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An interval multi-criteria decision-making model for evaluating blockchain-IoT technology in supply chain networks

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ABSTRACT

Supply Chain (SC) networks benefit from the integration of Blockchain Technology (BT) and the Internet of Things (IoT) in many ways, from data protection and transparency to fraud prevention, traceability, and cost reduction. As the technology is new, there is a lack of knowledge and experience in selecting suitable platforms for SC networks. Choosing the right platform is a difficult and complex task involving multiple and conflicting criteria. This study presents a novel practical approach for evaluating and selecting a BT-IoT platform in SC networks using multi-criteria decision-making. First, an extensive literature review is conducted to determine the most suitable criteria for BT-IoT platform selection. Then, using the interval Weighted Influence Non-linear Gauge System (WINGS) method, the weights of the criteria are calculated, and finally an interval VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique is used to assess the suitability of the platforms. The proposed approach uses the experts' preferences, considers the interdependencies among criteria in the weighting process, and enables implementation in a hierarchical and interconnected network. We present a case study in the food industry to demonstrate the applicability of the proposed model. Additional sensitivity analysis is conducted to exhibit the efficacy of the proposed model in selecting a suitable and robust platform in SC networks.

1. Introduction

Food supply chains (SCs) are one of the emerging applications of Blockchain Technology (BT) in SC management [1,2]. A food chain involves various players, such as farmers, processing centers, warehouses, distributors, and retailers. Its communications require heavy paper transactions susceptible to fraud and untransparent processes. The key characteristic of BT is its decentralized topology, which ensures the transmission of custody events between nodes to ensure security and trustworthiness. SCs mainly benefit from BT

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due to trusted information sharing among the entities [3,4]. It makes it possible to share immutable and transparent data of the entire process with all participants of the SC, including the government, farmers, businesses, and citizens alike [5]. Several problems in food SCs, such as food safety, integrity, security, traceability, quality, and sustainability, can be addressed with real-time and reliable access to relevant information based on a consensus mechanism [1,6].

BT impacts SC processes and operations like inventory, product management, and financial transactions (Shoaib et al., 2019; [7]). It extends the ability to monitor stocks and tracking processes in SCs and provides transparency for the customer [8,9], flexibility and stakeholder management, reducing fraudulent activities, reducing cost and errors [10], risk sensitivity assessment and elimination of manual structures in the whole process with tracking [11], decision process [12], improving the resiliency of SC [13] and sustainability [14], provenance tracking [15], SC finance with asset-backed securitization [16], eliminating third parties [17], cross-enterprise knowledge and services exchange [18], reducing delays and identifying problems faster as well as managing purchasing processes [19].

Very supportive literature for implementing the SC and its advantages led to increasing the number of BT platforms in the real world. Competitive pressures force companies to adopt the BT for supply chain management and operations [20,21]. Many software-producing companies, including international pioneers, as well as small startups, are considering including it in their products [22]. A list of available blockchain Internet of Things (IoT) platforms and products is provided by Raj [23], Wang et al. [24], and Choi et al. [19]. IBM and OriginTrail are examples of blockchain developed for SC management [15,23]. Warranteer platform uses the customers' feedback about the products and the services, and Blockverify focuses on the solutions verifying counterfeited products, stolen stock and merchandise, and deceitful transactions [15]. The BT is used by Blockverify to prevent fraud for banks and insurance companies [25]. In Blockverify, customers need to register their digital identity when using the relevant features to ensure privacy [26]. ShipChain uses smart contracts to remove the need for a middleman or third party in the contracting process in logistics operations [19]. Maersk's project incorporates IoT and blockchain to reduce "mountains of paperwork" and to verify the identities of individuals and assets [10].

Fig. 1 shows several parties, including suppliers, carriers, retailers, banks, etc., are involved in a typical SC network. Orders include complex information flows, such as details of orders, shipments, and payments that may not line up neatly. Common supply chains are characterized by independent records of transactions initiated by each party. The various documents kept for transactions related to an order require a manual audit by all parties to ensure compliance. The main idea behind the blockchain concept is that a shared digital record-keeping system allows for clarity. A blockchain environment identifies all transactions related to a specific order with a unique identifier. All transactions each stakeholder makes are shared in the token and available to all. Transactions are recorded as token transfers on the blockchain as each process step is completed.

Real-world deployment of BT faces significant challenges and barriers [27–29]. Some papers identified the risks and barriers to implementing BT platforms for SCs (e.g., [1]; [30,31]). A supplier should be capable of eliminating or minimizing barriers to implementing new technology, including general and industry-specific ones. The ability of the supplier to resolve these issues is one of several criteria for choosing a provider. In more complex situations, selecting a blockchain service provider impacts the successful implementation of BT [32]. The platform evaluation framework becomes more significant by increasing the number of BT platforms available for SC management [33]. Any decision-maker should be aware of blockchain requirements and customers' needs to select the available alternative [34]. Developing a framework that combines expert opinions and prioritizes the available platforms at the next

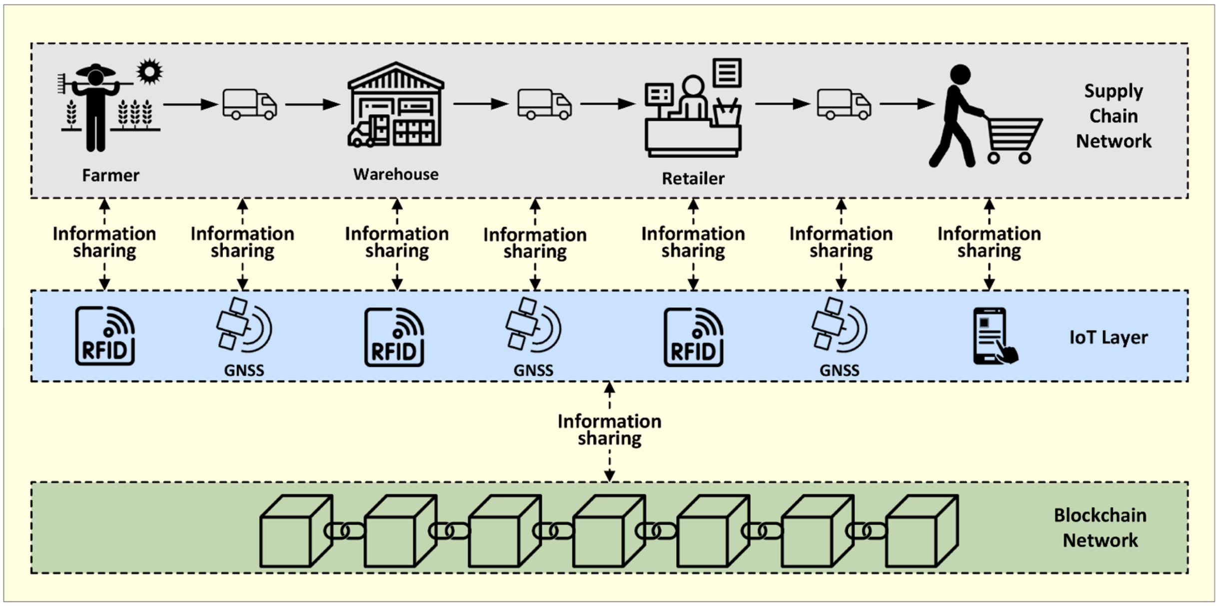

Fig. 1. Proposed blockchain-IoT supply chain network.

stage is necessary.

From a theoretical point of view, this paper aims to present an efficient and effective approach for evaluating BT-IoT platforms in food SCs. This research assesses BT platforms offered by different vendors in the food SCs. Many suppliers with varying levels of ability claim to be able to develop BT-IoT platforms to suit organizations' needs. The first step in an evaluation is to identify the evaluation features or criteria [35]. An extensive literature review is conducted first to identify factors affecting platform selection. A comprehensive list of influencing factors was described and classified. Next, the evaluation process involves the development of a practical approach to evaluating alternatives [35].

Because BT platforms' evaluation criteria are interdependent and the network under evaluation has a hierarchical structure, it makes sense to use hybrid Multi-Criteria Decision-Making (MCDM)-based approaches. Yet, numerous MCDM techniques assume that the assessment criteria are independent. If interactions are considered, the strength of the interactions with other criteria impacts their significance and importance. Several MCDM techniques in the literature have accounted for interdependencies among the evaluation criteria in the context of fraud in the subsidized food industry [36,37].

