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INTUITIONISTIC FUZZY DISTANCE MEASURE-BASED APPROACH FOR ADOPTING THE BLOCKCHAIN TECHNOLOGY IN THE LOGISTICS INDUSTRY

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Abstract. *Blockchain technology (BT) has appeared as a promising solution for addressing several challenges in the supply chain and logistics. Digital transformation in supply chain and logistics can drive significant business growth by updating outdated systems. Though, the BT-enabled digital transformation concerning BT for a logistics industry meets the numerous challenges of choosing a suitable blockchain platform for needs of logistics industry. In this paper, we introduce an integrated intuitionistic fuzzy information-based decision support system for selecting and assessing the blockchain platforms in the logistics industry. This method computes the decision experts' weight and combined weight of criteria with score function-rank sum model and model based on the removal effects of criteria (MEREC) on intuitionistic fuzzy sets (IFSs). In the following, a novel distance measure is proposed for IFSs to measure the degree of composite distance of alternatives. Next, the developed framework is implemented to a case study of blockchain platforms assessment problem. Sensitivity assessment and comparison with existing methods are discussed for determining the utility and advantages of proposed approach.*

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1. INTRODUCTION

Blockchain is described as a safe, distributed and decentralized database that enables the procedure of recording transactions and tracking resources in a business network. It is a technology which combines several features including distributed notes, smart contracting, storage device and decentralized system, consensus procedure, asymmetric encryption to ensure visibility, network security and transparency [1]. Digital signature in blockchain provides a secure and tamper-evident way to safeguard individuals' online identity and authenticate the transactions [2]. Blockchain technology (BT) provides a solution to improve the transparency and immutability in data-driven decision-making which builds trust among stakeholders, as they can independently preserves confidentiality, integrity and availability of all the transactions and data in the blockchain [3]. In the business operations, all latest transaction in blockchain is stored in an immutable block and timestamped to preserve track of the particular product in the end-to-end chain [4-7]. Due to its unique features, it has been globally recognized as a powerful system for enabling transparency and trust in data transactions [3].

Logistics is the process that comprises the management of arrangements of goods, services, and essential information from production location to the point of consumption [8-9]. It has a significant impact on business, though it faces some challenges that impact the efficacy and effectiveness of supply chain operations. Digital transformation (DT) revolutionizes logistics by offering supply chain visibility and powers significant cost savings across logistics operations [10]. BT's integration into DT facilitates greater efficiency in the business models by enabling the higher levels of transparency and safe exchange of data in logistics supply chain [11-12]. Jain et al. [13] gave a study that explores the role of blockchain in logistics industry. Moreover, they presented a model for testing the users' acceptance of BT in logistics and supply chain. Based on the comprehensive review, Berneis et al. [14] identified the economic advantages of BT implementation in logistics industry. Batta et al. [15] examined the actual level of adoption and diffusion of BT in logistics and transportation industries. Tan et al. [16] formed a prototype BT-based logistics system with its impact in a real logistics industry. Zeng et al. [17] presented a BT-enabled traceability system for cold-chain pharmaceutical logistics. Considering the multiple criteria/factors and decision experts (DEs), choosing an appropriate blockchain platform for the logistics industry can be defined as a multiple criteria group decision-making (MCGDM) problem.

As a goal-oriented process, MCGDM approaches allow for a comprehensive evaluation of alternatives based on multiple criteria that may have different weights in the decision-making procedure [18-19]. Uncertainty is a major issue that may occur during the assessment of alternative in the practical MCGDM problems [20-21]. In general, the classical MCGDM methods are failed to handle the uncertainty of realistic situations. To deal the uncertain situation, Zadeh [22] pioneered the notion of fuzzy set (FS), which offer a powerful and flexible tool to handle the ambiguous data [23]. Çıkmak et al. [24] used the FS-based model to study the effects of blockchain characteristics in the supply chain management (SCM). Chen et al. [25] presented a fuzzy large-scale DEMATEL model to analyze the influence of BT in humanitarian supply chain. Hamidi et al. [26] studied an integrated fuzzy decision support tool for assessing the readiness of BT execution in the maritime logistics industry. Hussain and Ullah [27] presented a model using Sugeno-Weber operators on spherical fuzzy sets to solve real-life MCGDM problem. Sahoo et al. [6] studied comprehensive bibliometric assessment of investigation on material selection problem with various MCGDM models considering the publications from 2010 to 2024.

As a refinement of FS, Atanassov [28] proposed the idea of intuitionistic fuzzy set (IFS) in which an element is considered by degree of membership (MD) (μ) and non-membership (ND) (v) with a constraint $\mu + v < 1$. The introduction of IFS theory into MCGDM approaches has increased the practical potential and offered new insights during the procedure of solving decision-making problems [29-33]. Wan et al. [34] integrated IF-best worst method (BWM) with additive consistency. Based on this method, they proposed a non-linear programming model for solving decision-making problems. Bajaj & Kumar [35] studied a new correlation measure on IFSs and implemented to the pattern recognition, medical diagnosis and clustering problems. Further, an integrated decision support tool has been to assess a set of options on IFSs. Majumder et al. [36] gave an intuitionistic fuzzy MCDM model for deriving the significance values of criteria. Moreover, they used a unique decision support system to assume a feasibility assessment of solar power plant. Şahin et al. [37] used two methods, geographic information measure and IFSs-based method to evaluate and rank the locations for solar-wind power plant establishment in Netherlands. Till now, there is no study that assesses the blockchain platforms in the logistic industry using IFSs-based decision-making model.

The algorithm of "distance-based approach (DBA)" commences with describing the optimum state of total objective, and determines the preferably good ratings of considered criteria during the assessment of alternatives. Because of the simple and easy-to-use computational steps, it has been analyzed as a flexible and effective technique for solving MCGDM problems from different perspectives [33,38-39]. For instance, Garg et al. [40] set forth an innovative fuzzy DBA model for evaluating and ranking the data base management system commercial off-the-shelf components under fuzzy environment. Sandhya et al. [41] evaluated the cloud service provider selection problem through classical distance-based approach and ranked the service provider alternatives according to the composite distances. Garg & Garg [42] used a modified DBA model to evaluate, select and rank the robots by means of various aspects and fuzzy information. In addition, their results have validated through comparison with four different approaches.

To efficiently select the suitable blockchain platform in the logistics industry, this paper introduces an integrated MCGDM approach based on DBA, method using removal effects of criteria (MEREC) and rank sum (RS) model with intuitionistic fuzzy information (IFI), and named as the "IF-MEREC-RS-DBA". In the proposed framework, the DEs' weights are computed through a combined IF-score function and RS model-based approach, while weights of criteria are computed via an integrated weighting model considering the objective weight with IF-MEREC tool and subjective weight with IF-RS method. Combining all these aspects, the proposed DBA offers an effective way to evaluate and select the blockchain platforms in the logistics industry. To compute the composite distance matrix in IF-MEREC-RS-DBA approach, we propose a new distance measure for IFSs that avoids the shortcomings of existing intuitionistic fuzzy distance measures by Iqbal & Rizwan [43], Wu et al. [44], Ejegwa & Agbetayo [45] and Li et al. [46]. To the best of authors' knowledge, no one has combined the DBA model with MEREC and RS model with IFI setting. The combination of objective and subjective weighting methods cannot only compute the criteria weights based on the quantitative data but also consider the DEs' opinions during the assessment of criteria weights. To evaluate the blockchain platforms, existing studies have not demonstrated how the combination of objective and subjective weighting approaches impacts the decision results. Furthermore, few studies assume the direct weights of attributes without considering the objective weight or subjective weight, which may cause information loss.

The novelties and key contributions of the paper are discussed as

- This paper proposes a new distance measure for IFSs, which quantifies the degree of dissimilarity between IFSs.
- To solve the MCGDM problems, a hybrid IF-MEREC-RS-DBA model is proposed wherein the information about the DEs and criteria is fully unknown.
- In this model, a combined IF-score function and IF-RS method-based formula is presented to determine weight of DEs, while an integrated weighting model for criteria is discussed which combines IF-MEREC for objective weight of factors and IF-RS approach for subjective weight of factors on IFI.
- The developed framework is used on a case study of blockchain platform selection problem with IFI.

Other sections are prepared as follows. Section 2 shows the basic idea and developed IF-distance measure. Section 3 develops an integrated IF-MEREC-RS-DBA model for dealing MCGDM problems. Section 4 shows the application of developed model to a case study of blockchain platform selection problem. This section further discusses the sensitivity assessment and comparison with extant MCGDM methods within the context of IFSs. Section 5 concludes this study and indicates some future research directions.

2. Proposed Distance Measure for IFSs

This section gives background of the work and develops new IF-distance measure to calculate degree of dissimilarity on IFSs.

2.1 Basic Concepts

This section shows the fundamental concepts about this work.

Definition 2.1 [28]. Let us consider a finite discourse set $\Omega = \{\iota_1, \iota_1, \ldots, \iota_p\}$. Atanassov [28] presented the mathematical definition of an IFS E on Ω given as

$$E = \left\{\left(\iota_k,\ \mu_E(\iota_k),\ \nu_E(\iota_k)\right) : \iota_k \in \Omega\right\}, \tag{1}$$

where μ_E: $\Omega \rightarrow [0, 1]$ denotes an MD and ν_E: $\Omega \rightarrow [0, 1]$ signifies an ND of an element ι_k to E in Ω, satisfying that $0 \le \mu_E(\iota_k), \nu_E(\iota_k) \le 1$, for each $\iota_k \in \Omega$. For each $\iota_k \in \Omega$, the hesitancy degree is defined as $\pi_E(\iota_k) = 1 - \mu_E(\iota_k) - \nu_E(\iota_k)$. For simplicity, the term "(μ_E, ν_E)" is defined as an 'intuitionistic fuzzy number (IFN)' [47] and can be denoted as $\beta = (\mu, \nu)$.

