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RESEARCH PAPER

An Integrated Soft Computing Method Based on Intuitionistic Fuzzy Environment to Appraise the Urban Bridge Maintenance Models

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Abstract

In today's world, communication between different communities is a must. One of the mechanisms of communication between humans has been the use of the bridge industry. Bridges can have an impact on the communication between two sections or two different geographical areas. In this study, it was found that the use of bridges includes two operations of bridge construction or bridge reconstruction. Due to resource constraints and issues related to the location of the new area and the exorbitant construction costs, the reconstruction of old bridges is considered a suitable approach. Therefore, some important candidate factors exist for the reconstruction of old bridges that should rank to help managers get an efficient decision. Meanwhile, this study proposed an intuitionistic fuzzy integrated-based compromise solution (CS) and DEMATEL approach to rank the candidate by computing experts' weights and determining criteria importance, respectively. In addition, the proposed approach is developed based on the last aggregation approach to prevent data loss during the preferences integration. Besides, a real case study of the bridge maintenance operation is proposed in Rasht city of Iran to represent the implementation procedure of the proposed IF-integrated approach. The results indicate that the pipeline project of water supply lines is considered as the best candidate among the four maintenance models candidate. Finally, the proposed method was compared with the TOPSIS method to indicate the validity and the efficiency of the proposed method and emphasize its appropriateness.

Keywords:
Bridge Construction,
Maintenance Models Selection,
Intuitionistic Fuzzy Set,
DEMATEL Method,
Weighting Process

Introduction

Nowadays, logistics and the transportation network have an essential position in the style and the quality of life of humans [1,2]. People need transportation tools to communicate with each other, and close to them to help other persons [3]. The transportation tools can be comprised of various types of vehicles, highways, subways, roads, and bridges [4]. In these parts, bridges have an important role to create the connection among several points in the cities, and urban structures. This structure existed from many years ago and in the baseline of history helped the persons to transfer between the different nodes [5]. These infrastructures are among the most strategic elements of transportation networks that have been constructed by crossing natural

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and artificial barriers and are more affected by the environment than other infrastructures related to this sector [6].

Bridges are among the structures that due to high service life, wear, damage and sometimes deterioration over time [7,8]. Despite the importance of this issue, it is often assumed that bridges are permanent structures and ignored the fact that they may deteriorate over time [9]. This failure can have significant economic consequences, including maintenance costs, occasionally and rebuilding of bridges [10]. Even assuming the correct design and precise execution of the bridge, many factors are effective in its durability and health or its deterioration. For example, various factors such as the shape of the bridge structure, building materials, build quality, design, execution, weather conditions, scour, heat, fatigue, earthquake, flood, air, density of loads passing over the bridge and such are among the issues. Which are effective in how and to what extent the bridge is worn and deteriorated [11].

Bridges have always been one of the most arterial structures in transportation networks, are valuable assets for any country and should be managed in such a way that in a relatively long time at a good level of service and service remains Stay. Because bridges are one of the most costly and sensitive structures in the transportation network, failure to maintain and repair them during operation may have many destructive effects on the entire network [12,13]. In addition, the deterioration of these vital infrastructures and the budgetary constraints on their maintenance and repair in recent years have led decision-makers and officials of relevant organizations to make more efficient use of available resources to maintain and preserve these assets has done [14,15]. Because on the one hand, bridge maintenance officials usually face the problem of lack of budget and its optimal allocation, and on the other hand, the longer the repair and reconstruction of bridges are delayed, the more critical their condition and the higher the cost and time of repair [16].

Considering the various technical and engineering factors as well as the available economic resources, it can be said that success in the maintenance of bridges depends on the scientific knowledge of geometric and physical defects and their various structural and non-structural components on the one hand and it is also how to eliminate them on the other hand [17]. In this regard, planning to maintain the correct components of the bridges and eliminate their defects and design and improve them in accordance with the existing natural conditions is necessary and the need for it is felt more and more [18]. It is essential to identify these limitations and to plan and conduct regular inspections of bridges based on a systematic system in order to prevent serious and hazardous failures as well as to avoid incurring high costs to compensate for these failures. This issue has led to the development of bridge management systems (BMS) in recent years [19].

A bridge management system is a systematic method that provides the most economical strategy for maintaining and repairing bridges by accurately assessing the current condition of bridges and predicting their future condition [20,21]. The purpose of developing bridge management systems is to provide a model for identifying the condition of existing bridges and evaluating their maintenance and repair conditions in order to allocate financial resources according to various inspections throughout the life of the bridge [22]. In such a way that it leads to optimal results with multi-purpose goals of maintaining the safety and usability of the bridge [23]. The importance of maintaining and repairing bridges has made the need to identify defects and eliminate them a necessity and inevitable. Because the study of issues related to the failure of a bridge in the bridge management system, including structural and non-structural defects of its components and understanding the causes of their occurrence, provides an important and sensitive role in eliminating defects and providing appropriate and optimal solutions to prevent and develop brings [24].