We propose a hybrid approach that combines the interval Weighted Influence Non-linear Gauge System (WINGS) method with the interval VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique for evaluating and selecting BT-IoT platforms in the food SC. WINGS assesses the significance of the criteria and their influence intensity. It creates indicators that reflect the direction and strength of the interdependent criteria. The indirect impacts inherited from the two-criteria interactions are adjusted to obtain a total metric for their strength and position. WINGS does not use the pairwise comparison matrix for weighting, so adding criteria and subcriteria does not increase computational complexity. Using the method also allows us to evaluate factors interrelated in hierarchical networks. A VIKOR method can also be employed to rank criteria based on several factors, considering expert preferences. This paper uses the WINGS interval to weigh the evaluation factors and the VIKOR interval to prioritize BT platforms.

This paper aims to identify and categorize a list of pivotal aspects influencing the selection of the BT platform to manage food safety cases through a literature review and expert opinions. Real-world examples of working subsidized food SC in Iran were used as case studies. The price gap between subsidized and market prices leads to false statements or inaccurate information. Even though authorities (or third parties) monitor warehouses and documents regularly, the current platforms cannot resolve the issue. Due to the secure sharing of information among entities and the reduction of information imbalance, blockchains facilitate the tracking and monitoring of SC inventories and processes. To our knowledge, no previous framework for selecting BT platforms for managing subsidized food SCs has been developed.

In this vein, the following research questions arise based on these motivations:

- RQ1: What are the main features to consider when selecting a BT-IoT platform to manage food supply chain transactions in an efficient way?
- RQ2: What are the main concerns of the decision makers for implementing and maintaining a BT-IoT platform in the food SC?
- RQ3: How can we aggregate the experts' preferences to weigh the factors and prioritize the alternatives in a unified framework?
- RQ4: How can we validate the proposed approach?

The remainder of this paper is organized as follows. Section 2 examines the related literature. In Section 3, we develop our proposed approach. Section 4 presents a case study in Iran to validate the efficiency of the proposed method. Sections 5 and 6 are assigned to discussion and managerial implications, respectively. Finally, the conclusion is presented in Section 7.

2. Literature review

Few research papers proposed frameworks for evaluating general BT-IoT platforms. For example, Lai and Liao [33] addressed the issue of platform evaluation in software companies aiming to integrate BT and IoT. Tang et al. [38] proposed a framework for evaluating public blockchain evaluation. Jin et al. [39] used Pythagorean fuzzy linguistic values to address the sustainable blockchain product assessment problem. Liu et al. [40] developed a supplier selection framework for blockchain tracing anti-counterfeiting platforms by integrating quality function deployment, the Best-Worst Method (BWM), and improved Decision-Making Trial and Evaluation Laboratory (DEMATEL).

As previously stated, there is a lack of knowledge regarding BT platform features among food SC managers, and therefore, there are concerns about implementation and maintenance. This section aims to extract and categorize the list of pivotal factors that may influence decision-making. Using the in-depth literature review, we compiled the criteria with the help of experts and refined them to fit the case better. In the following, these criteria are examined.

2.1. Popularity and support

Since BT is a newly developed technology, SC practitioners may lack sufficient knowledge. Therefore, they heavily depend on the expertise and service the platform provider provides. Previous solutions adopted by the industry will influence such decisions. Technical development, community support, and long-term maintenance are more mature in the widely implemented platform [41]. These issues are covered by the popularity and support criterion. For this, four sub-criteria are defined: Market recognition, Community activity, Previous experiments in deploying the platform to the sector, and Support plan for small partners (suppliers and retailers).

The term previous experiment indicates that the platform has been well accepted or implemented in the sector. It is inspired by Kuo et al. [41] that suppliers with more industry experience can better identify the processes, requirements, and risks of implementing the platform. Because of this, many suppliers publicize their leading clients and their success stories to attract new customers.

SCs can be composed of small or large entities. Large entities may have enough expert employees to handle the complexity of the BT. In spite of that, smaller entities may be lacking in resources. One sector in which this issue may be critical is food SCs, which may be involved with small farmers and SMEs [42]. A support plan for small partners includes training, easy-to-read documents, and customer support to deal with such issues. It should be noted that the number of experts in this field is limited, and SMEs may not be able to afford their recruitment costs. This calls for active customer support from the platform vendor.

Though technology's novelty is important, it should not be the only criterion for evaluating it. The term market recognition refers to the level of acceptance for blockchains among developers and others like users [38]. Due to market recognition, more data is available about the platform's actual situation, and its fundamentals are more accessible [40], resulting in better market adoption [43,44]. It could be measured with popularity indicators such as followers on Twitter, GitHub, etc. [38].

The activity of developers and others associated with the platform is measured by community activity. An active community indicates the popularity of a platform and decreases the risk of developers stopping maintaining and improving a blockchain, people stopping talking about it, or the blockchain becoming unpopular [38,43,44].

2.2. Transition complexity

Implementing the BT is different from implementing or upgrading software. Technology changes are drastic, and the transition process can be complex [27]. The cost-effective transition plan is intended to implement the BT economically. Blockchain systems do not necessarily have lower implementation costs than current systems (Dutta, 2021). Those costs are quantified by the cost of computing/IoT and platform equipment, training programs, and reskilling supply chain employees [28,31,45].

Business cases, roadmaps, and strategies for large-scale blockchain implementation in the supply chain are tied to the benefits of BT implementation [46]. As BT has a long lifecycle of development and performance, it is important to fully understand its capabilities and features [45]. The platform provider must have a clear upgrade plan to upgrade the current systems to BT. An agile and clear transition roadmap includes alignment of the BT implementation goals and the SC strategies, selecting a blockchain entry point to the supply chain, and ensuring compliance with governmental policies [28]. Data sharing may be defined as the primary goal [47]. High-quality documentation of the platform information provides the SC management with a platform knowledge base for future updates [28].

An SC may need to interact with multiple IT platforms, Application Programming Interfaces (APIs), and blockchains. The process of BT implementation may become complicated and time-consuming if there are incompatibilities [48]. The SCs may have to use smart contracts cross-chain technology to exchange value among blockchains [43]. A level of interoperability between various networks and multiple platforms is defined as interactivity with current platforms [28,33,34].

2.3. Supply chain operational features

Implementing the BT is key to facilitating the SC processes and operations, including traffic management and transport, warehousing, order processing, etc. [48,49]. Improving the traceability of cargo refers to enabling online shipment tracking information (by connecting inputs, suppliers, producers, buyers, and regulators, and making traceability and audibility available in order processing, transportation, and fleet management) and providing real-time tracking data [12,34,42]. Improving the traceability of inventory refers to activity records that are aimed at monitoring inventories, minimizing risk by managing demand and supply efficiently, improving forecasts, using available resources and reducing inventory costs, and improving inventory management [11,50,51].

The customer-specific traceability feature includes various options for customers to see in detail all the information related to their product all the way from the producer and retailer (e.g. origin of organic food) through a mobile or web application using QR codes. There is a large demand for food traceability; the market size is estimated to reach $26.1 billion by 2025 due to the recent Coronavirus disease 2019 (COVID-19) outbreak which has raised safety concerns.

In the IOT, the platform is integrated with emerging technologies such as sensors, RFID, and NFC, aiming to automate production, tracking logistics, etc. [12,52,53]. IoT components may be used to gather data on the SC operations and track every movement of containers, products, and packaging in real-time [54]. Along with these facilities, blockchain creates an environment that is resistant to data fraud and mismanagement and provides a reliable and effective tracing system [55]. Some applications of Iot-enabled BT for SC management are pharmaceutical [55] and agricultural [56].

Verifiable records of transactions among parties (supplier, distributor, retailer) refer to the facilitation of clear connections and information sharing and triggering action between nodes, collaboration, and partnerships between organizations aligned with the objectives of all participants in the supply chain [28,34]. Supply chain analytics refers to using big data analytics for building a real-time, analytics-driven supply chain [12]. Big data analytics is a disruptive technology that can help with agricultural issues including boosting output and production, preserving water, maintaining the health of the soil and plants, and enhancing environmental stewardship [57].

Integration with banks, insurance, and financing institutions refers to the facilitation of relationships with banks, insurers, financial services, and payment methods ([50]; Farshidi et al., 2021; [42]). Some authors have analyzed the price of products in terms of integrated BT-SC finance [16] and value creation through SC [58]. Fraud traceability refers to products and services that detect fraud, theft, smuggling, and counterfeiting [42]. Property Tokenizing refers to features related to reliable records identifying tangible and intangible property ownership [45,53]. Smart Contract expresses features such as automating rules, penalties, and property liquidations among parties by eliminating third-participants [15,19,43].

