomas Ng (2012) exploited the Ant Colony Optimization (ACO) for solving TCTP.

Technological development together with the rapid growth of worldwide construction projects and their increasing revenues, on the other hand, escalating the public concerns toward the environment, have led to emerging the time–cost–environmental impact trade-off (TCETP) problem recently (Xu et al. 2012; Zhong and Wu 2015; Wang et al. 2018). According to the definition, sustainable development must take the economic, environmental, and social targets into account to enhance the present societies' welfare (WCED 1987; Martens and Carvalho 2017).

There exist several conflicts in the definition of sustainability indicators (Moldan and Dahl 2007). Stanitsas et al. (2020) investigated the literature of the sustainability indicators corresponding with the project management. They categorized these sustainability indicators into three classifications comprising social, economic, and environmental facets. For the sake of environment, it is vital to concentrate on the environmental issues and problems raised by the construction sector as one of the most significant pollutants of environment (Yan et al. 2010). Therefore, the environmental consequences of construction projects should be analyzed and evaluated by the project practitioners and decision-makers to meet the sustainable development goals and objectives. The method of environmental impact assessment (EIA) originated from the United States. EIA deals with identifying project activities' impacts and the consequences of construction works on environment, society, and economy (Allett 1986). Hence, EIA assists project managers with choosing the most appropriate methods for implementing construction projects. Morrison-Saunders (2018) expresses: "*Think before act*". The problem of environmental effects of the construction industry has recently become a fascinating topic for researchers. The environmental impacts can be analyzed and evaluated throughout the implementation of projects and even after their completion (Asadollahfardi and Asadi 2018).

First, Marzouk et al. (2008) addressed the TCTP problem considering noxious gases, dust, and noise as the three sorts of pollutants. They proposed a multi-objective project scheduling model and solved it using the GA algorithm. Ozcan-Deniz et al. (2012) developed a model for the minimization of the project objectives of cost, time, and environmental effects. They assessed and analyzed the environmental effects using the life cycle assessment (LCA) method along with the NSGAII (Non-dominated Sorting Genetic Algorithm). Xu et al. (2012) investigated the discrete TCTP considering environmental consequences of the project comprising of air pollution, solid waste pollution, water and groundwater pollution, noise, and soil pollution. Liu et al. (2013) examined the primary components of greenhouse gas emissions caused by the industrial projects. They exploited a metaheuristic algorithm based on Multi-Objective Particle Swarm Optimization (MOPSO) to obtain the solutions for trading off CO_2 pollutants and costs in the construction works. Cheng and Tran (2015) investigated TCTP considering the environmental consequences of the project including the factors of noise pollution, gases, and dust in a case study. Ozcan-Deniz and Zhu (2017) addressed TCTP taking the greenhouse gas emissions in the highway construction projects into account. Lotfi et al. (2020) studied the trade-off among cost–time–quality–environmental effects in projects and concluded that initially pollution, cost, and energy decrease along with reducing the durations of project activities; however, they will increase afterward. Yu et al. (2020) introduced the multiple objectives optimization model to tackle the quality–cost–environmental effects trade-off problem in an asphalt pavement project. The results indicated that the costs and environmental effects were reduced by 96.5 and 97.3%, respectively; however, the quality was increased by 125.1% compared to the primary method. Other scholars such as Santos et al. (2015) and Vega et al. (2020) also examined the environmental impact assessment problem in the concrete pavement and hot asphalt projects. Huynh et al. (2021) studied the balancing problem of the three objectives of cost, time, and quality in the construction projects taking the emissions of carbon dioxide into account. Maceika et al. (2021) employed the Analytic Hierarchy Process (AHP) method for the evaluation of investor behavior in selecting the construction projects considering environmental aspects and sustainability. In addition, Wang et al. (2021) evaluated the sustainability of a railroad construction project in Tanzania.

Multi-criteria decision making (MCDM) methods in project management

The literature demonstrates the significance of the environmental impacts on the sustainable development of the construction industry. On the other hand, numerous studies have employed several MCDM methods in various engineering problems. The MCDM technique contains determining the most desirable solution among several alternatives considering the predefined criteria (Yazdani et al. 2019).

In the present study, the time–cost–environmental impact trade-off (TCETP) problem is addressed and solved using the CoCoSo MCDM method as the state-of-the-art method advanced by a thorough ranking index. Numerous MCDM methods initiating with a decision matrix have been used for ranking the predefined criteria. The privilege and superiority of the CoCoSo technique over other MCDM methods is that the CoCoSo technique presents a combined compromise solution for ranking alternatives (Yazdani et al. 2019). This method computes two amounts of weighted sum and weighted product for each alternative, and eventually it employs three strategies in ranking the alternatives: The first strategy identifies the arithmetic mean of the values for each alternative. The second strategy computes the values of each alternative compared to the best one. The third strategy compromises the first and second strategies. The ultimate ranking of each alternative is found by using the arithmetic and geometric means of the aforementioned three strategies. Consequently, the CoCoSo technique is the most flexible method in ranking alternatives compared to other MCDM methods proposed so far (Yazdani et al. 2019).

Materials and methods

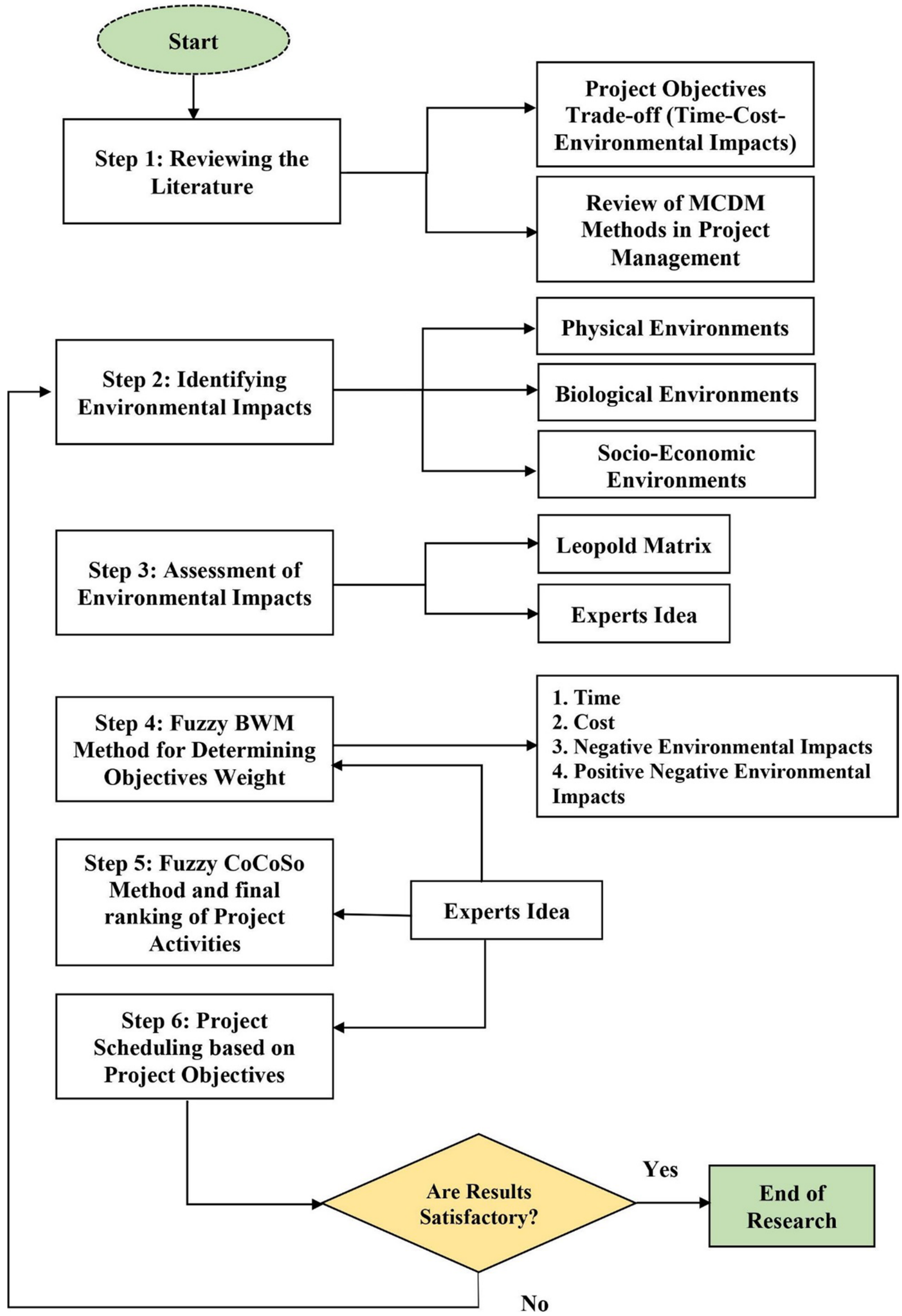
One of the challenging issues in the implementation of construction projects is environmental effects. EIA is a method that ensures the appropriate implementation of a project and is employed to identify, forecast, and clarify the environmental impacts of the projects. As the economic development of countries has serious impacts on the environment, it is vital to pay more attention to assessing these detrimental effects. In the present study, the Leopold matrix (LM) method is utilized to examine the environmental impacts. A real-world rural construction project is taken into account to investigate the effectiveness of the proposed hybrid method. After identifying the environmental effects of all activities, the most favorable method is selected for the project implementation using the CoCoSo MCDM method considering the four primary factors of cost, time, negative and positive environmental effects.

