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An intuitionistic fuzzy weighting and ranking model to evaluate the financing challenges of urban development with public-private partnership projects

S.M. Mortazavi[a], M.R. Adlparvar[a,b,*], and M. Shahbazi[c]

a. *Department of Civil Engineering, Qeshm Branch, Islamic Azad University, Qeshm, Iran.*
b. *Technical and Engineering Faculty, University of Qom, Qom, Iran.*
c. *Department of Architecture, Science and Research Branch, Islamic Azad University, Tehran, Iran.*

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Abstract. In today's world, one of the most important and basic parts of urban development deals with the creation and development of a project with infrastructure nature. Meanwhile, these developmental projects can be implemented under the Public-Private Partnership (3P) projects, and financial challenges are considered the main factors that affect the success of the project. This study develops a novel intuitionistic fuzzy soft computing-based ideal solution based on criteria importance determination and experts' weights computations. In this respect, the criteria importance is computed based on the presented intuitionistic fuzzy preference evaluation method and experts' weights are determined by proposing an intuitionistic fuzzy utility degree technique. Moreover, the proposed approach is developed based on the last aggregation process to reduce the data loss and cover the preferences and judgments of experts thorough the method execution. Finally, a real case study is provided to elaborate the process of the method execution and assess the values of effective criteria in 3P projects of urban development. In addition, a comparative assessment and a sensitivity analysis are considered to show the applicability and sensitiveness/robustness of the proposed approach, respectively.

1. Introduction

Today, with the development of urban life in different countries, the issue of urban infrastructure development has become one of the most attractive and important issues. Thus, progress in urban life on a large scale can lead to the improvements of economic factors [1,2]. In this respect, economic development by the expansion of employment, production, and economic prosperity always requires investment in various sectors [3]. To address the issue, development projects and their proper performance based on time and cost estimates are recognized as the main indicators of a dynamic and prosperous economy [4]. This means that well-managed development projects can reach reliable profitability and productivity by focusing on these indicators in the shortest possible time and contribute to the economy of a country [5]. Therefore, small changes in the huge financial cycle can lead to a significant impact on the economy [6].

In many projects, a large volume of required capital is strongly sensitive to the political, economic, and social problems that give rise to the unwillingness

*. *Corresponding author:*
E-mail addresses: mortazavi_masoud@yahoo.co.uk (S.M. Mortazavi); mr.adlparvar@gmail.com (M.R. Adlparvar); m-shahbazi@srbiau.ac.ir (M. Shahbazi)

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of investors [7]. A number of projects can be funded publicly through support from either the government or government-affiliated agencies; however, some issues are sometimes out of the government's control and full payment cannot be cannot made in some cases such as road construction and urban development projects [8,9]. Therefore, the most important financing method is to turn financial savings into investment by defining the Public-Private Partnership (3P) projects [10]. In recent decades, the financing of private sector in the framework of 3P projects is one of the most reliable methods for the infrastructure maintenance and some services that are related to the public sector for the urban development such as transportation, social infrastructure, and utility facilities [11].

In this respect, Jones and Wang [12] examined the failure factors of the private sector to construct the projects. This paper is organized based on the elements that private firms can cope with them in the length of the implementation of the projects. Moreover, Sarvari et al. [13] investigated the impact of using the private sector in the construction project. This article emphasized that this type of the construction form had higher reliability than other forms. Furthermore, Chung et al. [14] examined the impact of the used private sector in the clustering type of startup companies.

Moreover, 3P investment refers to the investment projects in which one of the subsidiaries of the central government with the participation of private companies is responsible for financing, construction, and operation of the project [15]. Also, the financing method and preparing the necessary executive budget to carry out infrastructure 3P projects and exploit the services provided by them has now become one of the most important challenges [16]. In this respect, some researchers have focused on this topic to survey the root causes of the problem.

Meanwhile, Kim and Choi [17] examined the conclusion of 3P contracts in large-scale projects with a case study of the Sungdo New Town project in South Korea. This article examines the project that is considered to be the largest private sector development in the world and investigates the expected benefits of the 3P approach. Kavishe et al. [18] evaluated issues and outcomes related to the delivery of construction projects based on 3P approach in developing countries such as Tanzania. The obtained results from the opinions of experts demonstrated that the most important reasons for the cost-effectiveness of the 3P method were the economics of the project in terms of attracting private sector investment, preserving the national currency, and facilitating affordable housing. In addition, Xiong et al. [19] examined the lessons learned from China and explored the 3P approach as a government response to sustainable urban development. Firman et al. [20] examined the benefit of the private sector in the process of manufacturing under 3P-type conditions. Moreover, Wang et al. [21] investigated the global research mapping system based on sustainability of the megaproject management. In this respect, Rahmah and Zaidun [22] analyzed the effect of using 3P in the construction project in Indonesian. Meanwhile, Seddighi et al. [23] examined application of the Private-Public-People Partnership (4P) in the COVID 19 pandemic. This paper used the people in the system of operations to control the impact of COVID 19.

One of the most important issues in the real-world problem is related to obtain and compute the importance of various criteria in 3P problems. In this respect, the most powerful and popular methodologies that can compute the criteria importance and 3P ranking is Multi-Criteria Group Decision-Making (MCGDM) technique [24]. In addition, the experts' judgments on and preferences for real cases may be vague and they define their opinions through linguistic terms. To address this issue, the Intuitionistic Fuzzy Set (IFS) theory is considered to deal with the qualitative assessment and the vagueness of experts' opinions. Therefore, several authors have considered intuitionistic fuzzy MCGDM techniques to solve their 3P problems.

In this respect, Chang et al. [25] tailored an intuitionistic fuzzy integrated group decision-making methodology to select the most powerful emergency plan. Geng et al. [26] proposed an interval-valued intuitionistic fuzzy loan approval evaluation framework of 3P projects in the field of battery storage power station for the commercial bank to assess and choose the optimal 3P project. Jokar et al. [27] presented an integration fuzzy decision-making approach based on fuzzy Analytic Hierarchy Process (AHP) and fuzzy TOPSIS to evaluate the risks of 3P freeway projects. Moreover, Tian et al. [28] developed a picture fuzzy hierarchical VIKOR method for sustainable assessment of water environment treatment-3P projects. In addition, Jokar et al. [29] tailored a fuzzy risk management framework by considering the fuzzy AHP, fuzzy TOPSIS, and fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) to determine the critical and common risks and assigning each risk to each partner in 3P projects.

The literature survey shows that proposing an integrated soft computing approach by considering the criteria importance, experts' weights, and last aggregation approach can improve the obtained results by increasing the accuracy of computations. In sum, the advantages and motivations of this study are expressed as follows:

- Proposing an Intuitionistic Fuzzy-Utility Degree (IF-UD) method to compute the expertise of each decision-maker;

- Proposing an Intuitionistic Fuzzy-Preference Evaluation (IF-PE) method to determine the criteria importance;
- Considering the last aggregation approach through the proposed approach to prevent data loss;
- Elaborating on an IF-soft computing-based ideal solution approach to rank the evaluated candidates;
- Defining a real case study based on Delphi methodology to represent the verification of the proposed approach.

The rest of the paper is organized as follows: in Section 2, preliminaries about the IFS are examined. In Section 3, the proposed method is illustrated in detail. In Section 4, one application example is considered to determine the ability and suitability of the proposed method. In addition, the respective analysis is considered to show the performance of the proposed approach. Moreover, in Section 5, a comparative assessment and sensitivity analysis are discussed to represent the applicability and sensitiveness/robustness of the proposed approach, respectively. Eventually, the conclusion and future suggestions are described in Section 6.

