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An intuitionistic fuzzy multi-class approach to risk assessment for sustainable BOT highway construction projects: A case study

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Abstract. Over the last decade, the emergence of various risks and hazards threatening large and infrastructure projects has become a concern for governments and government-affiliated institutions. Thereby, Build-Operation-Transfer (BOT) contracts have been set up to prevent these risks at the national level, leaving the design, construction, and operation of the projects with all investments to a foreign or private company. Meanwhile, a multi-phase weighting based collective criteria approach and Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology are proposed under Dynamic Intuitionistic Fuzzy (DIF) set environment. In this respect, the weight of each criterion is determined by DIF-collective criteria method and also, the interdependent relation between criteria is computed by developed DIF-DEMATEL methodology to tune the criteria weights. In addition, the weights of experts are determined by the proposed DIF-utility degree method to reach a precise solution. Moreover, the proposed approach of this study is extended based on last aggregation concept to reduce data loss. Then, the proposed methodology is implemented on a real case study and the results are compared with recent findings in the literature to ensure the reliability of the obtained results. Finally, a sensitivity analysis is manipulated to find the most effective parameters that can change the obtained results.

1. Introduction

Today, in developed and developing countries, the construction of large economic and development-oriented projects is one of the most important and fundamental measures [1]. In many infrastructure cases, governments prefer joint financing contracts for various reasons including lack of budget, lack of skilled and capable workforce, inability to provide adequate funding, and lack of capacity and tools for construction and production [2]. Meanwhile, there are different types of contracts that are facilitated by governments. One

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of these types is related to Build-Operation-Transfer (BOT) projects. BOT is the one type of finance contracts that can help governments handle highly sensitive projects [3] such as highway, bridge, railway etc [4,5]. In this stage, the government, as an investable institution, enters into negotiations with the private sector as an investor regarding the construction of a large project [6]. In the first stage, obligations are concluded between the two parts of the investee and the investor. The private sector is committed to providing sufficient financial resources for the construction and delivery of the project and to providing the required manpower, tools, and machinery. This supply of resources can be done from external sources. In contrast, the investable sector considers such benefits as the operation of the project for a certain period after the construction of the project for the investor company. This privilege can be subject to tolls on a highway construction project for a certain period of time. At the end of the specified time, the company returns all points to the host country [7].

The design, construction, operation, and construction of the project are the main tasks of private sector investment companies, which must act in accordance with the contract on time. Failure to comply with either of the specified obligations due to various disruptions can deal a significant blow to both parties. From a financial point of view, the investing company incurs much cost and in case of any mistake in carrying out the project, it incurs heavy financial costs. Furthermore, the public sector views the project as an asset and in case of violation of the delivery time, it will suffer numerous performance failures [8]. Therefore, in BOT projects, paying attention to project risks and managing them is one of the most fundamental issues. The net present value is a new concept that deals with risk identification in projects [9]. Different types of project risks in different countries can have a huge impact on the design and implementation of production operations, as well as construction of the project [10]. In developing countries, the imposition of economic sanctions, fluctuations in foreign exchange rates, fluctuations in interest rates and inflation, and changes in laws and regulations can be among the cases that give rise to a system crisis [11]. Investor companies, whose financial, human, and machinery capitals is involved in a project, constitute the first group that experience the risk and significant impact of the above-mentioned impositions on project implementation. In case of pressure and delay in the delivery of the public sector as an investable institution, it will incur heavy costs. Thus, identifying and managing project risks will help protect against them [12,13].

Initially, identifying project risks according to the type of project is essential and will significantly help rank these risks. Meanwhile, Jiang et al. [14] introduced the risk management policies for the BOT project receiving foreign direct investment. Wang and Jin [15] investigated the risk management in the case of the Metro of China under BOT project conditions. Patel et al. [16] generated the risk management in the case of toll roads in India under BOT project policy by proposing a fuzzy possibilistic method to deal with the uncertainty of real-world applications. In addition, Aladağ and Işık [17] investigated the issue of risk management in the BOT mega transportation projects and proposed various policies to control these risks with risk management administration. Le et al. [18] explored the risk of BOT transportation projects by introducing five main elements of risks for BOT transportation system projects in Vietnam. Moreover, Liu et al. [19] manipulated a risk management framework for the BOT bridge construction projects in Istanbul city. Vahdatmanesh and Firouzi [20] analyzed the impact of risk management in the BOT pipeline industry projects in the supply chain in Asian countries.

Also, Kasemsukh and Kokkaew [21] as well as Okudan et al. [22] identified some financial risk management factors in construction projects and analyzed the impact of the construction delay risks in BOT projects. Thereby, Shaktawat and Vadhera [23] introduced a risk management policy to control the risk of hydropower projects with the sustainable environment. Dheeriya and Singhvi [24] presented an artificial intelligence methodology for managing the human resource changing risks in the BOT projects.

Furthermore, suitable measures can be taken to control and respond to the risks within the appropriate time by properly identifying and ranking the risks in the BOT projects. In this respect, decision-making theory methods are popular and powerful tools to rank the identified risks [25], and each of these identified risks that affected the performance of BOT projects can be introduced as a criterion while as a sub-criterion in hierarchical structures. Therefore, Multi-Attribute Decision-Making (MADM) methods can be applied to assess the criteria and rank them according to the unique conditions of BOT projects. Meanwhile, the computation of criteria weights can determine the impact of each identified risk on the BOT projects while managers or decision-makers must keep these BOT project risks under control [26]. In this respect, Hetefi and Mohseni [27] proposed a fuzzy integrated approach based on Analytic Hierarchy Process (AHP) technique and TOPSIS method to control risks of the BOT projects. Moreover, one of the appropriate approaches to decision-making in the BOT context is to use the Multi-Criteria Group Decision-Making (MCGDM) approach. This methodology can be considered an efficient and effective method for calculating the weights of various risk attributes in BOT projects due to the preferences of different experts, decision-makers, and managers [28].

One of the important and basic issues that can affect MCGDM methods and ranking process is related to the criteria weights. Generally, there are six popular methods for calculating criteria weights including objective decision matrix information, standard deviation, maximizing deviation, entropy, AHP methods, and Delphi approach, which have been utilized in most of related studies [29–31]. Furthermore, two main types of weighting methods that are based on determination of criteria interdependencies are ANP and Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodologies [6,32–34]. Considering both of the aforementioned approaches to criteria weights determination can ensure the precision of the ranking results.

Further, one of the most important and necessary issues in today's world is related to the uncertainty in BOT projects. One effective way to deal with these uncertainties is to use fuzzy approaches. Using fuzzy approaches, the problem situation can be modeled more realistically and close to real-world cases, and the decisions made can be brought closer to reality. In this paper, the Intuitionistic Fuzzy (IF) approach is used in order to deal with uncertainty. The important point considered in this study is associated with the dynamics of the problem conditions and the dependence of the issues on different periods. Thus, decisions of experts, Decision-Makers (DMs), and managers in different periods may lead to different decisions and each decision can be specific to a particular period. For example, imposition of international sanctions on a country's economy or fluctuations in exchange rates must be evaluated in different periods. This dynamism in the nature of decisions has encouraged the current authors use the Dynamic Intuitionistic Fuzzy (DIF) approach to deal with dynamic imprecise information.

However, the aforementioned features of the proposed approach in this study are compared with those of recent studies in relevant literature so that research gaps can emerge. Meanwhile, the literature gap is represented in Table 1 to indicate the advantages and uniqueness of the proposed approach features.

As indicated in Table 1, the survey of the literature shows that the proposed approach has more unique features and may lead to a precise solution. In this study, an intuitionistic fuzzy standard deviation approach is proposed to calculate local weights of the risk criteria. Also, in order to calculate the weights of hierarchical structure with criteria interdependency, DEMATEL method is used under IF conditions. In addition, a novel DIF-utility grade approach is developed to obtain the weight of each expert. Then, weights of experts or DMs are incorporated into the determined multi-phase weighting method. Also, the Dynamic Intuitionistic Fuzzy Multi-Phase Weighting approach based on collective Criteria and DEMATEL (DIF-MPW-CI-DEMATEL) methodologies are developed via the last aggregation approach to prevent the

Table 1. The research gap representation.