Figure 1 displays the research framework.

The Leopold matrix (LM) method

This method was first proposed by Leopold in 1971 for analyzing the environmental effects. The LM method is capable of summarizing both negative and positive impacts of the project phases. Also, this method has a simple structure and is able to carry out multiple criteria evaluation. In the LM method, a matrix containing all activities is structured. The columns of this matrix represent the environmental factors. For each impact, a number ranging between + 5 and − 5 can be given. Numbers denote the significance of the impact. Also, negative and positive signs represent the sort of its consequence. Positive numbers show positive impacts and negative numbers represent negative impacts. Subsequently, the mean of negative and positive effects for each activity and each environmental factor is computed (Dehaghi and Khoshfetrat 2020). The vagueness and ambiguity of inaccurate data is associated with

Fig. 1 Research framework



the qualitative evaluation of the interactions among the activities of the project and environmental factors. The fuzzy sets theory is a proper method to tackle vagueness and uncertainty corresponding with the linguistic and verbal variables. Table 1 presents each triangular fuzzy number (TFN) associated with each linguistic variable.

A given fuzzy number $\tilde{A}$ is defined by its membership function μ_A in an α cut:

Table 1 The TFNs corresponding with the verbal and linguistic variables

Linguistic variable	Very low (VL) impact	Low impact (L)	Medium (M) impact	High (H) impact	Very high (VH) impact
Value	1	2	3	4	5
Triangular fuzzy number	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1)

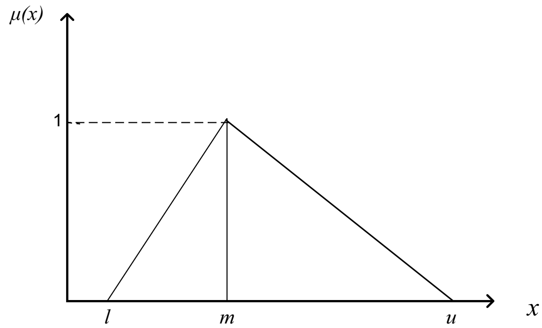


Fig. 2 TFN (Gupta and Mehlawat 2013)

$$A = \left\{X_i : \mu_{\tilde{A}}(X_i) \geq \alpha, x_i \in X\right\}, \quad (1)$$

in which, $\tilde{A}^{\alpha}$ denotes the members of $\tilde{A}$, whose membership degree is greater than or equal to α. A strong cut is defined when the membership degree is greater than α (Fig. 2):

$$A = \left\{X_i : \mu_{\tilde{A}}(X_i) > \alpha, x_i \in X\right\}. \quad (2)$$

The TFN $\tilde{M}$ is denoted as $\tilde{M} = (l, m, u)$ with the following membership function:

$$\mu_{\tilde{M}}(X) = \begin{cases} \frac{(x-l)}{(m-l)}; & l < x \leq m \\ \frac{(u-x)}{(u-m)} & m < x \leq u \\ 0 & \text{otherwise} \end{cases}. \quad (3)$$

Fuzzy Best Worst Method (BWM) method

The Best Worst Method (BWM) is a multi-criteria decision-making (MCDM) method introduced by Rezaei (2015). This method is based on measuring criteria by pairwise comparisons. In BWM, by determining the priority of the best criterion over the other criteria and the preference of all criteria over the worst criterion, the weight of the criteria is determined based on the scale between 1 and 9. Human qualitative judgments (such as decision makers' opinions in the BWM) inherently possess the features and characteristics of ambiguity and uncertainty and do not bear the accurate information Guo and Zhao (2017). Guo and Zhao (2017) developed the Fuzzy BWM method to model ambiguity and uncertainty in human judgments. The BWM technique as one the strongest MCDM methods has been broadly used in many applications such as ranking technology innovators (Gupta and Barua 2016), selecting green sources (Rezaei et al. 2016), selecting green suppliers (Gupta and Barua 2017), evaluating the research and development performance of companies (Salimi and Rezaei 2018), evaluating medical tourism strategy (Abadi et al. 2018), managing water rights in China (Xu et al. 2021), and selecting sustainable suppliers (Amiri et al. 2021).

The steps of the BWM method are described as follows:

(1) Choosing the best and worst criteria: In this step, the most important and least important criteria are determined using expert judgement or the fuzzy Delphi method. C_B shows the best criterion and C_W shows the worst criterion.
(2) Pair comparisons of the other criteria with the best and the worst criteria: In this step, pairwise comparisons can be made through any fuzzy spectrum, but the most common spectrum for the Fuzzy BWM method is the following 5-scale fuzzy spectrum. This spectrum is based on the verbal expressions of equal importance (EI), weak importance (WI), relatively important (FI), very important (VI), and quite important (AI).

The $\tilde{A}_B$ vector is formed as follows:

$$\tilde{A}_B = \left(\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn}\right), \quad (4)$$

where $\tilde{A}_B$ denotes the fuzzy vector of other criteria over the best criterion and $\tilde{a}_{Bj}$ denotes the fuzzy preference of the best C_B criterion over the j criterion. It is clear that $\tilde{a}_{BB} = (1, 1, 1)$.

Same as the previous step, the fuzzy preferences of all criteria over the worst criterion are determined using the linguistic variables shown in Table 2.