2.4. Technical

The platform's basic functions and performance are evaluated in the Technical criteria. These are the building blocks between which the platform's operation is composed. Modular Architecture refers to a modular architecture and a flexible environment that can be used for various purposes [28,34]. Performance efficiency relates to the throughput and performance of data processing, network delay, block confirmation, and data access to the blockchain at different layers [33,43]. Security refers to preventing data breaches and cyber-attacks via malicious actors and accidental loss of private keys [34,40,44]. A blockchain's reliability involves the fundamental conditions required to build trusts, such as maturity, availability, fault tolerance, and recovery ability [33,34]. The Extensibility of the platform becomes crucial when the network load exceeds the current node resource capacity [40]. Block sizes in private blockchains are determined by the network owner [59]

In a competitive environment, public keys provide visibility into data. In a food supply chain, for example, many actors compete with each other. Privacy of customers refers to the privacy of transactions and the confidentiality of data by maintaining a certain level of privacy on the platform [34,42,59]. Privacy can be ensured through some methods. The use of anonymized but verifiable identities, for instance, can ensure privacy [34]. Participants/Transaction and Data Confidentiality can determine the level of privacy [34]. Consider that privacy concerns can affect retailer profits and prices [26]. By reviewing the literature and applying the opinions of experts, a set of criteria was identified, which is given in Table 1.

3. Proposed approach

This paper aims to provide a practical approach to evaluate BT platforms in the food SC. Evaluation criteria and methods are the two main elements in the evaluation and selection process. Obviously, each field has its own criteria and these criteria are derived from literature, expert knowledge or a combination of both. The method of evaluation is also highly dependent on the criteria and nature of the problem. Hence, this paper presents a novel approach to evaluating BT platforms in SC food by combining MCDM methods. Since there is a hierarchical structure between the criteria and their sub-criteria and the evaluation criteria are intertwined, the interval WINGS method is proper for weighting. The interval VIKOR method is also used to prioritize BT platforms; the VIKOR interval is a good way to prioritize a number of alternatives based on several factors under uncertainty. Fig. 2 shows the structure of the proposed approach.

Stage 1: Calculating the weights of criteria using the interval WINGS method

In this stage, the weight of the criteria is calculated using the WINGS method interval. This stage consists of seven steps as follows:

Step 1.1: In this step, by reviewing the literature and using the experts' knowledge, evaluation criteria, their sub-criteria, and potential alternatives are identified.

Step 1.2: In this step, experts are asked to plot the interdependencies between the criteria by a causal relation graph.

Step 1.3: In this step, the strength of criteria and their sub-criteria, the influence intensity of the criteria on each other, and the influence intensity of the sub-criteria on their criteria are determined. For this purpose, experts are asked to perform this operations using the linguistic terms presented in Table 2. Finally, the interval direct strength-influence matrix is structured. In this matrix, the numbers on the main diameter indicate the strength of factors (criteria/sub-criteria) and the influence intensity of criteria *i* is on factor *j* placed in the *i*th row and *j*th column of this matrix. Eq. (1) represents the general structure of this matrix.

Insert Table 2 Here

$$\bar{D} = \left[\left(D^L, D^U\right)\right] = \begin{bmatrix} \left(d_{11}^L, d_{11}^U\right) & \cdots & \left(d_{1j}^L, d_{1j}^U\right) & \cdots & \left(d_{1n}^L, d_{1n}^U\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left(d_{i1}^L, d_{i1}^U\right) & \cdots & \left(d_{ij}^L, d_{ij}^U\right) & \cdots & \left(d_{in}^L, d_{in}^U\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left(d_{n1}^L, d_{n1}^U\right) & \cdots & \left(d_{nj}^L, d_{nj}^U\right) & \cdots & \left(d_{nn}^L, d_{nn}^U\right) \end{bmatrix} \tag{1}$$

Step 1.4: In this step, the interval direct strength-influence matrix is normalized via Eq. (2).

$$f = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij}^U \quad \bar{M} = \left[\left(M^L, M^U\right)\right] M^L = \frac{1}{f} D^L M^U = \frac{1}{f} D^U \tag{2}$$

Table 1
Evaluation criteria of BT-IoT platforms.

Criteria	[59]	[53]	[45]	[42]	[41]	[38]	[11]	[43]	[40]	[31]	[52]		[34]	[28]	[33]	[44]	[50]	[12]
Market recognition (PR1)					√	√		√	√									
Community activity (PR2)					√	√										√		
Previous experiments in deploying the platform to the sector (PR3)					√													
Support plan for small partners (suppliers and retailers) (PR4)				√										√				
Cost-effective transition plan (TS1)				√			√	√		√		√			√			
Agile and clear transition roadmap (TS2)														√				
High-quality documentation of platform information (TS3)														√				
Interactivity with current platforms (TS4)								√			√		√	√	√			
Improving the traceability of cargo (SC1)			√														√	
Improving the traceability of inventory (SC2)			√				√						√				√	
Customer-specific traceability feature (SC3)			√	√			√											
IoT (SC4)	√	√	√								√						√	√
Verifiable record of transactions among parties (supplier, distributors, retailers) (SC5)			√														√	
Supply chain analytics (SC6)																	√	√
Integration with financing institutions, banks, and insurance (SC7)		√		√														
Fraud traceability (SC8)		√		√				√				√						
Property tokenizing (SC9)		√																
Smart Contract (SC10)	√	√						√										
Modular architecture (TC1)								√					√					
Performance efficiency (TC2)															√			
Security (TC3)	√								√		√	√	√	√	√			
Reliability (TC4)							√						√		√			
Extensibility (TC5)									√						√			
Privacy of customers (TC6)				√								√	√	√				

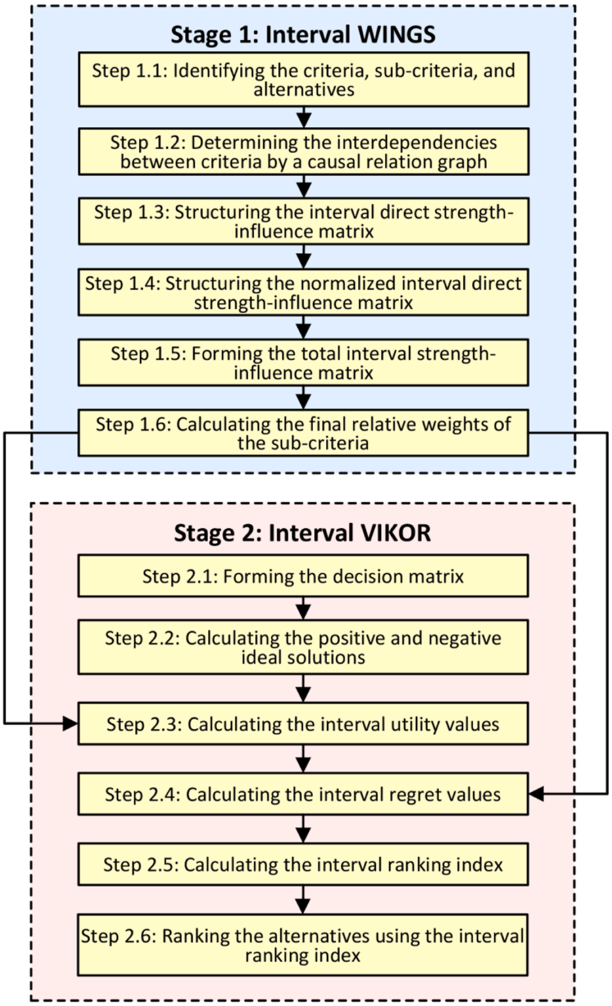

Fig. 2. The structure of the proposed approach.

Table 2
Linguistic terms of strength and influence [60].

Linguistic terms		Interval numbers
No strength	No influence	[0–0]
Low strength	Low influence	[0–1]
Medium strength	Medium influence	[1–2]
High strength	High influence	[2–3]
Very high strength	Very high influence	[3–4]

where $\bar{M} = [(M^L, M^U)]$ denotes the interval normalized matrix.