Authors	**Uncertainty**	**Dynamic uncertainty assessment**	**Experts' weights**	**Last aggregation approach**	**Criteria weights**	**Criteria interdependency relation consideration**	**Hierarchical structure**
Gitinavard & Akbarpour Shirazi [39]	√	–	√	–	√	–	–
Alilou et al. [32]	√	–	–	–	√	√	–
Davoudabadi et al. [29]	√	–	–	–	√	–	√
Cheng et al. [40]	√	√	–	–	√	√	–
Wu et al. [41]	√	–	√	–	√	√	–
Ghaderi et al. [42]	√	–	√	–	√	√	–
Liu et al. [43]	√	–	–	–	√	√	√
Tao et al. [44]	√	√	–	–	√	–	–
Liu et al. [45]	√	√	–	–	–	√	–
This study	√	√	√	√	√	√	√

data loss. The main contributions and innovations of the study are described as follows:

- Extending the essential risks of the construction in a highway BOT project;
- Tailoring the multiphase weighting approach and the DEMATEL methodology with DIF condition;
- Extending some novel equations to the DIF method;
- Using the experts' judgments to calculate DIF weight to reduce the local weight errors;
- Considering the last aggregation process through the proposed approach to reduce the data lost;
- Proposing a novel utility-based DIF approach to determine weights of experts;
- Considering the hierarchical structure to evaluate the risk of BOT project.

The rest of the paper is organized as follows: Section 2 defines the preliminaries and concepts of DIF theory. Then, Section 3 presents the proposed multi-phase weighting methodology based on collective criteria and DEMATEL approach under DIF conditions. Section 4 outlines the application of the proposed method considering a real case study. Section 5 describes the validation process and sensitivity analysis on the important parameters, and finally, Section 6 discusses some conclusions and future suggestions.

2. Preliminaries

This section examines some of the basic relations of the DIF and then, develops the proposed DIF-MPW-CI-DEMATEL relations.

Definition 1 [35]. Assume that t is the time variable. $a(t) = \left(\mu_{a(t)}, \nu_{a(t)}, \pi_{a(t)}\right)$ is the IF variable, where $\mu_{a(t)} \in [0,1]$, $\nu_{a(t)} \in [0,1]$, $\mu_{a(t)} + \nu_{a(t)} \leq 1$, and $\pi_{a(t)} = 1-\mu_{a(t)}-\nu_{a(t)}$. In IF variable $a(t) = \left(\mu_{a(t)}, \nu_{a(t)}, \pi_{a(t)}\right)$, for $t = t_1, t_2, ..., t_p$, $a(t_1), a(t_2), ..., a(t_p)$ determines p Intuitionistic Fuzzy Numbers (IFNs) collected in different time periods.

Definition 2 [35]. Basic relations are introduced with two IFNs $a(t_1) = \left(\mu_{a(t_1)}, \nu_{a(t_1)}, \pi_{a(t_1)}\right)$ and $a(t_2) = \left(\mu_{a(t_2)}, \nu_{a(t_2)}, \pi_{a(t_2)}\right)$.

$$a(t_1) \oplus a(t_2) = \begin{pmatrix} \mu_{a(t_1)} + \mu_{a(t_2)} - \mu_{a(t_1)}\mu_{a(t_2)}, \nu_{a(t_1)}\nu_{a(t_2)}, \\ (1-\mu_{a(t_1)})(1-\mu_{a(t_2)}) - \nu_{a(t_1)}\nu_{a(t_2)} \end{pmatrix}. \quad (1)$$

$$\lambda a(t_1) = \left(1 - \left(1-\mu_{a(t_1)}\right)^{\lambda}, {\nu_{a(t_1)}}^{\lambda}, \left(1-\mu_{a(t_1)}\right)^{\lambda} - {\nu_{a(t_1)}}^{\lambda}\right) \qquad \lambda \geq 0. \quad (2)$$

Definition 3 [35] . Assume that $R=\{a(t_1), a(t_2),\cdots, a(t_p)\}$ is a set of IFs; the summation and multiplication operators are shown in Eqs. (3) and (4):

$$\oplus_{p=1}^{P} = \left[1-\prod_{p=1}^{P}(1-\mu_{a(t_p)}), \prod_{p=1}^{P}\nu_{a(t_p)}, \prod_{p=1}^{P}(1-\mu_{a(t_p)}) - \prod_{p=1}^{P}\nu_{a(t_p)}\right], \quad (3)$$

$$\otimes_{p=1}^{P} = \left[\prod_{p=1}^{P}\mu_{a(t_p)}, 1-\prod_{p=1}^{P}(1-\nu_{a(t_p)}), \prod_{p=1}^{P}(1-\nu_{a(t_p)}) - \prod_{p=1}^{P}\mu_{a(t_p)}\right]. \quad (4)$$

Definition 4 [35] . Let $a(t_1)$, $a(t_2)$,$\cdots$, $a(t_p)$ be a collection of IFNs prepared in p different periods (t_p). $\lambda(t)=(\lambda(t_1), \lambda(t_2),\cdots, \lambda(t_p))^T$ is the weight vector of period t_p. A Dynamic Intuitionistic Fuzzy Weighted Geometric (DIFWG) operator is determined in Eq. (5):

$$DIFWG_{\lambda(t_p)}(a(t_1), a(t_2), ..., a(t_p)) = \begin{pmatrix} \prod_{p=1}^{P}\mu_{a(t_p)}^{\lambda(t_p)} - \prod_{p=1}^{P}\left(1-\nu_{a(t_p)}\right)^{\lambda(t_p)}, \\ \prod_{p=1}^{P}\left(1-\nu_{a(t_p)}\right)^{\lambda(t_p)} - \prod_{p=1}^{P}\mu_{a(t_p)}^{\lambda(t_p)} \end{pmatrix}, \quad (5)$$

where $\lambda(t_p) \geq 0$, $P = 1, 2, 3, \cdots, P$, and $\sum_{p=1}^{P}\lambda(t_p) = 1$.

Definition 5 [35] . The Dynamic Intuitionistic Fuzzy Geometric (DIFG) operation is determined via Eq. (6):

$$DIFG(a(t_1), a(t_2), ..., a(t_p)) = \begin{pmatrix} \prod_{p=1}^{P}\mu_{a(t_p)} - \prod_{p=1}^{P}\left(1-\nu_{a(t_p)}\right), \\ \prod_{p=1}^{P}\left(1-\nu_{a(t_p)}\right) - \prod_{p=1}^{P}\mu_{a(t_p)} \end{pmatrix}. \quad (6)$$

Definition 6 [35]. The DIFG Euclidean distance and hamming distance between $a(t_1)$ and $a(t_2)$ are obtained by Eqs. (7) and (8), as shown in Box I.

Definition 7 [35] . The normalized matrix (f_{ij}) is generated in Eq. (9):

$$f_{ij}(\lambda(t_p)) = \begin{cases} \{[\mu_{ij(tp)}, \nu_{ij(tp)}]\} \\ \{[1-\mu_{ij(tp)}, 1-\nu_{ij(tp)}]\} \end{cases} \quad \forall i, j, p. \quad (9)$$

$$d(a(t_1),a(t_2)) = \sqrt{\frac{1}{2}\sum_{p=1}^{P}\lambda(t_p)\left(\left|\mu_{a(t_1)}-\mu_{a(t_2)}\right|^2+\left|\nu_{a(t_1)}-\nu_{a(t_2)}\right|^2+\left|\pi_{a(t_1)}-\pi_{a(t_2)}\right|^2\right)}, \tag{7}$$

$$d(a(t_1),a(t_2)) = \frac{1}{2}\sum_{p=1}^{P}\lambda(t_p)\Big(|\mu_{a(t_1)}-\mu_{a(t_2)}|+|\nu_{a(t_1)}-\nu_{a(t_2)}|+|\pi_{a(t_1)}-\pi_{a(t_2)}|\Big). \tag{8}$$

Box I

3. Proposed DIF-MPW-CI-DEMATEL approach

This section proposes a weighting method consisting of collective approach and DEMATEL technique. This method is applied under DIF conditions based on the hierarchical structure and interdependent relations of attributes. This approach is considered in three classes: the DIF collective criteria class, the DIF-DEMATEL class, and the integrated class based on the two pervious methods. Moreover, this paper introduces the DIF-utility method to reduce the impact of the expert judgment error weights on the criteria. Figure 1 presents the framework of the proposed method. This method starts from groups of experts $(DM_k; DM_1, ..., DM_k)$ with alternatives $(A_i; A_1, ..., A_m)$ of criteria $(C_j; C_1, ..., C_j)$ and sub-criteria $(SC_r; SC_1, ..., SC_r)$ in multiple periods $(T_p; T_1, ..., T_p)$. The proposed method namely DIF-MPW-CI-DEMATEL has the three following main classes:

Class 1. This class is related to the collective index method that is applied in conjunction with standard deviation method to control the local weights of the criteria.

