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

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Abstract

In last decade, the emergence of various risks and hazards in large and infrastructure projects has become a concern for governments and government-affiliated institutions. Thereby, 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 approach based-collective criteria and DEMATEL methodology is 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 interdependencies relation between criteria is computed by developed DIF-DEMATEL methodology to tune the criteria weights. In addition, the weights of experts are specified by 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 the data loss. Then, the proposed methodology is implemented to a real case study and also compared with a recent relevant study in literature to ensure the reliability of the results. Finally, a sensitivity analysis is manipulated to find the most effective parameters that can change the obtained results.

Keywords: Sustainability approach, Multi-attribute decision making, Standard deviation method, Intuitionistic fuzzy, DEMATEL

1. Introduction

Today, in developed and developing countries, it is one of the most important and fundamental measures related to the construction of large economic and development-oriented projects [1]. In many infrastructure cases, governments prefer to joint financing contracts for various reasons such as 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 various types of contracts that come with the help of governments. One of these types is related to Build-operation-transfer (BOT) projects. BOT is the one type of finance contracts that can help governments to handle the highly sensitive projects [3] such as highway, bridge, railway [4, 5], etc. At 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 also be done from external sources. In contrast, the investable sector considers benefits such 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 a lot of costs and in case of any mistake in carrying out the project, it incurs heavy financial costs. On the other hand, the public sector also views the project as an asset and in case of violation of the delivery time, it will suffer from numerous performance failures [8]. Therefore, in BOT projects, paying attention to project risks and managing these factors is one of the most fundamental issues. The net present value is the new concept to cope with identification risk in the projects [9]. Different types of project risks in different countries can have a huge impact on the design to the implementation of production operations and construction of the project [10]. In developing countries, the imposition of economic sanctions and sanctions, fluctuations in foreign exchange rates, fluctuations in interest rates and inflation, and changes in laws and regulations can be among the cases that cause a system crisis [11]. The first group that sees a significant impact on project implementation risk is the investor company, whose financial, human and machinery capital is involved in the project. In case of pressure and delay in the delivery of the public sector as an investable institution, it will also incur heavy costs. Thus, identifying and managing these project risks will help prevent these from occurring [12, 13].

Initially, identifying project risks according to the type of project is essential and recognizing the risks will help significantly in ranking the risks. Meanwhile, Jiang et al. [14] introduced the risk management policies in the BOT project of the foreign direct investment. Wang and Jin [15] investigated the risk management in the Metro of China under BOT project condition. Patel et al. [16] generated the risk management in the toll roads in Indian country under BOT project policy by proposing a fuzzy possibilistic method to cope with the uncertain conditions of the real-world application. In addition, Aladağ and Işık [17] investigated the risk management in the BOT mega transportation projects and proposed the 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 systems 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 [22] identified some financial risk management factors in the 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 at 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 also each of these identified risks that can affect the performance BOT projects can be introduced as a criterion and in hierarchical structure as a sub-criterion. Therefore, multi-attribute decision making (MADM) methods can consider to assess the criteria and rank them according to the unique BOT projects conditions. Meanwhile, the criteria weights computation can determine the impact of each identified risks on the BOT projects and managers or decision makers can be under-controlled these BOT project risks [26]. In this sake, 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. On the other hand, one of the appropriate approaches to decision-making in the context of the BOT issue is to use the multi-criteria group decision-making (MCGDM) approach. This methodology can be considered as an efficient and effective method in 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 that are utilized in most studies [29-31]. On the other hand, two main types of weighting methods are based on criteria interdependencies determination including ANP and DEMATEL methodologies [6, 32-34]. However, considering both aforementioned approaches for criteria weights determination can lead the ranking results to a precise solution.

On the other hand, one of the most important and necessary issues in today's world is related to the uncertainties in the 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 the real-world cases, and the decisions made can be brought closer to reality. In this paper, the intuitionistic fuzzy (IF) approach has been used in order to deal with uncertainty. The important point that is considered in this study is related to the dynamics of the problem conditions and the dependence of the issues on different periods. Thus, decisions of experts, decision makers (DMs), and managers at different periods may lead to different decisions and each decision can be specific to a particular period. For example, the occurrence of sanctions on a country's economy or fluctuations in exchange rates should evaluate in different periods. This dynamism in the nature of decisions has led to the use of a dynamic intuitionistic fuzzy (DIF) approach in this paper to cope with dynamic imprecise information.