Step 1.5: In this step, the total interval strength-influence matrix ($\bar{T}$) is calculated by Eq. (3).

$$\bar{T} = \left[\left(T^L, T^U\right)\right] \qquad T^L = M^L \times \left(I - M^L\right)^{-1} \qquad T^U = M^U \times \left(I - M^U\right)^{-1} \tag{3}$$

Step 1.6: In this step, the final relative weights of the sub-criteria are calculated. For this purpose, first, Eq. (4) used to calculate the total impact ($\bar{r}_i$) and total receptivity ($\bar{c}_j$).

$$\bar{r}_i = \left[\left(r_i^L, r_i^U\right)\right] \quad \forall i \in \text{criteriaandsub} - \text{criteria} r_i^L = \sum_{j=1}^{n} t_{ij}^L, \quad r_i^U = \sum_{j=1}^{n} t_{ij}^U \bar{c}_j = \left[\left(c_j^L, c_j^U\right)\right] \quad \forall j \in \text{criteriaandsub} - \text{criteria} c_j^L = \sum_{i=1}^{n} t_{ij}^L, \quad c_j^U = \sum_{i=1}^{n} t_{ij}^U \tag{4}$$

Then, the total engagement ($\bar{r}_i + \bar{c}_i$) is calculated using Eq. (5).

$$\bar{r}_i + \bar{c}_i = \left[\left(r_i^L + c_i^L, r_i^U + c_i^U\right)\right] \quad \forall i \in \text{criteriaandsub} - \text{criteria} \tag{5}$$

Finally, the final relative weights of the sub-criteria ($\bar{w}_i$) are calculated via Eq. (6).

$$\bar{w}_i = \left[\left(w_i^L, w_i^U\right)\right] \quad \forall i \in \text{sub} - \text{criteria} w_i^L = \frac{r_i^L + c_i^L}{2 \times \sum_i \left(r_i^L + c_i^L + r_i^U + c_i^U\right)}, \quad w_i^U = \frac{r_i^U + c_i^U}{2 \times \sum_i \left(r_i^L + c_i^L + r_i^U + c_i^U\right)} \tag{6}$$

Stage 2: Ranking the alternatives using interval VIKOR technique

In this stage the alternatives are ranked using the interval VIKOR presented by Kannan et al. [61]. The following is the ranking process of the alternatives in six steps:

Step 2.1: In this step, the decision matrix ($\bar{E}$) is formed based on the experts' knowledge. For this purpose, the experts evaluate the performance of the alternatives per each sub-criterion using the linguistic terms presented in Table 3, and then the average of the experts' opinions is considered as the evaluated score of the alternatives per each sub-criterion. Eq. (7) represents the general structure of this matrix.

$$\bar{E} = \left[\left(E^L, E^U\right)\right] = \begin{bmatrix} \left(e_{11}^L, e_{11}^U\right) & \cdots & \left(e_{1j}^L, e_{1j}^U\right) & \cdots & \left(e_{1n}^L, e_{1n}^U\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left(e_{k1}^L, e_{k1}^U\right) & \cdots & \left(e_{kj}^L, e_{kj}^U\right) & \cdots & \left(e_{kn}^L, e_{kn}^U\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left(e_{K1}^L, e_{K1}^U\right) & \cdots & \left(e_{Kj}^L, e_{Kj}^U\right) & \cdots & \left(e_{Kn}^L, e_{Kn}^U\right) \end{bmatrix} \tag{7}$$

where (e_{kj}^L, e_{kj}^U) denotes the interval score of alternative k in sub-criterion j.

Insert Table 3 Here

Step 2.2: In this step, positive ideal solution (PIS) and negative ideal solution (NIS) are calculated by Eqs. (8) and (9), respectively.

$$\xi^* = \left\{e_1^*, e_2^*, \ldots, e_n^*\right\} = \left\{\left(\underset{k}{Max}\, e_{kj}^U | j \in \psi\right) \text{ or } \left(\underset{k}{Min}\, e_{kj}^L | j \in \psi\right)\right\} \quad j = 1, 2, \ldots, n \tag{8}$$

$$\xi^- = \left\{e_1^-, e_2^-, \ldots, e_n^-\right\} = \left\{\left(\underset{k}{Min}\, e_{kj}^L | j \in \psi\right) \; or \; \left(\underset{k}{Max}\, e_{kj}^U | j \in \psi\right)\right\} \quad j = 1, 2, \ldots, n \tag{9}$$

Table 3
Linguistic terms for evaluating alternatives [61].

Linguistic terms	Interval numbers
Absolutely weak	[0–0]
Very weak	[0–1.5]
Weak	[1.5–3]
Slightly weak	[3–4.5]
Mid	[4.5–5.5]
Slightly strong	[5.5–7]
Strong	[7–8.5]
Very strong	[8.5–10]
Absolutely strong	[10–10]

where ξ^* and ξ^- shows the PIS and NIS, respectively, and, ψ and ψ pertains to the desirable and undesirable sub-criteria, respectively.

Step 2.3: In this step, the interval utility values ($\bar{\Phi}$) are calculated using Eq. (10).

$$\bar{\Phi} = [\Phi^L, \Phi^U]$$
$$\Phi_k^L = \sum_{j\in\psi} w_j^L \times \left(\frac{e_j^* - e_{kj}^U}{e_j^* - e_j^-}\right) + \sum_{j\in\psi} w_j^L \times \left(\frac{e_{kj}^L - e_j^*}{e_j^- - e_j^*}\right) \quad \forall k = 1,2,...,K$$
$$\Phi_k^U = \sum_{j\in\psi} w_j^U \times \left(\frac{e_j^* - e_{kj}^L}{e_j^* - e_j^-}\right) + \sum_{j\in\psi} w_j^U \times \left(\frac{e_{kj}^U - e_j^*}{e_j^- - e_j^*}\right) \quad \forall k = 1,2,...,K \tag{10}$$

Step 2.4: In this step, the interval regret values ($\bar{\Omega}$) are calculated using Eq. (11).

$$\bar{\Omega} = [\Omega^L, \Omega^U]$$
$$\Omega_k^L = Max\left\{ w_j^L \times \left(\frac{e_j^* - e_{kj}^U}{e_j^* - e_j^-}\right) | j \in \psi, \quad w_j^L \times \left(\frac{e_{kj}^L - e_j^*}{e_j^- - e_j^*}\right) | j \in \psi \right\} \quad k = 1,2,...,K$$
$$\Omega_k^U = Max\left\{ w_j^U \times \left(\frac{e_j^* - e_{kj}^L}{e_j^* - e_j^-}\right) | j \in \psi, \quad w_j^U \times \left(\frac{e_{kj}^U - e_j^*}{e_j^- - e_j^*}\right) | j \in \psi \right\} \quad k = 1,2,...,K \tag{11}$$

Step 2.5: This step calculates the interval ranking index ($\bar{\Upsilon}$) using Eq. (12).

$$\bar{\Upsilon} = [\Upsilon^L, \Upsilon^U]$$
$$\Upsilon_k^L = \vartheta \times \frac{(\Phi_k^L - \Phi^*)}{(\Phi^- - \Phi^*)} + (1-\vartheta) \times \frac{(\Omega_k^L - \Omega^*)}{(\Omega^- - \Omega^*)} \quad \forall k = 1,2,...,K$$
$$\Upsilon_k^U = \vartheta \times \frac{(\Phi_k^U - \Phi^*)}{(\Phi^- - \Phi^*)} + (1-\vartheta) \times \frac{(\Omega_k^U - \Omega^*)}{(\Omega^- - \Omega^*)} \quad \forall k = 1,2,...,K$$
$$\Phi^* = Min\{\Phi_k^L\}, \quad \Phi^- = Max\{\Phi_k^U\}$$
$$\Omega^* = Min\{\Omega_k^L\}, \quad \Omega^- = Max\{\Omega_k^U\} \tag{12}$$

"where ϑ is defined as the strategy weight for the maximum group utility and $1-\vartheta$ is the individual regret weight; here, it is considered 0.5 according to expert opinion."

Step 2.6: In this step, the interval ranking index is applied to rank the alternatives. Assume that $(\Upsilon_1^L, \Upsilon_1^U)$ and $(\Upsilon_2^L, \Upsilon_2^U)$ are two interval numbers whose purpose is to compare these two numbers and select the smallest interval number. For this end, following four rules is used to compare two interval numbers [62]:

- Rule 1: If $\Upsilon_1^L \le \Upsilon_1^U \le \Upsilon_2^L \le \Upsilon_2^U$ holds, then $(\Upsilon_1^L, \Upsilon_1^U)$ is the smallest interval numbers.
- Rule 2: If $\Upsilon_1^L = \Upsilon_2^L \le \Upsilon_1^U = \Upsilon_2^U$ holds, then both rank the same and neither has priority over the other one.
- Rule 3: If $\Upsilon_1^L \le \Upsilon_2^L \le \Upsilon_2^U \le \Upsilon_1^U$ holds, then $(\Upsilon_1^L, \Upsilon_1^U)$ is the smallest interval numbers; if $\theta \times (\Upsilon_2^L - \Upsilon_1^L) \ge (1-\theta) \times (\Upsilon_1^U - \Upsilon_2^U)$ is true, otherwise $(\Upsilon_2^L, \Upsilon_2^U)$ is the smallest interval number.
- Rule 4: If $\Upsilon_1^L < \Upsilon_2^L < \Upsilon_1^U \le \Upsilon_2^U$ holds, then $(\Upsilon_2^L, \Upsilon_2^U)$ is the smallest interval numbers; if $\theta \times (\Upsilon_2^L - \Upsilon_1^L) \ge (1-\theta) \times (\Upsilon_2^U - \Upsilon_1^U)$ is true, otherwise $(\Upsilon_2^L, \Upsilon_2^U)$ is the smallest interval number.

where θ represents the optimism level of the decision-maker ($0 < \theta < 1$). If $\theta = 0.5$ is considered, the results obtained from method of Sayadi et al. [62] is similar to the interval numbers means method. It should be noted that the optimist decision-maker considers the value of θ to be greater than 0.5, and the pessimist decision-maker considers its value less than 0.5.