Maintenance, on the other hand, is a supportive process that provides equipment conditions for continuous productivity and service [25]. Maintenance is a set of activities that are specifically and usually planned to prevent the sudden breakdown of equipment and facilities. This work, which increases the reliability and availability of equipment, is called maintenance activities. Repairs also include a set of activities performed on a system that has crashed or crashed. This set of activities returns the system to a ready and efficient state and prepares it to perform the task assigned to it [26,27]. Since the development of a bridge management system is associated with complex components of assessing the current state of a set of bridges, so today various maintenance systems such as failure-based note (BM), preventive note (PM), pre-note Binomial (PDM), correctional note (CM) is presented, each of which has its own actions and suggestions [28]. Thus, manipulating a group of experts to assess decision-making problems under a fuzzy environment can help managers to select the best maintenance models [29,30]. In sum, the review of the literature is represented in Table 1 to represent the merits and advantages of the proposed approach.

Table 1. The research gap of energy decision-making literature

Authors	Approach's characteristics						
	Fuzzy environment	Criteria weights-based		Group decision tool	Risk preferences of experts	Last aggregation approach	Experts' weights
		Experts' preferences	New model				
Xiang [31]			√				√
Ren [32]	√	√					
Jeong and Ramírez-Gómez [33]	√		√				
Gomes et al. [34]			√	√	√		
Fathipour and Saidi-Mehrabad [35]		√	√				
Kofinas et al. [36]	√	√					
Rashidi and Cullinane [37]	√	√	√	√			
Rani et al. [38]	√	√		√	√		
Solangi et al. [39]	√		√	√			
This Study	√	√	√	√	√	√	√

Meanwhile, considering the costs of building a new concrete structure as a bridge and the costs associated with human resources, the use of maintenance approaches is very valuable and efficient. These methods can be planned and implemented under the bridge management approach. Next, uncertainty-based approaches are used as management levels decide on a project to maintain worn-out bridges and assess the extent of damage to the structure. In this research, an intuitive fuzzy method has been used to deal with uncertainty. Also, in order to make the right decision and correctly identify the factors affecting the maintenance management of concrete bridges, group decision-based approaches are considered and used the opinions of a group of experts. The proposed method is based on intuitive fuzzy and in order to evaluate its performance, a case study in Rasht is considered. Hence, the proposed method is based on the calculation of the criteria's weights and the alternatives rank, respectively. These two main sectors contain the proposed approach. However, the main contributions and merits of this study regarding the aforementioned survey of the literature are summarized as follows:

- Presenting an IF-DEMATEL approach to compute the criteria weights based on their interdependency relations;
- Developing an IF-CS methodology to compute the DMs' weights for decreasing the judgments errors;

- Considering the last aggregation concept to avoid the data loss during the ranking procedure;
- Proposing an IF-COMPRAS ranking methodology based on aforementioned contributions;
- Considering the real-case study of Rasht city to validate the proposed integrated approach.

In the following, in Section 2, a presentation of the preliminaries, in Section 3, development of the proposed method, in Section 4, a review of the case study, and in Section 5, the conclusions and future suggestions are presented.

Preliminaries

This part develops some basic definitions of the IF approach.

Definition 1. Let X be a universe discourse. The IF set (IFS) R from X is a goal presented in Eq. 1.

$$R = \{\langle x, \mu_R(x), v_R(x), \pi_R(x)\rangle | x \in X\} \tag{1}$$

The amount of the membership function $\mu_A: X \to [0,1]$, which means a rate of membership of the value x and non-membership function $v_A: X \to [0,1]$, which mean a rate of non-membership of it in the set R. furthermore, for every $x \in X$ exists $0 \leq \mu_R(x) + v_R(x) \leq 1, \pi_R = 1 - \mu_R - v_R$.

Definition 2. Let R and P are two IFSs from the set of X; although, the bonds are explained in Eqs. 2-8.

$$R \cup P = \{\langle x, max(\mu_R(x), \mu_P(x)), min(v_R(x), v_P(x)), \rangle | x \in R\} \tag{2}$$

$$R \cap P = \{\langle x, min(\mu_R(x), \mu_P(x)), max(v_R(x), v_P(x))\rangle | x \in R\} \tag{3}$$

$$\bar{R} = \{\langle x, v_R(x), \mu_P(x)\rangle | x \in R\} \tag{4}$$

$$\mathrm{R}\oplus\mathrm{P} = \{\langle x, \mu_R(x) + \mu_P(x) - \mu_R(x).\mu_P(x), v_R(x).v_P(x), 1 - \mu_R(x) - \mu_P(x) + \mu_R(x)\mu_P(x) - v_R(x)v_P(x)\rangle\} \tag{5}$$

$$R\otimes P = \{\langle x, \mu_R(x).\mu_R(x), v_R(x) + v_R(x) - v_R(x).v_P(x), 1 - \mu_R(x)\mu_P(x) - v_R(x) - \mu_P(x) + v_R(x)v_P(x)\rangle\} \tag{6}$$

$$R^\lambda = \{\langle x, \mu_R(x)^\lambda, 1 - (1 - v_R(x)^\lambda) | x \in R\rangle\}, \lambda > 0; \tag{7}$$

$$\lambda R = \{\langle x, 1 - (1 - \mu_R(x))^\lambda, v_R(x) | x \in R\rangle\}, \lambda > 0; \tag{8}$$