Step 1.1. The normalized DIF matrix (ϑ_k^p) is created with Eq. (9) in Eq. (10) as shown in Box II.

Step 1.2. Sub-criteria weights normalized based on the DMs' opinions about criterion $\left(\Delta_{kj}^p\right)$ and sub-criterion (Δ_{kr}^p) are calculated, and the normalized DIF-decision matrix (ϑ_k^{wp}) is obtained via Eq. (11):

$$\vartheta_k^{wp} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} SC_1 & \cdots & SC_r \end{array} \\ \begin{bmatrix} \chi_{1k}^p\left[\mu_{11}^{kp},\nu_{11}^{kp}\right] & \cdots & \chi_{rk}^p\left[\mu_{1r}^{kp},\nu_{1r}^{kp}\right] \\ & \ddots & \\ \chi_{1k}^p\left[\mu_{m1}^{kp},\nu_{m1}^{kp}\right] & \cdots & \chi_{rk}^p\left[\mu_{mr}^{kp},\nu_{mr}^{kp}\right] \end{bmatrix} \end{array} \quad \forall p,k. \tag{11}$$

The final weight of sub-criterion (χ_{rk}^p) is obtained through Eq. (12):

$$\chi_{rk}^p = \frac{\Delta_{kj}^p \Delta_{kr}^p}{\sum\limits_{r=1}^{R}\Delta_{kj}^p \Delta_{kr}^p} \qquad \forall r \subseteq j. \tag{12}$$

Step 1.3. The score function of DIF (ε_{ik}^p) based on expert judgment is shown in Eq. (13):

$$\varepsilon_{ik}^p = \left[1-\prod_{r=1}^{R}\left(1-\vartheta_{(ir)k}^{wp}\right)\right] \qquad \forall i,p,k. \tag{13}$$

Step 1.4. It is essential that the sub-criterion SC_r be removed from the set of criteria to present its impact on the decision-making process. The score function without $(\varepsilon_{ir'k}^p)$ is calculated through Eq. (14):

$$\vartheta_k^p = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} SC_1 & \cdots & SC_r \end{array} \\ \begin{bmatrix} \left\{\left[\mu_{11}^{1p},\nu_{11}^{1p}\right],\left[\mu_{11}^{2p},\nu_{11}^{2p}\right],...,\left[\mu_{11}^{kp},\nu_{11}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{1r}^{1p},\nu_{1r}^{1p}\right],\left[\mu_{1r}^{2p},\nu_{1r}^{2p}\right],...,\left[\mu_{1r}^{kp},\nu_{1r}^{kp}\right]\right\} \\ & \ddots & \\ \left\{\left[\mu_{m1}^{1p},\nu_{m1}^{1p}\right],\left[\mu_{m1}^{2p},\nu_{m1}^{2p}\right],...,\left[\mu_{m1}^{kp},\nu_{m1}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{mr}^{1p},\nu_{mr}^{1p}\right],\left[\mu_{mr}^{2p},\nu_{mr}^{2p}\right],...,\left[\mu_{mr}^{kp},\nu_{mr}^{kp}\right]\right\} \end{bmatrix} \end{array}$$

$$\forall p,k. \tag{10}$$

Box II

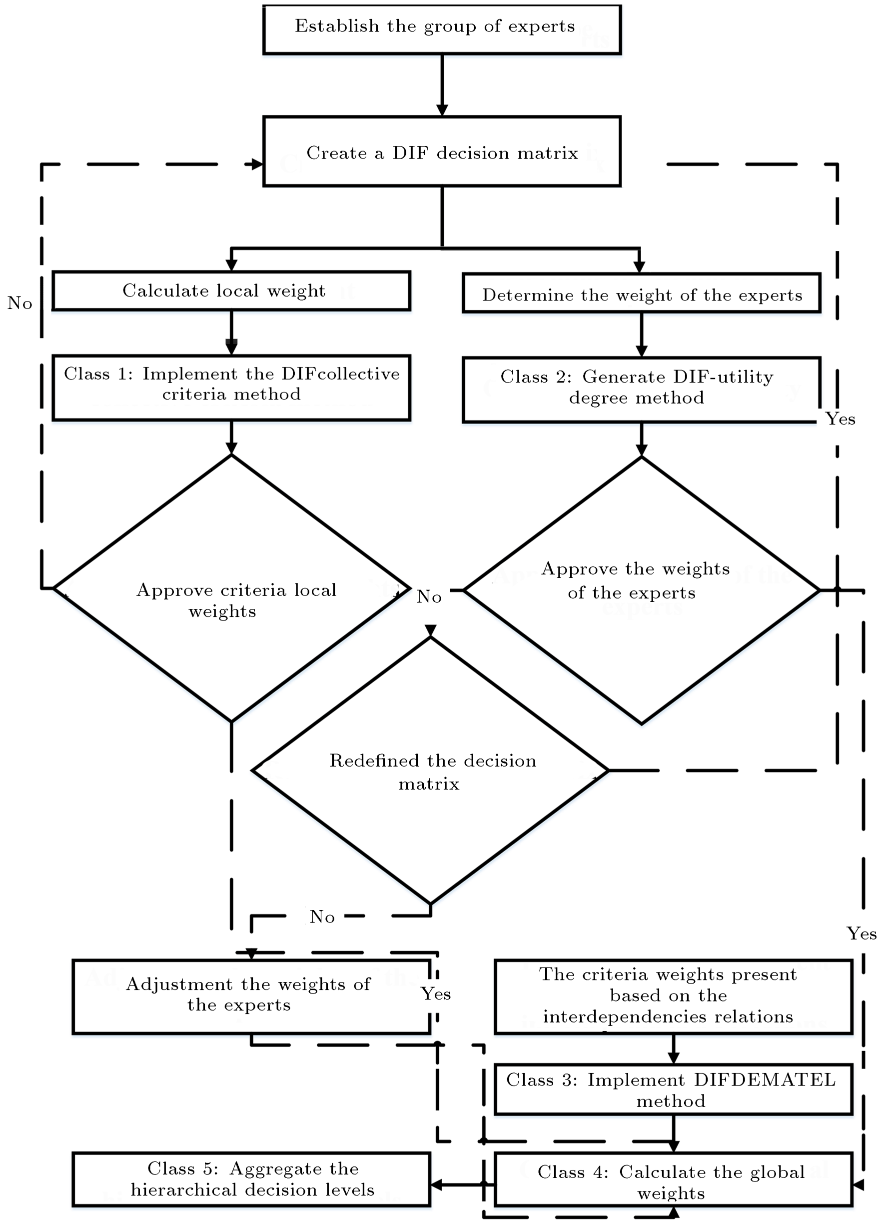

Figure 1. The proposed DIF-MPW-CI-DEMATEL method structure.

$$\varepsilon^p_{ir'k} = \left[1 - \prod_{r=1, r\neq r'}^{R} \left(1 - \vartheta^{wp}_{(ir)k}\right)\right]. \tag{14}$$

Step 1.5. The relation between the sub-criterion and the DIF evaluation score ($\wp^p_{rk}$) is obtained in Eq. (15) as shown in Box III.