Definition 2.2 [48]. For an IFN $\beta = (\mu, \nu)$, IF-score function and IF-accuracy function are defined via Eq. (2) and Eq. (3), respectively.

$$O(\beta) = \frac{1}{2}\left(1 + \mu - \nu\right), \tag{2}$$

where $O(\beta) \in [0, 1]$,

$$A(\beta) = \mu + \nu, \quad (3)$$

where $A \in (\beta)$ [0, 1].

Definition 2.3 [47]. To fuse the individual opinions into a group decision, Xu [47] introduced the IFWA and IFWG operators for IFNs, and given in Eq. (4) and Eq. (5), respectively.

$$IFWA(\beta_1, \beta_2, ..., \beta_p) = \mathop{\oplus}_{k=1}^{p} w_k\, \beta_k = \left[1 - \prod_{k=1}^{p}(1-\mu_k)^{w_k}, \prod_{k=1}^{p}\nu_k^{w_k}\right], \quad (4)$$

$$IFWG(\beta_1, \beta_2, ..., \beta_p) = \mathop{\otimes}_{k=1}^{p} \beta_k^{w_k} = \left[\prod_{k=1}^{p}\mu_k^{w_k},\ 1 - \prod_{k=1}^{p}(1-\nu_k)^{w_k}\right], \quad (5)$$

where $\beta_k = (\mu_k, \nu_k)$, $k = 1, 2, \ldots, p$ shows IFN and w_k is relative weight of IFN β_k satisfying w_k is non-negative and $w_1+w_2+\ldots+w_p = 1$.

Definition 2.4 [49]. Let $E, G, H \in IFSs(\Omega)$. A real-valued function ϖ: $IFSs(\Omega)\times IFSs(\Omega) \rightarrow [0,1]$ is said to be a distance measure for IFSs if it holds the following requirements:

(i). $0 \le \varpi(E, G) \le 1$,

(ii). $\varpi(E, G)$ if and only if $E = G$,

(iii). $\varpi(E, G) = \varpi(G, E)$,

(iv). If $E \subseteq G \subseteq H$, then $\varpi(E, G) \le \varpi(E, H)$ and $\varpi(G, H) \le \varpi(E, H)$.

2.2. Proposed Distance Measure on IFSs

As a mathematical tool, the concept of distance measure is used to compute degree of discrimination between two objects. It has been widely employed in medical diagnosis, pattern recognition and decision-making. In this subsection, we present new distance measure for IFSs.

Theorem 2.1. For $E, G \in IFSs(\Omega)$, new distance measure on IFSs (IF-DM) is defined as

$$\varpi(E,G) = \sqrt{\frac{3}{2p}\sum_{k=1}^{p}\left(\frac{(\mu_E(\iota_k)-\mu_G(\iota_k))^2}{\mu_E(\iota_k)+\mu_G(\iota_k)+2} + \frac{(\nu_E(\iota_k)-\nu_G(\iota_k))^2}{\nu_E(\iota_k)+\nu_G(\iota_k)+2} + \frac{(\pi_E(\iota_k)-\pi_G(\iota_k))^2}{\pi_E(\iota_k)+\pi_G(\iota_k)+2}\right)}. \quad (6)$$

Proof: (i) For two IFSs E and G, we have $0 \le \mu_E(\iota_k), \mu_G(\iota_k) \le 1$, $0 \le \nu_E(\iota_k), \nu_G(\iota_k) \le 1$ and $0 \le \pi_E(\iota_k), \pi_G(\iota_k) \le 1$, for each $\iota_k \in \Omega$. It implies that $0 \le \mu_E(\iota_k) - \mu_G(\iota_k) \le 1$, $0 \le \nu_E(\iota_k) - \nu_G(\iota_k) \le 1$ and $0 \le \pi_E(\iota_k) - \pi_G(\iota_k) \le 1$, for each $\iota_k \in \Omega$.

It implies that

$$0 \le \sqrt{\frac{3}{2p}\sum_{k=1}^{p}\left(\frac{(\mu_E(\iota_k)-\mu_G(\iota_k))^2}{\mu_E(\iota_k)+\mu_G(\iota_k)+2} + \frac{(\nu_E(\iota_k)-\nu_G(\iota_k))^2}{\nu_E(\iota_k)+\nu_G(\iota_k)+2} + \frac{(\pi_E(\iota_k)-\pi_G(\iota_k))^2}{\pi_E(\iota_k)+\pi_G(\iota_k)+2}\right)} \le 1.$$

Hence, $0 \le \varpi(E, G) \le 1$.

(ii)-(iii) These properties are obvious by the definition; therefore, we have omitted the proof.

(iv) Since E, G, $H \in IFSs(\Omega)$ and $E \subseteq G \subseteq H$, thus, $0 \le \mu_E(\iota_k) \le \mu_G(\iota_k) \le \mu_H(\iota_k) \le 1$, $0 \le \nu_H(\iota_k) \le \nu_G(\iota_k) \le \nu_E(\iota_k) \le 1$ and $0 \le \pi_E(\iota_k) \le \pi_G(\iota_k) \le \pi_H(\iota_k) \le 1$, $\forall \iota_k \in \Omega$.

From Eq. (6), we have

$$\varpi(E,G) = \sqrt{\frac{3}{2p}\sum_{k=1}^{p}\left(\frac{\left(\mu_E(\iota_k)-\mu_G(\iota_k)\right)^2}{\mu_E(\iota_k)+\mu_G(\iota_k)+2}+\frac{\left(\nu_E(\iota_k)-\nu_G(\iota_k)\right)^2}{\nu_E(\iota_k)+\nu_G(\iota_k)+2}+\frac{\left(\pi_E(\iota_k)-\pi_G(\iota_k)\right)^2}{\pi_E(\iota_k)+\pi_G(\iota_k)+2}\right)}$$

$$\le \sqrt{\frac{3}{2p}\sum_{k=1}^{p}\left(\frac{\left(\mu_E(\iota_k)-\mu_H(\iota_k)\right)^2}{\mu_E(\iota_k)+\mu_H(\iota_k)+2}+\frac{\left(\nu_E(\iota_k)-\nu_H(\iota_k)\right)^2}{\nu_E(\iota_k)+\nu_H(\iota_k)+2}+\frac{\left(\pi_E(\iota_k)-\pi_H(\iota_k)\right)^2}{\pi_E(\iota_k)+\pi_H(\iota_k)+2}\right)}$$

$$= \varpi(E,H).$$

Similarly, we can prove that $\varpi(E, H) \ge \varpi(G, H)$, as $E \subseteq G \subseteq H$.

Definition 2.5. Suppose that E, $G \in IFSs(\Omega)$, then the weighted distance measure $D_w{:}IFSs(\Omega) \times IFSs(\Omega) \to [0,1]$ is given by

$$\varpi_w(E,G) = \sqrt{\frac{3}{2}\sum_{k=1}^{p} w_k\left(\frac{\left(\mu_E(\iota_k)-\mu_G(\iota_k)\right)^2}{\mu_E(\iota_k)+\mu_G(\iota_k)+2}+\frac{\left(\nu_E(\iota_k)-\nu_G(\iota_k)\right)^2}{\nu_E(\iota_k)+\nu_G(\iota_k)+2}+\frac{\left(\pi_E(\iota_k)-\pi_G(\iota_k)\right)^2}{\pi_E(\iota_k)+\pi_G(\iota_k)+2}\right)}.$$

where w_k is the weight of ι_k on Ω satisfying $w_k \in [0, 1]$ and $\sum_{k=1}^{p} w_k = 1$.

Further, we apply the proposed and existing IF-DMs on some data sets and find some useful results.

Example 2.1. Consider four different cases of IFSs, which are given as follows: *Set-I:* $\{E_1 = (0.7,0.3), G_1 = (0,0)$, *Set-II:* $\{E_2 = (0.4,0.6), G_2 = (0,0)\}$, *Set III:* $\{E_3 = (0.3,0.41), G_3 = (0.5,0.344)\}$ and *Set-IV:* $\{E_4 = (0.41,0.2), G_4 = (0.22,0.28)\}$. Here, we apply the proposed and existent IF-DMs (Iqbal & Rizwan [43], Wu et al. [44], Ejegwa & Agbetayo [45], Li et al. [46]) to compute the distance between given pairs of each set.

For two different sets (Set-I and Set-II), the IF-DMs by Ejegwa & Agbetayo [45] and Li et al. [46] failed to describe the difference between given pairs in Set-I and Set-II, i.e., $\varpi_{EA}(E_1, G_1) = 1.0 = \varpi_{EA}(E_2, G_2)$ and $\varpi_L(E_1, G_1) = 1.0 = \varpi_L(E_2, G_2)$, where $E_1 \ne E_2$, $G_1 = G_2$. In this case, the proposed IF-DM present the reasonable result and given as $\varpi(E_1, G_1) = 0.912$ and $\varpi(E_2, G_2) = 0.899$.

When we compare the pairs of Set-III and Set-IV, the IF-DMs by Iqbal & Rizwan [43] and Wu et al. [44] obtain unreasonable results as $\varpi_{IR}(E_3, G_3) = 0.013 = \varpi_{IR}(E_4, G_4)$ and $\varpi_W(E_3, G_3) = 0.139 = \varpi_W(E_4, G_4)$, where $E_3 \ne E_4$, $G_3 \ne G_4$. While the proposed measure successfully compares the given pairs of Set-III and Set-IV as $\varpi(E_3, G_3) = 0.187$ and $\varpi(E_4, G_4) = 0.175$.