The vector of other criteria compared to the worst criterion is as follows:

$$\tilde{A}_W = \left(\tilde{a}_{W1}, \tilde{a}_{W2}, \ldots, \tilde{a}_{Wn}\right), \quad (5)$$

where $\tilde{A}_W$ denotes the fuzzy vector of other criteria over the worst criterion and $\tilde{a}_{Wj}$ denotes the fuzzy preference of criterion i over the worst C_W criterion. It is clear that $\tilde{a}_{WW} = (1, 1, 1)$.

(3) Forming the fuzzy BWM model: In this step, the weights of criteria are calculated using the following nonlinear programming model. However, Guo and

Table 2 Transformation rules of linguistic variables of decision-makers

Linguistic terms	Membership function
Equally importance (EI)	(1, 1, 1)
Weakly important (WI)	(2/3, 1, 3/2)
Fairly important (FI)	(3/2, 2, 5/2)
Very important (VI)	(5/2, 3, 7/2)
Absolutely important (AI)	(7/2, 4, 9/2)

Zhao (2017) stated that for a number of criteria above 3, it is better to convert this model into linear programming model to achieve better results:

$$\min \tilde{\xi}^{*}$$
$$\text{s.t.}\begin{cases} \left| \frac{(l_{\mathrm{B}}^{W}, m_{\mathrm{B}}^{W}, u_{\mathrm{B}}^{W})}{(l_j^{W}, m_j^{W}, u_j^{W})} - (l_{\mathrm{B}j}, m_{\mathrm{B}j}, u_{\mathrm{B}j}) \right| \le (k^*, k^*, k^*) \\ \left| \frac{(l_j^{W}, m_j^{W}, u_j^{W})}{(l_{\mathrm{W}}^{W}, m_{\mathrm{W}}^{W}, u_{\mathrm{W}}^{W})} - (l_{j\mathrm{W}}, m_{j\mathrm{W}}, u_{j\mathrm{W}}) \right| \le (k^*, k^*, k^*) \\ \sum_{j=1}^{n} R(\tilde{W}_j) = 1 \\ l_j^{W} \le m_j^{W} \le u_j^{W} \\ l_j^{W} \ge 0 \\ j = 1, 2, \ldots, n \end{cases} \quad (6)$$

(4) Solving the model by one of the optimization soft wares such as Lingo: In this step, the weights of criteria $(\tilde{W}_1^*, \tilde{W}_2^*, \ldots, \tilde{W}_n^*)$ are obtained.

It should be noted that based on each expert's opinion, the best and the worst criterion can be separately identified. Then, a fuzzy BWM model is formed, and finally the obtained weights are aggregated. Given that the BWM method is expert-based, it is recommended that the number of experts be between 5 and 10 (Guo and Zhao 2017).

Fuzzy Combined Compromise Solution (CoCoSo) method

The CoCoSo MCDM method was recently proposed by Yazdani et al. (2019). The CoCosO method employs a compromise combination solution for ranking the given alternatives. This method includes an integrated weighted sum model (WSM) and weighted product model (WPM), which has the following steps (Ecer and Pamucar 2020):

Step 1: Constructing an initial decision matrix.

Forming a decision matrix is the initial step of all MCDM methods. X_{mn} matrix denotes evaluating the alternative m corresponding with the criterion n that can be in terms of both verbal (linguistic) expressions and real (quantitative) data. The fuzzy decision matrix is presented as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} = \begin{bmatrix} (\tilde{x}_{11}^{l}, \tilde{x}_{11}^{m}, \tilde{x}_{11}^{u}) & (\tilde{x}_{12}^{l}, \tilde{x}_{12}^{m}, \tilde{x}_{12}^{u}) & \cdots & (\tilde{x}_{1n}^{l}, \tilde{x}_{1n}^{m}, \tilde{x}_{1n}^{u}) \\ (\tilde{x}_{21}^{l}, \tilde{x}_{21}^{m}, \tilde{x}_{21}^{u}) & (\tilde{x}_{22}^{l}, \tilde{x}_{22}^{m}, \tilde{x}_{22}^{u}) & \cdots & (\tilde{x}_{2n}^{l}, \tilde{x}_{2n}^{m}, \tilde{x}_{2n}^{u}) \\ \vdots & \vdots & \cdots & \vdots \\ (\tilde{x}_{m1}^{l}, \tilde{x}_{m1}^{m}, \tilde{x}_{m1}^{u}) & (\tilde{x}_{m2}^{l}, \tilde{x}_{m2}^{m}, \tilde{x}_{m2}^{u}) & \cdots & (\tilde{x}_{mn}^{l}, \tilde{x}_{mn}^{m}, \tilde{x}_{mn}^{u}) \end{bmatrix}. \quad (7)$$

Step 2: Normalizing decision matrix.

This step normalizes the decision matrix. Two following equations are used for positive and negative criteria:

$$\tilde{X}^{N} = \left[\tilde{x}_{ij}^{N} \right], \; \tilde{x}_{ij}^{N} = \begin{cases} \left(\frac{\tilde{x}_{ij}^{l}}{\max_i \tilde{x}_{ij}^{u}}, \frac{\tilde{x}_{ij}^{m}}{\max_i \tilde{x}_{ij}^{u}}, \frac{\tilde{x}_{ij}^{u}}{\max_i \tilde{x}_{ij}^{u}} \right), & \text{Benefit-Criteria} \\ \left(\frac{\min_i \tilde{x}_{ij}^{l}}{\tilde{x}_{ij}^{u}}, \frac{\min_i \tilde{x}_{ij}^{l}}{\tilde{x}_{ij}^{m}}, \frac{\min_i \tilde{x}_{ij}^{l}}{\tilde{x}_{ij}^{l}} \right), & \text{Cost-Criteria} \end{cases}. \quad (8)$$

Step 3: Computing the values of the weighted sum and weighted product.

The values of weighted sum (SB) and weighted product (PB) are computed for all alternatives in this step. For this purpose, the fuzzy normalized weighted Bonferroni mean is applied (Zhou and He 2012).

In the following equations, W_j denotes the weight of the criterion j that is as input to the CoCoSo method. This weight is directly computed by the decision-maker or using the methods such as BWM, AHP, Shannon entropy, etc:

$$\mathrm{SB}_i^{p,q} = \left(\sum_{\substack{i,j=1 \\ i \ne j}}^{n} \frac{w_i w_j}{1 - w_i} \tilde{x}_i^{Np} \tilde{x}_j^{Nq} \right)^{\frac{1}{p+q}} = \begin{pmatrix} \sum_{\substack{i,j=1 \\ i \ne j}}^{n} \frac{w_i w_j}{1 - w_i} \tilde{x}_i^{(l)p} \tilde{x}_j^{(l)q}, \\ \sum_{\substack{i,j=1 \\ i \ne j}}^{n} \frac{w_i w_j}{1 - w_i} \tilde{x}_i^{(m)p} \tilde{x}_j^{(m)q}, \\ \sum_{\substack{i,j=1 \\ i \ne j}}^{n} \frac{w_i w_j}{1 - w_i} \tilde{x}_i^{(u)p} \tilde{x}_j^{(u)q} \end{pmatrix}^{\frac{1}{p+q}}, \quad (9)$$

$$\mathrm{PB}_i = \frac{1}{p+q} \prod_{\substack{i,j=1 \\ i \ne j}}^{n} (p\tilde{x}_i^{N} + q\tilde{x}_j^{N})^{\frac{w_i w_j}{1-w_i}} = \begin{pmatrix} \frac{1}{p+q} \prod_{\substack{i,j=1 \\ i \ne j}}^{n} (p\tilde{x}_i^{(l)} + q\tilde{x}_j^{(l)})^{\frac{w_i w_j}{1-w_i}}, \\ \frac{1}{p+q} \prod_{\substack{i,j=1 \\ i \ne j}}^{n} (p\tilde{x}_i^{(m)} + q\tilde{x}_j^{(m)})^{\frac{w_i w_j}{1-w_i}}, \\ \frac{1}{p+q} \prod_{\substack{i,j=1 \\ i \ne j}}^{n} (p\tilde{x}_i^{(u)} + q\tilde{x}_j^{(u)})^{\frac{w_i w_j}{1-w_i}} \end{pmatrix}, \quad (10)$$

in which p and q denote the stabilization parameters and their changes can influence on the final results' prioritization. For the initial solution: $p = q = 1$.