Eq. (15) is rewritten as Eq. (16) is shown in Box IV.

$$\wp^p_{rk} = \frac{1 - \prod_{i=1}^{m}\left(1 - \left\{\left(Score\left(\vartheta^p_{(ir)k}\right) - \overline{\vartheta}^p_{(r)k}\right) \cdot \left(Score\left(\varepsilon^p_{(ir)k}\right) - \overline{\varepsilon}^p_{(r)k}\right)\right\}\right)}{\sqrt{\left(1 - \prod_{i=1}^{m}\left(1 - \left(Score\left(\vartheta^p_{(ir)k}\right) - \overline{\vartheta}^p_{(r)k}\right)^2\right)\right) \cdot \left(1 - \prod_{i=1}^{m}\left(1 - \left(Score\left(\varepsilon^p_{(ir)k}\right) - \overline{\varepsilon}^p_{(r)k}\right)^2\right)\right)}} \qquad \forall r, p, k. \tag{15}$$

Box III

$$\wp^{p}_{rk}=\frac{1-\prod_{i=1}^{m}\left(1-\left\{\left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\vartheta^{\sigma(\lambda)p}_{(ir)k}\right)-\overline{\vartheta}^{p}_{(r)k}\right)\cdot\left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\varepsilon^{\sigma(\lambda)p}_{(ir)k}\right)-\overline{\varepsilon}^{p}_{(r)k}\right)\right\}\right)}{\sqrt{\left(1-\prod_{i=1}^{m}\left(1-\left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\vartheta^{\sigma(\lambda)p}_{(ir)k}\right)-\overline{\vartheta}^{p}_{(r)k}\right)^{2}\right)\right)\cdot\left(1-\prod_{i=1}^{m}\left(1-\left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\varepsilon^{\sigma(\lambda)p}_{(ir)k}\right)-\overline{\varepsilon}^{p}_{(r)k}\right)^{2}\right)\right)}}$$

$$\forall r,p,k. \tag{16}$$

Box IV

$\overline{\vartheta}^{p}_{(r)k}$ and $\overline{\varepsilon}^{p}_{(r)k}$ are computed using Eqs. (17) and (18):

$$\overline{\vartheta}^{p}_{(r)k}=1-\left(\coprod_{i=1}^{m}\vartheta^{p}_{(ir)k}\right)^{\frac{1}{m}}\qquad\forall r,p,k, \tag{17}$$

$$\overline{\varepsilon}^{p}_{(r)k}=1-\left(\coprod_{i=1}^{m}\varepsilon^{p}_{(ir)k}\right)^{\frac{1}{m}}\qquad\forall r,p,k. \tag{18}$$

Step 1.6. The local weight of sub-criterion is obtained via Eq. (19) as shown in Box V. The IF standard deviation value ($\sigma^{p}_{r'k}$) is obtained via Eq. (20) as shown in Box VI.

Class 2. This class is related to computation of the weight of every DM with the DIF-utility degree technique. Thus, the following steps are considered for representing the process of the second class:

Step 2.1. The normalized DIF decision matrix (ϑ^{p}_{k}) is obtained from Step 1.1.

Step 2.2. The DIF Positive Idea Solution (PIS) (φ^{+p}) and the Negative Ideal Solution (NIS) (φ^{-p}) are obtained through Eqs. (21) and (22):

$$\varphi^{+p}=\left(\left[\mu^{+p}_{ir},\nu^{+p}_{ir}\right]\right)_{m\times R}=\begin{cases}\mu^{+p}_{ir}=1-\sqrt[k]{\prod_{k=1}^{K}\left(1-\mu^{kp}_{ir}\right)}\\ \nu^{+p}_{ir}=1-\sqrt[k]{\prod_{k=1}^{K}\left(1-\nu^{kp}_{ir}\right)}\end{cases} \tag{21}$$

$$\varphi^{-p}=\left(\left[\mu^{-p}_{ir},\nu^{-p}_{ir}\right]\right)_{m\times R}=\min_{k}\left\{\left[\nu^{p}_{(ir)k}\right]_{m\times R}\right\}. \tag{22}$$

Step 2.3. The DIF separation scale from PIS and NIS values (η^{+p}_{k}, η^{-p}_{k}) is calculated via Eqs. (23) and (24):

$$\eta^{+p}_{k}=\frac{\left(\sum_{i=1}^{m}\sum_{r=1}^{R}\sum_{\lambda=1}^{l}\left(\left|\vartheta^{\sigma(\lambda)p}_{(ir)k}-\varepsilon^{+\sigma(\lambda)p}_{(ir)k}\right|^{2}\right)\right)^{\frac{1}{2}}}{\sqrt{2l}}\quad\forall k,p, \tag{23}$$

$$\eta^{-p}_{k}=\frac{\left(\sum_{i=1}^{m}\sum_{r=1}^{R}\sum_{\lambda=1}^{l}\left(\left|\vartheta^{\sigma(\lambda)p}_{(ir)k}-\varepsilon^{-\sigma(\lambda)p}_{(ir)k}\right|^{2}\right)\right)^{\frac{1}{2}}}{\sqrt{2l}}\quad\forall k,p. \tag{24}$$

$$\partial^{p}_{r'k}=\frac{1-\left(1-\sqrt{1-\wp^{p}_{r'k}}\right)^{\sigma^{p}_{r'k}}}{\left[\sum_{r=1}^{R}\left(\frac{1-\left(1-\sqrt{1-\wp^{p}_{r'k}}\right)^{\sigma^{p}_{r'k}}}{1-\prod_{r=1,r\neq r'}^{R}\left(1-\left(1-\sqrt{1-\wp^{p}_{r'k}}\right)^{\sigma^{p}_{r'k}}\right)}\right)\right]\left(1-\prod_{r=1,r\neq r'}^{R}\left(1-\left(1-\sqrt{1-\wp^{p}_{r'k}}\right)^{\sigma^{p}_{r'k}}\right)\right)}\qquad\forall r',p,k. \tag{19}$$

Box V

$$\sigma^{p}_{r'k}=\sqrt[2R]{\left(1-\prod_{i=1}^{m}\left(1-\left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\left[\vartheta^{\sigma(\lambda)p}_{(ir')k}\right]\right)-\bar{\vartheta}^{p}_{(r')k}\right)^{2}\right)\right)}\qquad\forall r',p,k. \tag{20}$$

Box VI

Step 2.4. The DIF relative coefficient of each expert in each time period (θ_k^p) and the weights of the experts in the planning horizon (θ_k) are computed through Eqs. (25) and (26):

$$\theta_k^p = \frac{\eta_k^{-p}\left(\sum_{k=1}^{K}\frac{\eta_k^{-p}}{\eta_k^{-p}+\eta_k^{+p}}\right)^{-1}}{\eta_k^{-p}+\eta_k^{+p}} \quad \forall k,p, \tag{25}$$

$$\theta_k = \frac{\overset{P}{\underset{p=1}{\oplus}}(\theta_k^p)^{\frac{1}{P}}}{\sum_{k=1}^{K}\left(\overset{P}{\underset{p=1}{\oplus}}(\theta_k^p)^{\frac{1}{P}}\right)} = \frac{\prod_{p=1}^{P}(\theta_k^p)^{\frac{1}{P}}}{\sum_{k=1}^{K}\left(\overset{P}{\underset{p=1}{\oplus}}(\theta_k^p)^{\frac{1}{P}}\right)} \quad \forall k. \tag{26}$$

Class 3. This section proposes the DIF-DEMATEL method to handle and control the importance of the criteria with a hierarchical structure related to interdependency data. Thus, the following steps are considered for representing the process of the third class:

Step 3.1. The DIF comparison matrix with each period (ξ_k^p) is created which is relevant to experts' judgments. This matrix is shown in Eq. (27):

$$\xi_k^p = \begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array}\begin{array}{c} C_1 \quad \cdots \quad C_n \\ \begin{bmatrix} 0 & \cdots & [\mu_{1nk'}^p,\nu_{1nk}^p] \\ \vdots & \ddots & \vdots \\ [\mu_{n1k'}^p,\nu_{n1k}^p] & \cdots & 0 \end{bmatrix}_{n\times n} \end{array} \quad \forall k,p. \tag{27}$$

Step 3.2. This step proposes the direct-relation matrix of the DIF (ξ_k^{Dp}) obtained by Eqs. (28) and (29) as shown in Box VII.