3. Proposed IF-MEREC-RS-DBA Methodology for MCGDM Problems

This section proposes a hybrid IF-MEREC-RS-DBA framework to solve the MCGDM problems under IFSs environment. For a IFSs-based MCGDM problem, create an expert committee $F = \{f_1, f_2, ..., f_n\}$ to evaluate the alternatives' set $U = \{u_1, u_2, ..., u_r\}$ with respect to the criteria set $V = \{v_1, v_2, ..., v_t\}$. Each DE presents his/her linguistic opinion regarding the performance of each alternative by means of considered evaluation criteria. Consequently, we obtain a linguistic assessment matrix (LAM) $Y = (y_{ij}^{(k)})_{r\times t}$, $k = 1, 2, \ldots, n$, where $y_{ij}^{(k)}$ denotes the linguistic variable (LV) of option u_i over a criterion v_j presented by k^{th} DME and further, we make an IF-decision matrix (IFDM). In the following, we present the procedural steps of introduced IF-MEREC-RS-DBA framework (see Fig. 1):

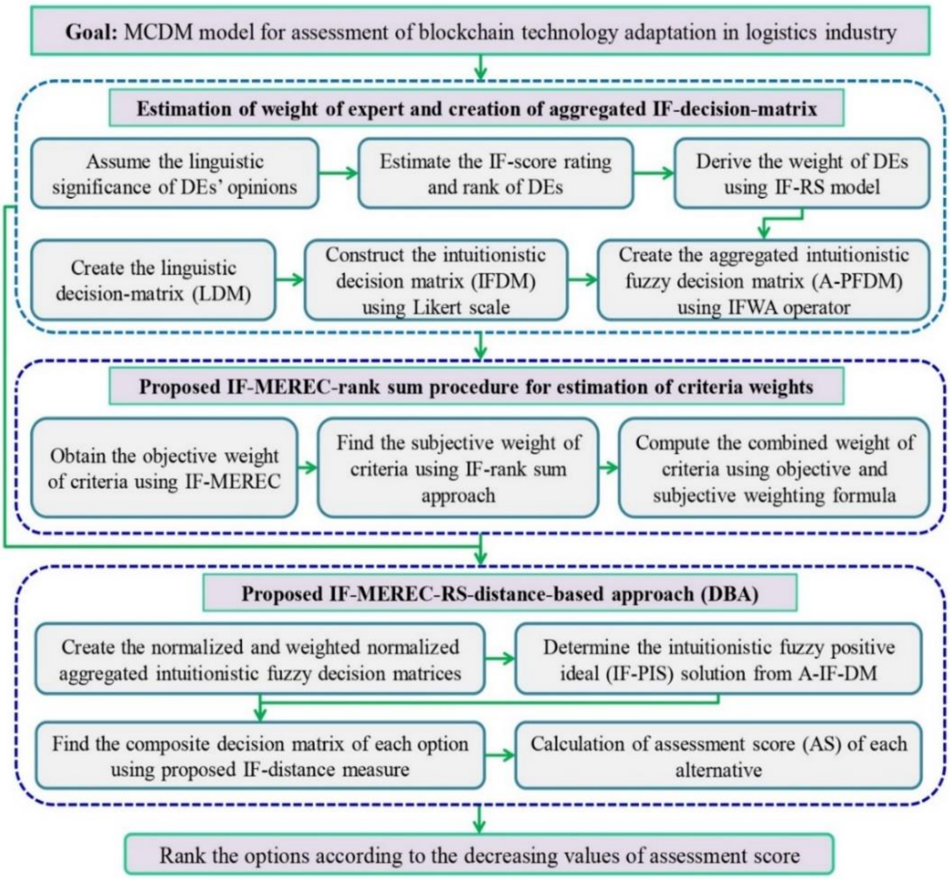

Fig. 1 Graphical structure of the proposed IF-MEREC-RS-DBA model

Step 1: Determination of DEs' weights.

Let $f_k = (\mu_k, \nu_k)$, $k = 1, 2, \ldots, n$ be the intuitionistic fuzzy significance rating of k^{th} expert. Then, a weighting formula to find the weight of k^{th} expert is given by

$$\lambda_k = \frac{1}{2}\left(\frac{\mu_k\left(2-\mu_k-\nu_k\right)}{\sum_{k=1}^{n}\left[\mu_k\left(2-\mu_k-\nu_k\right)\right]}+\frac{n-r_k+1}{\sum_{k=1}^{n}\left(n-r_k+1\right)}\right), \tag{7}$$

where r_k signifies the preference of expert, $k = 1, 2, \ldots, n$. Moreover, λ_k is non-negative and $\lambda_1 + \lambda_2 + \ldots + \lambda_n = 1$.

Step 2: Creation of an aggregated IFDM (A-IFDM).

To get the individual opinion by combining different DEs' opinions, we apply the IFWA operator (or IFWG operator) on the IFDM and obtain the A-IFDM $Z = (z_{ij})_{r\times t}$, where

$$z_{ij} = \left(\mu_{ij}, \nu_{ij}\right) = IFWA\left(y_{ij}^{(1)}, y_{ij}^{(2)}, \ldots, y_{ij}^{(n)}\right) \text{ or } IFWG\left(y_{ij}^{(1)}, y_{ij}^{(2)}, \ldots, y_{ij}^{(n)}\right). \tag{8}$$

Step 3: Computation of criteria weights using IF-MEREC-RS model.

Assume that $W = (w_1, w_2, ..., w_t)^T$ be the weight vector of criteria set, satisfying $w_j \in [0, 1]$ and $w_1 + w_2 + \ldots + w_t = 1$. To determine the criteria weights, we discuss an integrated weighting procedure combining the objective and subjective weights of criteria through IF-MEREC and IF-RS models, respectively.

Case I: Finding the objective weight with IF-MEREC.

To determine objective weight of criteria, MEREC (Keshavarz-Ghorabaee et al. [50]) is applied on IFI setting. Here, process of IF-MEREC is given as

Step 3a: Normalization of an A-IFDM.

This step involves linear normalization for the purpose of scaling the elements of the A-IFDM $Z = (z_{ij})_{r\times t}$ and creates the normalized A-IFDM (NA-IFDM) $N = (\varsigma_{ij})_{r\times t}$. If v_b denotes the set of beneficial types of criteria and v_n stands for the non-beneficial criteria set, then Eq. (9) is applied for normalization.

$$\varsigma_{ij} = \left(\bar{\mu}_{ij}, \bar{\nu}_{ij}\right) = \begin{cases} z_{ij} = \left(\mu_{ij}, \nu_{ij}\right), & j \in v_b, \\ \left(z_{ij}\right)^c = \left(\nu_{ij}, \mu_{ij}\right), & j \in v_n. \end{cases} \tag{9}$$

Step 3b: Create the IF-score matrix (IF-SM).

With the use of score function given by Eq. (2), the IF-SM $\Omega = (\eta_{ij})_{r\times t}$ is created, where $\eta_{ij} = 0.5\left(\left(\bar{\mu}_{ij}\right)-\left(\bar{\nu}_{ij}\right)+1\right)$.

Step 3c: Calculation of overall performance of options.

The normalized ratings achieved from the step 3b make sure that the smaller ratings of η_{ij} obtain greater performance ratings. Here, Eq. (10) is applied to compute overall performance of i^{th} option.

$$Q_i = ln\left(1+\left(\frac{1}{t}\sum_j\left|ln\left(\eta_{ij}\right)\right|\right)\right), \forall i. \tag{10}$$

Step 3d: Finding the performance of option by removing each criterion.

Let Q_{ij} stands the overall performance of i^{th} option by the removal of j^{th} criterion. This process is done using Eq. (11).

$$Q_{ij} = ln\left(1+\left(\frac{1}{t}\sum_{l,l\neq j}\left|ln\left(\eta_{il}\right)\right|\right)\right). \tag{11}$$

Step 3e: Calculate the sum of absolute deviations using Eq. (12).

$$D_j = \sum_i \left|Q_{ij} - Q_i\right|. \tag{12}$$

Step 3f: Determination of objective weight of j^{th} criterion from Eq. (13), where $j = 1, 2, \ldots, t$.

$$w_j^o = \frac{D_j}{\sum_{j=1}^{t} D_j},\ j = 1, 2, \ldots, t. \tag{13}$$

Case II: Estimation of subjective weight via IF-RS model.

Step 3g: Using IFWA operator, aggregate the IFNs provided by the DEs and obtain an aggregated column matrix $B = (b_j)_{1\times t}$. Using Eq. (2), find IF-score value of A-IFN of column matrix $B = (b_j)_{1\times t}$.

Step 3h: On the basis of decreasing score values, determine the preference (m_j) of j^{th} criterion and compute weight of criterion using $\bar{w}_j^s = t - m_j + 1$, j = 1, 2, 3, ..., t. Finally, derive the normalized subjective weight of criteria with Eq. (14.) as

$$w_j^s = \frac{\bar{w}_j^s}{\sum_{j=1}^{t} \bar{w}_j^s},\ \ j = 1, 2, \ldots t. \tag{14}$$

Case III: Estimation of integrated weight of criteria.

We combine the outcomes determined by IF-MEREC and IF-RS models. The process of finding combined weight of criteria is given by

$$w_j = \tau w_j^o + \left(1-\tau\right) w_j^s, \tag{15}$$

where satisfying $\tau \in [0, 1]$ is a weight strategy parameter. If $\tau = 1$, then the objective weight by IF-MEREC is fully considered to estimate the criteria weights, while subjective weight of criteria is completely overlooked. Conversely, when $\tau = 0$, the subjective weight by IF-RS model is fully considered for deriving the criteria weights, while objective weight of criteria is completely neglected. When $\tau = 0.5$, then the combined weight of criteria is estimated as the arithmetic mean of objective and subjective weights of attributes/criteria.

Step 4: Create the weighted NA-IFDM.