4. Case study

This paper outlines a framework specific to food supply chains. In practice, the weights extracted from the criteria may differ between cases. This paper examined the selection of BT platforms for a subsidized food SC. Subsidies are government financial assistance providing public access to goods or services at a lower price. Due to the price difference between the regulated price and the market price, corruption and financial fraud in the form of theft, product leakages, incomplete delivery of subsidized goods to the target populations, falsifying records, or the dissemination of false information are unavoidable. Hence, government agencies regularly control the SC of a subsidy product. Governments also employ online platforms to prevent fraud in logging transactions and confirm the legitimacy of documents. Yet, there is no assurance that there would be fewer possibilities for snatching. By enabling real-time access to reliable data, blockchain-based systems can help overcome these challenges. The Iranian government has subsidized some strategic goods, such as wheat, to support low-income groups and increase their purchasing power. These goods are heavily monitored due to the government's protectionist policy, which is the responsibility of the Ministry of Industry, Mines, and Trade. It is imperative to control the warehouses, track the products, and ensure they are delivered to the target group. If there is a price difference between controlled and market prices, corrupt practices and fiscal scams, such as theft, making fake documents, or providing inaccurate information, are inevitable.

Authorities report that some subsidized products are leaked and aren't delivered to intended groups. Security, transparency, and traceability are essential for monitoring operations. BT platforms can address this concern because they have these features. In this section, we intend to rank five BT platforms in food SC using the proposed approach and with the help of nine experts with more than ten years of experience, including three information system managers, three distribution managers in the food industry, two food industry consultants, and one business manager. Table 4 presents the experts' demographic profiles. It should be noted that the consensus of experts' opinions has been used to fill in the questionnaires, and the opinions of experts are converged using the brainstorming method. The process of implementing the proposed approach in the real world is as follows:

Stage 1: In this stage, the evaluation criteria of BT-IoT platforms are identified and weighed using the interval WINGS method. The following is the weighting process in six steps:

Step 1.1: In the literature review section, a comprehensive review was conducted to identify the evaluation factors of BT-IoT platforms. In this section, with the help of experts, the identified factors were analyzed and finally a comprehensive set of factors in the form of five criteria and 24 sub-criteria was extracted to evaluate BT-IoT platforms in the food industry, which is shown in Table 5.

Step 1.2: The experts depict the causal relationship between criteria in this step. Fig. 3 shows the relationship between criteria, their sub-criteria, and alternatives.

Step 1.3: The interval direct strength-influence matrix is formed in this step. Experts are asked to first determine the strength of the factors (criteria and their sub-criteria) by the linguistic terms presented in Table 2 and then place them in the main diameter of the matrix. In the next step, experts determine the influence intensity of factor i on factor j and place it in the ith row and jth column. Based on these operations, we arrive at the interval direct strength-influence matrix illustrated in Table 6.

Step 1.4: In this step, the matrix obtained from the previous step is normalized using Eq. (2). Tables 7 and 8 indicate the lower and upper bounds of the normalized direct strength-influence matrix.

Step 1.5: In this step, the total interval strength-influence matrix is calculated by Eq. (3). Tables 9 and 10 show the lower and upper bounds of the total strength-influence matrix.

Step 1.6: This step calculates the final relative weights of sub-criteria. For this purpose, first, the total impact and total receptivity are calculated using Eq. (4). Then, total engagement is determined by Eq. (5). Finally, the final relative weights of sub-criteria are calculated via Eq. (6). The results of this operations are given in Table 11.

Stage 2: In this stage, the platforms are ranked using the interval VIKOR. The following is the platform ranking process in five steps:

Step 2.1: Experts at this stage are required to evaluate the performance of BT platforms in regard to the sub-criteria presented in Table 3 by answering the question: What is the BT platform k's performance with sub-criterion j? The decision matrix that resulted from this evaluation is shown in Table 12.

Table 4
The experts' demographic profile.

Profile	Number of experts
Gender	
Male	8
Female	1
Age	
40–50 years	5
50–60 years	3
Above 60 years	1
Experience	
0–10 years	0
10–15 years	4
15–20 years	4
Above 20 years	1
Expertise	
information system managers	3
distribution managers in food industry	3
food industry consultants	2
business manager	1

Table 5
Evaluation criteria and their sub-criteria of BT-IoT platforms.

Criteria	Sub-criteria	Definition	References
Popularity and support (PR)	Market recognition (PR1)	Level of acceptance for blockchains among developers and other	[40,38]
	Community activity (PR2)	Keeping an active community as a secondary indicator of a platform's technical attractiveness lowers the risk that developers will cease updating and developing it.	[43,44, 38]
	Previous experiments in deploying the platform to the sector (PR3)	An indication that the platform has been widely adopted in the industry.	[41]
	Support plan for small partners (suppliers and retailers) (PR4)	Active customer support from the vendor to the clients	[42,41]
Transition simplicity (TS)	Cost-effective transition plan (TS1)	The capacity of the platform to be implemented economically	[45,28, 31]
	Agile and clear transition roadmap (TS2)	Standardized procedures for measuring a company's maturity level for selecting the right entry point in the initial stages ensure compliance with governmental policies	[28]
	High-quality documentation of platform information (TS3)	Build a knowledge base for future upgrades.	[28]
	Interactivity with current platforms (TS4)	Level of interoperability between different networks and multiple platforms, especially current internal platforms of the organization, in all stages of implementation	[34,28, 33]
Supply chain operational features (SC)	Improving the traceability of cargo (SC1)	Providing all stakeholders with real-time shipment tracking data	[34,42, 12]
	Improving the traceability of inventory (SC2)	Real-time monitoring of inventories, minimizing risk by managing demand and supply efficiently, improving forecasts, using available resources, and reducing inventory costs	[11,50, 51]
	Customer-specific traceability feature (SC3)	Customer-friendly user interfaces that allow them to get information about their product from the manufacturer and store	[50]
	IoT (SC4)	Integration of the platform with emerging technologies such as sensors, RFID, and NFC	[52,53, 12]
	Verifiable record of transactions among parties (supplier, distributors, retailers) (SC5)	Clear information-sharing rules and triggering action between nodes aligned with the objectives of all participants in the supply chain	[34,28]
	Supply chain analytics (SC6)	Big data analytics	[12]
	Integration with financing institutions, banks, and insurance (SC7)	Facilitation of relationships with banks, insurers, financial services, and payment method	[50]; [42]
	Fraud traceability (SC8)	Ability to detect fraud, theft, smuggling, and counterfeiting	[42]
	Property tokenizing (SC9)	Records for identifying tangible and intangible property ownership	[53,45]
	Smart Contract (SC10)	Automating rules, penalties, and property liquidations among parties by eliminating third-participants	[45]
Technical (TC)	Modular architecture (TC1)	A flexible environment that can be used for various new ideas and purposes	[34,28]
	Performance efficiency (TC2)	Throughput and performance of data processing, network delay, block confirmation, and data access to the blockchain	[43,33]
	Security (TC3)	Preventing data breaches and cyber-attacks	[34,40, 44]
	Reliability (TC4)	Fundamental conditions required to build trust, such as maturity, availability, fault tolerance, and recovery ability	[34,33]
	Extensibility (TC5)	Upgrading node resource capacity	[40]
	Privacy of customers (TC6)	Includes privacy of transactions and the confidentiality of data by maintaining a certain level of privacy	[34,42, 59]

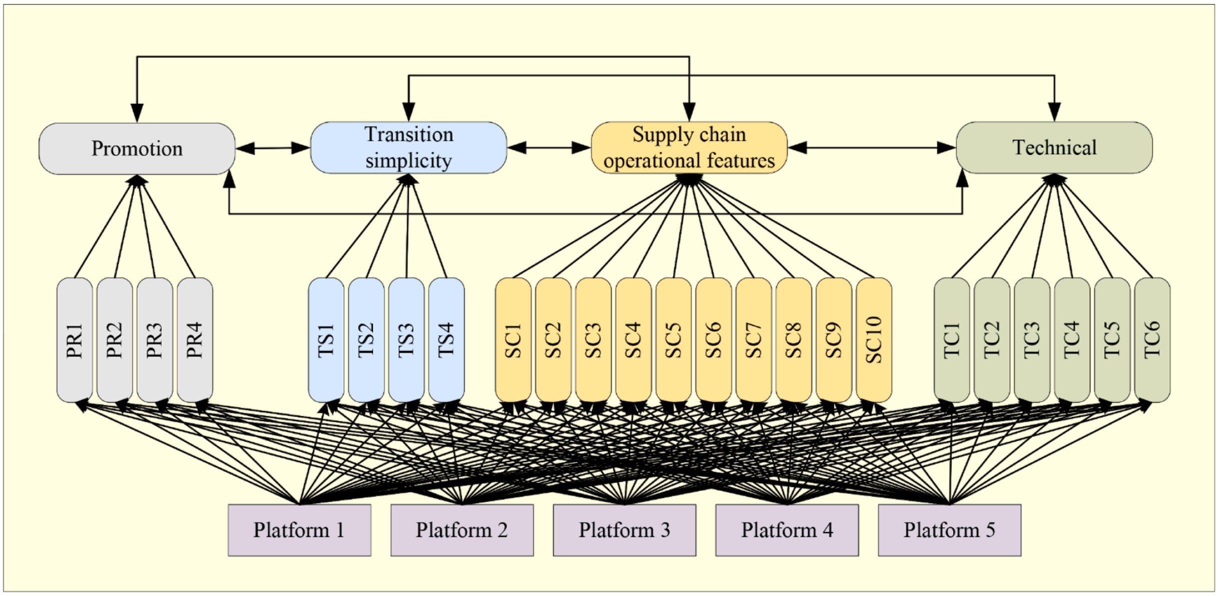

Fig. 3. Causal relation graph.