Definition 3. Let T be the set of the IFs $T = \{R_1, R_2, \dots, R_n\}$. The summation and multiplication of n-dimensional can be obtain from Eqs. 9 and 10.

$$\oplus_{i=1}^{N} R(x_i) = \left[1 - \prod_{i=1}^{N}(1 - \mu_R(x_i)), \prod_{i=1}^{N} v_R(x_i), \prod_{i=1}^{N}(1 - \mu_R(x_i)) - \prod_{i=1}^{N} v_R(x_i)\right] \tag{9}$$

$$\otimes_{i=1}^{N} R(x_i) = \left[\prod_{i=1}^{N} \mu_R(x_i), 1 - \prod_{i=1}^{N}(1 - v_R(x_i)), \prod_{i=1}^{N}(1 - v_R(x_i)) - \prod_{i=1}^{N} \mu_R(x_i)\right] \tag{10}$$

Definition 4. The operation of division is computed using Eq. 11.

$$\frac{R(x_i)}{T(x_i)} = R(x_i).T(x_i)^{-1} = ([min(\mu_R(x_i)), min(\mu_T(x_i))], [max(v_R(x_i)), max(v_T(x_i))]) \tag{11}$$

Definition 5. The hamming distance and Euclidean distance of two IFSs for $X = \{x_1, x_2, \ldots, x_N\}$ are obtained with Eqs. 12 and 13.

$$d_H(R,P) = \sum_{i=1}^{N} \frac{1}{2n} (|\mu_R(x_i) - \mu_P(x_i)| + |v_R(x_i) - v_P(x_i)| + |\pi_R(x_i) - \pi_P(x_i)|) \quad (12)$$

$$d(R,P) = \sqrt{\frac{1}{2n} \sum_{i=1}^{N} ((\mu_R(x_i) - \mu_P(x_i))^2 + (v_R(x_i) - v_P(x_i))^2 + (\pi_R(x_i) - \pi_P(x_i))^2)} \quad (13)$$

Definition 6. The intuitionistic fuzzy weighted geometric (IFWG) is obtained from Eq. 14. The weight vector in this equation presents $w_i = (w_1, w_2, \ldots, w_N)^T$ and $\sum_i w_i = 1$.

$$IFWG(R(x_1), R(x_2), \ldots, R(x_i)) = \langle \frac{2\prod_{i=1}^{N}(\mu_R(x_i))^{w_i}}{\prod_{i=1}^{N}(2 - \mu_R(x_i))^{w_i} + \prod_{i=1}^{N}(\mu_R(x_i))^{w_i}}, \frac{\prod_{i=1}^{N}(1 + v_R(x_i))^{w_i} - (1 - v_R(x_i))^{w_i}}{\prod_{i=1}^{N}(1 + v_R(x_i))^{w_i} + (1 - v_R(x_i))^{w_i}} \rangle \quad (14)$$

Definition 7. The matrix of positive and negative normalized IF t_{ij} is determined in Eq. 15 $(\forall\, i = 1,2, \ldots, m; j = 1,2, \ldots, n)$.

$$t_{ij} = \begin{cases} \{[\mu_{ij}, v_{ij}]\} & \text{for positive criteria} \\ \{[1 - \mu_{ij}, 1 - v_{ij}]\} & \text{for negetive criteria} \end{cases} \quad (15)$$

Proposed IF-integrated approach

This section is formed based on three methods that are comprised of the IF-DEMATEL method, and the IF-CS approach use to obtain the weights and the ranking approach. Furthermore, the IF-DEMATEL and the IF-CS generate to obtain the weights of criteria and DMs, respectively. his paper is organized based on group DMs $(DM_k, k = 1,2, \ldots, K)$, several criteria $(C_j, j = 1,2, \ldots, n)$, and some of the various alternatives $(A_i, i = 1, 2, \ldots m)$. Finally, the structure of the proposed approach is depicted in Fig. 1.