On the basis of obtained criteria weights and Eq. (16), the weighted NA-IFDM $N_w = (\xi_{ij})_{r\times t}$. where $\xi_{ij} = \left(\hat{\mu}_{ij}, \hat{\nu}_{ij}\right)$ is an aggregated IFN.

$$\xi_{ij} = w_j \otimes \varsigma_{ij} = \left[1-\left(1-\bar{\mu}_{ij}\right)^{w_j}, \bar{\nu}_{ij}^{w_j}\right]. \tag{16}$$

Step 5: Compute the IF-ideal solution (IF-IS) matrix $M = (M_j)_{1\times t}$ using

$$M_j = \left(\bar{\mu}_{ij}, \nu_{ij}\right)_{1\times t} = \begin{cases} \max\limits_i \left(S\left(\xi_{ij}\right)\right), & j \in \nu_b, \\ \min\limits_i \left(S\left(\xi_{ij}\right)\right), & j \in \nu_b. \end{cases} \tag{17}$$

Step 6: Analyze the composite distance matrix $CD = (cd_{ij})_{r\times t}$ of each alternative from the IF-IS using Eq. (18).

$$cd_{ij} = \sqrt{\frac{3}{2}\left(\frac{\left(\hat{\mu}_j - \bar{\mu}_{ij}\right)^2}{\hat{\mu}_j + \bar{\mu}_{ij} + 2} + \frac{\left(\hat{\nu}_j - \bar{\nu}_{ij}\right)^2}{\hat{\nu}_j + \bar{\nu}_{ij} + 2} + \frac{\left(\hat{\pi}_j - \bar{\pi}_{ij}\right)^2}{\hat{\pi}_j + \bar{\pi}_{ij} + 2}\right)}. \tag{18}$$

Step 7: Computation of assessment score (AS) L_i, $i = 1, 2, 3, ..., r$, of options based on Eq. (19) as

$$L_i = 1 - \left(\sum_{j=1}^{t} cd_{ij}\right), i = 1, 2, ..., r. \tag{19}$$

Step 8: Prioritize the options based on descending ratings of L_i, $i = 1, 2, 3, ..., r$. The option with the maximum assessment score is the most desirable option.

4. Results and Discussion

In this section, we first implement the developed approach on a case study of blockchain platform selection problem. Further, we discuss the sensitivity assessment over varying values of criteria weights to test the robustness of introduced method.

4.1. Case Study: Blockchain Platform Selection in the Logistics Industry

As a promising and revolutionary technology, blockchain helps to ensure the authenticity of information and transparency during upstream transactions in a business network. In a logistics supply chain, blockchain records each step of a product's journey on an immutable ledger and ensures that each transaction is securely stored and cannot be changed retroactively [51]. It can increase trust, security, transparency among associate organizations by enhancing traceability of data across a business system [52]. New technologies like as internet of things (IoT), blockchain, cloud computing (CC) and big data (BD), significantly streamline the logistics process and improve its efficiency [8]. This subsection utilizes the developed framework on a case study of blockchain platform selection with respect to the multiple criteria. To collect the data for assessment, we have organized in-person meetings with the experts; though we have invited ten DEs, out of which four DEs, including a chief marketing manager of the company, a chief executive officer, a technology expert and an environmental expert, accepted to cooperate with us for preparing the questionnaires. In the expert committee, the DEs are having more than 10 years of expertise in the respective disciplines and provided their views in taking an appropriate decision. Based on the experts' opinions, six blockchain platforms are identified as alternatives for this study, which are Corda R3 (u_1), Linux (u_2), Hydrachain (u_3), IBM (u_4), Chain Inc. (u_5) and Microsoft (u_6). Considering the literature and DEs' views, 17 different factors/criteria are recognized and shown in Table 1.

Table 1 Details of considered criteria for BT selection

Factors	References	Type
Transparency	Sanka & Cheung [53], Dabbagh et al. [54], Ronaghi [55], Siddiqui & Haroon [56]	Benefit
Speed	Dabbagh et al. [54], Ronaghi [55], Chan et al. [57],	Benefit
Stability	Siddiqui & Haroon [56], Pathak et al. [3]	Benefit
Audit	Gorçün et al. [8], Pathak et al. [3]	Benefit
Accuracy	Xu et al. [58], Ronaghi [55]	Benefit
Productivity	Siddiqui & Haroon [56], Gorçün et al. [8], Pathak et al. [3]	Benefit
Traceability	Sanka & Cheung [53], Dabbagh et al. [54], Ronaghi [55], Siddiqui & Haroon [56], Gorçün et al. [8], Pathak et al. [3]	Benefit
Security	Sanka & Cheung [3], Dabbagh et al. [54], Chan et al. [57], Ronaghi [55], Siddiqui & Haroon [56], Pathak et al. [3]	Benefit
Cost Reduction	Gorçün et al. [8], Pathak et al. [3]	Benefit
Flexibility	Siddiqui & Haroon [56], Pathak et al. [3]	Benefit
Network availability	Xu et al. [58], Dabbagh et al. [54]	Benefit
Scope	Siddiqui & Haroon [56], Pathak et al. [3]	Benefit
Accountability	Xu et al. [58], Ronaghi [55]	Benefit
Planning	Gorçün et al. [8], Pathak et al. [3]	Benefit
Privacy	Rana et al. [59], Xu et al. [58], Jabbar & Dani [60], Dabbagh et al. [54], Chan et al. [57], Siddiqui & Haroon [56], Pathak et al. [3]	Benefit
Reliability	Siddiqui & Haroon [56], Gorçün et al. [8], Pathak et al. [3]	Benefit
Fraud Prevention	Lai & Liao [61], Jabbar & Dani [60], Pathak et al. [3]	Benefit

The experts' committee has planned some strategies to evaluate these six blockchain platforms on the basis of considered evaluation criteria. Here, Table 2 (adopted from [30,31]) shows the linguistic ratings (LRs) and related to IFNs. Table 3 shows linguistic opinions of four DEs to assess the BT platforms in the logistics industry over given criteria.

In the subsequent steps, we present the computational steps of the developed IF-MEREC-RS-DBA framework in order to prioritize the given six options over considered 17 assessment factors.

Steps 1-2: By means of Table 2 and Eq. (7), the weights of four DEs are calculated and mentioned in Table 4. To fuse the individual opinions into a combined opinion of each alternative over diverse criteria, the IFWA operator is applied on intuitionistic fuzzy decision matrix (IFDM) obtained by Table 2 and Table 3, and therefore, an A-IFDM is created and given in Table 5.

Table 2 LRs and related IFNs for criteria and DEs

LRs	IFNs
Extremely good (EG)	(0.95, 0.05)
Very very good (VVG)	(0.85, 0.10)
Very good (VG)	(0.80, 0.15)
Good (G)	(0.70, 0.20)
Slightly good (MG)	(0.60, 0.30)
Average (A)	(0.50, 0.40)
Slightly low (ML)	(0.40, 0.50)
Low (L)	(0.30,0.60)
Very very low (VL)	(0.20, 0.70)
Very low (VVL)	(0.10, 0.80)
Extremely low (EL)	(0.05, 0.95)

Table 3 LAM of blockchain platform options over diverse criteria

	u_1	u_2	u_3	u_4	u_5	u_6
v_1	(MG,G, ML,M)	(M,G, MG,M)	(M,VG, M,G)	(M,G, VG,G)	(ML,MG, L,M)	(MG,G, MG,M)
v_2	(M,M, ML,VL)	(MG,G, M,MG)	(M,M, MG,M)	(ML,ML, G,ML)	(M,G, M,ML)	(ML,G, MG,M)
v_3	(L,G, G,VG)	(M,L, ML,G)	(ML,M, VL,MG)	(MG,L, M,VG)	(ML,M, VL,M)	(G,ML, M,G)
v_4	(G,VL, M,L)	(L,L, ML,MG)	(G,L, ML,M)	(G,MG, L,VL)	(MG,L, L,G)	(VL,G, M,L)
v_5	(MG,M, G,G)	(MG,MG, L,M)	(VG,L, M,VG)	(M,VVG, G,G)	(ML,M, VL,MG)	(MG,VG, VL,ML)
v_6	(ML,MG, VL,M)	(G,VG, MG,M)	(G,MG, M,MG)	(ML,M, M,ML)	(ML,M, M,L)	(L,VG, MG,MG)
v_7	(G,ML, ML,L)	(ML,L, MG,M)	(M,G, M,ML)	(M,M, VL,ML)	(G,VL, M,ML)	(ML,M, L,M)
v_8	(G,M, VVG,VG)	(MG,L, M,MG)	(L,M, G,ML)	(MG,G, L,VL)	(G,G, ML,VG)	(VL,G, MG,MG)
v_9	(ML,M, VG,G)	(M,M, ML,G)	(MG,L, VG,MG)	(M,VVG, G,M)	(ML,G, VG,M)	(M,VG, G,VG)
v_{10}	(ML,ML, MG,G)	(G,M, MG,ML)	(M,MG, ML,MG)	(MG,G, M,VL)	(ML,M, L,VL)	(MG,VG, M,G)
v_{11}	(M,MG, ML,L)	(L,G, VG,M)	(VG,G, M,MG)	(M,MG, G,M)	(MG,M, L,VL)	(MG,M, VG,G)
v_{12}	(M,L, MG,ML)	(G,G, VG,M)	(L,G, M,MG)	(M,MG, M,MG)	(G,G, ML,VL)	(ML,MG, L,ML)
v_{13}	(MG,M, G,G)	(M,M, MG,ML)	(ML,M, ML,M)	(ML,G, M,VL)	(VG,G, ML,L)	(M,MG, L,ML)
v_{14}	(ML,M, G,MG)	(G,L, MG,MG)	(VL,G, MG,M)	(G,VVG, G,M)	(ML,MG, VG,VL)	(MG,VG, L,L)

v_{15}	(M,L, VVG,G)	(G,M, ML,VVG)	(ML,L, G,MG)	(MG,M, M,ML)	(MG,G, MG,M)	(M,VG, MG,M)
v_{16}	(MG,M, ML,VL)	(M,MG, G,VG)	(ML,MG, G,G)	(VG,M, ML,L)	(MG,M, ML,MG)	(MG,VG, MG,L)
v_{17}	(VG,ML, M,ML)	(VL,MG, ML,M)	(M,ML, M,MG)	(MG,L, M,VG)	(M,G, MG,L)	(M,ML, G,MG)

Table 4 Computational results for weight of DEs

DEs	f_1	f_2	f_3	f_4
LRs	VG	VVG	EG	G
IF-score values	0.840	0.8925	0.950	0.770
r_k	3	2	1	4
Weight	0.2217	0.2793	0.3376	0.1615