Step 4: Identifying the alternatives' scores using three strategies.

The final alternatives' scores are calculated in this step. The following equations represent the sum of the geometric mean and arithmetic mean of the three strategies of step 3.

$$k_{ia} = \frac{PB_i + SB_i}{\sum_{i=1}^{m}(PB_i + SB_i)}, \quad (11)$$

$$k_{ib} = \frac{SB_i}{\min_i(SB_i)} + \frac{PB_i}{\min_i(PB_i)}, \quad (12)$$

$$k_{ic} = \frac{(1-\lambda)PB_i + \lambda SB_i}{(1-\lambda)\max_i(PB_i) + \lambda \max_i(SB_i)}, 0 \le \lambda \le 1, \quad (13)$$

$$k_i = \frac{1}{(k_{ia}k_{ib}k_{ic})^3} + \frac{(k_{ia}+k_{ib}+k_{ic})}{3}. \quad (14)$$

Equation (11) calculates the arithmetic mean of PB and SB. Equation (12) evaluates the relative scores compared to the best ones. According to Eq. (13), the value of the coefficient l is chosen by the decision-maker, who takes the values $0 \le \lambda \le 1$. The coefficient λ expresses the stability and flexibility of the proposed fuzzy CoCoSo model. The analysis of the value of the coefficient λ ($0 \le \lambda \le 1$) and its influence on the final decision is an indispensable analysis of the robustness of the solution in the MCDM problems. Eventually, the final score of each alternative is determined based on the three strategies (Eqs. (11–13)). The higher the score k of each alternative, the better it is.

The benefits of the CoCoSo method can be briefly stated as follows:

(1) This method is flexible for decision-making considering the interactions among multiple inputs attributes;
(2) The CoCoSo method takes the interactions between attributes into account and removes the effects of extreme/awkward data;
(3) This flexible model is represented by the parameters l, p, and q;
(4) The method checks the robustness of the outcomes through changing the parameters l, p, and q and assessing their effects on the final decision.

Results and discussion

Numerical example

The proposed model is implemented in a real-world project related to a part of a rural water supply project comprising 16 activities. The dummy start and finish activities show the start and finish times of the project. The finish-to-start type activity precedence relationship with zero time is considered. The network of project activities is shown in Fig. 3, and the definitions of project activities are presented in Table 3.

The environmental consequences of each activity are investigated in numerous execution modes for the evaluation of the whole project's environmental impacts. Five different execution modes are described for each activity as follows:

Fig. 3 Network of project activities

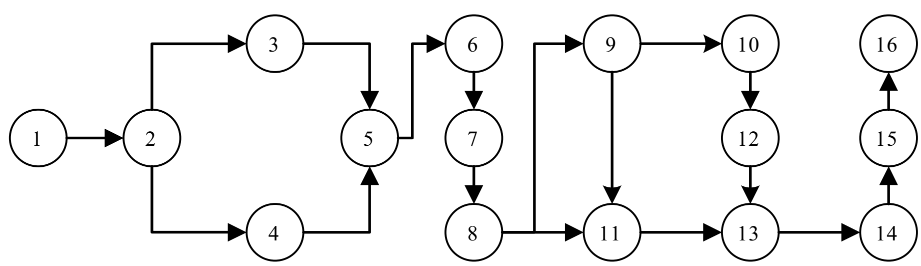


Table 3 Project activities

Project activity	No.	Project activity	No.
Dummy start activity	1	Lining and drilling the canal floor	2
Spinning pipes	3	Regulating and leveling the canal floor	4
Welding and transferring pipes to the floor of the canal	5	Piping and screening operations	6
Testing	7	Embanking the canal	8
Leveling and regulating the tank floor	9	Drilling and excavating the path	10
Drilling and underpinning the tank place	11	Concreting	12
Preparing and reinforcing, form working and concreting floor	13	Reinforcing and molding walls and ceilings	14
Concreting roof and walls	15	Dummy finish activity	16

1. The execution mode M_1: this mode corresponds with the implementation of each activity with the minimum amount of resources.
2. The execution mode M_2: this mode is the most likely activity execution mode implemented with the most accessible resources.
3. The execution mode M_3: this mode corresponds with the implementation of each activity with the minimum duration.
4. The execution mode M_4: this mode corresponds with the implementation of each activity with the minimum cost.
5. The execution mode M_5: this mode corresponds with the implementation of each activity with the most pessimistic condition.

First, a list of environmental impacts of construction projects was handed over to the experts to review and specify the environmental impacts of the project under study. Factors that the experts agreed with their impacts on the given project were selected as the final affecting factors including: 1—soil pollution, erosion, and sedimentation (E11), 2—surface and groundwater pollution (E12), 3—air pollution and dust (E14), 4—noise pollution (E14), 5—plant species, wildlife and habitats (E15), 6—employment and migration rate of local people (E16), 7—facilities and services in the region and the income level of the local people (E17). The first four factors including physicochemical environment with negative effects (E11–E14), the biological environment factor with negative effects (E15), and socioeconomic environment factor with positive effects (E17). The detrimental negative environmental impacts of the first five factors (EI1–EI5) should be minimized. On the other hand, the positive environmental impacts of socioeconomic factors (E16 and E17) should be maximized.

The LM method is employed to evaluate the environmental impacts of project activities. In addition, the triangular fuzzy numbers are used to deal with the vagueness of the linguistic variables corresponding with the experts' opinions. For this purpose, the experts were asked to express the impact of each activity execution modes based on the aforementioned factors. Then, the average of experts' opinions is calculated in terms of the triangular fuzzy numbers, shown in Table 4.

Each activity execution mode has dissimilar impacts on environmental factors. The TFNs shown in Table 4 are defuzzified by using Eq. (15) (Guo and Zhao 2017). Finally, the amount of effect of each environmental factor on the whole project is determined according to each execution mode.

R_i is the defuzzified amount of the TFN (1, m, n):

$$R_i = \frac{l_i + 4m_i + u_i}{6}. \tag{15}$$

The defuzzified amounts of the environmental impacts based on the three physical environments (E_{I1}, E_{I2}, E_{I3}, E_{I4}), the biological environment (E_{I5}) and the two socioeconomic environments (E_{I6}, E_{I7}) are displayed in Fig. 4.

According to Fig. 4, the positive environmental impacts (E16 and E17) of the third execution mode are higher than the other modes. Hence, the third execution mode is the best mode in terms of positive environmental impacts. However, the first execution mode is the best mode in terms of negative environmental impacts. The project data are represented in Table 5.