Step 3.3. The DIF influence matrix (ψ_k^p) is shown in Eqs. (30) and (31):

$$\psi_k^p = \begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array}\begin{array}{c} C_1 \quad \cdots \quad C_n \\ \begin{bmatrix} \psi_{11k}^p & \cdots & \psi_{1nk}^p \\ \vdots & \ddots & \vdots \\ \psi_{n1k}^p & \cdots & \psi_{nnk}^p \end{bmatrix}_{n\times n} \end{array} \quad \forall k,p, \tag{30}$$

$$\psi_{(jj')k}^p = \left(score\left(\xi_{(jj')k}^{Dp}\right)\right) \left|\left(1 - score\left(\xi_{(jj')k}^{Dp}\right)\right)^{-1}\right| \quad \forall k,p. \tag{31}$$

Eq. (31) can be converted into Eq. (32):

$$\psi_{(jj')k}^p = \left(\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\left[\varepsilon_{(jj')k}^{D\sigma(\lambda)p}\right]\right)\right) \left|\left(-\frac{1}{E}\sum_{e=1}^{E}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\left[\varepsilon_{(jj')k}^{D\sigma(\lambda)p}\right]\right)\right)^{-1}\right| \quad \forall k,p. \tag{32}$$

Step 3.4. The weights of interdependency criteria ($\varpi_{k(j)}^p$) are shown in Eq. (33):

$$\varpi_{k(j)}^p = \frac{\Delta_{k(j)}^p + \Delta_{k(j)}^p \times \psi_{k(j)}^p}{\sum_{j=1}^{n}\left(\Delta_{k(j)}^p + \Delta_{k(j)}^p \times \psi_{k(j)}^p\right)} \quad \forall k,p,j, \tag{33}$$

where $\left[\Delta_{k(j)}^p\right]_{1\times n}$ is $1\times n$ matrix and $[\psi_k^p]_{n\times n}$ is $n\times n$ matrix.

Class 4. The global weight of DIF-DEMATEL and DIF-collective index ($\omega_{kr'}^p$) is calculated via Eq. (34):

$$\omega_{kr'}^p = \frac{\varpi_{kj}^p\partial_{kr'}^p}{\sum_{r'=1}^{R}\left(\varpi_{kj}^p\partial_{kr'}^p\right)} \quad \forall k,p,r' \subseteq j. \tag{34}$$

$$\lambda = \frac{1}{\left[1 - \prod_{j'=1}^{n}\left(1 - \xi_{(jj')k}^p\right)\right]}, \tag{28}$$

$$\xi_k^{Dp} = \begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array}\begin{array}{c} C_1 \quad \cdots \quad C_n \\ \begin{bmatrix} 0 & \cdots & \left[1-(1-\mu_{1nk}^p)^{\lambda_k^p}, 1-(1-\nu_{1nk}^p)^{\lambda_k^p}\right] \\ \vdots & \ddots & \vdots \\ \left[1-(1-\mu_{n1k}^p)^{\lambda_k^p}, 1-(1-\nu_{n1k}^p)^{\lambda_k^p}\right] & \cdots & 0 \end{bmatrix}_{n\times n} \end{array} \quad \forall k,p. \tag{29}$$

Box VII

The final global weight of sub-criterion ($\omega^p_{r'}$) with aggregating expert judgment is expressed in Eq. (35):

$$\omega^p_{r'} = \overset{K}{\underset{k=1}{\oplus}} (\omega^p_k)^{\theta^p_k} = \prod_{k=1}^{K} (\omega^p_k)^{\theta^p_k} \quad \forall p, r'. \tag{35}$$

Eventually, the final weight of the sub-criterion with planning horizon ($\omega_{r'}$) can be achieved via Eq. (36):

$$\omega_{r'} = \overset{P}{\underset{p=1}{\oplus}} (\omega^p)^{\frac{1}{P}} = \prod_{p=1}^{P} (\omega^p)^{\frac{1}{P}} \qquad \forall r'. \tag{36}$$

Class 5. The final global weight of aggregation hierarchical decision level (w_j) is calculated through Eq. (37):

$$w_j = \frac{\omega_{(r)} \times \varpi_{(j)}}{\sum_{r=1}^{R} \left(\omega_{(r)} \times \varpi_{(j)}\right)} \qquad \forall j \subseteq r, \tag{37}$$

where w_{rj} denotes the rth sub-criterion belonging to the jth criterion.

4. Case study

4.1. Problem description

This section presents a real case study in Tehran, Iran in which strategy selection gains significance in dealing with the bridge construction BOT problem. In this regard, a real case study is proposed to validate the computation results of the generated approach. Unlike a numerical example, the advantage of this case study lies in its real form of the problem and the helping process aiding the managers with real implementation data.

Hence, three DMs were consulted to obtain and evaluate the three main strategies with eight sub-criteria in two periods. Also, the criterion (C_j) and the sub-criterion (SC_j) are judgments based on DMs' opinions and are incorporated into the hierarchical structure method. This section is prepared with four essential criteria including infrastructure and resources criteria, design and implementation criteria, financial criteria, and environmental criteria. These consist of the 16 sub-criteria that help appraise the decision-making procedure in a hierarchical structure. This paper generates the proposed method in two periods. The first period is related to the normal condition, while the second period involves various disruption scenarios in an economic environment. In this respect, the DMs consider their dynamic evaluations at the first and third phases of the project life cycle as two important factors and the believe that risks can affect the project deliverables. The life cycle phases of the project are shown in Figure 2.

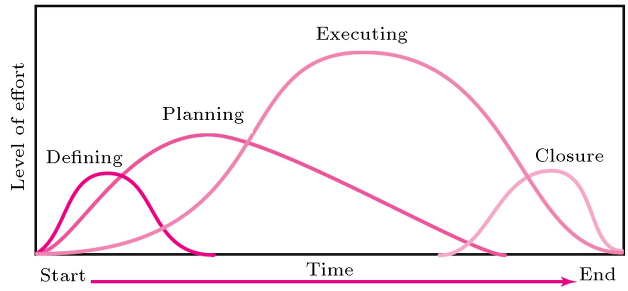

Figure 2. Project life cycle phases.

Table 2. The linguistic variables to evaluate the importance of the attributes.

Linguistic variables	IFVs
Very Low (VL)	(0.1,0.1)
Low (L)	(0.2,0.3)
Medium (M)	(0.3,0.5)
High (H)	(0.4,0.6)
Very High (VH)	(0.45,0.55)

Table 3. The linguistic variables to rate the potential strategies.

Linguistic variable	IFVs
Absolutely High (AH)	(0.49,0.5)
Very Very High (VVH)	(0.47,0.49)
Very High (VH)	(0.45,0.47)
High (H)	(0.43,0.45)
Medium High (MH)	(0.4,0.43)
Medium (M)	(0.35,0.4)
Medium Low (ML)	(0.3,0.35)
Low (L)	(0.2,0.25)
Very Low (VL)	(0.15,0.2)
Very Very Low (VVL)	(0.1,0.1)

Furthermore, the problem is analyzed in two kinds of situations and the outcome helps DMs make appropriate decisions in several conditions. The main strategies are generated in the following:

- S_1: Tender winner performance strategy;
- S_2: Outsourcing strategy;
- S_3: Joint venture strategy.