Table 5 A-IFDM for assessing the blockchain platforms

	U_1	u_2	u_3	u_4	u_5	u_6
v_1	(0.561, 0.333)	(0.598, 0.299)	(0.644, 0.272)	(0.707, 0.212)	(0.452, 0.445)	(0.617, 0.281)
v_2	(0.426, 0.472)	(0.602, 0.295)	(0.536, 0.363)	(0.525, 0.367)	(0.554, 0.342)	(0.581, 0.314)
v_3	(0.661, 0.244)	(0.462, 0.432)	(0.411, 0.485)	(0.549, 0.359)	(0.390, 0.508)	(0.567, 0.326)
v_4	(0.463, 0.428)	(0.393, 0.504)	(0.478, 0.414)	(0.493, 0.397)	(0.461, 0.431)	(0.492, 0.398)
v_5	(0.631, 0.266)	(0.499, 0.397)	(0.613, 0.308)	(0.723, 0.192)	(0.411, 0.485)	(0.555, 0.357)
v_6	(0.427, 0.468)	(0.679, 0.237)	(0.595, 0.302)	(0.464, 0.436)	(0.450, 0.449)	(0.627, 0.288)
v_7	(0.473, 0.420)	(0.470, 0.427)	(0.554, 0.342)	(0.397, 0.501)	(0.476, 0.416)	(0.417, 0.482)
v_8	(0.744, 0.183)	(0.496, 0.401)	(0.533, 0.359)	(0.501, 0.388)	(0.645, 0.260)	(0.570, 0.323)
v_9	(0.648, 0.27)	(0.510, 0.386)	(0.630, 0.288)	(0.699, 0.215)	(0.669, 0.249)	(0.719, 0.205)
v_{10}	(0.532, 0.363)	(0.574, 0.323)	(0.518, 0.380)	(0.555, 0.338)	(0.371, 0.527)	(0.661, 0.255)
v_{11}	(0.473, 0.425)	(0.657, 0.259)	(0.659, 0.253)	(0.605, 0.292)	(0.425, 0.471)	(0.678, 0.241)
v_{12}	(0.475, 0.421)	(0.716, 0.203)	(0.549, 0.344)	(0.547, 0.352)	(0.556, 0.334)	(0.436, 0.461)
v_{13}	(0.631, 0.266)	(0.522, 0.376)	(0.446, 0.453)	(0.513, 0.379)	(0.603, 0.305)	(0.458, 0.439)
v_{14}	(0.577, 0.317)	(0.561, 0.333)	(0.554, 0.339)	(0.732, 0.184)	(0.613, 0.305)	(0.564, 0.349)
v_{15}	(0.663, 0.251)	(0.609, 0.296)	(0.536, 0.356)	(0.510, 0.389)	(0.617, 0.281)	(0.641, 0.276)
v_{16}	(0.454, 0.443)	(0.659, 0.249)	(0.621, 0.274)	(0.542, 0.37)	(0.512, 0.386)	(0.639, 0.276)
v_{17}	(0.558, 0.355)	(0.446, 0.451)	(0.493, 0.406)	(0.549, 0.359)	(0.576, 0.319)	(0.573, 0.322)

Step 3: To derive the objective weight through IF-MEREC, the first step is to normalize the A-IFDM. However, all considered criteria are benefit-type, thus, there is no requirement to normalize A-IFDM and consequently there is no use of Eq. (9). Next, we find IF-score value of each A-IFDM object of Table 5.

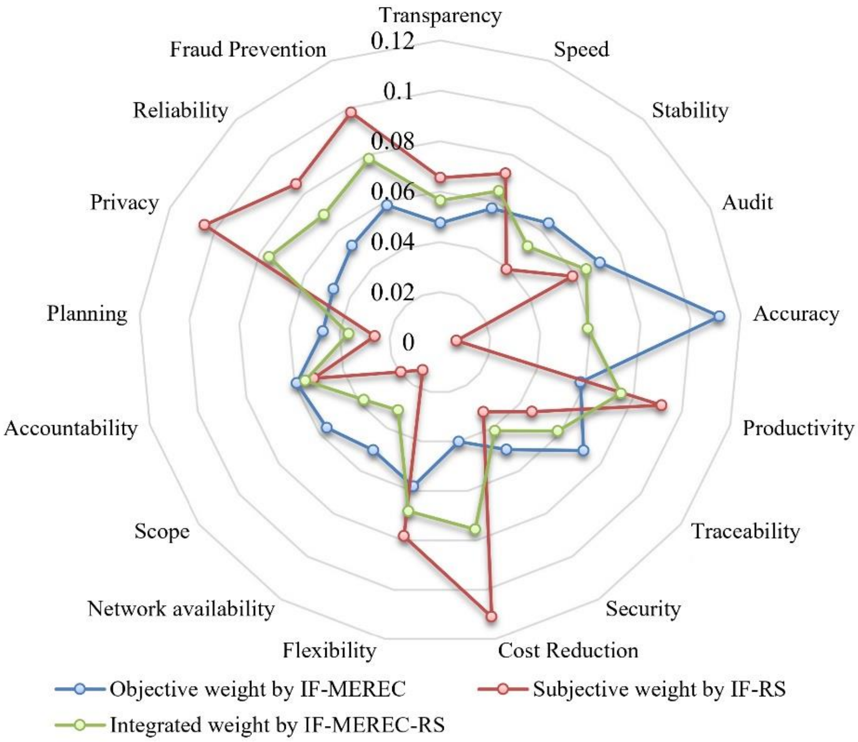

Fig. 2 Variation of criteria weight by IF-MEREC-RS tool for BT platforms assessment

On the basis of IF-score values, overall performance of each option is derived with Eq. (10) and given as $Q_1 = 0.418$, $Q_2 = 0.413$, $Q_3 = 0.416$, $Q_4 = 0.404$, $Q_5 = 0.458$ and $Q_6 = 0.393$. Using Eq. (11), overall performance of i^{th} option by removing j^{th} criterion is estimated in Table 6, where $i = 1, 2, 3, ..., 6$ and $j = 1, 2, 3, ..., 17$. Further, the sum of the deviations is determined via Eq. (12) and given in last second column of Table 6. Lastly, objective weight of criteria is obtained through Eq. (13) and shown in last column of Table 6, which as w_j^o = (0.0474, 0.0571, 0.0640, 0.0710, 0.1116, 0.0580, 0.0715, 0.0502, 0.0403, 0.0583, 0.0505, 0.0564, 0.0593, 0.0468, 0.0474, 0.0520, 0.0584).

To find subjective weight of criteria with RS approach [62] on IFSs as IF-RS, the first step is to obtain the performance rating of each attribute by different expert. Further, individual performances are aggregated through IFWA operator and find IF-score rating of each A-IFN. Table 7 presents computational steps of IF-RS model.

Applying Eq. (14), objective weight of criteria is calculated via Eq. (13) and shown in last column of Table 7, which as w_j^s = (0.0654, 0.0719, 0.0392, 0.0588, 0.0065, 0.0915, 0.0458, 0.0327, 0.1111, 0.0784, 0.0131, 0.0196, 0.0523, 0.0261, 0.1046, 0.0850, 0.0980).

By integrating the objective and subjective weights of factors using Eq. (15), combined weight for τ = 0.5 is computed and presented as w_j = (0.0564, 0.0645, 0.0516, 0.0649, 0.0590, 0.0747, 0.0586, 0.0414, 0.0757, 0.0684, 0.0318, 0.0380, 0.0558, 0.0365, 0.0760, 0.0685, 0.0782).

Table 6 Computational steps of IF-MEREC tool to find objective weight

Criteria	Q_{ij}' values						D_j	w_j^o
	u_1	u_2	u_3	u_4	u_5	u_6		
v_1	0.399	0.396	0.401	0.393	0.432	0.376	0.104	0.0474
v_2	0.389	0.397	0.395	0.383	0.439	0.374	0.125	0.0571
v_3	0.404	0.387	0.385	0.384	0.427	0.373	0.141	0.0640
v_4	0.392	0.381	0.391	0.380	0.433	0.368	0.156	0.0710
v_5	0.403	0.390	0.269	0.394	0.429	0.372	0.245	0.1116
v_6	0.389	0.401	0.399	0.378	0.432	0.377	0.127	0.0580
v_7	0.393	0.388	0.396	0.372	0.434	0.362	0.157	0.0715
v_8	0.408	0.390	0.395	0.381	0.444	0.374	0.110	0.0502
v_9	0.403	0.391	0.400	0.392	0.445	0.381	0.089	0.0403
v_{10}	0.397	0.395	0.393	0.384	0.425	0.379	0.128	0.0583
v_{11}	0.392	0.399	0.402	0.388	0.430	0.379	0.111	0.0505
v_{12}	0.393	0.402	0.396	0.384	0.439	0.364	0.124	0.0564
v_{13}	0.403	0.391	0.388	0.382	0.442	0.365	0.130	0.0593
v_{14}	0.400	0.394	0.396	0.394	0.442	0.373	0.103	0.0468
v_{15}	0.404	0.397	0.395	0.381	0.443	0.377	0.104	0.0474
v_{16}	0.391	0.400	0.400	0.383	0.436	0.377	0.114	0.0520
v_{17}	0.398	0.386	0.392	0.384	0.440	0.374	0.128	0.0584

Fig. 2 presents the pictorial representation of weights of criteria by objective, subjective and integrated weight forms. "Fraud prevention (v_{17})" with weight 0.0782 is the most significant factor during evaluation of blockchain platforms in the logistics industry. "Privacy" (v_{15}) with weight 0.0760 is the second significant indicator in blockchain platforms assessment. "Cost reduction (v_9)" has come out to be third significant indicator with weight 0.0757, "productivity (v_6)" with weight value 0.0747 has fourth factor and others are considered crucial factors in the evaluation of blockchain platforms for the given data.

Step 4: In accordance with Eq. (16), the weighted normalized A-IFDM is created for assessing the blockchain platforms in the logistics industry and given in Table 8.