Step 1. The critical criteria compute to satisfy potential alternatives.
Step 2. Based on the opinions of the DMs', shows the intuitionistic fuzzy decision matrix (IF-decision matrix). This matrix is depicted in Eq. 16.

$$R = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \cdots & C_j \end{array} \\ \begin{bmatrix} \{[\mu_{11}^1, v_{11}^1], [\mu_{11}^2, v_{11}^2], \ldots, [\mu_{11}^k, v_{11}^k]\} & \cdots & \{[\mu_{1n}^1, v_{1n}^1], [\mu_{1n}^2, v_{1n}^2], \ldots, [\mu_{1n}^k, v_{1n}^k]\} \\ \vdots & \ddots & \vdots \\ \{[\mu_{m1}^1, v_{m1}^1], [\mu_{m1}^2, v_{m1}^2], \ldots, [\mu_{m1}^k, v_{m1}^k]\} & \cdots & \{[\mu_{mn}^1, v_{mn}^1], [\mu_{mn}^2, v_{mn}^2], \ldots, [\mu_{mn}^k, v_{mn}^k]\} \end{bmatrix}_{m \times n} \end{array} \quad \forall k \quad (16)$$

Step 3. The IF-CS method obtains the weights of the DMs.
Step 3.1. The normalized IF-decision matrix weight is estimated using Eq. 17.

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

Step 3.2. Estimate the IF positive and negative ideal solutions (IF-PIS and IF-NIS) with Eqs. 18 and 19, respectively.

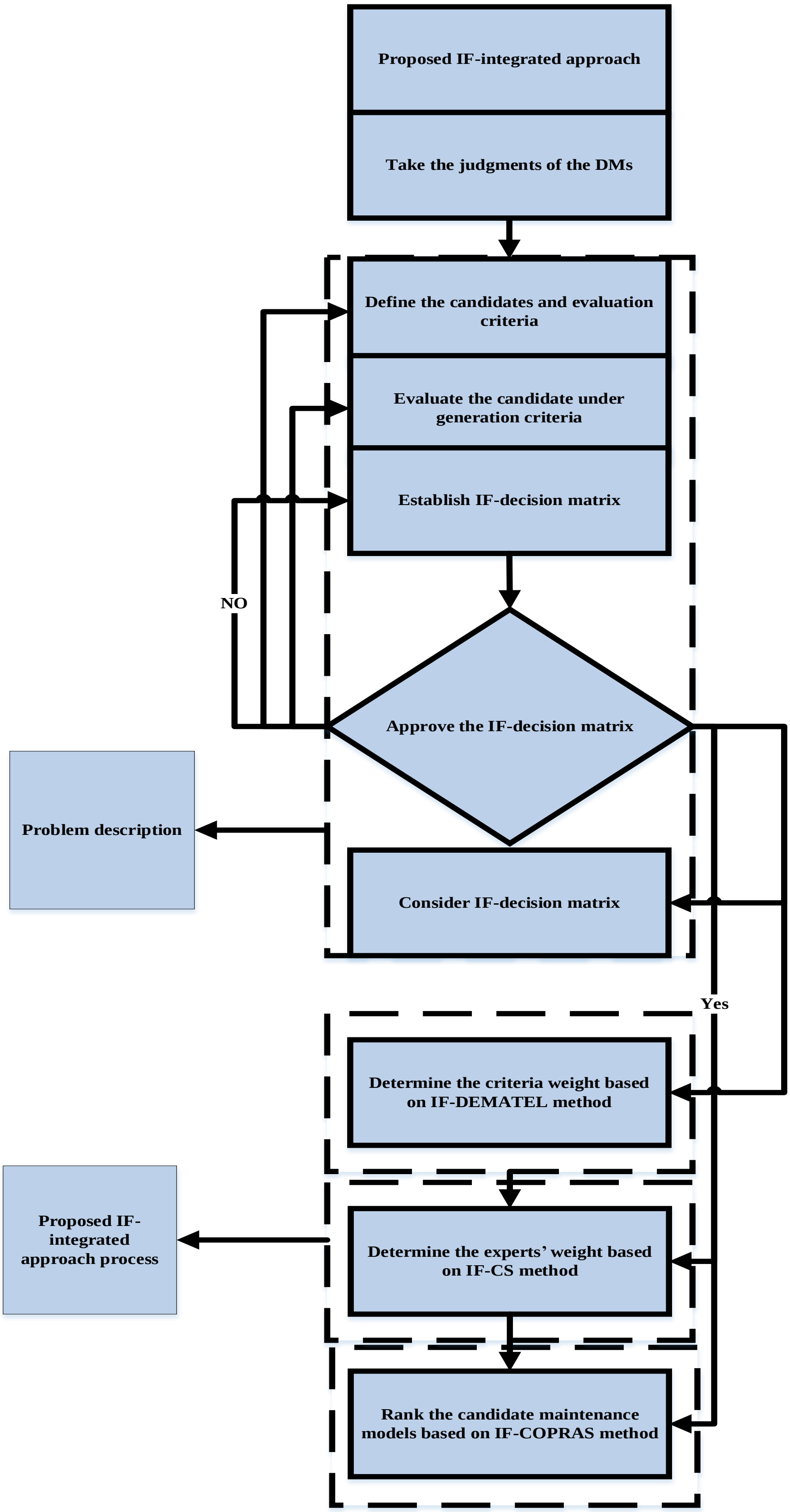

Fig. 1. The structure of the proposed IF-integrated method

$$S^+ = \left([\mu_{ij}^+, v_{ij}^+]\right)_{m\times n} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} [\mu_{11}^+, v_{11}^+] & \cdots & [\mu_{1n}^+, v_{1n}^+] \\ \vdots & \ddots & \vdots \\ [\mu_{m1}^+, v_{m1}^+] & \cdots & [\mu_{mn}^+, v_{mn}^+] \end{bmatrix}_{m\times n} \end{array} \tag{18}$$