Accordingly, the linguistic variables generated in Table 2 aim to evaluate the criterion and sub-criterion associated with the DMs. The IF values of the linguistic terms employed to evaluate the candidates are shown in Table 3. Hence, the pairwise comparison matrix criteria and sub-criteria and the assessment of candidate strategies, criteria, and sub-criteria matter are given in Appendix A (Tables A.1–A.4). Moreover, the criteria exploitations are defined as follows:

Infrastructure and resources criteria (C_1)

- Technological capability (SC_{11})
- Employment (SC_{12})
- Risk of shortage of raw materials in the market (SC_{13})
- Risk of delay in raw material supply (SC_{14})
- Risk of not attracting skilled labor (SC_{15})
- Risk of embargo on materials or equipment (SC_{16})

Design and implementation criteria (C_2)

- Run time (SC_{21})
- Resilience (SC_{22})
- Reliable quality (SC_{23})
- Execution complexity risk (SC_{24})
- Risk of design error (SC_{25})
- Risk of design changes (SC_{26})

Financial criteria (C_3)

- Profitability (SC_{31})
- Return on Investment Rate (SC_{32})
- Purity feature (SC_{33})
- Non-financing risk (SC_{34})
- Contractor Financial Failure Risk (SC_{35})
- Risk of late payment of status statements (SC_{36})
- Investment risk (SC_{37})
- External Sanctions Risk (SC_{38})
- Currency or domestic currency transfer risk (SC_{39})
- Inflation risk (SC_{310})

Environmental criteria (C_4)

- Environmental Damage Risk (SC_{41})
- Risk of contingencies (corona, earthquake, etc.) (SC_{42})
- Weather risk (SC_{43})
- Risk of transfer of project site without residents' consent (SC_{44})

4.2. Obtained results

This section reviews the performance of the proposed approach and reports the obtained results by solving the case study. In this respect, the DIF-collective index approach is obtained by combining the DIF-correlation with standard deviation method to compute the local weights of attributes. The normalized decision matrix is obtained from Eq. (11) and the normalized weights based on expert opinions are computed. Furthermore, the DIF overall evaluations of candidates based on the experts' judgment are conducted in Eq. (13). Afterward, the DIF overall evaluations of sub-attributes are done via Eq. (14). This measure is calculated without the rth sub-criterion. Finally, the correlation between the sub-criterion and the DIF overall evaluation scores is obtained from Eqs. (15)–(18). Table 4 presents the final local calculation standard deviation method weights of the sub-attributes with Eqs. (19) and (20).

Table 5 shows the calculated weights of the experts. This table shows the degree of the computation measured by the DIF utility technique, NIS, and PIS based on Eqs. (21)–(26).

Moreover, the DIF-DEMETAL approach is one of the critical methods to compute the weights of the interdependence criteria. Meanwhile, the comparison between the decision matrix and direct relation matrix obtained from Eqs. (27)–(29), respectively. Afterward, the DIF-influence matrix is measured based on Eqs. (30)–(32). In this respect, the obtained results from DIF-DEMATEL methodology are reported in Table 6. Eventually, the final weight is calculated from Eq. (33). Moreover, the final global weight measured by the DIF-DEMATEL approach and aggregating hierarchical decision levels are shown in Table 7.

In this regard, the generated DIF-MPW-CI-EMATEL is appropriate in four classes in terms of collective index and DEMATEL methodologies with dynamic uncertainty under IF environment. In addition, weights of DMs are measured via the proposed DIF-utility degree technique and are practical to the proposed method to reduce the errors in computations of local weights of attributes. Hence, the proposed DIF-MPW-CI-DEMATEL is developed via the last aggregation to prevent data loss. Finally, the hierarchical structure is proposed in the process of the offered method to assess the Group Decision Making (GDM) problem with more assessment aspects.

5. Validation and sensitivity analysis

5.1. Validation process

In this section, the obtained results from the proposed approach of this study are compared with the findings from two closely related methods suggested by Xu and Zhang [36] and Tavakkoli-Moghaddam and Mousavi [37] in order to ensure validation through performance measurement. In this respect, the obtained results from all the three approaches are depicted in Figure 3. As represented in this figure, the behavior trends of all the approaches are similar and it is ensured that the proposed approach leads to reliable results. In addition, standard deviation measurement is considered to represent the performances of all the three approaches. The standard deviation measurement demonstrates that a method with high standard deviation can help

Table 4. The final local weights of sub-criteria.

Criteria	**Sub-criteria**	**DM1**		**DM2**		**DM3**	
		T_1	T_2	T_1	T_2	T_1	T_2
C_1	SC_{11}	0.04257	0.04584	0.04479	0.04495	0.02275	0.04162
	SC_{12}	0.04883	0.04101	0.04460	0.04712	0.05755	0.04752
	SC_{13}	0.05096	0.01749	0.03889	0.02567	0.05364	0.04219
	SC_{14}	0.00792	0.02665	0.01089	0.02783	0.05470	0.04472
	SC_{15}	0.05227	0.04393	0.04911	0.04591	0.04870	0.04529
	SC_{16}	0.00726	0.03795	0.02714	0.03874	0.01842	0.04202
C_2	SC_{21}	0.04318	0.03456	0.03836	0.02881	0.01480	0.02012
	SC_{22}	0.04325	0.03589	0.04190	0.03179	0.05742	0.04734
	SC_{23}	0.05651	0.04720	0.05053	0.04759	0.05953	0.04702
	SC_{24}	0.05234	0.04583	0.05061	0.04528	0.03732	0.04747
	SC_{25}	0.04524	0.03467	0.03852	0.01070	0.00680	0.01327
	SC_{26}	0.04965	0.04339	0.04675	0.04500	0.05459	0.03916
C_3	SC_{31}	0.04804	0.04031	0.03770	0.04452	0.05266	0.04198
	SC_{32}	0.05497	0.04629	0.05050	0.04547	0.05989	0.04751
	SC_{33}	0.05347	0.04495	0.05009	0.04684	0.04956	0.04574
	SC_{34}	0.00834	0.02106	0.02289	0.03761	0.01766	0.02736
	SC_{35}	0.02572	0.04149	0.02502	0.04153	0.00513	0.03465
	SC_{36}	0.01346	0.03443	0.02225	0.00114	0.01722	0.03303
	SC_{37}	0.01350	0.03998	0.02501	0.04270	0.01381	0.02847
	SC_{38}	0.05228	0.04496	0.05067	0.04840	0.04878	0.03223
	SC_{39}	0.05028	0.04389	0.04715	0.04539	0.05518	0.03961
	SC_{310}	0.05215	0.01856	0.03994	0.02651	0.05384	0.04232
C_4	SC_{41}	0.01465	0.04109	0.02574	0.04339	0.01396	0.02854
	SC_{42}	0.05370	0.04621	0.05211	0.04988	0.05089	0.03374
	SC_{43}	0.04937	0.04148	0.03915	0.04592	0.05455	0.04339
	SC_{44}	0.01007	0.04089	0.02970	0.04129	0.02066	0.04370

Table 5. Computational results of the weights of the experts.

DM	η_k^{+p}		η_k^{-p}		θ_k^p		θ_k
	T_1	T_1	T_1	T_1	T_1	T_1	
DM1	30.17361	30.04904	0.58410	0.64850	0.89893	0.02350	0.36076
DM2	30.06948	30.27360	0.67970	0.62120	1.09935	0.01829	0.33999
DM3	30.48117	30.77508	0.57940	0.56660	1.03185	0.01752	0.29925

Table 6. Criteria interdependency computation based on the developed DIF-DEMATEL methodology.

Criteria	C_1	C_2	C_3	C_4
DM1				
C_1	0.00000	0.55890	0.39270	0.39270
C_2	0.55890	0.00000	0.69363	0.55890
C_3	0.39270	0.69363	0.00000	0.16782
C_4	0.39270	0.55890	0.16782	0.00000
DM2				
C_1	0.00000	0.57799	0.44515	0.44515
C_2	0.57799	0.00000	0.58000	0.57799
C_3	0.44515	0.58000	0.00000	0.44515
C_4	0.44515	0.57799	0.44515	0.00000
DM3				
C_1	0.00000	0.51161	0.33430	0.48649
C_2	0.48649	0.00000	0.62493	0.48649
C_3	0.33430	0.62493	0.00000	0.48649
C_4	0.48649	0.48649	0.48649	0.00000

Table 7. The final global and normalized global weights of attributes.