Step 5: Applying Eq. (17), an IF-IS is determined as M_j = {(0.067, 0.916), (0.058, 0.924), (0.054, 0.93), (0.043, 0.942), (0.073, 0.907), (0.081, 0.898), (0.046, 0.939), (0.055, 0.932), (0.092, 0.887), (0.071, 0.911), (0.035, 0.956), (0.047, 0.941), (0.054, 0.929), (0.047, 0.94), (0.079, 0.9), (0.071, 0.909), (0.065, 0.915)}.

Table 7 Computational steps of IF-RS model for finding subjective weight

Criteria	f_1	f_2	f_3	f_4	Aggregated IFNs	Score values	Rank	w_j^s
v_1	M	H	M	ML	(0.554, 0.342)	0.606	8	0.0654
v_2	H	MH	M	ML	(0.568, 0.328)	0.620	7	0.0719
v_3	M	M	MH	L	(0.510, 0.388)	0.561	12	0.0392
v_4	VH	MH	L	ML	(0.558, 0.353)	0.602	9	0.0588
v_5	MH	ML	ML	L	(0.438, 0.46)	0.489	17	0.0065
v_6	ML	MH	H	MH	(0.603, 0.293)	0.655	4	0.0915
v_7	M	ML	M	H	(0.516, 0.381)	0.567	11	0.0458
v_8	M	MH	M	L	(0.504, 0.394)	0.555	13	0.0327
v_9	VH	M	MH	MH	(0.635, 0.279)	0.678	1	0.1111
v_{10}	ML	VH	M	ML	(0.585, 0.331)	0.627	6	0.0784
v_{11}	MH	L	ML	MH	(0.464, 0.433)	0.516	16	0.0131
v_{12}	M	ML	M	MH	(0.493, 0.406)	0.543	15	0.0196
v_{13}	ML	VH	ML	L	(0.547, 0.368)	0.590	10	0.0523
v_{14}	M	H	L	ML	(0.500, 0.392)	0.554	14	0.0261
v_{15}	M	MH	VH	L	(0.636, 0.283)	0.676	2	0.1046
v_{16}	MH	M	H	M	(0.600, 0.297)	0.651	5	0.0850
v_{17}	H	ML	H	MH	(0.619, 0.276)	0.671	3	0.0980

Step 6: In this step, the composite distance matrix $CD = (cd_{ij})_{6\times17}$ is determined using Eq. (18), where cd_{ij} is given as $cd_{11} = 0.023$, $cd_{12} = 0.026$, $cd_{13} = 0$, $cd_{14} = 0.004$, $cd_{15} = 0.017$, $cd_{16} = 0.045$, $cd_{17} = 0.011$, $cd_{18} = 0$, $cd_{19} = 0.018$, $cd_{110} = 0.022$, $cd_{111} = 0.017$, $cd_{112} = 0.025$, $cd_{113} = 0$, $cd_{114} = 0.018$, $cd_{115} = 0$, $cd_{116} = 0.035$, $cd_{117} = 0.007$, $cd_{21} = 0.018$, $cd_{22} = 0$, $cd_{23} = 0.026$, $cd_{24} = 0.014$, $cd_{25} = 0.038$, $cd_{26} = 0$, $cd_{27} = 0.011$, $cd_{28} = 0.03$, $cd_{29} = 0.043$, $cd_{210} = 0.015$, $cd_{211} = 0.002$, $cd_{212} = 0$, $cd_{213} = 0.017$, $cd_{214} = 0.02$, $cd_{215} = 0.011$, $cd_{216} = 0$, $cd_{217} = 0.023$, $cd_{31} = 0.012$, $cd_{32} = 0.011$, $cd_{33} = 0.032$, $cd_{34} = 0.002$, $cd_{35} = 0.023$, $cd_{36} = 0.017$, $cd_{37} = 0$, $cd_{38} = 0.026$, $cd_{39} = 0.022$, $cd_{310} = 0.025$, $cd_{311} = 0.002$, $cd_{312} = 0.019$, $cd_{313} = 0.026$, $cd_{314} = 0.020$, $cd_{315} = 0.024$, $cd_{316} = 0.007$, $cd_{317} = 0.016$, $cd_{41} = 0$, $cd_{42} = 0.012$, $cd_{43} = 0.017$, $cd_{44} = 0$, $c_{45} = 0$, $cd_{46} = 0.040$, $cd_{47} = 0.02$, $cd_{48} = 0.029$, $cd_{49} = 0.005$, $cd_{410} = 0.018$, $cd_{411} = 0.007$, $cd_{412} = 0.019$, $cd_{413} = 0.017$, $cd_{414} = 0$, $cd_{415} = 0.030$, $cd_{416} = 0.023$, $cd_{417} = 0.007$, $cd_{51} = 0.038$, $cd_{52} = 0.008$, $cd_{53} = 0.034$, $cd_{54} = 0.005$, $cd_{55} = 0.048$, $cd_{56} = 0.042$, $cd_{57} = 0.01$, $cd_{58} = 0.014$, $cd_{59} = 0.013$, $cd_{510} = 0.045$, $cd_{511} = 0.02$, $cd_{512} = 0.018$, $cd_{513} = 0.006$, $cd_{514} = 0.016$, $cd_{515} = 0.009$, $cd_{516} = 0.026$, $cd_{517} = 0$, $cd_{61} = 0.015$, $cd_{62} = 0.004$, $cd_{63} = 0.013$, $cd_{64} = 0$, $cd_{65} = 0.031$, $cd_{66} = 0.012$, $cd_{67} = 0.018$, $cd_{68} = 0.022$, $cd_{69} = 0$, $cd_{610} = 0$, $cd_{611} = 0$, $cd_{612} = 0.029$, $cd_{613} = 0.024$, $cd_{614} = 0.02$, $cd_{615} = 0.006$, $cd_{616} = 0.006$ and $cd_{617} = 0.001$.

Step 7: Using Eq. (19), the assessment score of each option is calculated and presented as $L_1 = (1- 0.27) = 0.73$, $L_2 = (1- 0.2683) = 0.7317$, $L_3 = (1- 0.284) = 0.716$, $L_4 = (1- 0.2447) = 0.7553$, $L_5 = (1- 0.3518) = 0.6482$, $L_6 = (1- 0.2015) = 0.7985$.

Table 8 Weighted normalized A-IFDM for assessing the blockchain platforms

	u_1	u_2	u_3	u_4	u_5	u_6
v_1	(0.045, 0.940)	(0.050, 0.934)	(0.057, 0.929)	(0.067, 0.916)	(0.033, 0.955)	(0.053, 0.931)
v_2	(0.035, 0.953)	(0.058, 0.924)	(0.048, 0.937)	(0.047, 0.937)	(0.051, 0.933)	(0.055, 0.928)
v_3	(0.054, 0.930)	(0.031, 0.958)	(0.027, 0.963)	(0.040, 0.948)	(0.025, 0.966)	(0.042, 0.944)
v_4	(0.039, 0.946)	(0.032, 0.957)	(0.041, 0.944)	(0.043, 0.942)	(0.039, 0.947)	(0.043, 0.942)
v_5	(0.057, 0.925)	(0.040, 0.947)	(0.055, 0.933)	(0.073, 0.907)	(0.031, 0.958)	(0.047, 0.941)
v_6	(0.041, 0.945)	(0.082, 0.898)	(0.065, 0.914)	(0.046, 0.94)	(0.044, 0.942)	(0.071, 0.911)
v_7	(0.037, 0.95)	(0.037, 0.951)	(0.046, 0.939)	(0.029, 0.960)	(0.037, 0.95)	(0.031, 0.958)
v_8	(0.055, 0.932)	(0.028, 0.963)	(0.031, 0.958)	(0.028, 0.962)	(0.042, 0.946)	(0.034, 0.954)
v_9	(0.076, 0.906)	(0.053, 0.930)	(0.072, 0.91)	(0.087, 0.89)	(0.08, 0.9)	(0.092, 0.887)
v_{10}	(0.051, 0.933)	(0.057, 0.926)	(0.049, 0.936)	(0.054, 0.929)	(0.031, 0.957)	(0.071, 0.911)
v_{11}	(0.02, 0.973)	(0.033, 0.958)	(0.034, 0.957)	(0.029, 0.962)	(0.017, 0.976)	(0.035, 0.956)
v_{12}	(0.024, 0.968)	(0.047, 0.941)	(0.03, 0.96)	(0.03, 0.961)	(0.03, 0.959)	(0.021, 0.971)
v_{13}	(0.054, 0.929)	(0.04, 0.947)	(0.032, 0.957)	(0.039, 0.947)	(0.05, 0.936)	(0.034, 0.955)
v_{14}	(0.031, 0.959)	(0.03, 0.961)	(0.029, 0.961)	(0.047, 0.94)	(0.034, 0.958)	(0.03, 0.962)
v_{15}	(0.079, 0.9)	(0.069, 0.912)	(0.057, 0.924)	(0.053, 0.931)	(0.07, 0.908)	(0.075, 0.907)
v_{16}	(0.041, 0.946)	(0.071, 0.909)	(0.064, 0.915)	(0.052, 0.934)	(0.048, 0.937)	(0.067, 0.916)
v_{17}	(0.062, 0.922)	(0.045, 0.94)	(0.052, 0.932)	(0.06, 0.923)	(0.065, 0.915)	(0.064, 0.915)

Step 8: On the basis of decreasing ratings of assessment scores of options, the ranking order of blockchain platforms is obtained as u_6 (0.7985) > u_4 (0.7553) > u_2 (0.7317) > u_1 (0.73) > u_3 (0.716) > u_5 (0.6482). Thus, an option "Microsoft (u_6)" is the most suitable platform with highest assessment score (0.7985) among a set of six alternatives concerning 17 criteria.