$$S^- = \left([\mu_{ij}^-, v_{ij}^-]\right)_{m\times n} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} [\mu_{11}^-, v_{11}^-] & \cdots & [\mu_{1n}^-, v_{1n}^-] \\ \vdots & \ddots & \vdots \\ [\mu_{m1}^-, v_{m1}^-] & \cdots & [\mu_{mn}^-, v_{mn}^-] \end{bmatrix}_{m\times n} \end{array} \tag{19}$$

where, the decision matrix values are obtained from Eqs. 20-23.

$$\mu_{ij}^+ = \frac{1}{K}\sum_{k=1}^{K} \mu_{ij}^k \tag{20}$$

$$v_{ij}^+ = \frac{1}{K}\sum_{k=1}^{K} v_{ij}^k \tag{21}$$

$$\mu_{ij}^- = \min_k(\mu_{ij}^k) \tag{22}$$

$$v_{ij}^- = \min_k(v_{ij}^k) \tag{23}$$

The decision matrix separation measure of the IF-PIS and IF-NIS obtained based on the Euclidean distance with n-dimensional IF in Eqs. 24 and 25.

$$\xi_k^+ = \sqrt{\frac{1}{2n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\mu_{ij}^k(x_i) - S_{ij}^+(x_i)\right|^2 + \left|v_{ij}^k(x_i) - S_{ij}^+(x_i)\right|^2\right)} \quad \forall k \tag{24}$$

$$\xi_k^- = \sqrt{\frac{1}{2n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\mu_{ij}^k(x_i) - S_{ij}^-(x_i)\right|^2 + \left|v_{ij}^k(x_i) - S_{ij}^-(x_i)\right|^2\right)} \quad \forall k \tag{25}$$

Step 3.4. The weights of each DM (ϖ_k) are computed from Eq. 26.

$$\varpi_k = \frac{\xi_k^-}{(\xi_k^- + \xi_k^+)\left(\sum_{k=1}^{K}\frac{\xi_k^-}{\xi_k^- + \xi_k^+}\right)} \quad \forall k \tag{26}$$

Step 4. The IF-DEMATEL method is used to calculate the weights of criteria.
Step 4.1. Construct the comparison matrix for selected criteria **(**E).

$$E = \begin{array}{c} \\ C_1 \\ \vdots \\ C_j \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} [\mu_{11}^k, v_{11}^k] & \cdots & [\mu_{1n}^k, v_{1n}^k] \\ \vdots & \ddots & \vdots \\ [\mu_{n1}^k, v_{n1}^k] & \cdots & [\mu_{nn}^k, v_{nn}^k] \end{bmatrix}_{n\times n} \end{array} \tag{27}$$

Step 4.2. Establish the IF-directed relationships matrix ($[H_{jj}]_{n\times n}$).

$$v_{ij} = score\left(\underset{k\,=\,1}{\overset{K}{\oplus}}\left(\frac{1}{k}[\mu_{ij}, v_{ij}]\right)\right) = \frac{1}{R}\sum_{r=1}^{R}\left(\frac{1}{l}\sum_{\lambda=1}^{l}\left[1 - \frac{\prod_{k=1}^{K}\left(1-[\mu_{ij}, v_{ij}]^{\sigma(\lambda)}\right)^{\frac{1}{k}}}{2}\right]\right) \tag{28}$$

$$H = \begin{array}{c} \\ C_1 \\ \vdots \\ C_j \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} 0 & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & 0 \end{bmatrix}_{n\times n} \end{array} \tag{29}$$

Step 4.3. Normalize the IF-direct relationship matrix.

$$H^N = \begin{array}{c} \\ C_1 \\ \vdots \\ C_j \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} 0 & \cdots & v^N_{1n} \\ \vdots & \ddots & \vdots \\ v^N_{n1} & \cdots & 0 \end{bmatrix}_{n\times n} \end{array} \tag{30}$$

$$v^N_{ij} = \frac{v_{ij}}{\max\limits_{0\le i\le n}\left\{\sum_{j=1}^{n} v_{ij}\right\}} \qquad \forall i,j \tag{31}$$

Step 4.4. Generate the IF-influence matrix ($[U_{ij}]_{n\times n}$).