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

{Please insert here Table 1}

As indicated in Table 1, the survey of the literature shows that the proposed approach has more unique features and may lead to precise solution. In this study, an intuitionistic fuzzy standard deviation approach is proposed to calculate local weight of the risk criteria. Also, in order to calculate the weights of hierarchical structure with interdependencies criteria, decision-making trial and evaluation laboratory (DEMATEL) method is used under IF condition. In addition, a novel DIF-utility grade approach is developed to obtain the weight of each expert. Then, weights of experts or DMs are taken into account in the determined multi-phase weighting method. Also, the DIF-MPW-CI–DEMATEL methodologies is developed via a last aggregation approach to keep around from the data loss. The main contributions and innovations of the study are described as follows:

- Extending the essential risks of the construction in highway BOT project;
- Tailoring the multiphase weighting approach and the DEMATEL methodology with DIF condition;
- Extending some novel equations on the DIF method;
- Using the experts' judgments to calculate DIF weight to decrease the local weight errors;
- Considering the last aggregation process thorough 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: the preliminaries concepts of DIF theory are defined in Section 2. Then, the proposed multi-phase weighting methodology based on collective criteria and DEMATEL approach under DIF condition is presented in Section 3. Section 4 is relevant to performing of the proposed method with considering a real case study. Section 5 describes validation process and sensitivity analysis on the important parameters, and finally, some conclusions and future suggestions are discussed in Section 6.

2. Preliminaries

This section is examined the some of the basic relations of the DIF, and then is developed the proposed dynamic intuitionistic fuzzy multi-phase weighting approach based on collective criteria and DEMATEL (DIF-MPW-CI-DEMATEL) relations.

Definition 1 [35]. Assume that the *t* is the time variable. $a(t)=\left(\mu_{a(t)},\nu_{a(t)},\pi_{a(t)}\right)$ is the IF variable, where $\mu_{a(t)}\in[0,1]$, $\nu_{a(t)}\in[0,1]$, $\mu_{a(t)}+\nu_{a(t)}\le 1$, $\pi_{a(t)}=1-\mu_{a(t)}-\nu_{a(t)}$. In IF variable $a(t)=\left(\mu_{a(t)},\nu_{a(t)},\pi_{a(t)}\right)$, for $t=t_1,t_2,...,t_p$, $a(t_1),a(t_2),...,a(t_p)$ determine p intuitionistic fuzzy numbers (IFNs) collected at different period times.

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

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

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

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

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

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

Definition 4 [35]. Let $a(t_1),a(t_2),...,a(t_p)$ be a collection of IFNs prepared at *p* different periods t_p. $\lambda(t)=\left(\lambda(t_1),\lambda(t_2),...,\lambda(t_p)\right)^T$ is the weight vector of period t_p. A dynamic intuitionistic fuzzy weighted geometric (DIFWG) operator determines 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,…,P* and $\sum_{p=1}^{P}\lambda(t_p)=1$.

Definition 5 [35]. The dynamic intuitionistic fuzzy geometric (DIFG) operation determines in 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 $a(t_2)$ show in Eqs. (7) and (8), respectively.

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

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

Definition 7 [35]. The normalized matrix $\left(f_{ij}\right)$ generated in Eq. (9).

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

3. Proposed DIF-MPW-CI–DEMATEL approach

This section proposed a weighting method consist of collective approach and DEMATEL technique. This method is occurred under DIF condition based on hierarchical structure and interdependencies relations of attributes. This approach is considered in the three classes that are included: the DIF collective criteria class, the DIF-DEMATEL class, and the integrated class based on two pervious methods. Also, this paper is introduced the DIF-utility method to decrease the impact of the expert judgment error weights on the criteria. Fig 1. Presents the framework of the proposed method. This method starts from groups of experts $\left(DM_k;DM_1,...,DM_k\right)$ with alternatives $\left(A_i;A_1,...,A_m\right)$ of criteria $\left(C_j;C_1,...,C_j\right)$ and sub-criteria $\left(SC_r;SC_1,...,SC_r\right)$ under multi-period $\left(T_p;T_1,...,T_p\right)$. The proposed method DIF-MPW-CI-DEMATEL has three main classes that are included:

Class 1. This class is related to collective index method that is occurred with standard deviation method to control the criteria local weight.