4.2. Sensitivity Analysis

This subsection discusses sensitivity assessment over varying ratings of weight strategy coefficient τ. This analysis can validate the superiority and stability of developed IF-MEREC-RS-DBA framework to assess the blockchain platforms in the logistics industry. In this process, we observed the variations of assessment scores with respect to diverse values of parameter τ and required outcomes are discussed in Table 9 and Fig. 3. By means of the assessment scores for $\tau = 0.0$ in Table 9, the preference of blockchain platforms is $u_6 \succ u_2 \succ u_4 \succ u_1 \succ u_3 \succ u_5$, whereas prioritization of blockchain platforms for $\tau = 0.1$ to 0.5 is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, while for $\tau = 0.6$ to 0.9, the ranking order of blockchain alternatives is $u_6 \succ u_4 \succ u_1 \succ u_2 \succ u_3 \succ u_5$, and at $\tau = 1.0$, the prioritization of blockchain platforms is $u_6 \succ u_4 \succ u_1 \succ u_2 \succ u_3 \succ u_5$. Here, we can easily be observed that the alternative "Microsoft (u_6)" has always obtained a maximum preference over the others alternatives except at $\tau = 1.0$. Thus, the assessment process of alternatives is relied on and sensitive to the parameter τ.

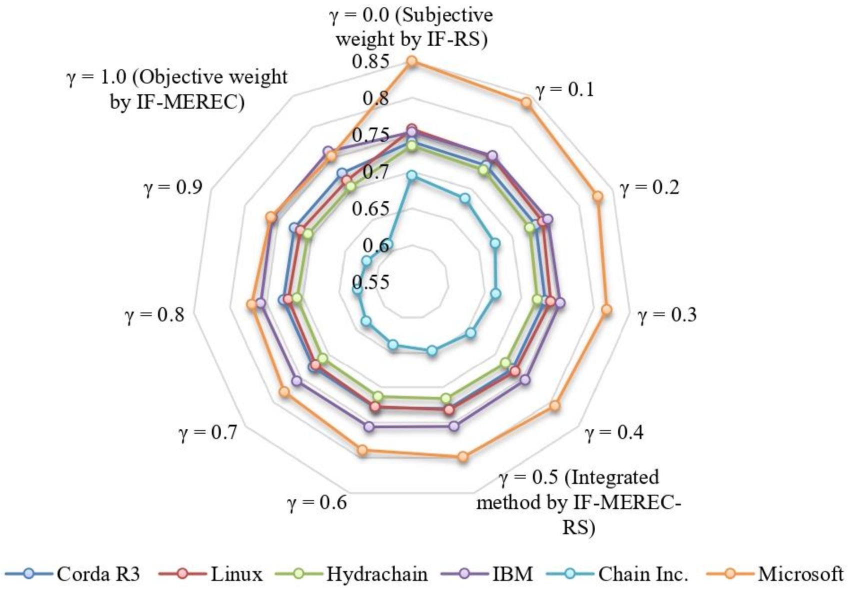

Fig. 3 Sensitivity results of assessment scores based on different values of parameter τ

Table 9 Prioritization outcomes of BT platforms with different τ values

τ	u_1	u_2	u_3	u_4	u_5	u_6
$\tau = 0.0$ (Subjective weight by IF-RS)	0.7402	0.7572	0.7345	0.7531	0.6941	0.8497
$\tau = 0.1$	0.7377	0.7515	0.7303	0.7533	0.6842	0.839
$\tau = 0.2$	0.7355	0.7461	0.7264	0.7537	0.6747	0.8285
$\tau = 0.3$	0.7335	0.741	0.7227	0.7541	0.6656	0.8183
$\tau = 0.4$	0.7317	0.7362	0.7192	0.7546	0.6568	0.8083
$\tau = 0.5$ (Integrated method by IF-MEREC-RS)	0.73	0.7317	0.716	0.7553	0.6482	0.7985
$\tau = 0.6$	0.7286	0.7274	0.713	0.756	0.6401	0.7888
$\tau = 0.7$	0.7274	0.7235	0.7103	0.7569	0.6322	0.7794
$\tau = 0.8$	0.7264	0.7198	0.7077	0.7578	0.6246	0.7702
$\tau = 0.9$	0.7256	0.7164	0.7054	0.7589	0.6174	0.7612
$\tau = 1.0$ (Objective weight by IF-MEREC)	0.725	0.7133	0.7034	0.7601	0.6104	0.7524

4.3. Comparative Study

This subsection compares the proposed IF-MEREC-RS-DBA and existing IF-information based MCGDM methods to check the robustness of introduced framework. To validate the outcomes obtained from the IF-MEREC-RS-DBA approach, four well-known MCDM approaches are selected, which are given by Qin et al. [29], Mishra et al. [30], Deb et al. [31] and Liu [32]. By applying these methods on the aforesaid case study, we aim to confirm and emphasize the findings determined from developed IF-MEREC-RS-DBA method.

Table 10: Optimal performance rating and weighted normalized aggregated IFNs

Criteria	OPR	u_1	u_2	u_3	u_4	u_5	u_6
v_1	(0.067, 0.916)	(0.045, 0.94)	(0.05, 0.934)	(0.057, 0.929)	(0.067, 0.916)	(0.033, 0.955)	(0.053, 0.931)
v_2	(0.058, 0.924)	(0.035, 0.953)	(0.058, 0.924)	(0.048, 0.937)	(0.047, 0.937)	(0.051, 0.933)	(0.055, 0.928)
v_3	(0.054, 0.93)	(0.054, 0.93)	(0.031, 0.958)	(0.027, 0.963)	(0.04, 0.948)	(0.025, 0.966)	(0.042, 0.944)
v_4	(0.043, 0.942)	(0.039, 0.946)	(0.032, 0.957)	(0.041, 0.944)	(0.043, 0.942)	(0.039, 0.947)	(0.043, 0.942)
v_5	(0.073, 0.907)	(0.057, 0.925)	(0.04, 0.947)	(0.055, 0.933)	(0.073, 0.907)	(0.031, 0.958)	(0.047, 0.941)
v_6	(0.081, 0.898)	(0.041, 0.945)	(0.082, 0.898)	(0.065, 0.914)	(0.046, 0.94)	(0.044, 0.942)	(0.071, 0.911)
v_7	(0.046, 0.939)	(0.037, 0.95)	(0.037, 0.951)	(0.046, 0.939)	(0.029, 0.96)	(0.037, 0.95)	(0.031, 0.958)
v_8	(0.055, 0.932)	(0.055, 0.932)	(0.028, 0.963)	(0.031, 0.958)	(0.028, 0.962)	(0.042, 0.946)	(0.034, 0.954)
v_9	(0.092, 0.887)	(0.076, 0.906)	(0.053, 0.93)	(0.072, 0.91)	(0.087, 0.89)	(0.08, 0.9)	(0.092, 0.887)
v_{10}	(0.071, 0.911)	(0.051, 0.933)	(0.057, 0.926)	(0.049, 0.936)	(0.054, 0.929)	(0.031, 0.957)	(0.071, 0.911)
v_{11}	(0.035, 0.956)	(0.02, 0.973)	(0.033, 0.958)	(0.034, 0.957)	(0.029, 0.962)	(0.017, 0.976)	(0.035, 0.956)
v_{12}	(0.047, 0.941)	(0.024, 0.968)	(0.047, 0.941)	(0.03, 0.96)	(0.03, 0.961)	(0.03, 0.959)	(0.021, 0.971)
v_{13}	(0.054, 0.929)	(0.054, 0.929)	(0.04, 0.947)	(0.032, 0.957)	(0.039, 0.947)	(0.05, 0.936)	(0.034, 0.955)
v_{14}	(0.047, 0.94)	(0.031, 0.959)	(0.03, 0.961)	(0.029, 0.961)	(0.047, 0.94)	(0.034, 0.958)	(0.03, 0.962)
v_{15}	(0.079, 0.9)	(0.079, 0.9)	(0.069, 0.912)	(0.057, 0.924)	(0.053, 0.931)	(0.07, 0.908)	(0.075, 0.907)
v_{16}	(0.071, 0.909)	(0.041, 0.946)	(0.071, 0.909)	(0.064, 0.915)	(0.052, 0.934)	(0.048, 0.937)	(0.067, 0.916)
v_{17}	(0.065, 0.915)	(0.062, 0.922)	(0.045, 0.94)	(0.052, 0.932)	(0.06, 0.923)	(0.065, 0.915)	(0.064, 0.915)

4.3.1. IF-TOPSIS Method

The IF-TOPSIS method proposed by Qin et al. [29] is used on aforesaid case study for assessing and prioritizing blockchain platform alternatives by means of the given 17 criteria. Using this method, we obtain the ideal solution as {(0.707, 0.212), (0.602, 0.295), (0.661, 0.244), (0.493, 0.397), (0.723, 0.192), (0.679, 0.237), (0.554, 0.342), (0.744, 0.183), (0.719, 0.205), (0.661, 0.255), (0.678, 0.241), (0.716, 0.203), (0.631, 0.266), (0.732, 0.184), (0.663, 0.251), (0.659, 0.249), (0.576, 0.319)} and the anti-ideal solution as {(0.452, 0.445), (0.426, 0.472), (0.390, 0.508), (0.393, 0.504), (0.411, 0.485), (0.427, 0.468), (0.397, 0.501), (0.496, 0.401), (0.510, 0.386), (0.371, 0.527), (0.425, 0.471), (0.436, 0.461), (0.446, 0.453), (0.564, 0.349), (0.510, 0.389), (0.454, 0.443), (0.446, 0.451)}. Next, IF-distance on each option with IF-ideal solution is computed as 0.103, 0.101, 0.103, 0.094, 0.136 and 0.071. Similarly, IF-distance on each option with IF-anti-ideal solution is computed as 0.110, 0.111, 0.110, 0.120, 0.076 and 0.141. Finally, relative closeness coefficient is calculated for each option and given as 0.5162, 0.5223, 0.5160, 0.5610, 0.3588 and 0.6647. On the basis of obtained relative closeness coefficient, the ranking order of blockchain platforms is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, and the platform "Microsoft (u_6)" is the most suitable choice among the others.