2. Preliminaries

This section examines various operators of the IFS, which is used in the proposed method Intuitionistic Fuzzy Multi-Criteria Weighting and Ranking (IF-MCWR). Also, the preliminaries of the IFS issue are described in this section.

Definition 1 [30]. Let X be a universe discourse. The IFS A of X is an object shown in Eq. (1):

$$A = \{\langle x, \mu_A(x), \nu_A(x), \pi_A(x)\rangle \,|x \in X\}, \tag{1}$$

where the values of the membership function $\mu_A : X \to [0,1]$ and non-membership function $\nu_A : X \to [0,1]$, where the membership function and non-membership function imply a degree of membership of the element x and a degree of non-membership of it in the set A. Also, for every $x \in X$, we have $0 \leq \mu_A(x) + \nu_A(x) \leq 1, \pi_A = 1 - \mu_A - \nu_A$.

Definition 2 [31,32] . Let A and B be two IFSs from a set of X's; then, the relations are described in Eqs. (2)–(8):

$$A \cup B = \{\langle x, \max(\mu_A(x), \mu_B(x)), \min(\nu_A(x), \nu_B(x))\rangle | x \in A\}, \tag{2}$$

$$A \cap B = \langle x, \min(\mu_A(x), \mu_B(x)), \max(\nu_A(x), \nu_B(x))\rangle | x \in A\}, \tag{3}$$

$$\bar{A} = \{\langle x, \nu_A(x), \mu_A(x)\rangle | x \in A\}, \tag{4}$$

$$A \oplus B = \left\{ \left\langle \begin{array}{l} x, \mu_A(x) + \mu_B(x) - \mu_A(x).\mu_B(x), \\ \nu_A(x).\nu_B(x), 1 - \mu_A(x) - \mu_B(x) \\ +\mu_A(x).\mu_B(x) - \nu_A(x).\nu_B(x) \end{array} \right\rangle | x \in A \right\}, \tag{5}$$

$$A \oplus B = \left\{ \left\langle \begin{array}{l} x, \mu_A(x).\mu_B(x), \nu_A(x) + \nu_B(x) \\ -\nu_A(x).\nu_B(x), 1 - \mu_A(x).\mu_B(x) \\ -\nu_A(x) - \mu_B(x) + \nu_A(x).\nu_B(x) \end{array} \right\rangle | x \in A \right\}, \tag{6}$$

$$A^\lambda = \left\{ \left\langle x, \mu_A(x)^\lambda, 1 - (1 - \nu_A(x)^\lambda) | x \in A \right\rangle, \ \lambda > 0 \right\}, \tag{7}$$

$$\lambda_A = \left\{ \left\langle x, 1 - (1 - \mu_A(x))^\lambda, \nu_A(x) | x \in A \right\rangle, \lambda > 0 \right\}. \tag{8}$$

Definition 3 [32]. Let E be the collection of the IFS $E = A_1, A_2, \cdots, A_n$. The summation and multiplication of the n-dimensional are obtained from Eqs. (9) and (10):

$$\overset{N}{\underset{i=1}{\oplus}} A(x_i) = \left[1 - \prod_{i=1}^{N} (1 - \mu_A(x_i)), \prod_{i=1}^{N} \nu_A(x_i), \prod_{i=1}^{N} (1 - \mu_A(x_i)) - \prod_{i=1}^{N} \nu_A(x_i) \right], \tag{9}$$

$$\overset{N}{\underset{i=1}{\otimes}} A(x_i) = \left[\prod_{i=1}^{N} \mu_A(x_i), 1 - \prod_{i=1}^{N} (1 - \nu_A(x_i)), \prod_{i=1}^{N} (1 - \nu_A(x_i)) - \prod_{i=1}^{N} \mu_A(x_i) \right]. \tag{10}$$

Definition 4 [33]. The hamming distance and Euclidean distance of two IFSs for $X = \{x_1, x_2, \cdots, x_N\}$ are calculated via Eqs. (11) and (12). Eq. (12) is shown on Box I.

$$d_H(A,B) = \frac{1}{2n} \sum_{i=1}^{N} (|\mu_A(x_i) - \mu_B(x_i)| + |\nu_A(x_i) - \nu_B(x_i)| + |\pi_A(x_i) - \pi_B(x_i)|). \tag{11}$$

Definition 5 [32] . The Intuitionistic Fuzzy Weight Averaging (IFWA) is computed via Eq. (13):

$$IFWA(A(x_1), A(x_2), ..., A(x_i)) = \left[\prod_{i=1}^{N} (\mu_A(x_i))^{w_i}, 1 - \prod_{i=1}^{N} (1 - \nu_A(x_i))^{w_i}, \right.$$

$$d(A,B)=\sqrt{\frac{1}{2n}\sum_{i=1}^{N}((\mu_A(x_i)-\mu_B(x_i))^2+(\nu_A(x_i)-\nu_B(x_i))^2+(\pi_A(x_i)-\pi_B(x_i))^2)}. \quad (12)$$

Box I

$$\prod_{i=1}^{N}(1-\nu_A(x_i))^{w_i}-\prod_{i=1}^{N}(\mu_A(x_i))^{w_i}\Bigg], \quad (13)$$

The weight vector in this equation generates $w_i = (w_1, w_2, \cdots, w_N)^T$.

Definition 6 [34]. The Intuitionistic Fuzzy Weighted Geometric (IFWG) is obtained via Eq. (14).

$$IFWG(A(x_1), A(x_2), ..., A(x_i)) =$$

$$\left[\frac{2\prod_{i=1}^{N}(\mu_A(x_i))^{w_i}}{\prod_{i=1}^{N}(2-\mu_A(x_i))^{w_i}+\prod_{i=1}^{N}(\mu_A(x_i))^{w_i}},\right.$$

$$\left.\frac{\prod_{i=1}^{N}(1+\nu_A(x_i))^{w_i}-(1-\nu_A(x_i))^{w_i}}{\prod_{i=1}^{N}(1+\nu_A(x_i))^{w_i}+(1-\nu_A(x_i))^{w_i}}\right]. \quad (14)$$

Definition 7. The normalized decision matrix is determined via Eq. (15). PC_j and NC_j are positive and negative attributes, respectively.

$$f_{ij}(\lambda(t_p))=\begin{cases}\{[\mu_{ij(tp)},\nu_{ij(tp)}]\}\\ \{[1-\mu_{ij(tp)},1-\nu_{ij(tp)}]\}\end{cases} \quad \forall i,j,p. \quad (15)$$

3. The proposed soft computing-based ideal solution approach

This section proposes a new intuitionistic fuzzy method to compute the weights of criteria and decision-makers and rank the candidate alternatives. The structure of the proposed method generates a new index to show the appropriate candidate. This approach is determined in Figure 1.

This study is created based on the group of Decision Makers (DMs) $(DM_k, k = 1,2,3,\cdots,K)$ and the potential candidate alternatives $(A_i, i = 1,2,3,\cdots,m)$. Furthermore, this situation exists under conflicting criteria $(C_j, j = 1,2,3,\cdots,n)$. At first, the matrix of group decision-making Intuitionistic Fuzzy Value (IFV) with linguistic judgment term of the experts is formed. Then, the values of this matrix should be changed into numerical values as given in Tables 1 and 2 [35].