$$U = \begin{array}{c} \\ C_1 \\ \vdots \\ C_j \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} u_{11} & \cdots & u_{1n} \\ \vdots & \ddots & \vdots \\ u_{n1} & \cdots & u_{nn} \end{bmatrix}_{n\times n} \end{array} \tag{32}$$

$$u = H^N|(1 - H^N)^{-1}| \tag{33}$$

Step 4.5. The local weights (W_j^*) are computed based on Eq. 34.

$$W_j^* = \frac{1 - \prod_{k=1}^{K}\left(1 - W_j^k\right)^{\frac{1}{k}}}{n - \sum_{j=1}^{n}\prod_{k=1}^{K}\left(1 - W_j^k\right)^{\frac{1}{k}}} \qquad \forall j \tag{34}$$

Step 4.6. Compute the global weight with Eq. 35.

$$GW = W^* + W^*U \tag{35}$$

Step 4.7. The final weights of criteria (Fw_j) are computed using Eq. 36.

$$Fw_j = \frac{GW_{(1,j)} \times GW_{(1,\acute{j})}}{\sum_{j=1}^{n} GW_{(1,j)} \times GW_{(1,\acute{j})}} \qquad \forall j, \acute{j} \tag{36}$$

Step 4. The weighted normalized IF-decision matrix (μ_k^W) is obtained by Eq. 37.

$$\mu_k^W = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_j \end{array} \\ \begin{bmatrix} Fw_1[\mu^k_{11}, v^k_{11}] & \cdots & Fw_n[\mu^k_{1n}, v^k_{1n}] \\ \vdots & \ddots & \vdots \\ Fw_1[\mu^k_{m1}, v^k_{m1}] & \cdots & Fw_n[\mu^k_{mn}, v^k_{mn}] \end{bmatrix}_{m\times n} \end{array} \qquad \forall k \tag{37}$$

Step 5. The positive criteria values $\left(p_i^k\right)$ are computed using Eq. 38. In this formulation *r* is the number of positive criteria.

$$p_i^k = \left[1 - \prod_{j=1}^{r}(1 - \mu_{ij}^k), 1 - \prod_{j=1}^{r}(1 - v_{ij}^k)\right] \qquad \forall k, i \qquad (38)$$

Step 6. The negative criteria values (R_i^k) obtained from Eq. 39.

$$R_i^k = \left[1 - \prod_{j=r+1}^{n}(1 - \mu_{ij}^k), 1 - \prod_{j=r+1}^{n}(1 - v_{ij}^k)\right] \qquad \forall k, i \qquad (39)$$

Step 7. Compute the smallest value of the R_i^k with Eq. 40.

$$R_i^k = \left[\min_i R_i^k\right] \qquad \forall k \qquad (40)$$

Step 8. The relative importance of each alternative (Q_i^k) calculated with Eq. 41.

$$Q_i^k = \left[p_i^k + (1 - p_i^k)\left(\frac{1 - \left(\prod_{i=1}^{m}(1 - R_i^k)\right)^{R_{min}^k}}{1 - \left(\prod_{i=1}^{m}\left(1 - \frac{R_{min}^k}{R_i^k}\right)\right)^{R_i^k}}\right)\right] \qquad \forall k, i \qquad (41)$$

Step 9. The Q_i value is determined with the DMs weight by Eq. 42.

$$Q_i = \bigcup \tilde{Q}_1 \in \tilde{h}_{q1}, \dots, \tilde{Q}_k \in \tilde{h}_{qk} \times \left\{\left[\prod_{k=1}^{K} Q_i^{k^{\varpi_k}}\right]\right\} \qquad \forall i \qquad (42)$$

Step 10. The utility degree of every alternative is computed with Eq. 43.

$$N_i = \left[\frac{Q_i}{\max(Q_i)}\right] 100\% \qquad \forall i \qquad (43)$$

Step 11. The rank of the alternatives calculated with Q_i value and utility degree by decreasing sorting.

Case study: Maintenance models evaluation

Problem description

In this section, the real case study of the bridge construction or maintenance operation is proposed in Rasht city of Iran. The bridge project includes two practices construction the new bridge to make a relation between several various locations. The second act is related to the maintenance practice of the old bridges with rebuilding them. In general, from a financial and human resource perspective, the use of old bridge repair and maintenance systems is more practical than building a new bridge. Also, in this type of activity, the appropriate location of the bridge is pre-determined, which helps the project team a lot, and their actions in order to provide a proper communication route. These acts are very essential for the maintenance of the bridge. Iran has various kinds of old bridges that are needed to rebuild to use in the transportation system. One of these cities, which is had this position, is Rasht city. This section includes four criteria (C_1, C_2, C_3, C_4) and the four alternatives (A_1, A_2, A_3, A_4) that are take values with linguistic variables with three DMs (DM_1, DM_2, DM_3, DM_4). These alternatives are included concreting concrete and repairing faulty concretes (A_1), focus on preventing territory ablation (A_2), piping and transfer of surface water (A_3), and restoration of old structures (A_4). These variables are determined in Tables 2 and 3. Furthermore, the criteria of this problem are shown in Table 4.