Criteria	Sub-criteria	$\omega_{kr'}$			W_j
		DM1	DM2	DM3	
C_1	SC_{11}	0.02779	0.02442	0.01611	0.03892
	SC_{12}	0.02824	0.02494	0.02589	0.04439
	SC_{13}	0.02176	0.01774	0.02370	0.03525
	SC_{14}	0.01111	0.01075	0.02455	0.02525
	SC_{15}	0.03017	0.02581	0.02325	0.04473
	SC_{16}	0.01451	0.01809	0.01516	0.02676
C_2	SC_{21}	0.03521	0.02343	0.01213	0.04090
	SC_{22}	0.03582	0.02565	0.03549	0.05423
	SC_{23}	0.04653	0.03385	0.03608	0.06571
	SC_{24}	0.04413	0.03311	0.02893	0.06025
	SC_{25}	0.03616	0.01735	0.00701	0.03548
	SC_{26}	0.04190	0.03172	0.03189	0.05958
C_3	SC_{31}	0.01826	0.02247	0.02581	0.03689
	SC_{32}	0.02083	0.02610	0.02915	0.04221
	SC_{33}	0.02027	0.02635	0.02597	0.04041
	SC_{34}	0.00621	0.01668	0.01249	0.01959
	SC_{35}	0.01401	0.01831	0.01112	0.02455
	SC_{36}	0.01006	0.00656	0.01393	0.02455
	SC_{37}	0.01122	0.01862	0.01176	0.01686
	SC_{38}	0.02003	0.02691	0.02221	0.02336
	SC_{39}	0.01942	0.02520	0.02585	0.03869
	SC_{310}	0.01476	0.01827	0.02621	0.03918
C_4	SC_{41}	0.01081	0.01896	0.01304	0.03259
	SC_{42}	0.01901	0.02761	0.02556	0.02395
	SC_{43}	0.01734	0.02317	0.02943	0.04017
	SC_{44}	0.00991	0.01944	0.01960	0.03857

the experts select the most effective criteria easily. Meanwhile, the standard deviation of the proposed approach is lower than those of two other approaches, thus ensuring that the presented methodology can lead to suitable results.

5.2. Sensitivity analysis

In this section, a sensitivity analysis is prepared based on two indices including criteria interdependency elimination and last aggregation approach elimination. At first, the effects of criteria interdependency are eliminated and depicted in Figure 4. Consequently, the results show that the elimination of criteria interdependency could affect the criteria weights.

Moreover, the issue of last aggregation is excluded from the proposed method procedure in which the expert's preferences are aggregated in the first step of the proposed DIF-MPW-CI-DEMATEL methodology, which is called the first aggregation manner. As depicted in Figure 5, implementing the proposed method under the first aggregation manner can affect the criteria weighting results. Thus, calculated results are sensitive to the omission of the last aggregation procedure.

Finally, the criteria and sub-criteria are ranked based on the obtained weights. The second criterion is of larger value than other attributes and this case is relevant to the third sub-criterion. Therefore, the sub-criterion of reliable quality is an important factor in the design and implementation criterion and this implies the reliability of quality requirements during the project progress. This is one of the main risks for BOT contract projects that may occur during the implementation of the project activities.

6. Conclusions and future direction

The present article was prepared and compiled based on Build-Operation-Transfer (BOT) contracts. Such organizational relationships are in the form of outsourcing infrastructure works and outsourcing to the private sector, which provides the capital needed to build, construct, and operate the projects. Basically, investing companies to participate the construction of a road or highway projects requests a toll for a certain period of time, the specified time expires, all required material, and legal rights. Therefore, there are a number of criteria and sub-criteria as BOT projects risks as well as appropriate strategies for risks management that should be defined. In this study, four

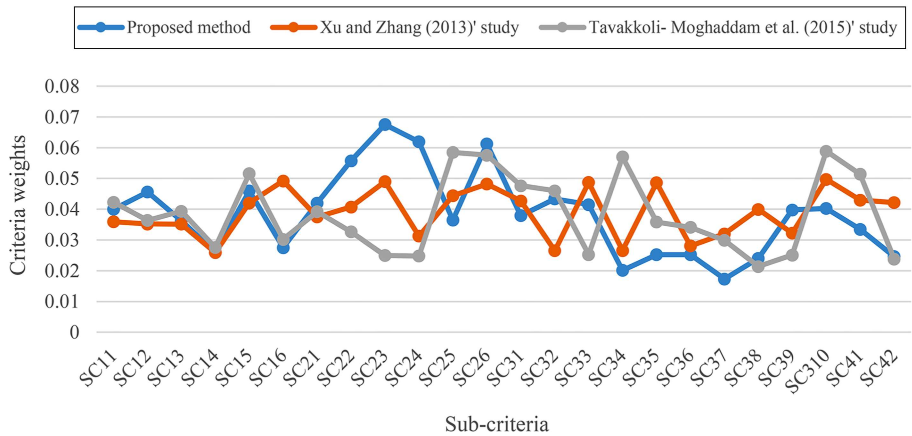

Figure 3. The comparison of the three methods.

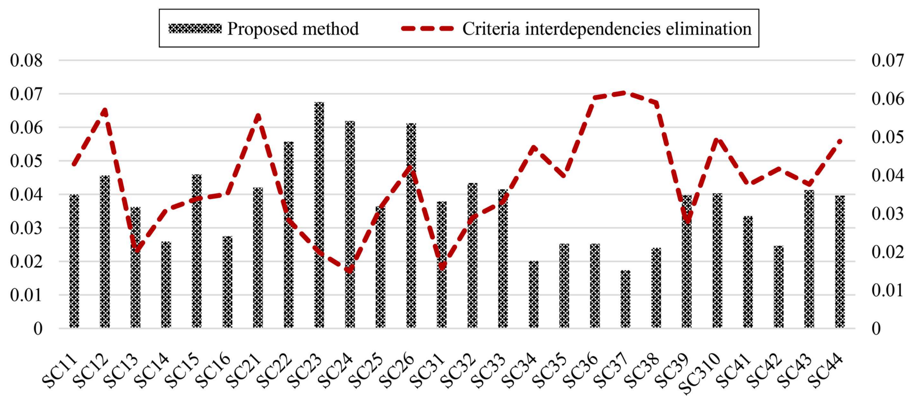

Figure 4. Sensitivity analysis for criteria interdependency relations.

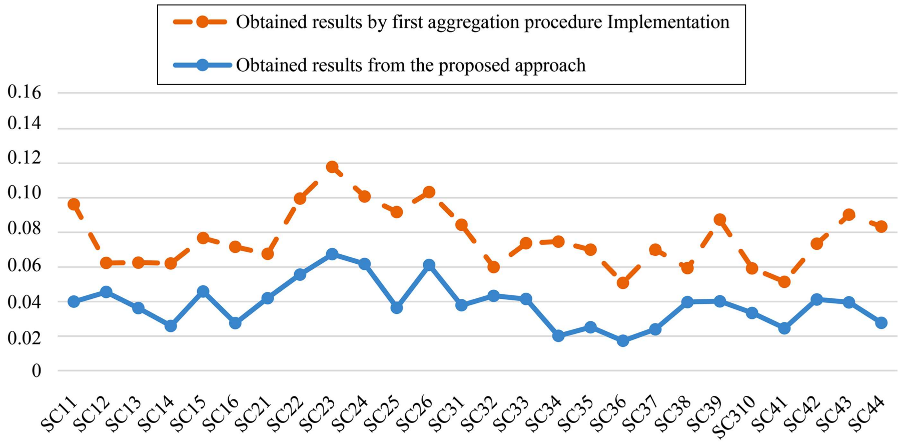

Figure 5. Sensitivity analysis for the important parameter of the first aggregation issue.

sustainability risks as criteria and 26 sub-criteria are defined to evaluate three strategies for risk response by three experts in the field of highway construction and construction projects for two periods. To address this issue, a Dynamic Intuitionistic Fuzzy (DIF) multi-phase weighting method was proposed based on last aggregation approach and in a hierarchical structure. In the process of implementing the proposed approach, a criterion weighting mechanism was developed based on the developed DIF standard deviation method and extended DIF-DEMATEL methodology. In addition, the experts' weights were computed based on the proposed DIF utility approach to reduce the judgments errors. However, the obtained results of sustainable BOT highway construction projects indicate that the most effective criterion and sub-criterion were design and implementation and reliable quality, respectively. Finally, a validation procedure and sensitivity analysis were employed to represent the verification of the proposed approach, and the sensitiveness and robustness of the considered parameters were surveyed. In this respect, the proposed approach was compared with approaches employed in two closely relevant studies and the same results were obtained. Moreover, computation of the standard deviation measure for all the three approaches represents that the proposed approach with high standard deviation can help experts choose the most effective criterion, easily. Furthermore, sensitivity analysis illustrates that the proposed approach is sensitive to the elimination of both criteria interdependency and last aggregation concept.