However, the proposed IF-MCWR method is defined based on the following steps:

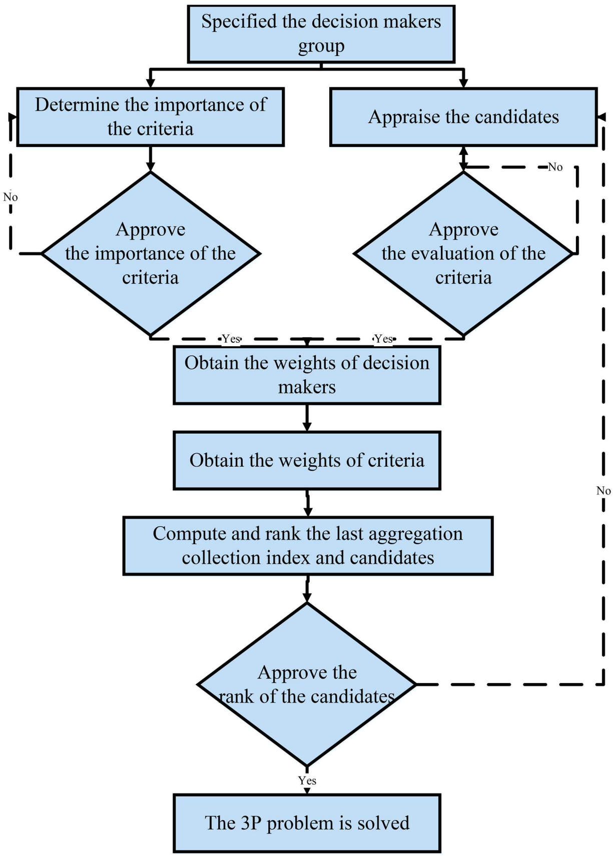

Figure 1. The structure of the proposed method.

Table 1. The linguistic variables for evaluating the criteria's importance.

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)

Step 1. Determine the matrix of group decision matrix (h) in Eq. (16) is shown in Box II.

Step 2. Generate the normalized group decision matrix with Definition 7.

Step 3. Compute the weights of the experts using the proposed intuitionistic fuzzy utility degree (IF-UD) method through the following steps:

$$h = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array}$$

$$\begin{bmatrix} \begin{array}{ccc} C_1 & \cdots & C_j \\ \left\{\left[\mu_{11}^{1p},\nu_{11}^{1p}\right],\left[\mu_{11}^{2p},\nu_{11}^{2p}\right],...,\left[\mu_{11}^{kp},\nu_{11}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{1n}^{1p},\nu_{1n}^{1p}\right],\left[\mu_{1n}^{2p},\nu_{1n}^{2p}\right],...,\left[\mu_{1n}^{kp},\nu_{1n}^{kp}\right]\right\} \\ & \ddots & \\ \left\{\left[\mu_{m1}^{1p},\nu_{m1}^{1p}\right],\left[\mu_{m1}^{2p},\nu_{m1}^{2p}\right],...,\left[\mu_{m1}^{kp},\nu_{m1}^{kp}\right]\right\} & \cdots & \left\{\left[\mu_{mn}^{1p},\nu_{mn}^{1p}\right],\left[\mu_{mn}^{2p},\nu_{mn}^{2p}\right],...,\left[\mu_{mn}^{kp},\nu_{mn}^{kp}\right]\right\} \end{array} \end{bmatrix}_{m\times n} \quad \forall p,k \qquad (16)$$

Box II

Table 2. The linguistic variables for rating the alternatives.

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)

Step 3.1. Present the normalized decision matrix for each expert (ξ_k) in Eq. (17):

$$\xi_k = \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} \begin{bmatrix} \begin{array}{ccc} C_1 & \cdots & C_j \\ [\mu_{11}^k,\nu_{11}^k] & \cdots & [\mu_{1n}^k,\nu_{1n}^k] \\ & \ddots & \\ [\mu_{m1}^k,\nu_{m1}^k] & \cdots & [\mu_{mn}^k,\nu_{mn}^k] \end{array} \end{bmatrix}_{m\times n} \quad \forall k. \qquad (17)$$

Step 3.2. Compute the positive (ρ^+) as well as left and right negative ideal decision matrix (ρ^{-L},ρ^{+L}) in Eqs. (18)–(23), respectively.

$$\rho^+ = [h_{ij}^+]_{m\times n} \qquad \forall k, \qquad (18)$$

$$h_{ij}^+ = \begin{cases} \{x_j, \max_k \langle R_{k(ij)}\rangle\} \\ \{x_j, \min_k \langle R_{k(ij)}\rangle\} \end{cases} \qquad \forall J, J'. \qquad (19)$$

Eq. (19) determines the establishment based on μ_{ij}^+ and ν_{ij}^+.

$$\rho^{-L} = [h_{ij}^{-L}]_{m\times n} \quad \forall k, \qquad (20)$$

$$h_{ij}^{-L} = \begin{cases} \left\{x_j, \min_k \left\langle [\mu_{ij}^k,\nu_{ij}^k] \in R_{k(ij)} \mid [\mu_{ij}^k,\nu_{ij}^k] \leq h_{ij}^+ \right\rangle\right\} \\ \left\{x_j, \max_k \left\langle [\mu_{ij}^k,\nu_{ij}^k] \in R_{k(ij)} \mid [\mu_{ij}^k,\nu_{ij}^k] \leq h_{ij}^+ \right\rangle\right\} \end{cases} \quad \forall J, J', \qquad (21)$$

$$\rho^{-R} = [h_{ij}^{-R}]_{m\times n} \quad \forall k, \qquad (22)$$

$$h_{ij}^{-R} = \begin{cases} \left\{x_j, \max_k \left\langle [\mu_{ij}^k,\nu_{ij}^k] \in R_{k(ij)} \mid [\mu_{ij}^k,\nu_{ij}^k] \geq h_{ij}^+ \right\rangle\right\} \\ \left\{x_j, \min_k \left\langle [\mu_{ij}^k,\nu_{ij}^k] \in R_{k(ij)} \mid [\mu_{ij}^k,\nu_{ij}^k] \geq h_{ij}^+ \right\rangle\right\} \end{cases} \quad \forall J, J', \qquad (23)$$

where h_{ij}^{-L} and h_{ij}^{-R} are obtained from $[\mu_{ij}^{-L},\nu_{ij}^{-L}]$ and $[\mu_{ij}^{-R},\nu_{ij}^{-R}]$, and the sets of J, J' are the benefit and cost of the criteria, respectively.