Each project activity must be performed in one execution mode. Considering 5 different execution modes for each activity, the total number of different combinations of activity execution modes is equal to 537,824.

The importance weight of each project objective is determined using the fuzzy BWM method. Cost (C2) is the most important project goal, and the positive environmental impact (C4) is the least important project objective based on the experts' opinions. Consequently, the $\tilde{A}_{\mathrm{B}}$ and $\tilde{A}_{\mathrm{w}}$ vectors are determined as follows:

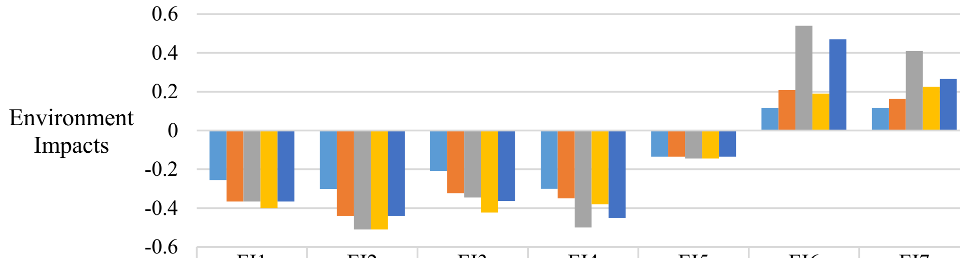
$$\tilde{A}_{\mathrm{B}} = [(0.7, 1, 1.5), (1, 1, 1), (1.5, 2, 2.5), (2.5, 3, 3.5)],$$

$$\tilde{A}_{\mathrm{w}} = [(2.5, 3, 3.5), (2.5, 3, 3.5), (0.7, 1, 1.5), (1, 1, 1)].$$

The final weights of the project objectives, the best objective value, and the inconsistency ratio are shown in Table 6.

Table 4 Decision matrix of fuzzy positive and negative environmental impacts of the activity execution modes

Activity mode	M_1	M_2	M_3	M_4	M_5
EI1 (negative)	(0.08, 0.25, 0.45)	(0.18, 0.36, 0.56)	(0.18, 0.36, 0.56)	(0.2, 0.4, 0.6)	(0.18, 0.36, 0.56)
EI2 (negative)	(0.11, 0.3, 0.5)	(0.24, 0.44, 0.64)	(0.31, 0.51, 0.71)	(0.31, 0.51, 0.71)	(0.24, 0.44, 0.64)
EI3 (negative)	(0.05, 0.2, 0.4)	(0.14, 0.32, 0.52)	(0.17, 0.34, 0.54)	(0.24, 0.42, 0.62)	(0.18, 0.36, 0.56)
EI4 (negative)	(0.1, 0.3, 0.5)	(0.15, 0.35, 0.55)	(0.3, 0.5, 0.7)	(0.18, 0.38, 0.58)	(0.25, 0.45, 0.65)
EI5 (negative)	(0.014, 0.12, 0.32)	(0.014, 0.12, 0.32)	(0.016, 0.13, 0.33)	(0.016, 0.13, 0.33)	(0.014, 0.12, 0.32)
EI6 (positive)	(0, 0.1, 0.3)	(0.053, 0.20, 0.40)	(0.34, 0.54, 0.74)	(0.041, 0.18, 0.38)	(0.27, 0.47, 0.67)
EI7 (positive)	(0, 0.1, 0.3)	(0.028, 0.15, 0.35)	(0.21, 0.42, 0.57)	(0.06, 0.22, 0.42)	(0.1, 0.26, 0.46)



	EI1	EI2	EI3	EI4	EI5	EI6	EI7
M1	-0.255	-0.301	-0.208	-0.3	-0.135	0.116	0.116
M2	-0.366	-0.44	-0.323	-0.35	-0.135	0.208	0.163
M3	-0.366	-0.51	-0.345	-0.5	-0.144	0.54	0.41
M4	-0.4	-0.51	-0.423	-0.38	-0.144	0.19	0.226
M5	-0.366	-0.44	-0.363	-0.45	-0.135	0.47	0.266

Fig. 4 Environmental impacts of the activity execution modes (total project)

The inconsistency ratio is acceptable. Subsequently, different modes of executing each project activity are ranked using the fuzzy CoCoSo method based on the importance weights of the objectives. It should be noted that the three project goals and objectives of cost, time, and negative environmental impacts are minimized and the positive environmental impacts are maximized. The execution modes of each project activity are ranked based on the weighted project goals and objectives.

Table 7 displays the rankings of the activity execution modes. $K(ia)$, $K(ib)$, and $K(ic)$ are the scores of the alternatives (activity execution modes) based on the three strategies (according to Eqs. (11–13). Eventually, the final ranking of each alternative (activity execution mode), $K(i)$, is determined using Eq. (14).

The activity execution mode with the highest $K(i)$ score is chosen as the best mode. The project implementation with the most favorable execution mode for each activity will achieve the following results, shown in Table 8.

It should be noted that the proposed model can be applied to any project with any amount of time lag and any type of precedence relationships. The corresponding execution modes of each activity are separately ranked and the high-ranked execution mode is selected for performing the activity. After choosing the best activity execution modes, the project completion time is determined through project network and activity precedence relationships.

Discussion

Construction industry has a crucial role in the economic growth of the countries. Construction contractors attempt to reduce the project cost and duration to survive in this competitive sector. However, the activities of the construction industry have considerable effect on the environment. For this reason, the consequences of construction activities have received more attention from organizations and governments. EIA is a method in which the consequences of a project on the environment are studied and evaluated so that the project is implemented in such a way as to have the least impact on the environment. The environmental impacts can be classified into positive and negative effects.

In this study, in addition to time and cost objectives, positive and negative environmental consequences and impacts were also considered in implementing project activities. In order to select the best mode for executing each activity, the balance of the four primary project objectives of cost, time, negative environmental impacts and most positive environmental impacts was taken into consideration. The environmental effects of construction projects were analyzed using the LM in three physicochemical, biological and socioeconomic aspects. Seven environmental parameters were taken into account for the first time, which have not been considered in the previous studies. For example, Xu et al. (2012) addressed only the physicochemical and biological environment. Also, other studies merely investigated greenhouse gas emissions (Marzouk et al. 2008; Liu et al. 2013; Moretti et al. 2018; Sandanayake et al. 2019; Lotfi et al. 2020; Huynh et al. 2021). In the present research, in addition to the negative environmental effects on the physicochemical and biological environment, the positive environmental effects on the socioeconomic environment have been analyzed and evaluated.