Step 1.1. Create the normalized DIF matrix $\left(\vartheta_k^p\right)$ with Eq. (9) in Eq. (10).

$$\vartheta_k^p = \begin{matrix} \\ A_1 \\ \vdots \\ A_m \end{matrix} \begin{matrix} SC_1 & \cdots & SC_r \\ \left[\begin{matrix} \left\{\left[\mu_{11}^{1p},\nu_{11}^{1p}\right],\left[\mu_{11}^{2p},\nu_{11}^{2p}\right],...,\left[\mu_{11}^{kp},\nu_{11}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{1r}^{1p},\nu_{1r}^{1p}\right],\left[\mu_{1r}^{2p},\nu_{1r}^{2p}\right],...,\left[\mu_{1r}^{kp},\nu_{1r}^{kp}\right]\right\} \\ & \ddots & \\ \left\{\left[\mu_{m1}^{1p},\nu_{m1}^{1p}\right],\left[\mu_{m1}^{2p},\nu_{m1}^{2p}\right],...,\left[\mu_{m1}^{kp},\nu_{m1}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{mr}^{1p},\nu_{mr}^{1p}\right],\left[\mu_{mr}^{2p},\nu_{mr}^{2p}\right],...,\left[\mu_{mr}^{kp},\nu_{mr}^{kp}\right]\right\} \end{matrix}\right] \end{matrix} \quad \forall p,k \tag{10}$$

Step 1.2. Sub-criteria weights normalized based on the DMs opinions about criteria $\left(\Delta_{kj}^p\right)$ and sub-criteria $\left(\Delta_{kr}^p\right)$ calculate, and the normalized DIF-decision matrix $\left(\vartheta_k^{wp}\right)$ obtains in Eq. (11).

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

The final weights of sub-criteria $\left(\chi_{rk}^p\right)$ obtains from Eq. (12).

$$\chi_{rk}^p = \frac{\Delta_{kj}^p \Delta_{kr}^p}{\sum_{r=1}^{R} \Delta_{kj}^p \Delta_{kr}^p} \quad \forall r \subseteq j \tag{12}$$

Step 1.3. The score function of DIF $\left(\varepsilon_{ik}^p\right)$ based on expert judgment shows in Eq. (13).

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

Step 1.4. It is essential to remove the sub-criterion SC_r from the set of criteria to present the impact of it on the decision-making process. The score function without $\left(\varepsilon_{ir'k}^p\right)$ calculates with Eq. (14).

$$\varepsilon_{ir'k}^{p} = \left[1 - \prod_{r=1, r \neq r'}^{R} \left(1 - \vartheta_{(ir)k}^{wp} \right) \right] \qquad \forall i, r', p, k \qquad (14)$$

{Please insert here Figure 1}

Step 1.5. The relation between the sub-criteria and the DIF evaluation score $\left(\wp_{rk}^{p}\right)$ obtains in Eq. (15).

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

The Eq. (15) is rewritten as Eq. (16).

$$\wp_{rk}^{p} = \frac{1 - \prod_{i=1}^{m} \left(1 - \left\{ \left(\frac{1}{E} \sum_{e=1}^{E} \left(\frac{1}{l} \sum_{\lambda=1}^{l} \vartheta_{(ir)k}^{\sigma(\lambda)p} \right) - \overline{\vartheta}_{(r)k}^{p} \right) . \left(\frac{1}{E} \sum_{e=1}^{E} \left(\frac{1}{l} \sum_{\lambda=1}^{l} \varepsilon_{(ir)k}^{\sigma(\lambda)p} \right) - \overline{\varepsilon}_{(r)k}^{p} \right) \right\} \right)}{\sqrt{\left(1 - \prod_{i=1}^{m} \left(1 - \left(\frac{1}{E} \sum_{e=1}^{E} \left(\frac{1}{l} \sum_{\lambda=1}^{l} \vartheta_{(ir)k}^{\sigma(\lambda)p} \right) - \overline{\vartheta}_{(r)k}^{p} \right)^{2} \right) \right) . \left(1 - \prod_{i=1}^{m} \left(1 - \left(\frac{1}{E} \sum_{e=1}^{E} \left(\frac{1}{l} \sum_{\lambda=1}^{l} \varepsilon_{(ir)k}^{\sigma(\lambda)p} \right) - \overline{\varepsilon}_{(r)k}^{p} \right)^{2} \right) \right)}} \qquad \forall r, p, k \qquad (16)$$

The $\overline{\vartheta}_{(r)k}^{p}$ and $\overline{\varepsilon}_{(r)k}^{p}$ compute with Eqs. (17) and (18).