Step 3.3. Obtain the separation measure with positive ideal decision matrix (ϑ_k^+) from Eq. (24):

$$\vartheta_k^+ = \sqrt{\frac{1}{2n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(|\mu_{ij}^{k\in} - \mu_{ij}^{+\in}|^2 + |\nu_{ij}^{k\in} - \nu_{ij}^{+\in}|^2\right)} \quad \forall k. \qquad (24)$$

Step 3.4. Describe the separation measures from left and right negative ideal decision matrix (ϑ_k^{-L}, ϑ_k^{-R}) in Eqs. (25) and (26), respectively:

$$\vartheta_k^{-L} =$$

$$\sqrt{\frac{1}{2n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(|\mu_{ij}^{k\in}-\mu_{ij}^{-L\in}|^2+|\nu_{ij}^{k\in}-\nu_{ij}^{-L\in}|^2\right)} \quad \forall k, \tag{25}$$

$$\vartheta_k^{-R}=\sqrt{\frac{1}{2n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(|\mu_{ij}^{k\in}-\mu_{ij}^{-R\in}|^2+|\nu_{ij}^{k\in}-\nu_{ij}^{-R\in}|^2\right)} \quad \forall k. \tag{26}$$

Step 3.5. Obtain the importance degree of every expert (φ_k) from Eq. (27):

$$\varphi_k=\frac{\vartheta_k^{-L}+\vartheta_k^{-R}}{(\vartheta_k^{-L}+\vartheta_k^{-R}+\vartheta_k^{+})\left(\sum_{k=1}^{K}\frac{\vartheta_k^{-L}+\vartheta_k^{-R}}{\vartheta_k^{-L}+\vartheta_k^{-R}+\vartheta_k^{+}}\right)} \quad \forall k. \tag{27}$$

Step 4. Compute the weights of criteria are computed through the following steps using IF-PE method:

Step 4.1. Determine the normalized criteria intuitionistic fuzzy group decision matrix (T_j) based on Definition 7 in Eq. (28):

$$T_j=\begin{array}{c} \\ A_1 \\ \vdots \\ A_m\end{array}\begin{bmatrix} DM_1 & \dots & DM_K \\ [\mu_{1j}^1,\nu_{11}^1] & \dots & [\mu_{1n}^K,\nu_{1n}^K] \\ & \ddots & \\ [\mu_{mj}^1,\nu_{mj}^1] & \dots & [\mu_{mj}^K,\nu_{mj}^K]\end{bmatrix}_{m\times n} \quad \forall j. \tag{28}$$

Step 4.2. Obtain the IF-PE value (θ_j) from Eq. (29) as shown in Box III.

Step 4.3. Obtain the weights of criteria (χ_j) based on IF-PE method with Eq. (30) as shown in Box IV.

Step 4.4. Determine the final weight criteria (ϖ_j^f) using Eq. (31) where w_j^k is the importance degree of the jth creation taken from the kth DM.

$$\varpi_j^f=\frac{\chi_j\left(\prod_{k=1}^{K}(w_j^k)^{\varphi_k}\right)}{\sum_{j=1}^{n}\left(\chi_j\left(\prod_{k=1}^{K}(w_j^k)^{\varphi_k}\right)\right)} \quad \forall j. \tag{31}$$

Step 5. Obtain the IF-based normalized decision matrix of the weights of the experts ($S_{ij}^k=[\mu_{ij}^k,\nu_{ij}^k]_{m\times n}$) in Eq. (32):

$$S^k=\begin{array}{c} \\ A_1 \\ \vdots \\ A_m\end{array}\begin{bmatrix} C_1 & \dots & C_n \\ \varpi_1^f\,[\mu_{1j}^k,\nu_{11}^k] & \dots & \varpi_n^f\,[\mu_{1n}^k,\nu_{1n}^k] \\ & \ddots & \\ \varpi_1^f\,[\mu_{mj}^k,\nu_{mj}^k] & \dots & \varpi_n^f\,[\mu_{mn}^k,\nu_{mn}^k]\end{bmatrix}_{m\times n} \quad \forall k. \tag{32}$$

Step 6. Obtain the IF normalized weights of positive, left, and right negative ideal decision matrix for each expert (S^k).

Step 7. Compute the distance between the positive ideal value (ρ^+) and the IF normalized weighted decision matrix for each expert (S^k) with Eq. (33):

$$\zeta_i^{+k}=\sum_{j=1}^{n}\sqrt{\frac{1}{2n}\left(|S_{ij}^k-\mu_{ij}^{+\in}|^2+|S_{ij}^k-\nu_{ij}^{+\in}|^2\right)} \quad \forall i,k. \tag{33}$$

Step 8. Obtain the distance between the left and right negative $\left(\rho^{-L},\rho^{-R}\right)$ ideal decision matrix and

$$\theta_j=\sqrt{\frac{1}{2n}\sum_{k=1}^{K}\sum_{i=1}^{m}\left(|\mu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\mu_{ij}^{kp}|^2+|\nu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\nu_{ij}^{kp}|^2\right)} \quad \forall j. \tag{29}$$

Box III

$$\chi_j=\frac{\left|1-\left(\frac{1}{2}\sum_{k=1}^{K}\sum_{i=1}^{m}\left(|\mu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\mu_{ij}^{kp}|^2+|\nu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\nu_{ij}^{kp}|^2\right)\right)^{\frac{1}{2}}\right|}{\sum_{j=1}^{n}\left(\left|1-\left(\frac{1}{2}\sum_{k=1}^{K}\sum_{i=1}^{m}\left(|\mu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\mu_{ij}^{kp}|^2+|\nu_{ij}^{kp\in}-\frac{1}{2Km}\sum_{k=1}^{K}\sum_{i=1}^{m}\nu_{ij}^{kp}|^2\right)\right)^{\frac{1}{2}}\right|\right)} \quad \forall j. \tag{30}$$

Box IV

the IF normalized weighted decision matrix for each expert with Eqs. (34) and (35):

$$\zeta_i^{-kL} = \sum_{j=1}^{n} \sqrt{\frac{1}{2n}\left(|S_{ij}^k - \mu_{ij}^{-L\in}|^2 + |S_{ij}^k - \nu_{ij}^{-L\in}|^2\right)} \quad \forall i, k, \tag{34}$$

$$\zeta_i^{-kR} = \sum_{j=1}^{n} \sqrt{\frac{1}{2n}\left(|S_{ij}^k - \mu_{ij}^{-R\in}|^2 + |S_{ij}^k - \nu_{ij}^{-R\in}|^2\right)} \quad \forall i, k. \tag{35}$$

Step 9. Determine the importance degree of the candidate from the aggregation collection approach (ψ_i) with Eq. (36):

$$\psi_i = \frac{\prod_{k=1}^{K} (\zeta_i^{-kL})^{\varphi_k} + \prod_{k=1}^{K} (\zeta_i^{-kR})^{\varphi_k}}{\prod_{k=1}^{K} (\zeta_i^{-kL})^{\varphi_k} + \prod_{k=1}^{K} (\zeta_i^{-kR})^{\varphi_k} + \prod_{k=1}^{K} (\zeta_i^{+k})^{\varphi_k}} \quad \forall i. \tag{36}$$

Step 10. Rank the candidates with the aggregation collection set by incrementing sorting method.

However, the proposed procedure is summarized in the four following classes:

- **Class 1.** Create the IF group decision matrix based on experts' opinions for each criterion (Eq. (16));
- **Class 2.** Calculate the weights of decision-makers based on the proposed IF-UD approach (Eqs. (17)–(27));
- **Class 3.** Compute the weights of criteria based on the proposed IF-PE method (Eqs. (28)–(31));
- **Class 4.** Rank the alternatives based on proposed IF-soft computing-based ideal solution methodology by last aggregation approach (Eqs. (32)–(36)).

4. Case study

4.1. Urban development problem definition

This section is considered a case study based on the 3P urban development problem and the proposed method. The four DMs (DM_1, DM_2, DM_3, DM_4) are used to compute the weights of 20 financing challenge criteria ($C_1, C_2, \cdots, C_{20}$), which are defined in Table 3, to evaluate the four 3P problems ($3PP_1$, $3PP_2$, $3PP_3$, $3PP_4$). Furthermore, the criteria are gathered from the current exercises of the same company and based on experts' experience by implementing Delphi method. Therefore, the suggested criteria are provided for the experts to ask their opinions and this process is then continued until all four experts come to an agreement.