Table 2. The linguistic variables to evaluate 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)

Table 3. The linguistic variables to rate 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)

Table 4. The description of the criteria

Criteria	Description
C_1	Concrete bridge scour index
C_2	Average traffic load index
C_3	Seismic hazard index
C_4	Bridge status indicator

Furthermore, the relation among criteria and alternatives determines in Table 5 that is received based on the experts' judgment. The criteria's weights based on DMs opinions are defined in Table 6. Also, Table 7 is the criteria comparison pairwise that is judged by experts. Moreover, the linguistic terms are converted to the intuitionistic fuzzy elements based on Tables 2 and 3. Besides, Tables 5-7 are defined as the input parameters of the proposed IF-integrated approach.

Table 5. The alternatives performance measure with linguistic variables

Criteria	Alternatives	DMs			
		DM1	DM2	DM3	DM4
C1	A_1	VH	H	H	H
	A_2	H	VH	H	H
	A_3	VH	M	M	MH
	A_4	H	VVH	MH	H
C2	A_1	L	L	M	L
	A_2	MH	M	M	M
	A_3	M	H	VVL	VL
	A_4	VH	H	VL	M
C3	A_1	H	VH	H	H
	A_2	H	H	L	M
	A_3	M	M	H	L
	A_4	L	MH	VH	H
C4	A_1	VH	VVH	H	VH
	A_2	VH	VVH	VVH	VH
	A_3	H	VVH	VH	H
	A_4	VVH	VVH	VVH	VVH

Table 6. The weights of the criteria based on experts' opinion

Criteria	DMs			
	DM_1	DM_2	DM_3	DM_4
C_1	AH	VH	VH	VVH
C_2	AH	AH	H	H
C_3	VH	VVH	H	AH
C_4	H	H	VH	AH

Table 7. The pairwise comparison among criteria

DMs		C_1	C_2	C_3	C_4
DM_1	C_1	0	MH	H	L
	C_2	L	0	M	VL
	C_3	ML	M	0	VVL
	C_4	H	VH	VVH	0
DM_2	C_1	0	H	VH	ML
	C_2	M	0	MH	L
	C_3	VL	ML	0	VVL
	C_4	MH	VVH	VVH	0
DM_3	C_1	0	H	H	M
	C_2	MH	0	H	L
	C_3	L	ML	0	VL
	C_4	H	VH	VVH	0
DM_4	C_1	0	M	MH	ML
	C_2	ML	0	H	L
	C_3	VL	L	0	VVL
	C_4	H	VH	VH	0

Proposed IF-integrated approach implementation

In this section, the process of the proposed IF-integrated approach is represented to show its performance. Meanwhile, the criteria's normalized weights obtain from Eq. 34 that is represented in Table 8. The normal weights (W_j^*) of criteria with for alternative obtain, and are determined in Table 9.

Table 8. The weight value of criteria

Criteria	w_j
C_1	0.273
C_2	0.165
C_3	0.273
C_4	0.287

Table 9. Normal weights of criteria for each alternative

Criteria	Alternatives	W_j^*
C_1	A_1	0.070
	A_2	0.061
	A_3	0.064
	A_4	0.069
C_2	A_1	0.047
	A_2	0.052
	A_3	0.034
	A_4	0.059
C_3	A_1	0.067
	A_2	0.051
	A_3	0.064
	A_4	0.061
C_4	A_1	0.072
	A_2	0.074
	A_3	0.071
	A_4	0.075

The computed weight value presents that the first attribute (concrete bridge scour index criterion) has a high value than other attributes. On the other hand, the third criterion (seismic hazard index criterion) is represented as lower importance. This means that managers and companies in order to expand the prosperity of a new brand in the capital market or business and industrial markets must pay more attention to the customer loyalty attribute. The global final criteria weights (Fw_j) and the weights of DMs based on IF-PIS and IF-NIS values obtain from Eqs. 24-26 in Tables 10 and 11, respectively.

Table 10. The final global criteria's' weights

Criteria	Fw_j
C_1	0.07948
C_2	0.07080
C_3	0.06617
C_4	0.06738

Table 11. The DMs' weights

DMs	ξ_k^+	ξ_k^-	ϖ_k
DM_1	0.05029	0.09285	0.26257
DM_2	0.07583	0.12509	0.25200
DM_3	0.07898	0.09967	0.22582
DM_4	0.05752	0.10287	0.25961

Finally, the ranking is presented based on the Q_i value in Table 12. In order to evaluate the efficiency of the proposed method under consideration in bridge construction issues, a comparison between the two TOPSIS methods and the proposed method in ranking has been used. The results can be seen in Table 12 and the process of quantifying each option in Fig. 2 can be seen between the two methods mentioned. The final results of both methods show that the third alternative has more priority than the other alternatives and has the highest rank.