For further study, generating an inference engine to recognize the attribute significance of strategy election in a micromanagement for the highway construction problem is important to achieve sustainability competence to appoint the DIF decision matrix. Moreover, the introduced multi-phase weighting method can be applied to various decision-making problems such as third-party reverse logistics provider selection problem [5] and site selection of high-speed railway station problem [38]. In addition, one of the main limitations of the proposed approach is mathematical complexity, which leads to a longer time for solving large case problems. To address the issue, developing an intelligent Decision Support System (DSS) as future research can help users of the presented approach to solve their Multi Criteria Group Decision Making (MCGDM) problems quickly.

Declaration of interest

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Appendix.

The input parameters for solving the BOT highway construction projects are defined in Tables A1-A4.

Table A.1. Pairwise comparison matrix to determine linguistic values of criteria weights.

Criteria	Infrastructure and resources criteria	Design and implementation criteria	Financial criteria	Environmental criteria
DM1				
Infrastructure and resources criteria	0	M	L	L
Design and implementation criteria	M	0	H	M
Financial criteria	L	H	0	VL
Environmental criteria	L	M	VL	0
DM2				
Infrastructure and resources criteria	0	H	M	M
Design and implementation criteria	H	0	VH	H
Financial criteria	M	VH	0	M
Environmental criteria	M	H	M	0
DM3				
Infrastructure and resources criteria	0	M	L	M
Design and implementation criteria	M	0	VH	M
Financial criteria	L	VH	0	M
Environmental criteria	M	M	M	0

Table A.2. Linguistic terms of the local weights of criteria.

Criteria	DM1		DM2		DM3	
	T_1	T_2	T_1	T_2	T_1	T_2
C_1	VH	H	M	M	H	M
C_2	H	VH	VH	H	VH	H
C_3	M	H	H	VH	H	M
C_4	M	H	M	M	L	M

Table A.3. Linguistic terms of the local weights of sub-criteria.

Criteria	Sub-criteria	DM1		DM2		DM3	
		T_1	T_2	T_1	T_2	T_1	T_2
C_1	SC_{11}	VH	H	M	H	H	VH
	SC_{12}	VH	VH	VH	H	H	M
	SC_{13}	H	VH	H	VH	VH	VH
	SC_{14}	L	M	VH	H	M	M
	SC_{15}	H	H	M	M	VH	H
	SC_{16}	H	M	M	M	H	M
C_2	SC_{21}	VH	H	M	H	H	M
	SC_{22}	H	M	VH	H	M	H
	SC_{23}	VH	H	H	VH	M	M
	SC_{24}	M	M	VH	M	M	M
	SC_{25}	H	M	H	VH	H	H
	SC_{26}	H	H	H	M	H	VH
C_3	SC_{31}	VH	VH	M	M	H	M
	SC_{32}	VH	VH	M	H	VH	H
	SC_{33}	H	M	H	M	VH	H
	SC_{34}	H	H	VH	VH	VH	VH
	SC_{35}	M	H	M	M	M	M
	SC_{36}	VH	VH	VH	M	H	VH
	SC_{37}	H	M	H	VH	VH	M
	SC_{38}	M	M	M	M	H	VH
	SC_{39}	VH	VH	VH	VH	H	VH
	SC_{310}	VH	H	M	H	H	M
C_4	SC_{41}	L	M	VH	H	M	M
	SC_{42}	VL	VL	H	M	M	M
	SC_{43}	L	L	L	M	L	M
	SC_{44}	VL	VL	L	M	L	L

Table A.4. Evaluating the candidate strategies under the criteria via linguistic variables.

Criteria	Sub-criteria	DM1						DM2						DM3					
		T_1			T_2			T_1			T_2			T_1			T_2		
		S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
Infrastructure and resources criteria (C_1)	Technological capability (SC_{11})	M	H	AH	MH	MH	VVH	L	M	H	ML	MH	VH	M	M	VVH	M	H	H
	Employment (SC_{12})	AH	M	H	VVH	MH	VH	VH	MH	VH	H	M	H	AH	H	H	VH	H	VH
	Risk of shortage of raw materials in the market (SC_{13})	VH	H	L	VH	M	ML	VH	H	MH	H	H	MH	H	MH	L	H	M	MH
	Risk of delay in raw material supply (SC_{14})	VL	M	M	L	ML	ML	VVH	VH	VVH	VH	H	VH	L	H	M	H	L	VH
	Risk of not attracting skilled labor (SC_{15})	VH	VH	H	VH	VH	H	MH	M	H	MH	MH	VH	VH	MH	VH	M	H	VVH
	Risk of embargo on materials or equipment (SC_{16})	VVL	VH	VH	VL	VH	H	VL	VH	AH	VL	H	VVH	VVL	VH	H	L	H	VH
Design and implementation criteria (C_2)	Run time (SC_{21})	M	H	M	M	MH	M	L	M	ML	L	M	ML	M	M	M	VL	VH	ML
	Resilience (SC_{22})	M	H	M	MH	MH	ML	VVH	VH	VVH	VH	VVH	AH	M	VH	M	VH	H	VH
	Reliable quality (SC_{23})	AH	AH	VH	VVH	VVH	H	VH	H	H	VH	VH	VH	VVH	H	VH	VVH	VVH	VH
	Execution Complexity Risk (SC_{24})	H	VVH	VH	VH	VVH	VVH	L	VH	VVH	ML	H	VVH	H	VH	H	ML	VVH	VVH
	Risk of design error (SC_{25})	M	VH	M	ML	VH	L	ML	L	ML	L	M	L	M	L	M	VL	VH	ML
	Risk of design changes (SC_{26})	H	H	H	VH	MH	H	MH	H	M	MH	MH	M	H	VH	VH	M	MH	M
Financial criteria (C_3)	Profitability (SC_{31})	H	MH	H	ML	H	H	MH	VH	H	M	VH	H	H	M	MH	L	VH	H
	Return on Investment Rate (SC_{32})	VVH	VH	VH	VH	VVH	MH	VH	H	VH	M	VH	VH	AH	HH	VVH	ML	VH	MH
	Purity feature (SC_{33})	VH	VH	H	VH	VH	H	MH	M	H	MH	MH	VH	VH	MH	VH	M	H	VVH
	Non-financing risk (SC_{34})	VVL	VH	ML	VL	VVH	VH	VL	VVH	ML	VH	VH	ML	VVL	VVH	VH	VL	AH	VH
	Contractor Financial Failure Risk (SC_{35})	VL	AH	VH	VVL	AH	VVH	VVL	VVH	VVH	VVL	VVH	VH	VVL	AH	AH	VL	MH	VH
	Risk of late payment of status statements (SC_{36})	VVL	AH	MH	VVL	AH	VL	VL	VVH	H	VL	MH	MH	L	H	H	VL	VH	MH
	Investment risk (SC_{37})	VVL	AH	VH	VVL	AH	VVH	VL	H	MH	VVL	H	MH	L	H	H	VL	VH	H
	External Sanctions Risk (SC_{38})	H	VH	H	H	AH	VH	M	MH	ML	M	VVH	VH	ML	MH	MH	ML	H	H
	Currency or domestic currency transfer risk (SC_{39})	H	H	H	VH	MH	H	MH	H	M	MH	MH	M	H	VH	VH	M	MH	M
	Inflation risk (SC_{310})	VH	H	L	VH	M	ML	VH	H	MH	H	H	MH	H	MH	L	H	M	MH
Environmental criteria (C_4)	Environmental Damage Risk (SC_{41})	VVL	AH	VH	VVL	AH	VVH	VL	H	MH	VVL	H	MH	L	H	H	VL	VH	H
	Risk of contingencies (corona, earthquake, etc.) (SC_{42})	H	VH	H	H	AH	VH	M	MH	ML	M	VVH	VH	ML	MH	MH	ML	H	H
	Weather risk (SC_{43})	H	MH	H	ML	H	H	MH	VH	H	M	VH	H	H	M	MH	L	VH	H
	Risk of transfer of project site without residents' consent (SC_{44})	VVL	VH	VH	VL	VH	H	VL	VH	AH	VL	H	VVH	VVL	VH	H	L	H	VH

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