Furthermore, this paper is organized based on four main alternatives, namely the highway construction ($3PP_1$), bridge construction ($3PP_2$), conducting

Table 3. The definition of the criteria.

Criteria	Description
C_1	Currency fluctuations
C_2	Constant changes in national laws
C_3	Government support for the private sector
C_4	Inflation and its effect on construction and operation
C_5	Obtaining a bank loan
C_6	Failure to pay bills on time by the government
C_7	How to acquire the subject matter of the project
C_8	Adequate familiarity with international law
C_9	Boycott
C_{10}	Appropriate selection of partner (second hand contractors)
C_{11}	Complications of obtaining licenses
C_{12}	Instability of financial organizations in relation to national laws
C_{13}	Ability to provide facilities to banks
C_{14}	Working capital of the company
C_{15}	Supply of equipment, machinery and raw materials
C_{16}	Private sector competition with governments
C_{17}	Change the priority of projects at runtime
C_{18}	Risk of the possibility of pursuing the rights of private companies in the judiciary
C_{19}	Risk of non-fulfillment of employer obligations during project implementation and operation
C_{20}	Risk of high-level managers' taste in dealing with projects

Table 4. The linguistic values of the criteria.

Criteria	Decision-makers DM_1	DM_2	DM_3	DM_4
C_1	VH	H	H	VH
C_2	H	VH	VH	VH
C_3	L	VL	L	M
C_4	VH	VH	VH	VH
C_5	VL	M	H	H
C_6	VH	VH	VH	H
C_7	M	L	M	M
C_8	VL	VL	VL	M
C_9	VH	VH	VH	H
C_{10}	L	L	M	L
C_{11}	VH	VH	H	VH
C_{12}	VH	VH	VH	VH
C_{13}	M	H	M	H
C_{14}	H	H	H	VH
C_{15}	VH	VH	H	VH
C_{16}	VH	VH	M	H
C_{17}	H	M	VH	VH
C_{18}	VH	VH	VH	VH
C_{19}	VH	H	VH	H
C_{20}	H	H	VH	M

surface water ($3PP_3$), and metro development ($3PP_3$). In addition, experts' judgments are gathered to evaluate the importance degrees of the criteria. Afterward, this table is changed to the IF values, and the criteria are ranked based on the proposed method.

This section describes the aforementioned judgments based on multi-criteria with linguistic variables. After that, these values are changed into IFVs, and the criteria are ranked based on the candidate alternative using the proposed IF-UD method. Although the linguistic judgment about the criteria importance is shown in Table 4, the values of potential alternatives compared to the criteria based on experts' judgment are determined in Table 5. Afterward, the linguistic terms are changed into the IF values, as can be seen in Tables 1 and 2. These evaluation processes based on linguistic terms and experts' judgments are tailored by Delphi method where each decision-maker defines opinions about the criteria importance and alternatives evaluation to construct a group decision-making matrix. Finally, the established group decision-making matrix is confirmed by all experts.

4.2. Execution

This section explores the implementation of the proposed IF-UD approach to compute the weight of each DM in reducing the errors. To this point, the positive ideal decision matrix as well as the left and right ideal decision matrices are computed via Eqs. (20)–(25), and the aforementioned ideal decision matrices are obtained using Eqs. (24)–(26). Eventually, the relevant importance of DMs is determined by Eq. (27). These are shown in Table 6.

The criteria's weights are calculated by Eq. (29) based on the experts' opinions and the proposed IF-PE method. Afterward, the computed preference value is

Table 6. The DM weights obtained based on IF-UD approach.

Decision -makers	ϑ_k^{+}	ϑ_k^{-L}	ϑ_k^{-R}	φ_k
DM_1	0.73021	1.21709	0.53810	0.27003
DM_2	0.91701	1.10743	0.74219	0.25563
DM_3	1.07096	0.92323	0.92315	0.24200
DM_4	1.20808	0.79803	1.07289	0.23234

Table 5. The linguistic assessment of alternatives.

Alternatives	DMs	Criteria C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}
$3PP_1$	DM_1	VVH	VH	VL	VVH	VL	VVH	MH	ML	VVH	ML	H	AH	H	MH	VVH	MH	VVH	VH	AH	VVH
	DM_2	VVH	VVH	L	AH	L	AH	H	L	VVH	L	VVH	VH	VH	H	VH	MH	VVH	VH	VVH	VVH
	DM_3	VH	AH	VL	VVH	ML	AH	M	L	VVH	ML	VH	VH	MH	H	VH	H	VH	H	VVH	VH
	DM_4	AH	MH	ML	VVH	M	MH	H	VL	AH	M	VH	VVH	MH	VH	VVH	MH	VVH	VH	VVH	MH
$3PP_2$	DM_1	M	H	AH	MH	MH	VVH	L	M	H	ML	MH	VH	M	M	VVH	M	H	H	H	H
	DM_2	AH	M	H	VVH	MH	VH	VH	MH	VH	H	M	H	AH	H	H	VH	H	VH	H	VVH
	DM_3	VH	H	L	VH	M	ML	VH	H	MH	H	H	MH	H	MH	L	H	M	MH	VH	VH
	DM_4	VL	M	M	L	ML	ML	VVH	VH	VVH	VH	H	VH	L	H	M	H	L	VH	H	VH
$3PP_3$	DM_1	H	VVH	VH	VH	VVH	VVH	L	VH	VVH	ML	H	VVH	H	VH	H	ML	VVH	VVH	H	VH
	DM_2	M	VH	M	ML	VH	L	ML	L	ML	L	M	L	M	L	M	VL	VH	ML	H	VVH
	DM_3	H	H	H	VH	MH	H	MH	H	M	MH	MH	M	H	VH	VH	M	MH	M	H	VH
	DM_4	H	MH	H	ML	H	H	MH	VH	H	M	VH	H	H	M	MH	L	VH	H	H	VH
$3PP_4$	DM_1	VVH	VH	VH	VH	VVH	MH	VH	H	VH	M	VH	VH	AH	HH	VVH	ML	VH	MH	VVH	H
	DM_2	VH	VH	H	VH	VH	H	MH	M	H	MH	MH	VH	VH	MH	VH	M	H	VVH	VH	H
	DM_3	VVL	VH	ML	VL	VVH	VH	VL	VVH	ML	VH	VH	ML	VVL	VVH	VH	VL	AH	VH	VH	VH
	DM_4	VL	AH	VH	VVL	AH	VVH	VVL	VVH	VVH	VVL	VVH	VH	VVL	AH	AH	VL	MH	VH	MH	H

Table 7. The criteria weights computed based on IF-PE approach.

Criteria	θ_k	χ_i	ϖ_j^f
C_1	0.72424	0.03889	0.04475
C_2	0.61315	0.05456	0.06280
C_3	0.73772	0.03699	0.01872
C_4	0.71381	0.04036	0.04651
C_5	0.58702	0.05824	0.04084
C_6	0.64211	0.05047	0.05811
C_7	0.66759	0.04688	0.03831
C_8	0.64757	0.04970	0.01827
C_9	0.62550	0.05282	0.06080
C_{10}	0.60562	0.05562	0.03590
C_{11}	0.59826	0.05666	0.06522
C_{12}	0.63486	0.05149	0.05934
C_{13}	0.70806	0.04117	0.04231
C_{14}	0.61453	0.05436	0.05908
C_{15}	0.63738	0.05114	0.05887
C_{16}	0.61222	0.05469	0.05957
C_{17}	0.63571	0.05138	0.05580
C_{18}	1.33599	0.04738	0.05460
C_{19}	1.37408	0.05276	0.06071
C_{20}	0.61392	0.05445	0.05948

utilized in Eq. (30). Furthermore, the final weights of criteria are obtained from Eq. (31). These results are determined in Table 7.