Step 2.2: In this step, the PIS and NIS were determined by Eqs. (8) and (9), respectively, which are presented in Table 13.
Step 2.3: In this step, interval utility values are calculated for alternatives via Eq. (10). For example, the lower bound of utility value for platform 1 is calculated as follows:

$$\Phi_1^L = 0.019212 \times \frac{(10-10)}{(10-4.5)} + 0 \times \frac{(8.5-3)}{(8.5-1.5)} + 0.058357 \times \frac{(10-10)}{(10-4.5)} + 0.032193 \times \frac{(7-7)}{(7-1.5)} +$$
$$0.059225 \times \frac{(8.5-5.5)}{(8.5-3)} + 0.019498 \times \frac{(10-8.5)}{(10-1.5)} + 0.045996 \times \frac{(5.5-5.5)}{(5.5-0)} + 0.052341 \times \frac{(10-10)}{(10-1.5)} +$$
$$0.052341 \times \frac{(10-10)}{(10-1.5)} + 0.045871 \times \frac{(10-5.5)}{(10-4.5)} + 0.019457 \times \frac{(10-10)}{(10-1.5)} + 0.0591 \times \frac{(10-10)}{(10-1.5)} +$$
$$0.032806 \times \frac{(5.5-3)}{(5.5-1.5)} + 0 \times \frac{(7-3)}{(7-0)} + 0.045871 \times \frac{(10-10)}{(10-0)} + 0 \times \frac{(3-3)}{(3-0)} + 0.012782 \times \frac{(8.5-5.5)}{(8.5-4.5)} +$$
$$0.026056 \times \frac{(10-10)}{(10-1.5)} + 0.039079 \times \frac{(8.5-8.5)}{(8.5-5.5)} + 0.052265 \times \frac{(8.5-8.5)}{(8.5-5.5)} + 0.006596 \times \frac{(8.5-8.5)}{(8.5-5.5)} +$$
$$0.012782 \times \frac{(10-10)}{(10-3)} + 0.045545 \times \frac{(8.5-8.5)}{(8.5-1.5)} = 0.11451$$

Similarly, the upper bound of the utility value for platform 1 is calculated as follows:

$$\Phi_1^U = 0.039 \times \frac{(10-8.5)}{(10-4.5)} + 0.01938 \times \frac{(8.5-1.5)}{(8.5-1.5)} + 0.078982 \times \frac{(10-8.5)}{(10-4.5)} + 0.052186 \times \frac{(7-5.5)}{(7-1.5)} +$$
$$0.080176 \times \frac{(8.5-4.5)}{(8.5-3)} + 0.03959 \times \frac{(10-7)}{(10-1.5)} + 0.03959 \times \frac{(7-1.5)}{(7-0)} + 0.066734 \times \frac{(5.5-4.5)}{(5.5-0)} +$$
$$0.073026 \times \frac{(10-8.5)}{(10-1.5)} + 0.073026 \times \frac{(10-8.5)}{(10-1.5)} + 0.066562 \times \frac{(10-4.5)}{(10-4.5)} + 0.039505 \times \frac{(10-8.5)}{(10-1.5)} +$$
$$0.080004 \times \frac{(10-8.5)}{(10-1.5)} + 0.053288 \times \frac{(5.5-1.5)}{(5.5-1.5)} + 0.019631 \times \frac{(7-1.5)}{(7-0)} + 0.066562 \times \frac{(10-8.5)}{(10-0)} +$$
$$0.019631 \times \frac{(3-1.5)}{(3-0)} + 0.032614 \times \frac{(8.5-4.5)}{(8.5-4.5)} + 0.04628 \times \frac{(10-10)}{(10-1.5)} + 0.05951 \times \frac{(8.5-7)}{(8.5-5.5)} +$$
$$0.072908 \times \frac{(8.5-7)}{(8.5-5.5)} + 0.026402 \times \frac{(8.5-7)}{(8.5-5.5)} + 0.032575 \times \frac{(10-8.5)}{(10-3)} + 0.065969 \times \frac{(8.5-7)}{(8.5-1.5)} = 0.51639$$

Table 6
The interval direct strength-influence matrix.

	PR	TS	SC	TC	PR1	PR2	PR3	PR4	TS1	TS2	TS3	TS4	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	TC1	TC2	TC3	TC4	TC5	TC6
PR	[1–2]	[0–1]	[0–1]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TS	[2–3]	[3–4]	[2–3]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC	[2–3]	[2–3]	[2–3]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TC	[0–1]	[3–4]	[2–3]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
PR1	[1–2]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
PR2	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
PR3	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
PR4	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TS1	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TS2	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TS3	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TS4	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC1	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC2	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC3	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC4	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC5	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC6	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC7	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC8	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC9	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
SC10	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TC1	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]
TC2	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]
TC3	[0–0]	[0–0]	[0–0]	[2–3]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]	[0–0]	[0–0]	[0–0]
TC4	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]
TC5	[0–0]	[0–0]	[0–0]	[0–1]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]
TC6	[0–0]	[0–0]	[0–0]	[1–2]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[0–0]	[3–4]

Table 7
The lower bound of the normalized direct strength-influence matrix.

	PR	TS	SC	TC	PR1	PR2	PR3	PR4	TS1	TS2	TS3	TS4	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	TC1	TC2	TC3	TC4	TC5	TC6
PR	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS	0.01227	0.0184	0.01227	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC	0.01227	0.01227	0.01227	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	0	0.0184	0.01227	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR1	0.00613	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR3	0.0184	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR4	0.00613	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS1	0	0.0184	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS2	0	0.00613	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS3	0	0.00613	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS4	0	0.0184	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC1	0	0	0.01227	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC2	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC3	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0
SC4	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0
SC5	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0
SC6	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0
SC7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC8	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0
SC9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0
TC1	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0
TC2	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0
TC3	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0
TC4	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0
TC6	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0184

Table 8
The upper bound of the normalized direct strength-influence matrix.

	PR	TS	SC	TC	PR1	PR2	PR3	PR4	TS1	TS2	TS3	TS4	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	TC1	TC2	TC3	TC4	TC5	TC6
PR	0.01227	0.00613	0.00613	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS	0.0184	0.02454	0.0184	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC	0.0184	0.0184	0.0184	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	0.00613	0.02454	0.0184	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR1	0.01227	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR2	0.00613	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR3	0.02454	0	0	0	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR4	0.01227	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS1	0	0.02454	0	0	0	0	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS2	0	0.01227	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS3	0	0.01227	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS4	0	0.02454	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC1	0	0	0.0184	0	0	0	0	0	0	0	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC2	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC3	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0
SC4	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0
SC5	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0
SC6	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0
SC7	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0	0	0
SC8	0	0	0.02454	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0	0	0	0	0
SC9	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0	0	0	0	0	0
SC10	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0	0
TC1	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0	0	0	0	0
TC2	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0184	0	0	0	0
TC3	0	0	0	0.0184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02454	0	0	0
TC4	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00613	0	0
TC5	0	0	0	0.00613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01227	0
TC6	0	0	0	0.01227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.02454

Table 9
The lower bound of the total strength-influence matrix.