Apart from the negative environmental impacts, implementation of construction projects in a region has various positive environmental impacts such as reducing migration rate, increasing employment rate, increasing facilities and services, and increasing the income level of that region, which have not been considered in other studies. Therefore, it is not enough to merely consider the two alternatives of implementing or not implementing projects in terms of environmental impacts. Besides, if a construction project is approved, the project manager should attempt to implement project activities with the least negative environmental impacts. In the current research, five executive methods were considered for activities. Each activity execution mode

Table 5 Project data based on duration (*D*), cost (*C*), negative environmental impact (NE) and positive environmental impact (PE)

Activity	Objective	Activity mode				
		M_1	M_2	M_3	M_4	M_5
2	D	(11, 14, 17)	(7, 10, 13)	(4, 7, 10)	(5, 8, 11)	(9, 12, 15)
	C	(990, 1260, 1530)	(854, 1220, 1586)	(860, 1376, 1892)	(584, 1022, 1460)	(1098, 1464, 1830)
	NE	(0.08, 0.26, 0.46)	(0.16, 0.34, 0.54)	(0.36, 0.54, 0.74)	(0.16, 0.34, 0.54)	(0.24, 0.42, 0.62)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)	(0.05, 0.2, 0.4)
3	D	(21, 25, 29)	(16, 20, 24)	(8, 12, 16)	(12, 16, 20)	(18, 22, 26)
	C	(640, 960, 1280)	(640, 800, 960)	(672, 896, 1120)	(336, 400, 464)	(720, 880, 1040)
	NE	(0, 0.1, 0.3)	(0.05, 0.2, 0.4)	(0.15, 0.3, 0.5)	(0.25, 0.4, 0.6)	(0.15, 0.3, 0.5)
	PE	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.15, 0.3, 0.5)	(0.1, 0.3, 0.5)	0
4	D	(4, 5, 6)	(3, 4, 5)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)
	C	(128, 160, 192)	(168, 224, 280)	(160, 240, 320)	(104, 208, 312)	(224, 280, 336)
	NE	(0.03, 0.16, 0.36)	(0.13, 0.3, 0.5)	(0.2, 0.36, 0.56)	(0.26, 0.43, 0.63)	(0.13, 0.3, 0.5)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.05, 0.2, 0.4)	(0.2, 0.4, 0.6)
5	D	(4, 5, 6)	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(4, 5, 6)
	C	(456, 570, 684)	(276, 414, 552)	(366, 488, 610)	(154, 308, 462)	(448, 610, 732)
	NE	(0.15, 0.35, 0.55)	(0.3, 0.5, 0.7)	(0.15, 0.35, 0.55)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.05, 0.2, 0.4)	(0.3, 0.5, 0.7)
6	D	(19, 22, 25)	(17, 20, 23)	(12, 15, 18)	(14, 17, 20)	(16, 19, 22)
	C	(608, 704, 800)	(680, 800, 920)	(672, 840, 1008)	(672, 816, 960)	(784, 952, 1120)
	NE	(0.05, 0.2, 0.4)	(0.1, 0.3, 0.5)	(0.2, 0.4, 0.6)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)
	PE	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.4, 0.6, 0.8)	(0, 0.1, 0.3)	(0, 0.1, 0.3)
7	D	(9, 11, 13)	(5, 7, 9)	(1, 2, 3)	(2, 4, 6)	(6, 8, 10)
	C	(72, 88, 104)	(80, 112, 144)	(48, 96, 144)	(32, 64, 96)	(96, 128, 160)
	NE	(0.1, 0.3, 0.5)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.3, 0.5, 0.7)	(0.2, 0.4, 0.6)
	PE	0	(0.1, 0.3, 0.5)	(0, 0.1, 0.3)	0	(0.1, 0.3, 0.5)
8	D	(17, 19, 21)	(13, 15, 17)	(3, 5, 7)	(5, 7, 9)	(14, 16, 18)
	C	(1088, 1216, 1344)	(1040, 1200, 1360)	(456, 684, 912)	(390, 650, 910)	(1120, 1280, 1440)
	NE	(0.05, 0.2, 0.4)	(0.1, 0.25, 0.45)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.05, 0.2, 0.4)
	PE	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.15, 0.3, 0.5)	(0, 0.1, 0.3)	(0.5, 0.7, 0.9)
9	D	(5, 7, 9)	(5, 6, 7)	(2, 3, 4)	(3, 4, 5)	(6, 7, 8)
	C	(280, 392, 504)	(490, 588, 686)	(344, 516, 688)	(160, 240, 320)	(588, 686, 784)
	NE	(0.03, 0.16, 0.43)	(0.25, 0.45, 0.65)	(0.1, 0.23, 0.43)	(0.35, 0.55, 0.75)	(0.3, 0.5, 0.7)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)
10	D	(11, 13, 15)	(7, 9, 11)	(5, 7, 9)	(6, 8, 10)	(8, 10, 12)
	C	(990, 1170, 1350)	(854, 1098, 1342)	(1032, 1376, 1720)	(730, 1022, 1314)	(976, 1220, 1464)
	NE	(0.08, 0.26, 0.46)	(0.16, 0.34, 0.54)	(0.36, 0.54, 0.74)	(0.16, 0.34, 0.54)	(0.24, 0.42, 0.62)
	PE	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0.05, 0.2, 0.4)	(0.1, 0.3, 0.5)
11	D	(6, 8, 10)	(4, 6, 8)	(1, 2, 3)	(3, 4, 5)	(5, 7, 9)
	C	(144, 192, 240)	(128, 192, 256)	(120, 160, 200)	(48, 96, 144)	(160, 224, 288)
	NE	(0.01, 0.1, 0.3)	(0.13, 0.3, 0.5)	(0.06, 0.23, 0.43)	(0.2, 0.36, 0.56)	(0.06, 0.23, 0.43)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)
12	D	(2, 3, 4)	(1, 2, 3)	(1, 1, 2)	(1, 2, 3)	(2, 3, 4)
	C	(40, 60, 80)	(38, 59, 89)	(38, 38, 89)	(30, 58, 89)	(60, 90, 120)
	NE	(0.07, 0.25, 0.45)	(0.17, 0.35, 0.55)	(0.17, 0.35, 0.55)	(0.17, 0.35, 0.55)	(0.17, 0.35, 0.55)
	PE	(0, 0.1, 0.3)	(0.05, 0.2, 0.4)	(0.5, 0.7, 0.9)	(0.05, 0.2, 0.4)	0
13	D	(18, 22, 26)	(16, 20, 24)	(13, 17, 21)	(16, 21, 24)	(18, 22, 26)
	C	(1872, 2288, 2704)	(1920, 2400, 2880)	(2184, 2856, 3528)	(1920, 2550, 2880)	(2160, 2640, 3120)
	NE	(0.06, 0.23, 0.43)	(0.06, 0.23, 0.43)	(0.13, 0.3, 0.5)	(0.13, 0.3, 0.5)	(0.06, 0.23, 0.43)
	PE	(0, 0.1, 0.3)	(0.05, 0.2, 0.4)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)

Table 5 (continued)

Activity	Objective	Activity mode				
		M_1	M_2	M_3	M_4	M_5
14	D	(22, 26, 30)	(20, 24, 28)	(18, 22, 26)	(19, 23, 27)	(21, 25, 29)
	C	(2992, 3536, 4080)	(3040, 3648, 4256)	(3168, 3872, 4576)	(2888, 3496, 4104)	(3192, 3800, 4408)
	NE	(0.13, 0.3, 0.5)	(0.13, 0.3, 0.5)	(0.2, 0.36, 0.56)	(0.13, 0.3, 0.5)	(0.13, 0.3, 0.5)
	PE	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)	(0.5, 0.7, 0.9)
15	D	(4, 6, 7)	(3, 5, 7)	(1, 2, 3)	(2, 3, 4)	(4, 6, 8)
	C	(227, 341, 398)	(185, 308, 431)	(156, 234, 312)	(81, 162, 242)	(246, 370, 493)
	NE	(0.16, 0.36, 0.56)	(0.23, 0.43, 0.63)	(0.23, 0.43, 0.63)	(0.23, 0.43, 0.63)	(0.23, 0.43, 0.63)
	PE	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.3, 0.5, 0.7)

Table 6 The weights of the project objective in project scheduling

Objectives	Fuzzy weight	Final weight
Time (C1)	(0.29307, 0.35925, 0.35925)	0.348
Cost (C2)	(0.35125, 0.35818, 0.35820)	0.357
Negative environment impacts (C3)	(0.12895, 0.16812, 0.19759)	0.167
Positive environment impacts (C4)	(0.11116, 0.13157, 0.13188)	0.128
Objective value	0.27777	
Inconsistency ratio	0.17041	

has dissimilar duration, cost, negative and positive environmental impacts. As a result, numerous combinations of cost, time, and environmental impacts were defined for the project implementation.