Then, the last aggregation approach is considered in process of solving the urban development 3P project selection problem. Meanwhile, the expert decision matrix based on IF is constructed based on Eq. (32) and the weighted normalized IF-decision matrix is generated by the IF-PE approach. The separation measures of all alternatives based on DMs' opinions and by Euclidean distance are obtained from Eqs. (33)-(35). The aforementioned result is determined in Table 8.

Hence, the results of the aggregation collection index method based on the last aggregation approach and IF-UD method are shown in Table 9. The last aggregation method is employed to aggregate separate measures fitting the weights of DMs. These weights are computed via the IF-UD approach.

Finally, the proposed method is compared with two other approaches namely Simple Additive Weighting (SAW) method and fuzzy-TOPSIS methodology from the study of Jokar et al. [29]. The computation results and ranking of the alternatives using these approaches are shown in Table 10.

The computational results show that the second alternative is of higher priority than other alternatives with two various ranking approaches. After that, the third, fourth, and first alternatives have other places regarding Table 10, respectively. It is now clear that the first alternative is the worst case while the second alternative is the best case for the product in the 3P urban development projects. In addition, as shown in Figure 2, the obtain ranking results from both approach are similar. Similar responses in the ranking of options indicate the acceptability of the proposed method and that the method is in alignment with the other considered methods.

Moreover, Figure 3 reports the trend of criteria weights using the proposed approach and that in the study of Jokar et al. [29]. According to the figure, both of the approaches confirmed that the 11th criterion is the most important indicator, which is related to the complications of obtaining licenses. In addition, the 8th criterion, i.e., "adequate familiarity with interna-

Table 8. The positive, negative left, and negative right separation measures.

DMs	Alternatives	ζ_i^{+k}	ζ_i^{-kL}	ζ_i^{-kR}
DM_1	$3PP_1$	0.02694	0.02657	0.02687
	$3PP_2$	0.04773	0.07891	0.04671
	$3PP_3$	0.01719	0.11067	0.01719
	$3PP_4$	0.02690	0.11083	0.02690
DM_2	$3PP_1$	0.02481	0.02897	0.02481
	$3PP_2$	0.01902	0.11016	0.01902
	$3PP_3$	0.11367	0.01224	0.11604
	$3PP_4$	0.03307	0.10991	0.03307
DM_3	$3PP_1$	0.02634	0.02740	0.02634
	$3PP_2$	0.05427	0.07501	0.05427
	$3PP_3$	0.03455	0.09382	0.03455
	$3PP_4$	0.10057	0.04273	0.10057
DM_4	$3PP_1$	0.02374	0.03001	0.02374
	$3PP_2$	0.07876	0.05046	0.07876
	$3PP_3$	0.04222	0.08619	0.04222
	$3PP_4$	0.09651	0.04657	0.09651

Table 9. The aggregation of separation measures and last aggregation index.

Alternatives	ζ_i^{+k}	ζ_i^{-kl}	ζ_i^{-kR}	ψ_i
$3PP_1$	0.02548	0.02815	0.02546	0.67788
$3PP_2$	0.04372	0.07651	0.04177	0.73014
$3PP_3$	0.04065	0.05715	0.04086	0.70685
$3PP_4$	0.05250	0.07179	0.05250	0.70304

Table 10. The comparison of ranking for the three different methods.

Alternatives	Ranking of proposed method	Final weight by SAW method	Ranking based on SAW method	Closeness index by Jokar et al. [29]	Ranking based on Jokar et al. [29]
$3PP_1$	4	0.06084	4	0.78881	4
$3PP_2$	1	0.10465	1	0.87233	1
$3PP_3$	2	0.07232	2	0.84003	2
$3PP_4$	3	0.06128	3	0.80919	3

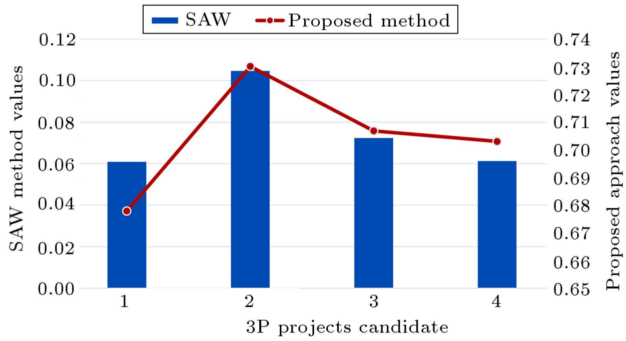

Figure 2. The obtained ranking results for the proposed approach and SAW method.

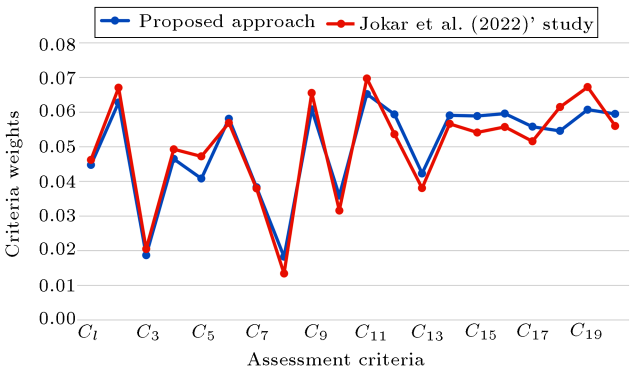

Figure 3. The comparison of criteria normal weights.

tional law", has the lowest weight based on the mentioned confirmation from both approaches. Although the similarity of the final results brings about agreement between the accuracy and precision of the proposed method, the advantages and superiority of the proposed approach are discussed in the next section.

5. Discussion

5.1. Comparative analysis

In this section, a comparative analysis is carried out based on some comparison factors such as uncertainty modeling, last aggregation approach, group decision analysis, criteria weights determination, and experts' weight computations from the study of Gitinavard et al. [36] in order to represent the advantages of the proposed approach with respect to the SAW methodology and the approach set by Jokar et al. [29]. However, the comparative reports are explained in detail as follows:

- **Uncertainty modeling:** This factor is associated with the considered process to deal with imprecise information. The proposed approach of this study, similar to that of Jokar et al. [29], considers fuzzy set theory to cover uncertainty;
- **Last aggregation approach:** This factor is concerned with data loss and unlike the two other approaches, the proposed approach was developed based on last aggregation process;
- **Group decision analysis:** This comparison factor follows the group decision-making process in which all the three approaches can consider the judgments of a group of experts;
- **Criteria weights determination:** This factor represents the criteria importance to reach a precise solution. In this respect, the presented approach, similar to the approach of Jokar et al; [29], provides a criteria weight process;
- **Experts' weights computation:** This factor determines the expertise of each decision-maker to balance their judgments. In this respect, this paper, unlike two other studies, proposed an IF-UD method to compute the experts' weights.

Therefore, the aforementioned comparisons illustrate that the proposed intuitionistic fuzzy soft computing-based ideal solution can yield reliable and accurate results. In this respect, unlike two other approaches, the proposed approach is deemed superior by satisfying both last aggregation approach and experts' weight computation factors.