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

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

Step 1.6. The local weight of sub-criteria obtains with Eq. (19).

$$\partial_{r'k}^{p} = \frac{1 - \left(1 - \sqrt{1 - \wp_{r'k}^{p}} \right)^{\sigma_{r'k}^{p}}}{\left[\sum_{r=1}^{R} \left(\frac{1 - \left(1 - \sqrt{1 - \wp_{r'k}^{p}} \right)^{\sigma_{r'k}^{p}}}{1 - \prod_{r=1, r \neq r'}^{R} \left(1 - \left(1 - \sqrt{1 - \wp_{r'k}^{p}} \right)^{\sigma_{r'k}^{p}} \right)} \right) \right] \left(1 - \prod_{r=1, r \neq r'}^{R} \left(1 - \left(1 - \sqrt{1 - \wp_{r'k}^{p}} \right)^{\sigma_{r'k}^{p}} \right) \right)} \qquad \forall r', p, k \qquad (19)$$

The IF standard deviation value ($\sigma_{r'k}^{p}$) obtains with Eq. (20).

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

Class 2. This class is related to compute the weight of every DM with the DIF-utility degree technique.

Step 2.1. The normalized DIF decision matrix (ϑ_k^p) obtain from step 1.1.

Step 2.2. The DIF positive idea solution (PIS) (φ^{+p}) and the negative ideal solution (NIS) (φ^{-p}) obtain with Eqs. (21) and (22).

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

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

Step 2.3. The DIF separation scale from PIS and NIS values (η_k^{+p}, η_k^{-p}) calculate with Eqs. (23) and (24).

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

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

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) compute in Eqs. (25) and (26).

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

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

Class 3. This section is proposed the DIF-DEMATEL method to handle and control the importance of the criteria with a hierarchical structure that is related to interdependencies data.

Step 3.1. Create the DIF comparison matrix with each period (ξ_k^p) that is relevant to judgment experts. This matrix is shown in Eq. (27).

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

Step 3.2. This step is proposed the direct-relation matrix of the DIF (ξ_k^{Dp}) in Eqs. (28) and (29).

$$\lambda = \frac{1}{\left[1 - \prod_{j'=1}^{n}\left(1 - \xi_{(jj')k}^p\right)\right]} \tag{29}$$

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

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

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

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

The Eq. (31) can be changed to 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 weight of interdependencies criteria ($\varpi_{k(j)}^p$) show 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 $\left[\psi_k^p\right]_{n\times n}$ is $n \times n$ matrix.

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

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

The final global weight of sub-criteria ($\omega_{r'}^{p}$) with aggregating expert judgment shows in Eq. (35).

$$\omega_{r'}^{p} = \bigoplus_{k=1}^{K}\left(\omega_{k}^{p}\right)^{\theta_{k}^{p}} = \prod_{k=1}^{K}\left(\omega_{k}^{p}\right)^{\theta_{k}^{p}} \qquad \forall p, r' \tag{35}$$

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

$$\omega_{r'} = \bigoplus_{p=1}^{P}\left(\omega^{p}\right)^{\frac{1}{P}} = \prod_{p=1}^{P}\left(\omega^{p}\right)^{\frac{1}{P}} \qquad \forall r' \tag{36}$$

Class 5. The final global weights of aggregation hierarchical decision level (w_j) calculate based on 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} can be denoted as the *rth* sub-criteria belonging to jth criterion.

4. Case Study

4.1. Problem description

This section is proposed the real case study in Tehran, Iran which is related to the strategy selection in the bridge construction BOT problem. Furthermore, the real case study proposes to validate the computation results of the generated approach. The advantage of the case study instead of the numerical example is related to the real form of the problem and the helping process to the managers with real implementation data.

Hence, the three DMs use to obtain and evaluate the three main strategies with eight sub-criteria under two period. Also, the criteria $(C_j)$and the sub-criteria (SC_j) are judgment based on DMs opinions and use in the hierarchical structure method. This sector is prepared with four essential criteria that are included infrastructure and resources criteria, design and implementation criteria, financial criteria, and environmental criteria. These are consist of the 16 sub-criteria to appraise the decision-making procedure in a hierarchical structure. This paper is generated the proposed method in two periods. The first period is related to the normal condition, and the second period is relevant to the various disruption scenarios in the economic environment. In this respect, the DMs considered their dynamic evaluations in first and third phases of the project life cycle as two important factors that their risks can be affected the project deliverables. Give the project life cycle phases in Fig. 2.

{Please insert here Figure 2}

Furthermore, this issue is determined that the problem is analyzed in two kinds of situations, which is helped to the DMs to keep the appropriate decisions in the several conditions. The main strategies are generated following:

- S_1: Tender winner performance strategy;

- S_2: Outsourcing strategy;
- S_3: Joint venture strategy.