Environmental factors of the studied project were identified in three different physicochemical, biological and socioeconomic aspects according to expert judgement. Then, based on the LM method, the environmental consequences of every activity execution mode were evaluated based on the identified factors.

The findings revealed that the project implementation with the M_3 mode for all activities has the highest positive and negative environmental consequences. However, performing project activities in the M_1 mode has the minimum positive and negative environmental consequences. As aforementioned, carrying out the project in each execution mode will result in dissimilar cost, duration, negative and positive environmental impacts. For instance, in terms of duration, the best and most favorable execution mode for the second activity of the project is the M_3 mode with the minimum duration. However, the M_3 mode of the second project activity will lead to the cost increase by 34% compared to the minimum cost as well as the increase of negative environmental effects by about 106%. On the other hand, the third execution mode has the most desirable rate of positive environmental effects. is at its optimal. Hence, two factors of positive environmental impacts and time are the most favorable in the M_3 mode, while the other two factors (negative environmental impacts and cost) are undesirable compared with the other execution modes.

In other studies on TCTP, the importance of the project goals and objectives has been considered equally (Marzouk et al. 2008; Liu et al. 2013; Moretti et al. 2018; Sandanayake et al. 2019; Lotfi et al. 2020; Huynh et al. 2021). However, the project goals and objectives do not have the same importance weights. For this reason, the importance weights of four project objectives (cost, time, positive environmental impacts, and negative environmental impacts) were determined using the fuzzy BWM method based on the project stakeholders' perspectives. The findings showed that carrying out the project with the lowest cost was of primary importance with a weight of 0.357. The project implementation with the shortest duration was ranked the second with a weight of 0.348, followed by the least negative environmental impacts with a weight of 0.167, and the highest positive environmental impacts with a weight of 0.128. These results indicate that time and cost are much more important than the negative environmental consequences of the project under study from the perspective of stakeholders. However, the importance weights of project objectives are different in various construction projects.

Subsequently, the fuzzy CoCoSo method was utilized for ranking the different execution modes according to the weights of four main factors of time, cost, negative environmental impacts, and positive environmental impacts. In this method, each project activity was separately considered and

Table 7 Ultimate rankings of activities regarding time–cost–negative and positive environmental impacts

Activity	Activity mode	SB	PB	$K(ia)$	Rank $K(ia)$	$K(ib)$	Rank $K(ib)$	K(ic)	Rank $K(ic)$	$K(i)$	Final Rank
2	M_1	0.3450	0.3442	0.1758	4	2.1008	4	0.7249	1	1.6452	3
	M_2	0.3708	0.3682	0.1885	3	2.2526	3	0.3039	4	1.4206	4
	M_3	0.4786	0.4721	0.2425	1	2.8980	1	0.3910	2	1.8275	1
	M_4	0.4453	0.4409	0.2260	2	2.7012	2	0.3644	3	1.7035	2
	M_5	0.3284	0.3277	0.1673	5	2.0000	5	0.2698	5	1.2614	5
3	M_1	0.3012	0.2978	0.1620	4	2.5634	4	0.5789	1	1.7235	4
	M_2	0.3712	0.3615	0.1981	3	3.1346	3	0.3121	4	1.7939	3
	M_3	0.4356	0.4288	0.2337	2	3.6985	2	0.3681	3	2.1164	2
	M_4	0.5207	0.5140	0.2797	1	4.4275	1	0.4407	2	2.5334	1
	M_5	0.2428	0.2251	0.1265	5	2.0000	5	0.1993	5	1.1451	5
4	M_1	0.4197	0.4176	0.2074	2	2.3410	2	0.8633	1	1.8858	1
	M_2	0.3632	0.3567	0.1783	4	2.0125	4	0.2887	4	1.2964	4
	M_3	0.4889	0.4810	0.2402	1	2.7115	1	0.3889	2	1.7466	2
	M_4	0.4002	0.3953	0.1970	3	2.2242	3	0.3190	3	1.4328	3
	M_5	0.3611	0.3543	0.1772	5	2.0000	5	0.2869	5	1.2884	5
5	M_1	0.2698	0.2657	0.1533	5	2.0000	5	0.5548	1	1.4571	4
	M_2	0.3269	0.3248	0.1865	3	2.4337	3	0.2927	4	1.4816	3
	M_3	0.4816	0.4837	0.2763	1	3.6050	1	0.4335	2	2.1943	1
	M_4	0.3610	0.3679	0.2086	2	2.7220	2	0.3273	3	1.6570	2
	M_5	0.3096	0.3030	0.1753	4	2.2875	4	0.2751	5	1.3926	5
6	M_1	0.5374	0.5324	0.1999	3	2.2787	3	0.8424	1	1.8339	1
	M_2	0.5385	0.5351	0.2006	2	2.2867	2	0.3258	3	1.4687	3
	M_3	0.6393	0.6306	0.2373	1	2.7049	1	0.3854	2	1.7372	2
	M_4	0.5077	0.4925	0.1869	4	2.1304	4	0.3036	4	1.3684	4
	M_5	0.4741	0.4649	0.1754	5	2.0000	5	0.2850	5	1.2846	5
7	M_1	0.2087	0.2018	0.1447	5	2.0000	5	0.5306	1	1.4277	5
	M_2	0.2772	0.2742	0.1945	3	2.6876	3	0.3070	4	1.6067	3
	M_3	0.3867	0.3868	0.2728	1	3.7704	1	0.4306	2	2.2537	1
	M_4	0.2967	0.2943	0.2084	2	2.8803	2	0.3290	3	1.7219	2
	M_5	0.2567	0.2526	0.1796	4	2.4818	4	0.2835	5	1.4838	4
8	M_1	0.2349	0.2348	0.1393	5	2.0000	5	0.4957	1	1.3955	4
	M_2	0.2649	0.2658	0.1574	4	2.2601	4	0.2464	5	1.3326	5
	M_3	0.4760	0.4715	0.2810	1	4.0349	1	0.4400	2	2.3786	1
	M_4	0.3873	0.3828	0.2284	2	3.2794	2	0.3576	3	1.9334	2
	M_5	0.3310	0.3226	0.1939	3	2.7837	3	0.3035	4	1.6412	3
9	M_1	0.3060	0.3034	0.1835	3	2.6819	3	0.6648	1	1.8660	3
	M_2	0.2290	0.2255	0.1369	5	2.0000	5	0.2153	4	1.1735	5
	M_3	0.4600	0.4567	0.2761	1	4.0343	1	0.4342	2	2.3666	1
	M_4	0.4439	0.4388	0.2658	2	3.8846	2	0.4181	3	2.2788	2
	M_5	0.2308	0.2267	0.1378	4	2.0132	4	0.2167	5	1.1813	4
10	M_1	0.4257	0.4246	0.1706	5	2.0000	5	0.7797	1	1.6268	2
	M_2	0.5193	0.5175	0.2080	3	2.4387	3	0.3419	4	1.5542	4
	M_3	0.5484	0.5422	0.2188	1	2.5652	1	0.3596	2	1.6348	1
	M_4	0.5407	0.5368	0.2162	2	2.5345	2	0.3553	3	1.6152	3
	M_5	0.4656	0.4633	0.1864	4	2.1848	4	0.3063	5	1.3924	5