5.2. Sensitivity analysis

In this section, a sensitivity analysis is elaborated to determine the sensitiveness and robustness of the both last aggregation approach and experts' weights novelties that are defined as two superior cases in the previous section. In this respect, two scenarios are defined in which at the first scenario the last aggregation mechanism is removed from the proposed approach process. At the second one, the experts' weights is eliminated from the process of proposed method. As

Table 11. The sensitivity analysis results.

	Before scenario implementation		After 1st scenario implementation		After 2nd scenario implementation	
Alternatives	ψ_i	**Ranking**	ψ_i	**Ranking**	ψ_i	**Ranking**
$3PP_1$	0.67788	4	0.69823	4	0.70039	3
$3PP_2$	0.73014	1	0.74083	2	0.75308	1
$3PP_3$	0.70685	2	0.76247	1	0.72823	2
$3PP_4$	0.70304	3	0.71356	3	0.68387	4

indicated in Table 11, both scenarios can affect the obtained ranking results. Therefore, considering the last aggregation approach and providing the experts' weights could lead to appropriate results.

5.3. Managerial implications

In this section, managerial implications are defined based on the obtained results, comparative analysis, and sensitivity analysis:

- The users employing the proposed approach can consider the Delphi method to gather experts' judgments;
- The proposed approach has the ability to change the number of assessment criteria or candidates;
- The managers should consider the experts' weights to reach a precise solution;
- The obtained results indicate that the "complications of obtaining licenses" and "adequate familiarity with international law" are the highest and lowest weights in decision-making results, respectively;
- The ranking results are sensitive to experts' weights and last aggregation process;
- Classical methods like SAW could not yield suitable and accurate results;
- The proposed approach can be applied to a wide range of group decision-making problems;
- Fuzzy set theory can be considered to deal with uncertain situation and imprecise information;
- Comparative analysis represents that the proposed approach has several merits that help users obtain the best solution;
- The proposed approach does not have a hierarchical structure and effects of interdependencies on determining the criteria weights;
- The proposed soft computing-based ideal solution methodology may be time-consuming for large case studies, and it is suggested the Python software be used to solve them.

6. Conclusions and future directions

In real-world relations, one of the most important challenges is the necessity of proper decision-making. These challenges are not limited to one industry per se; they affect any actions or plans one intends to perform. Urban development is one of such actions that has a high priority for urban mangers. The Public Private Partnership (3P) project policy manager helps managers and the government to assign a project to another department in a secure manner. Moreover, different types of the challenges constrain firms' contractors, which should be handled in order to construct a project properly. Financing challenge is a significant drawback that many companies are struggling with. This study managed this type of challenge by proposing a novel decision technique under uncertainty. The intuitionistic fuzzy approach was employed to deal with uncertain condition and to help the Decision Makers (DMs) make the best decision in the real world. Hence, the proposed method was established based on the IF-Utility Degree (IF-UD) method to compute the weights of the experts' opinions. In addition, the IF-Preference Evaluation (IF-PE) method and the aggregation collection method were applied to obtain the criteria weights and rank various alternatives, respectively. Afterward, one practical example was considered to determine the validity of the proposed method. This example was constructed based on the urban development 3P project with four DMs and 20 criteria. It also generated four types of candidate alternatives. Furthermore, the weights of the elements were calculated using the proposed approach, and the sensitivity of the proposed approach was analyzed and compared with both the Simple Additive Weighting (SAW) method and another approach suggested by a recent study for the ranking issue. These measures showed the performance and accuracy of the proposed method. Moreover, the comparative analysis demonstrated that the proposed soft computing-based ideal solution method had several advantages compared to the recent approaches existing in the literature such as last aggregation mechanism and experts' weight determination. In this regard, the sensitivity analysis indicated that the obtained ranking results were sensitive to both of the aforementioned comparison factors. For further study, it is recommended that the inference engine be used to identify the main selection criteria and the candidate alternatives of the 3P urban development project. Moreover, the proposed approach can be enhanced by applying it to a practical case [37,38].

References

1. Gitinavard, H., Mousavi, S.M., Vahdani, B., et al. "Project safety evaluation by a new soft computing approach-based last aggregation hesitant fuzzy complex proportional assessment in construction industry", *Scientia Iranica*, **27**(2), pp. 983–1000 (2020).
2. Gan, T., Yang, H., and Liang, W. "How do urban haze pollution and economic development affect each other? Empirical evidence from 287 Chinese cities during 2000–2016", *Sustainable Cities and Society*, **65**, 102642 (2021).
3. Abad–Segura, E. and González-Zamar, M.-D. "Sustainable economic development in higher education institutions: A global analysis within the SDGs framework", *Journal of Cleaner Production*, **294**, 126133 (2021).
4. Ghaderi, H., Gitinavard, H., and Mehralizadeh, M. "An intuitionistic fuzzy DEA cross-efficiency methodology with an application to production group decision-making problems", *Journal of Quality Engineering and Production Optimization*, **5**(2), pp. 69–86 (2020).
5. Solgi, E., Gitinavard, H., and Tavakkoli-Moghaddam, R. "Sustainable high-tech brick production with energy-oriented consumption: An integrated possibilistic approach based on criteria interdependencies", *Sustainability*, **14**(1), 202 (2021).
6. Gitinavard, H. "Strategic evaluation of sustainable projects based on hybrid group decision analysis with incomplete information", *Journal of Quality Engineering and Production Optimization*, **4**(2), pp. 17–30 (2019).
7. Vakili, R., Akbarpour Shirazi, M., and Gitinavard, H. "Multi-echelon green open-location-routing problem: A robust-based stochastic optimization approach", *Scientia Iranica*, **28**(2), pp. 985–1000 (2021).
8. Botlhale, E. "Financing development through public private partnerships (PPPs) in Botswana", *Africa's Public Service Delivery and Performance Review*, **4**(1), pp. 26–49 (2016).
9. Solgi, E., Husseini, S.M.M., Ahmadi, A., et al. "A hybrid hierarchical soft computing approach for the technology selection problem in brick industry considering environmental competencies: A case study", *Journal of Environmental Management*, **248**, 109219 (2019).
10. Du, J., Wu, H., and Zhao, X. "Critical factors on the capital structure of public-private partnership projects: A sustainability perspective", *Sustainability*, **10**(6), 2066 (2018).
11. Davoudabadi, R., Mousavi, S.M., Šaparauskas, J., et al. "Solving construction project selection problem by a new uncertain weighting and ranking based on compromise solution with linear assignment approach", *Journal of Civil Engineering and Management*, **25**(3), pp. 241–251 (2019).
12. Jones, S. and Wang, T. "Predicting private company failure: A multi–class analysis", *Journal of International Financial Markets, Institutions and Money*, **61**, pp. 161–188 (2019).
13. Sarvari, H., Nassereddine, H., Chan, D.W., et al. "Determining and assessing the significant barriers of transferring unfinished construction projects from the public sector to the private sector in Iran", *Construction Innovation*, **21**(4), pp. 592–607 (2020).
14. Chung, W.Y., Jo, Y., and Lee, D. "Where should ICT startup companies be established? Efficiency comparison between cluster types", *Telematics and Informatics*, **56**, 101482 (2021).
15. Behzadipour, A., Gitinavard, H., and Akbarpour Shirazi, M. "A novel hierarchical dynamic group decision-based fuzzy ranking approach to evaluate the green road construction suppliers", *Scientia Iranica* (2022). doi. 10.24200/SCI.2022.58112.5571
16. Hamzeh, A.M., Mousavi, S.M., and Gitinavard, H. "Imprecise earned duration model for time evaluation of construction projects with risk considerations", *Automation in Construction*, **111**, 102993 (2020).
17. Kim, Y.-j. and Choi, M.J. "Contracting-out public-private partnerships in mega-scale developments: The case of New Songdo City in Korea", *Cities*, **72**, pp. 43–50 (2018).
18. Kavishe, N., Jefferson, I., and Chileshe, N. "Evaluating issues and outcomes associated with public-private partnership housing project delivery: Tanzanian practitioners' preliminary observations", *International Journal of Construction Management*, **19**(4), pp. 354–369 (2019).
19. Xiong, W., Chen, B., Wang, H., et al. "Public-private partnerships as a governance response to sustainable urbanization: Lessons from China", *Habitat international*, **95**, 102095 (2020).
20. Firman, A., Ilyas, G.B., and Putra, A. "Planning strategy of operation business and maintenance by analytical hierarchy process and strength", *International Journal of Energy Economics and Policy*, **11**(3), pp. 126–143 (2020).
21. Wang, G., Wu, P., Wu, X., et al. "Mapping global research on sustainability of megaproject management: A scientometric review", *Journal of Cleaner Production*, **259**, 120831 (2020).
22. Rahmah, M. and Zaidun, M. "The construction of indonesian maritime infrastructure through public