Accordingly, the linguistic variables generate in Table 2 to evaluate the criteria and sub-criteria with the DMs. The IF values of the linguistic terms to evaluate the candidates present in Table 3. Hence, the pairwise comparison matrix criteria and sub-criteria, the assessment of candidate strategies, criteria, and sub-criteria matter can be given in Appendix (Tables A1-A4). 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})

{Please insert here Table 2}

{Please insert here Table 3}

4.2. Obtained results

In this section, the performance of the proposed approach is reviewed and the obtained results by solving the case study are reported. In this sake, the DIF-collective index approach generates with combining the DIF-correlation and standard deviation method to compute the local weights of attributes. The normalized decision matrix obtains from Eq. (11) and the normalized weights based on expert opinions is computed. Furthermore, the DIF-overall evaluations of candidate based on the judgment of the experts obtains from Eq. (13). Afterward, the DIF-overall evaluations sub-attributes computes from Eq. (14). This measure is calculated without *rth* sub-criteria. Finally, the correlation between the sub-criteria and the DIF-overall evaluations scores obtains from Eqs. (15)-(18). Table 4 present the final local calculation standard deviation method weights of the sub-attributes with Eqs. (19) and (20).

{Please insert here Table 4}

Table 5 computes the weights of the experts. This Table is computed the DIF-utility proposed technique, NIS and PIS degree of the computation based on Eqs. (21)-(26).

{Please insert here Table 5}

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

{Please insert here Table 6}

{Please insert here Table 7}

In this regard, generated DIF-MPW-CI– DEMATEL is appropriate under four classes about collective index and DEMATEL methodologies with dynamic uncertainty under IF-environment. In addition, weights of DMs can be shown via the proposed DIF-utility degree technique and practical to the proposed method to reduce the errors in computations of attributes' local weights. Hence, the proposed DIF-MPW-CI–DEMATEL could be developed via the last aggregation to prevent data loss. Finally, the hierarchical structure is proposed in the process of offered method to assess the 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 two closely related methods as Xu and Zhang [36] and Tavakkoli-Moghaddam et al. [37] to check the performance measurement for validation guarantee. In this respect, the obtained results from all three approaches are depicted in Fig. 3. As represented in this figure, the behavior trends of all approaches are similar and it ensure that the proposed approach can lead to reliable results. In addition, standard deviation measurement is considered to represent the performance of the all three approaches. The standard deviation measurement demonstrates that a method with high standard deviation can help the experts to select the most effective criteria easily. Meanwhile, the standard deviation of proposed approach is lower than two other approaches that ensure the presented methodology could lead to suitable results.

{Please insert here Figure 3}

5.2. Sensitivity analysis

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

{Please insert here Figure 4}

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

{Please insert here Figure 5}

Finally, the rank of criteria and sub-criteria based on the obtained weights is shown that the second criteria have high level than other attributes and this case is relevant to the third sub-criterion. Therefore, the reliable quality sub-criterion is an important factor for the design and the implementation criterion and it means that the reliability of quality requirements that should be happened during the project progress. This is one of the main risks for BOT contract projects that may occur during the project activities implementation.

6. Conclusions and future direction

The present article has been prepared and compiled based on 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, the number of criteria and sub-criteria as BOT projects risks and the selected strategies for risks response should defined. In this study, four 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 the issue, a dynamic intuitionistic fuzzy multi-phase weighting method is proposed based on last aggregation approach and in hierarchy structure. In process of the proposed approach, a criterion weighting mechanism is developed based developed DIF-standard deviation method and extended DIF-DEMATEL methodology. In addition, the experts' weights are computed based on proposed DIF-utility approach to reduce the judgments errors. However, the solving results of sustainable BOT highway construction projects problem indicate that the most effective criteria and sub-criteria are design and implementation and reliable quality, respectively. Finally, a validation procedure and sensitivity analysis is performed to represent the verification of the proposed approach and surveyed on sensitiveness and robustness of the considered parameters. In this sake, the proposed approach is compared with two closely relevant studies and the same results are obtained. Moreover, computing the standard deviation measure for all three approaches represents that the proposed approach with high standard deviation can help experts to choose the most effective criteria easily. On the other hand, the sensitivity analysis shows that the proposed approach are sensitive to criteria interdependencies elimination and last aggregation concept elimination.