	PR	TS	SC	TC	PR1	PR2	PR3	PR4	TS1	TS2	TS3	TS4	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	TC1	TC2	TC3	TC4	TC5	TC6
PR	0.006173	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS	0.012738	0.019029	0.012738	0.006369	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC	0.01266	0.012777	0.01266	0.00633	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	0.000392	0.019029	0.012738	0.006369	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR1	0.006211	0	0	0	0.006173	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR3	0.018866	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR4	0.00625	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS1	0.0002388	0.019107	0.000239	0.000119	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS2	7.86E-05	0.00629	7.86E-05	3.93E-05	0	0	0	0	0	0.006173	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS3	7.86E-05	0.00629	7.86E-05	3.93E-05	0	0	0	0	0	0	0.006173	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS4	0.000237	0.018988	0.000238	0.000119	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC1	0.000158	0.00016	0.012658	7.91E-05	0	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC2	0.000158	0.00016	0.012658	7.91E-05	0	0	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC3	0.000236	0.000238	0.018869	0.000118	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0
SC4	7.81E-05	7.89E-05	0.00625	3.91E-05	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0	0	0	0	0	0	0	0
SC5	0.000237	0.00024	0.018987	0.000119	0	0	0	0	0	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0
SC6	0.000234	0.000237	0.01875	0.000117	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0	0	0	0	0	0
SC7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC8	0.000236	0.000238	0.018869	0.000118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0
SC9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0	0
TC1	4.84E-06	0.000235	0.000157	0.012424	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0
TC2	4.87E-06	0.000237	0.000158	0.012502	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0124224	0	0	0	0
TC3	4.90E-06	0.000238	0.000159	0.01258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01875	0	0	0
TC4	2.41E-06	0.000117	7.81E-05	0.006174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0
TC6	2.45E-06	0.000119	7.96E-05	0.00629	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01875

Table 10
The upper bound of the total strength-influence matrix.

	PR	TS	SC	TC	PR1	PR2	PR3	PR4	TS1	TS2	TS3	TS4	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	TC1	TC2	TC3	TC4	TC5	TC6
PR	0.012709	0.006656	0.006575	0.006455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS	0.019564	0.02598	0.019605	0.01311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC	0.019444	0.019686	0.019485	0.01303	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC	0.007139	0.025898	0.019525	0.013031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR1	0.01258	8.27E-05	8.17E-05	8.02E-05	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR2	0.006251	4.11E-05	4.06E-05	3.98E-05	0	0.006173	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR3	0.02548	0.000167	0.000165	0.000162	0	0	0.025157	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PR4	0.012659	8.32E-05	8.22E-05	8.07E-05	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS1	0.000492	0.02581	0.000493	0.00033	0	0	0	0	0.025157	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS2	2.43E-04	0.012745	2.44E-04	1.63E-04	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS3	2.43E-04	0.012745	2.44E-04	1.63E-04	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TS4	0.000489	0.02565	0.00049	0.000328	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC1	0.000367	0.000371	0.019236	2.46E-04	0	0	0	0	0	0	0	0	0.025157	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC2	0.000367	0.000371	0.019236	2.46E-04	0	0	0	0	0	0	0	0	0	0.025157	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC3	0.000486	0.000492	0.025487	0.000326	0	0	0	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0	0	0	0	0	0
SC4	2.42E-04	2.45E-04	0.012664	1.62E-04	0	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0	0	0
SC5	0.000489	0.000495	0.025647	0.000328	0	0	0	0	0	0	0	0	0	0	0	0	0.025157	0	0	0	0	0	0	0	0	0	0	0
SC6	0.000483	0.000489	0.025329	0.000324	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0	0	0	0	0
SC7	0.00012	0.000122	0.006293	8.04E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0	0	0	0	0
SC8	0.000486	0.000492	0.025487	0.000326	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01875	0	0	0	0	0	0	0	0
SC9	0.00012	0.000122	0.006293	8.04E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0	0	0	0	0	0
SC10	0.00012	0.000122	0.006332	8.09E-05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0	0
TC1	1.33E-04	0.000483	0.000364	0.018876	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012422	0	0	0	0	0
TC2	1.34E-04	0.000486	0.000366	0.018994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01875	0	0	0	0
TC3	1.35E-04	0.000489	0.000368	0.019114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.025157	0	0	0
TC4	8.81E-05	0.00032	2.41E-04	0.012507	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.006173	0	0
TC5	4.43E-05	0.000161	0.000121	0.006292	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012422	0
TC6	8.98E-05	0.000326	2.46E-04	0.012743	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.025157

Table 11
The total impact, total receptivity, total engagement, and final relative weights of the sub-criteria.

	Total Impact		Total receptivity		Total engagement		Final relative weight	
	r_i^L	r_i^U	c_i^L	c_i^U	$r_i^L + c_i^L$	$r_i^U + c_i^U$	w_i^L	w_i^U
PR1	0.012384	0.025247	0.006173	0.012422	0.018557	0.037669	0.019212	0.039
PR2	0	0.012546	0	0.006173	0	0.018718	0	0.01938
PR3	0.037616	0.051129	0.01875	0.025157	0.056366	0.076287	0.058357	0.078982
PR4	0.018672	0.031655	0.012422	0.01875	0.031094	0.050405	0.032193	0.052186
TS1	0.038454	0.052283	0.01875	0.025157	0.057204	0.07744	0.059225	0.080176
TS2	0.01266	0.025817	0.006173	0.012422	0.018833	0.038239	0.019498	0.03959
TS3	0.01266	0.025817	0.006173	0.012422	0.018833	0.038239	0.019498	0.03959
TS4	0.032004	0.045706	0.012422	0.01875	0.044426	0.064456	0.045996	0.066734
SC1	0.031805	0.045377	0.01875	0.025157	0.050555	0.070534	0.052341	0.073026
SC2	0.031805	0.045377	0.01875	0.025157	0.050555	0.070534	0.052341	0.073026
SC3	0.031884	0.045541	0.012422	0.01875	0.044306	0.064291	0.045871	0.066562
SC4	0.01262	0.025735	0.006173	0.012422	0.018793	0.038157	0.019457	0.039505
SC5	0.038333	0.052117	0.01875	0.025157	0.057083	0.077274	0.0591	0.080004
SC6	0.025514	0.039047	0.006173	0.012422	0.031687	0.051469	0.032806	0.053288
SC7	0	0.012788	0	0.006173	0	0.018961	0	0.019631
SC8	0.031884	0.045541	0.012422	0.01875	0.044306	0.064291	0.045871	0.066562
SC9	0	0.012788	0	0.006173	0	0.018961	0	0.019631
SC10	0.006173	0.019079	0.006173	0.012422	0.012346	0.031501	0.012782	0.032614
TC1	0.018994	0.032278	0.006173	0.012422	0.025167	0.0447	0.026056	0.04628
TC2	0.025323	0.03873	0.012422	0.01875	0.037746	0.05748	0.039079	0.05951
TC3	0.031732	0.045263	0.01875	0.025157	0.050482	0.07042	0.052265	0.072908
TC4	0.006371	0.019328	0	0.006173	0.006371	0.025501	0.006596	0.026402
TC5	0.006173	0.019041	0.006173	0.012422	0.012346	0.031463	0.012782	0.032575
TC6	0.025241	0.038561	0.01875	0.025157	0.043991	0.063718	0.045545	0.065969

Table 12
The decision matrix.

Sub-criteria	Platform				
	1	2	3	4	5
Market recognition	[8.5–10]	[5.5–7]	[8.5–10]	[4.5–5.5]	[5.5–7]
Community activity	[1.5–3]	[7–8.5]	[1.5–3]	[1.5–3]	[1.5–3]
Previous experiments in deploying the platform to the sector	[8.5–10]	[7–8.5]	[4.5–5.5]	[5.5–7]	[5.5–7]
Support plan for small partners (suppliers and retailers)	[5.5–7]	[1.5–3]	[4.5–5.5]	[1.5–3]	[5.5–7]
Cost-effective transition plan	[4.5–5.5]	[7–8.5]	[3–4.5]	[4.5–5.5]	[4.5–5.5]
Agile and clear transition roadmap	[7–8.5]	[8.5–10]	[8.5–10]	[1.5–3]	[4.5–5.5]
High-quality documentation of platform information	[1.5–3]	[1.5–3]	[1.5–3]	[0–1.5]	[5.5–7]
Interactivity with current platforms	[4.5–5.5]	[1.5–3]	[4.5–5.5]	[0–1.5]	[4.5–5.5]
Improving the traceability of cargo	[8.5–10]	[7–8.5]	[10–10]	[1.5–3]	[8.5–10]
Improving the traceability of inventory	[8.5–10]	[7–8.5]	[10–10]	[1.5–3]	[10–10]
Customer-specific traceability feature	[4.5–5.5]	[8.5–10]	[7–8.5]	[7–8.5]	[8.5–10]
IoT	[8.5–10]	[1.5–3]	[8.5–10]	[1.5–3]	[5.5–7]
Verifiable record of transactions among parties (supplier, distributors, retailers)	[8.5–10]	[7–8.5]	[8.5–10]	[1.5–3]	[7–8.5]
Supply chain analytics	[1.5–3]	[1.5–3]	[1.5–3]	[1.5–3]	[4.5–5.5]
Integration with financing institutions, banks, and insurance	[1.5–3]	[0–1.5]	[1.5–3]	[5.5–7]	[1.5–3]
Fraud traceability	[8.5–10]	[0–1.5]	[10–10]	[5.5–7]	[10–10]
Property tokenizing	[1.5–3]	[0–1.5]	[1.5–3]	[1.5–3]	[1.5–3]
Smart Contract	[4.5–5.5]	[7–8.5]	[4.5–5.5]	[7–8.5]	[4.5–5.5]
Modular architecture	[10–10]	[1.5–3]	[10–10]	[1.5–3]	[1.5–3]
Performance efficiency	[7–8.5]	[5.5–7]	[7–8.5]	[5.5–7]	[5.5–7]
Security	[7–8.5]	[5.5–7]	[7–8.5]	[5.5–7]	[5.5–7]
Reliability	[7–8.5]	[5.5–7]	[7–8.5]	[5.5–7]	[5.5–7]
Extensibility	[8.5–10]	[3–4.5]	[8.5–10]	[3–4.5]	[3–4.5]
Privacy of customers	[7–8.5]	[3–4.5]	[7–8.5]	[1.5–3]	[5.5–7]

Table 13
The PIS and NIS.