Table 11: OPD of options for BT platforms assessment

Criteria	Optimal rating	Score values					
		u_1	u_2	u_3	u_4	u_5	u_6
v_1	0.075	0.053	0.058	0.064	0.075	0.039	0.061
v_2	0.067	0.041	0.067	0.056	0.055	0.059	0.063
v_3	0.062	0.062	0.037	0.032	0.046	0.030	0.049
v_4	0.051	0.047	0.038	0.048	0.051	0.046	0.050
v_5	0.083	0.066	0.047	0.061	0.083	0.036	0.053
v_6	0.092	0.048	0.092	0.075	0.053	0.051	0.080
v_7	0.054	0.043	0.043	0.054	0.034	0.044	0.037
v_8	0.061	0.061	0.033	0.036	0.033	0.048	0.040
v_9	0.102	0.085	0.061	0.081	0.098	0.090	0.102
v_{10}	0.080	0.059	0.066	0.056	0.063	0.037	0.080
v_{11}	0.040	0.023	0.038	0.038	0.034	0.021	0.040
v_{12}	0.053	0.028	0.053	0.035	0.034	0.036	0.025
v_{13}	0.063	0.063	0.047	0.038	0.046	0.057	0.039
v_{14}	0.053	0.036	0.034	0.034	0.053	0.038	0.034
v_{15}	0.090	0.090	0.079	0.066	0.061	0.081	0.084
v_{16}	0.081	0.047	0.081	0.074	0.059	0.055	0.076
v_{17}	0.075	0.070	0.053	0.060	0.069	0.075	0.075
OPD	1.181	0.923	0.923	0.909	0.947	0.843	0.988
UD	-	0.7810	0.7816	0.7692	0.8019	0.7138	0.8366
Ranking		4	3	5	2	6	1

4.3.2. IF-ARAS Method

After applying this method on the abovementioned blockchain platforms assessment problem, the optimal performance rating (OPR) is determined as {(0.707, 0.212), (0.602, 0.295), (0.661, 0.244), (0.493, 0.397), (0.723, 0.192), (0.679, 0.237), (0.554, 0.342), (0.744, 0.183), (0.719, 0.205), (0.661, 0.255), (0.678, 0.241), (0.716, 0.203), (0.631, 0.266), (0.732, 0.184), (0.663, 0.251), (0.659, 0.249), (0.576, 0.319)}. Next, the weighted normalized A-IFDM is made and given in Table 10.

Further, the score value of each entry of Table 10 is determined and presented in Table 11. By adding the corresponding score values of each column in Table 11, the optimal performance degree (OPD) is calculated as 1.181, 0.923, 0.923, 0.909, 0.947, 0.843 and 0.988. Further, the utility degree (UD) of each alternative is derived as 0.7810, 0.7816, 0.7692, 0.8019, 0.7138 and 0.8366, respectively. On account of the decreasing utility degrees, the ranking order of blockchain platforms is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, and the platform "Microsoft (u_6)" is the most suitable choice among the others.

4.3.3. IF-WASPAS Method

Based on the execution of IF-WASPAS method on the aforesaid blockchain platforms assessment problem, the additive relative importance of each alternative is determined as (0.561, 0.339), (0.561, 0.339), (0.555, 0.345), (0.571, 0.33), (0.526, 0.372) and (0.590, 0.315), respectively, and their corresponding score values are 0.611, 0.611, 0.605, 0.621, 0.577 and 0.637, respectively. Next, the multiplicative relative importance of each alternative is computed as (0.543, 0.357), (0.545, 0.354), (0.546, 0.353), (0.553, 0.348), (0.509, 0.388) and (0.576, 0.328), and their corresponding score values are 0.593, 0.595, 0.596, 0.603, 0.560 and 0.624, respectively. Lastly, the total relative importance of each alternative is determined as 0.6020, 0.6032, 0.6006, 0.6118, 0.5688 and 0.6308, respectively. Arranging the values of total relative importance, the ranking order of blockchain platforms is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, and the platform "Microsoft (u_6)" is the most suitable choice among the others for the logistics industry.

4.3.4. IF-CoCoSo Method

The IF-CoCoSo method is applied to the aforesaid case study of blockchain platforms evaluation in the logistics industry. The additive and multiplicative importance is same as Liu (2024). Next, the relative compromise rating of each option is computed as $r_1^{(1)} = 0.1664$, $r_2^{(1)} = 0.1668$, $r_3^{(1)} = 0.166$, $r_4^{(1)} = 0.1691$, $r_5^{(1)} = 0.1608$, $r_6^{(1)} = 0.1744$, $r_1^{(2)} = 0.767$, $r_2^{(2)} = 0.769$, $r_3^{(2)} = 0.766$, $r_4^{(2)} = 0.780$, $r_5^{(2)} = 0.725$, $r_6^{(2)} = 0.804$, $r_1^{(3)} = 0.954$, $r_2^{(3)} = 0.956$, $r_3^{(3)} = 0.952$, $r_4^{(3)} = 0.97$, $r_5^{(3)} = 0.902$ and $r_6^{(3)} = 1.0$. Based on the relative compromise rating, the overall compromise rating of each alternative is determined as 0.5626, 0.5638, 0.5613, 0.5717, 0.5339 and 0.5895, respectively. Based on decreasing ratings of overall compromise ratings, preference of blockchain platforms is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, and the platform "Microsoft (u_6)" is the most suitable choice among the others for the logistics industry.

Fig. 4 presents the pictorial representation of ranking orders of blockchain platforms using diverse methods. On the basis of obtained results, it can be observed that the proposed and existent approaches attain the same ranking order, which is $u_6 \succ u_4 \succ u_2 \succ u_1 \succ u_3 \succ u_5$, and the most optimal choice is "Microsoft (u_6)". The IF-MEREC-RS-DBA framework has the following advantages over the existing models (Qin et al. [29], Mishra et al. [30], Deb et al. [31], Liu [32]):

- Existing methods given by (Qin et al. [29], Deb et al. [31], and Liu [32]) doesn't consider the DEs' weights, while developed IF-MEREC-RS-DBA framework estimates weights of DEs with IF-score function and RS model-based weighting approach. Therefore, proposed approach is more suitable for MCGDM problems under IFI setting.

- Qin et al. [29] and Deb et al. [31] assumes weight of criteria without any logical explanation, while Liu [32] derives the objective weight of criteria via entropy method. Although, developed IF-MEREC-RS-DBA framework find weights of criteria through integrated IF-MEREC-RS model consisting of objective weight with IF-MEREC and subjective weight with IF-RS approach. Thus, the consistency of outcomes is more practical than existing models.
- The proposed distance measure computes the composite distance matrix in the IF-MEREC-RS-DBA method, while the existing DBA methods by (Sandhya et al. [41], Garg et al. [40], Garg & Garg [42]) determine the composite distance matrix through hamming distance formula.

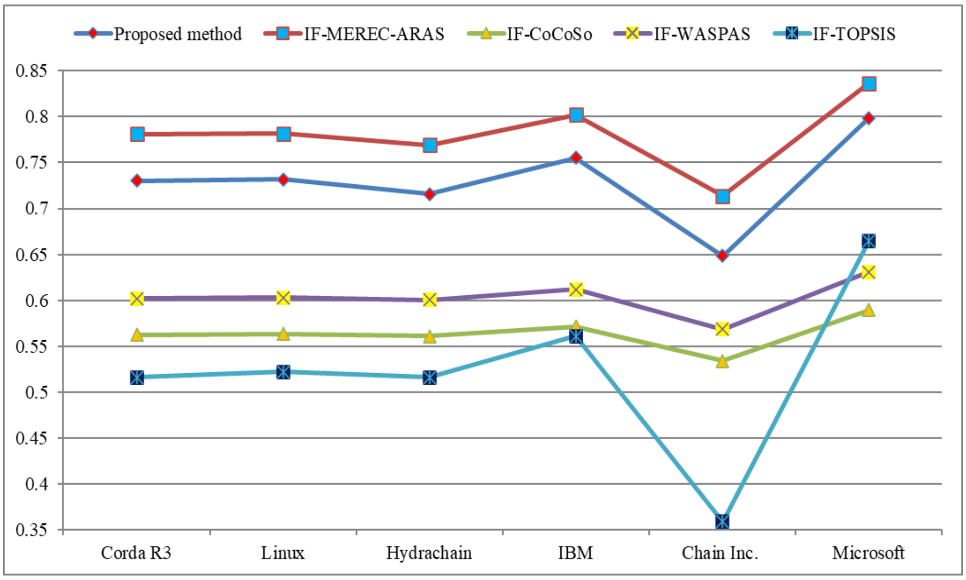

Fig. 4 Assessment degree of blockchain platforms by diverse methods

5. Conclusion

In the current digital economy era, the DT has offered many opportunities to preserve the competitiveness in the business models. Nowadays, the DT in logistics companies is reshaping the businesses by using innovative technologies and improving the productivity with aster, leaner, and more efficient operations. As a decentralized digital ledger, BT improves logistics' operations by providing transparency, security, and efficiency, and ensures secure and transparent transaction records. To select a suitable blockchain platform in the logistics industry, we have proposed an integrated IF-MEREC-RS-DBA framework by combining the weighting model and ranking method within the settings of IFSs. In this method, the significance value of each DE has been computed through IF-score function and IF-RS model-based formula. Next, weights of criteria have been derived via a combined weighting process consisting of objective weight with IF-MEREC and subjective weight with IF-RS approach. Further, an integrated intuitionistic fuzzy distance-based approach has been presented utilizing developed IF-distance measure, DEs' weighting system and criteria weight-determination model. To this aim, a new distance measure has been introduced with the combination of MD, ND and hesitancy degree, and applied to find the composite distance matrix in the proposed IF-MEREC-RS-DBA model. Moreover, the proposed approach has been applied to a case study of blockchain platform selection problem in the logistics industry, which shows its usefulness. Sensitivity and comparative analyses have been performed to validate the stability and robustness of the IF-MEREC-RS-DBA framework. In future, some new MCGDM model will be developed, which can consider the interrelationships among the criteria. Future works will consider a greater number of experts from global and local regions, which will provide an extensive perspective to this study. Furthermore, the DBA model can be applied to group clustering, large-scale group consensus decision-making, texture identification and other areas.

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