Although the proposed IF-integrated approach and the TOPSIS method reach to same candidate ranking results, the proposed approach of this study has some advantages that can help users of the methodology to obtain a precise solution. To address the issue, the main merits and advantages of the proposed approach that can assist users and managers are discussed at the following section.

Table 12. The comparison between two various methods

	Proposed method		TOPSIS method	
A_i	Total value	Alternatives rank	Total value	Alternatives rank
A_1	82.26947	4	76.27457	4
A_2	84.69814	2	76.84761	2
A_3	84.74769	1	77.01457	1
A_4	83.25478	3	76.72145	3

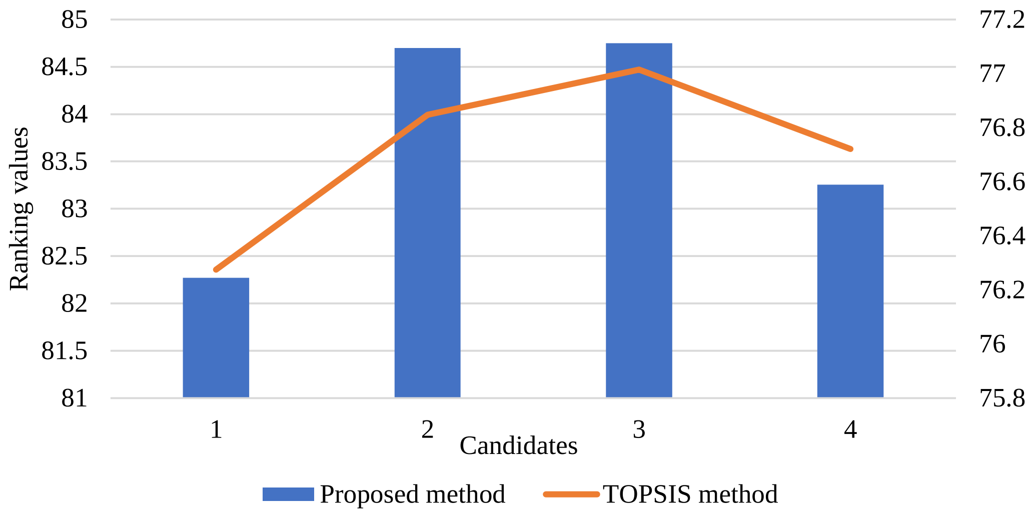

Fig. 2. The comparison between two ranking methods values

Managerial implications

In this section, some managerial implications are defined to assist the managers in real cases to solve the maintenance model selection problem. By doing so, the implications should be considered based on features of the selected criteria such as concrete bridge scour index, average traffic load index, seismic hazard index, and bridge status indicator during maintenance model selection. Therefore, managers and users who performed the proposed approach should be careful about the following insights:

– The proposed approach can determine the experts' weights regarding their expertise by implementing the IF-CS methodology;
– Considering the IF-DEMATEL approach to compute the criteria weights can help the managers to identify the most important criterion regarding their interdependencies relations;
– The proposed IF-integrated approach assists managers to reach a precise solution by preserving the intuitionistic fuzzy setting information during the process of the proposed approach;
– Experts can define their judgments based on linguistic terms by considering the proposed approach and also their opinions can be converted to intuitionistic fuzzy elements based on Tables 1 and 2.

- Managers can sort the candidate maintenance models by applying the proposed IF-COMPRAS ranking methodology and selecting the most suitable option.

Conclusions and future suggestion

Today, one of the most important and effective ways of communication between human beings in different societies is related to the use of transportation systems and the use of appropriate mechanisms and tools in this field. One of these tools that is effective in communicating between communities is the bridge. Bridges make a significant contribution to the connection between the two regions and make it easy for people to travel to different parts and geographical parts. In this regard, two operations of construction and reconstruction of bridges have been discussed. It was found that due to the high cost of location and raw materials, bridge reconstruction projects are more important than building a new bridge. In this regard, various indicators and options were proposed and in order to make appropriate decisions for managers and decision-makers in the bridge industry, a new approach combining CS and DEMATEL methods under the conditions of intuitive fuzzy uncertainty was proposed. After calculating the weights and ranking the options, the third option was selected as the most effective option, which is related to the pipeline project of water supply lines. In this regard, in order to validate the proposed method, a case study was used and the results were compared with a traditional method in TOPSIS literature. Although the results emphasized the importance and efficiency of the proposed method, the proposed integrated approach has time complexity limitations that may require high process time for large-size problems. Its' limitation is caused by considering the processes of criteria weights determination, Experts' weights computation, last aggregation mechanism, and intuitionistic fuzzy setting information. However, the proposed IF-integrated approach can be manipulated under an efficient decision support system for future direction to reduce its performance time. In addition, more elements from the outside world can be introduced into the problem under a mathematical modeling approach and the proposed method can be developed as a combination of meta-heuristic solution methods.

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