For future suggestions, generating an inference engine to recognize the attribute significance of strategy election in micromanagement for the highway construction problem was more intrigued regarding the sustainability competencies to appoint the DIF-decision matrix. Moreover, the introduced multi-phase weighting method can be implemented to some 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 that led to spend more time for solving the 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 MCGDM problems quickly.

Declaration of interest

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Figures captions:

Tables captions:

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

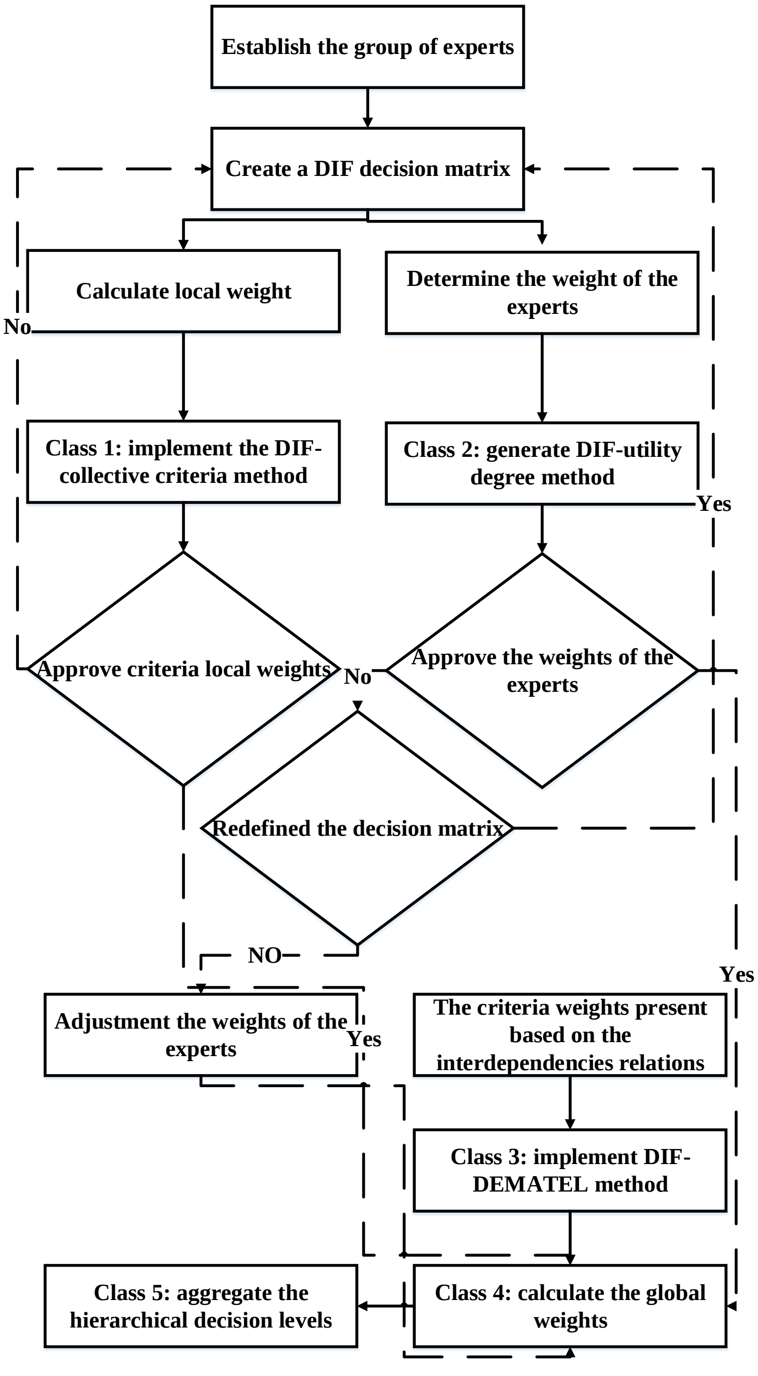

Fig. 1. The proposed DIF-MPW-CI–DEMATEL method structure

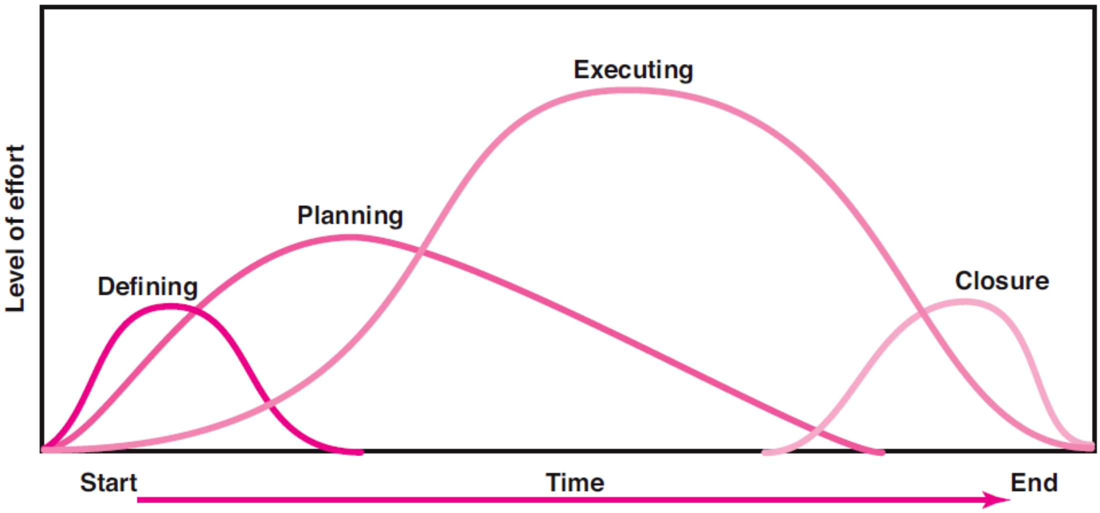

Fig. 2. Project life cycle phases

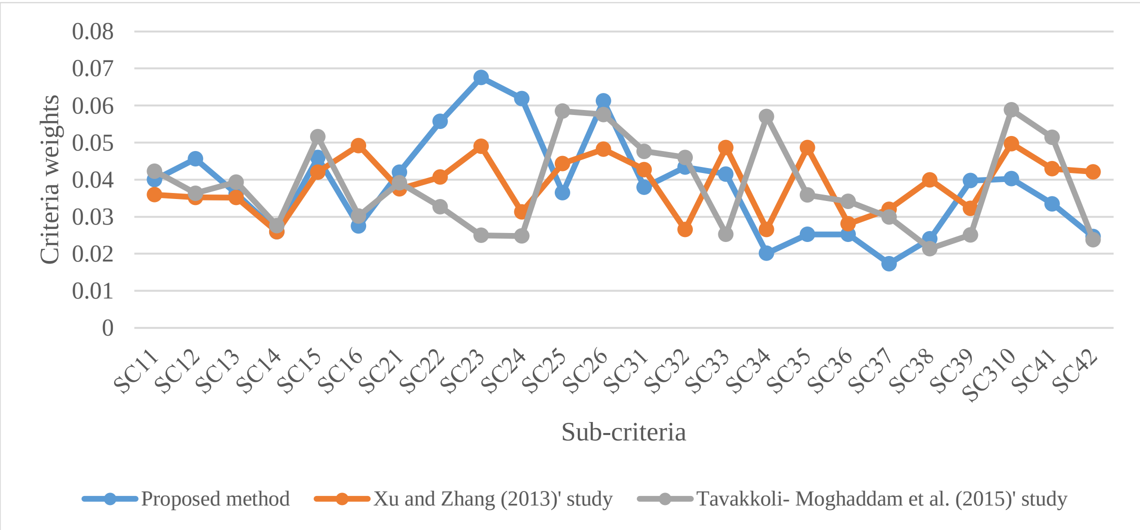

Fig. 3. The comparison among three methods