Table 7 (continued)

Activity	Activity mode	SB	PB	*K*(*ia*)	Rank *K*(*ia*)	*K*(*ib*)	Rank *K*(*ib*)	K(ic)	Rank *K*(*ic*)	*K*(*i*)	Final Rank
11	M_1	0.1868	0.1870	0.1523	4	2.2095	4	0.4892	1	1.4987	3
	M_2	0.1702	0.1682	0.1379	5	2.0000	5	0.2115	5	1.1713	5
	M_3	0.3869	0.3772	0.3113	1	4.5162	1	0.4776	2	2.6442	1
	M_4	0.2733	0.2739	0.2230	2	3.2348	2	0.3420	3	1.8941	2
	M_5	0.2240	0.2067	0.1755	3	2.5453	3	0.2692	4	1.4906	4
12	M_1	0.3709	0.3685	0.1692	4	2.8075	4	0.5406	1	1.8084	4
	M_2	0.4288	0.4260	0.1956	3	3.2457	3	0.2988	4	1.8216	3
	M_3	0.6867	0.6811	0.3130	1	5.1932	1	0.4780	2	2.9141	1
	M_4	0.4423	0.4390	0.2017	2	3.3463	2	0.3080	3	1.8780	2
	M_5	0.2669	0.2599	0.1205	5	2.0000	5	0.1841	5	1.1227	5
13	M_1	0.5438	0.5362	0.1910	5	2.0000	5	0.8590	1	1.7066	1
	M_2	0.5725	0.5667	0.2014	2	2.1095	2	0.3305	3	1.4006	3
	M_3	0.6317	0.6257	0.2223	1	2.3285	1	0.3649	2	1.5460	2
	M_4	0.5462	0.5423	0.1925	4	2.0157	4	0.3158	5	1.3384	5
	M_5	0.5465	0.5437	0.1928	3	2.0188	3	0.3163	4	1.3405	4
14	M_1	0.6073	0.5981	0.1845	5	2.0000	5	0.8592	1	1.6967	1
	M_2	0.6538	0.6498	0.1996	3	2.1630	3	0.3296	4	1.4198	4
	M_3	0.6750	0.6730	0.2064	2	2.2366	2	0.3408	3	1.4681	3
	M_4	0.6415	0.6308	0.1948	4	2.1111	4	0.3217	5	1.3857	5
	M_5	0.7024	0.7006	0.2148	1	2.3279	1	0.3548	2	1.5280	2
15	M_1	0.2550	0.2507	0.1462	5	2.0000	5	0.5270	1	1.4276	3
	M_2	0.2616	0.2592	0.1506	4	2.0600	4	0.2364	5	1.2346	5
	M_3	0.4796	0.4799	0.2775	1	3.7954	1	0.4355	2	2.2742	1
	M_4	0.4348	0.4378	0.2524	2	3.4515	2	0.3960	3	2.0682	2
	M_5	0.3029	0.2961	0.1732	3	2.3690	3	0.2719	4	1.4198	4

Table 8 The obtained values of project objectives

	Cost	Time	Negative environmental impact	Positive environmental impact
Total Project (Fuzzy)	(9356, 12,056, 14,807)	(89, 115, 142)	(2.35, 4.76, 7.56)	(2.75,5.00,7.80)
De-fuzzy	12,065	115	4.8250	5.0917

the execution modes were ranked according to the aforementioned four factors. The execution mode with the highest rank was chosen as the best and most desirable mode for performing the activity and the case study project was accomplished with the best and most favorable activity execution modes. The results of the Fuzzy BWM-CoCoSo method compared to the optimal and non-optimal solutions of single objective models are presented in Table 9.

According to Table 9, the value of the time objective is 20% greater than the optimal value for the time objective. Also, the value of the cost objective is only 9% more than the optimal value for the cost objective. In addition, the value of the negative environmental impacts is 44% greater than the optimal value for the negative environmental impacts. Finally, the value of the positive environmental impacts is 71% less than the optimal value for the positive environmental impacts. These findings are consistent with the importance weights of the four project objectives. For example, the obtained value for the cost objective, which is the most

Table 9 Project scheduling and optimal and non-optimal time–cost–negative and positive environmental impacts

Activity	Time	Cost	Negative environmental impacts	Positive environmental impacts
Optimal solutions considering one objective	95	11,033	3.3383	7.7083
Solution found by the fuzzy BWM-CoCoSo method	115	12,065	4.8250	5.0917
Non-optimal solutions according to single objective	173	14,956	6.2017	1.4667

important project goal, differs from the optimal value by only 9%.

Management and practical implications

During the decades, contractors have been seeking to minimize project duration and cost to achieve competitive advantages. However, nowadays the governments and non-governmental organizations around the world have focused on environment as one of the three main aspects of sustainable development. Environmental pollution of the construction industry should be reduced for the purpose of sustainable development of world-wide countries. The minimization of cost, time, and environmental consequences is known as one of the major problems facing decision makers in the construction projects. The proposed method in this study can be applied to different construction projects for weighting the project goals and objectives and selecting the best possible activity execution modes. This research can assist project managers with choosing the best mode for executing activities in order to complete the project with the shortest duration, lowest cost, lowest negative environmental impacts, and the highest positive environmental impacts.

Conclusion

Moving toward sustainable development in countries is not possible without considering environmental issues. Sustainable development should improve human health and the environment in the long term. In this regard, evaluating the environmental impacts of construction projects is one of the ways to achieve sustainable development. In this study, the environmental impacts of the construction project were categorized into two classifications of negative and positive effects. The LM method was applied to evaluate the environmental impacts of the project. In addition, a fuzzy hybrid multi-criteria decision-making method including the BWM and CoCoSo methods was proposed to solve TCETP. After weighting the importance of project goals and objectives, the execution modes of each activity were ranked and the best and most desirable execution mode for any single project activity was chosen. The contribution of the present research in the field of project scheduling can be expressed in three important sections: firstly, considering the whole environmental impacts in all aspects (physicochemical, biological, and socioeconomic) along with conventional time and cost goals, secondly, evaluating and calculating environmental impacts in two different categories including negative and positive effects, and finally, weighing the project objectives, ranking and selecting the best activity execution modes based on the different weighted project goals and objectives.

Lack of resources as well as several problems corresponding with computing and estimating the environmental impacts, time and cost of each single activity execution mode can be stated as one of the significant restrictions and limitations of the current study. In addition, the methods used for calculating and assessing the environmental effects are qualitative. Also, in this study, the environmental consequences of the activities in the project implementation phase have been taken into consideration; however, the corresponding environmental impacts of the project operation phase have not been considered.

As some suggestions for further research, other methods such as (Life Cycle Assessment) LCA and (International Commission on Large Dams) ICOLD can be employed for evaluating the environmental impacts of projects. In addition, other project goals and objectives such as quality, health, safety, and risk should be incorporated into the proposed model. Also, other fuzzy numbers such as trapezoidal or pentagon fuzzy numbers may be used to deal with the ambiguity and vagueness of the experts' opinions.

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Declarations

Conflict of interest There is no conflict of interest.

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