private partnerships", *Opción: Revista de Ciencias Humanas y Sociales*, **90**, pp. 461–475 (2019).

23. Seddighi, H., Seddighi, S., Salmani, I., et al. "Public-private-people partnerships (4P) for improving the response to COVID–19 in Iran", *Disaster Medicine and Public Health Preparedness*, **15**(1), pp. e44–e49 (2021).

24. Gitinavard, H., Shirazi, M.A., and Zarandi, M.H.F. "Sustainable feedstocks selection and renewable products allocation: A new hybrid adaptive utility-based consensus model", *Journal of Environmental Management*, **264**, pp. 110428 (2020).

25. Chang, J.-P., Chen, Z.-S., Xiong, S.-H., et al. "Intuitionistic fuzzy multiple criteria group decision making: A consolidated model with application to emergency plan selection", *IEEE Access*, **7**, pp. 41958–41980 (2019).

26. Geng, S., Lin, L., Yin, Y., et al. "Loan approval evaluation framework of public-private partnership project of battery storage power station under interval-valued intuitionistic fuzzy environment", *Journal of Cleaner Production*, **254**, 120133 (2020).

27. Jokar, E., Aminnejad, B., and Lork, A. "Assessing and prioritizing risks in Public-Private Partnership (PPP) projects using the integration of fuzzy multi-criteria decision-making methods", *Operations Research Perspectives*, **8**, 100190 (2021).

28. Tian, C., Peng, J.-j., Zhang, S., et al. "A sustainability evaluation framework for WET-PPP projects based on a picture fuzzy similarity-based VIKOR method", *Journal of Cleaner Production*, **289**, 125130 (2021).

29. Jokar, E., Aminnejad, B., and Lork, A. "A risk allocation model among the elements of freeway projects in public-private partnership (PPP) method using integrated fuzzy multi-criteria decision-making techniques", *Australian Journal of Civil Engineering*, **25**, pp. 1–25 (2022).

30. Bustince, H. and Burillo, P. "Vague sets are intuitionistic fuzzy sets", *Fuzzy Sets and Systems*, **79**(3), pp. 403–405 (1996).

31. Atanassov, K.T. "New operations defined over the intuitionistic fuzzy sets", *Fuzzy Sets and Systems*, **61**(2), pp. 137–142 (1994).

32. Xu, Z. and Yager, R.R. "Some geometric aggregation operators based on intuitionistic fuzzy sets", *International Journal of General Systems*, **35**(4), pp. 417–433 (2006).

33. Szmidt, E. and Kacprzyk, J. "Distances between intuitionistic fuzzy sets", *Fuzzy Sets and Systems*, **114**(3), pp. 505–518 (2000).

34. He, Y., Chen, H., Zhou, L., et al. "Intuitionistic fuzzy geometric interaction averaging operators and their application to multi-criteria decision making", *Information Sciences*, **259**, pp. 142–159 (2014).

35. Davoudabadi, R., Mousavi, S.M., Mohagheghi, V., et al. "Resilient supplier selection through introducing a new interval-valued intuitionistic fuzzy evaluation and decision-making framework", *Arabian Journal for Science and Engineering*, **44**(8), pp. 7351–7360 (2019).

36. Gitinavard, H., Ghaderi, H., and Pishvaee, M.S. "Green supplier evaluation in manufacturing systems: a novel interval-valued hesitant fuzzy group outranking approach", *Soft Computing*, **22**(19), pp. 6441–6460 (2018).

37. Chen, Z.-S., Zhang, X., Rodriguez, R.M., et al. "Expertise-structure and risk-appetite-integrated two-tiered collective opinion generation framework for large scale group decision making", *IEEE Transactions on Fuzzy Systems*, **30**(12), pp. 5496–5510 (2022).

38. Jiang, W.-H., Xu, L., Chen, Z.-S., et al. "Financing equilibrium in a capital constrained supply Chain: The impact of credit rating", *Transportation Research Part E: Logistics and Transportation Review*, **157**, 102559 (2022).

Biographies

Seyed Masoud Mortazavi is currently a PhD Candidate at the Department of Construction Engineering and Management, Islamic Azad University, Qeshm, Iran. He received his MSc degree in Earthquake Civil Engineering, Islamic Azad University of Shahrekord, Iran, and his BSc degree from the Islamic Azad University of Shahrekord, Iran. He has published one book and several papers in reputable journals and international conference proceedings. He has been a member of Construction Engineering Organization of Tehran Province, Iran and a member of official court expert, Iran.

Mohammad Reza Adlparvar is an Associate Professor at the Faculty of Technical and Engineering Structural Group at University of Qom, Iran. He is the Director of Iranian Association of Light Weight Structures, Tehran, Iran; a member of Iranian Civil Engineering Association Tehran, Iran; a member of Iranian Rail way Transportation Association Tehran, Iran; a member of Highest Degree in Civil Engineering Organization, Tehran; and Iran Guest Lecturer at Iranian Technical and Science Engineering University, Iranian Azad University Science and Research Center, Iranian Azad University International branch at Qeshm Azad University. He has been a guest lecturer at Semnan University, International University of Chabahar and a member of the Knowledge-Information Systems Laboratory at University of Toronto, Canada. His main research interests focus on precast and prestress concrete structures, cold form steel structures, lightweight structurers, and earthquake structures. Professor Mohammad Reza Adlparvar has published over 7 books and book chapters, more than 30 scientific journal papers, more than 240 refereed conference papers, and several technical reports in the above areas, most of which are also accessible on the website of Qom.ac.ir. He has taught several courses in Concrete Structures, Earthquake Engineering, and Light Weight Structures in Iran and Uroup, US, United Arb Emirate, and Africa. He has been a part of many design, inspection, and contract projects in Iran and Iraq, Kenya, and Serylanka.

Mahtiam Shahbazi is an Assistant Professor at the Department of Architecture at Science and Research Branch, Islamic Azad University, Tehran, Iran. She is an experienced project designer with a demonstrated history of working in the architecture and planning industry. She is skilled in landscape architecture design, lecturing, sustainable design, and design research. He enjoys professionalism in strong program and project management with a Doctor of Philosophy (PhD) in Landscape Architecture from Iran University of Science and Technology. She has published several papers in scientific journals and international conference proceedings.