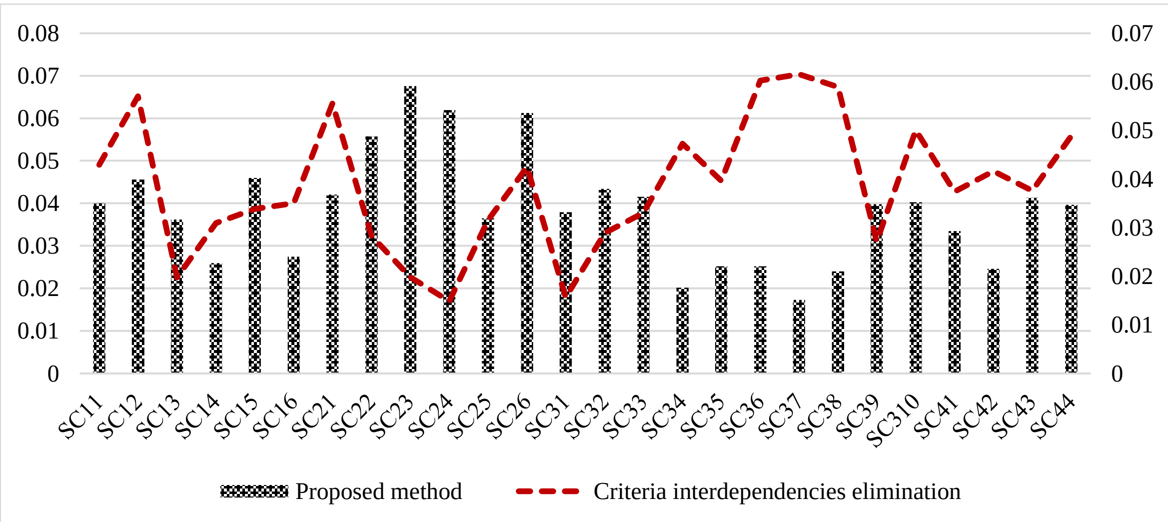

Fig. 4. Sensitive analysis on criteria interdependencies relations

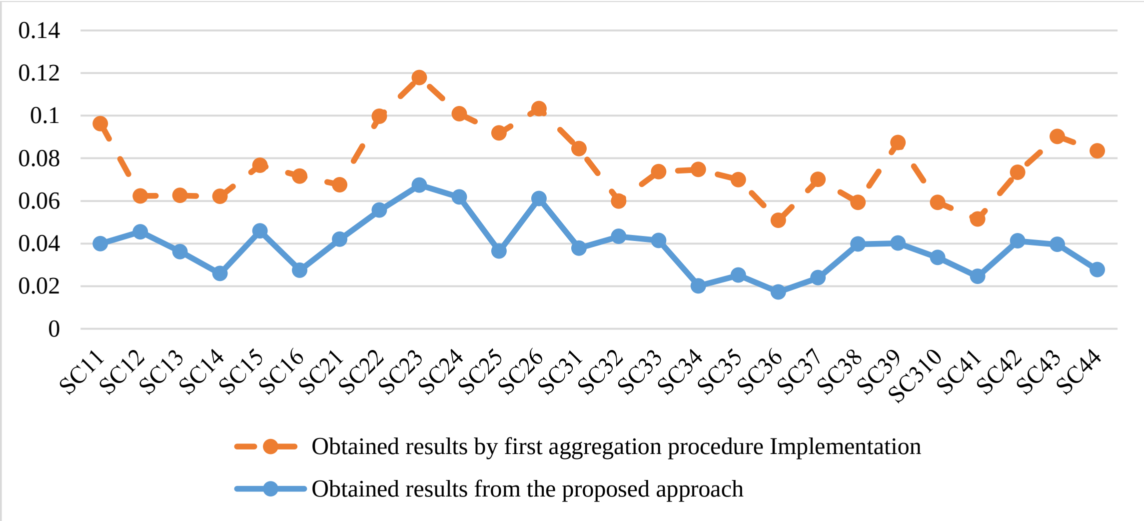

Fig. 5. Sensitivity analysis for important parameter of the first aggregation issue

Table 1. The research gap representation

Authors	Uncertainty	Dynamic uncertainty assessment	Experts' weights	Last aggregation approach	Criteria weights	Criteria interdependencies relation consideration	Hierarchical structure
Gitinavard & Akbarpour [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	☑	☑	☑	☑	☑	☑	☑

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)

Linguistic variable	IFVs
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)

Table 4. The final local weights of sub-criterions

Criteria	Sub-criteria	DM1		DM2		DM3	
		T1	T2	T1	T2	T1	T2
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
	T1	T2	T1	T2	T1	T2	
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 interdependencies computation based on developed DIF-DEMATEL methodology

Criteria / DM1	C_1	C_2	C_3	C_4
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	$\omega_{k\acute{r}}$			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

Appendix. The input parameters for solving the BOT highway construction projects.

Table A1. Pairwise comparison matrix to determine linguistic value 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 A2. Linguistic terms of the local weights of criteria

Criteria	DM1		DM2		DM3	
	T1	T2	T1	T2	T1	T2
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 A3. Linguistic terms of the local weights of sub-criteria

Criteria	Sub-criteria	DM1		DM2		DM3	
		T1	T2	T1	T2	T1	T2
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 A4. Evaluating the candidate strategies under the criteria via linguistic variables

Criteria	Sub-criteria	DM1						DM2						DM3					
		T1			T2			T1			T2			T1			T2		
		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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