Sub-criteria	PIS	NIS
Market recognition	10	4.5
Community activity	8.5	1.5
Previous experiments in deploying the platform to the sector	10	4.5
Support plan for small partners (suppliers and retailers)	7	1.5
Cost-effective transition plan	8.5	3
Agile and clear transition roadmap	10	1.5
High-quality documentation of platform information	7	0
Interactivity with current platforms	5.5	0
Improving the traceability of cargo	10	1.5
Improving the traceability of inventory	10	1.5
Customer-specific traceability feature	10	4.5
IoT	10	1.5
Verifiable record of transactions among parties (supplier, distributors, retailers)	10	1.5
Supply chain analytics	5.5	1.5
Integration with financing institutions, banks, and insurance	7	0
Fraud traceability	10	0
Property tokenizing	3	0
Smart Contract	8.5	4.5
Modular architecture	10	1.5
Performance efficiency	8.5	5.5
Security	8.5	5.5
Reliability	8.5	5.5
Extensibility	10	3
Privacy of customers	8.5	1.5

Table 14
The interval utility values.

Platform	Φ^L	Φ^U
1	0.11451	0.51639
2	0.29277	0.83812
3	0.15334	0.53219
4	0.48203	1.09442
5	0.20205	0.652

Thus, the lower and upper bounds of utility values for all platforms are calculated as given in Table 14.

Step 2.4: In this step, interval regret values are calculated for alternatives using Eq. (11). For example, the lower bound of regret value for platform 1 is calculated as follows:

$$\Omega_1^L = Max\{0.019212\times\frac{(10-10)}{(10-4.5)}, 0\times\frac{(8.5-3)}{(8.5-1.5)}, 0.058357\times\frac{(10-10)}{(10-4.5)}, 0.032193\times\frac{(7-7)}{(7-1.5)},$$
$$0.059225\times\frac{(8.5-5.5)}{(8.5-3)}, 0.019498\times\frac{(10-8.5)}{(10-1.5)}, 0.045996\times\frac{(5.5-5.5)}{(5.5-0)}, 0.052341\times\frac{(10-10)}{(10-1.5)},$$
$$0.052341\times\frac{(10-10)}{(10-1.5)}, 0.045871\times\frac{(10-5.5)}{(10-4.5)}, 0.019457\times\frac{(10-10)}{(10-1.5)}, 0.0591\times\frac{(10-10)}{(10-1.5)},$$
$$0.032806\times\frac{(5.5-3)}{(5.5-1.5)}, 0\times\frac{(7-3)}{(7-0)}, 0.045871\times\frac{(10-10)}{(10-0)}, 0\times\frac{(3-3)}{(3-0)}, 0.012782\times\frac{(8.5-5.5)}{(8.5-4.5)},$$
$$0.026056\times\frac{(10-10)}{(10-1.5)}, 0.039079\times\frac{(8.5-8.5)}{(8.5-5.5)}, 0.052265\times\frac{(8.5-8.5)}{(8.5-5.5)}, 0.006596\times\frac{(8.5-8.5)}{(8.5-5.5)},$$
$$0.012782\times\frac{(10-10)}{(10-3)}, 0.045545\times\frac{(8.5-8.5)}{(8.5-1.5)}\} = 0.03753$$

Similarly, the upper bound of regret value for platform 1 is calculated as follows:

Table 15
The interval regret values.

Platform	Ω^L	Ω^U
1	0.03753	0.06656
2	0.03899	0.07291
3	0.04775	0.08018
4	0.04867	0.08
5	0.03231	0.07291

$$\Omega_1^U = Max\{0.039\times\frac{(10-8.5)}{(10-4.5)}, 0.01938\times\frac{(8.5-1.5)}{(8.5-1.5)}, 0.078982\times\frac{(10-8.5)}{(10-4.5)}, 0.052186\times\frac{(7-5.5)}{(7-1.5)},$$
$$0.080176\times\frac{(8.5-4.5)}{(8.5-3)}, 0.03959\times\frac{(10-7)}{(10-1.5)}, 0.03959\times\frac{(7-1.5)}{(7-0)}, 0.066734\times\frac{(5.5-4.5)}{(5.5-0)},$$
$$0.073026\times\frac{(10-8.5)}{(10-1.5)}, 0.073026\times\frac{(10-8.5)}{(10-1.5)}, 0.066562\times\frac{(10-4.5)}{(10-4.5)}, 0.039505\times\frac{(10-8.5)}{(10-1.5)},$$
$$0.080004\times\frac{(10-8.5)}{(10-1.5)}, 0.053288\times\frac{(5.5-1.5)}{(5.5-1.5)}, 0.019631\times\frac{(7-1.5)}{(7-0)}, 0.066562\times\frac{(10-8.5)}{(10-0)},$$
$$0.019631\times\frac{(3-1.5)}{(3-0)}, 0.032614\times\frac{(8.5-4.5)}{(8.5-4.5)}, 0.04628\times\frac{(10-10)}{(10-1.5)}, 0.05951\times\frac{(8.5-7)}{(8.5-5.5)},$$
$$0.072908\times\frac{(8.5-7)}{(8.5-5.5)}, 0.026402\times\frac{(8.5-7)}{(8.5-5.5)}, 0.032575\times\frac{(10-8.5)}{(10-3)}, 0.065969\times\frac{(8.5-7)}{(8.5-1.5)}\} = 0.06656$$

Thus, the lower and upper bounds of regret values for all platforms are calculated as shown in Table 15.

Step 2.5: In this step, the lower and upper bounds of the ranking index for the platforms are determined using Eq. (12). For example, the process of calculating the lower and upper bounds of the ranking index for platform 1 is given below. Similarly, the lower and upper bounds of the ranking index for other platforms are calculated as shown in Table 16.

$$\Upsilon_1^L = 0.5\times\frac{(0.11451-0.11451)}{(1.09442-0.11451)} + 0.5\times\frac{(0.03753-0.0323)}{(0.08018-0.0323)} = 0.05459$$

$$\Upsilon_1^U = 0.5\times\frac{(0.51639-0.11451)}{(1.09442-0.11451)} + 0.5\times\frac{(0.06656-0.0323)}{(0.08018-0.0323)} = 0.56287$$

Step 2.6: In this step, the platforms are ranked using four rules presented by Sayadi et al. [62]. Table 17 reports the results of comparing platforms with each other using the four mentioned rules. It should be noted that the θ value is considered 0.5.

The final ranking resulted from Table 17 is as follows:

Platform1 > Platform3 > Platform2 > Platform4 > Platform5

Table 16
The interval ranking index.

Platform	Υ^L	Υ^U
1	0.05459	0.56287
2	0.16079	0.79331
3	0.1811	0.71312
4	0.35847	0.9982
5	0.04467	0.69835

Table 17
The results obtained from comparing platforms ($\vartheta = 0.5$and$\theta = 0.5$).

Compared platform	Rule	Result
Platforms 1 and 2	4	Platform 1 > Platform 2
Platforms 1 and 3	4	Platform 1 > Platform 3
Platforms 2 and 3	3	Platform 3 > Platform 2
Platforms 2 and 4	4	Platform 2 > Platform 4
Platforms 4 and 5	4	Platform 4 > Platform 5

As can be seen, platform 1 is the most efficient, and Platform 5 is the least efficient platform.

5. Discussion

To analyze the importance of the sub-criteria, we need to sort the weights properly. The weights, however, are discrete numbers that could be sorted. We sorted the interval weights based on the upper bound extracted from Table 11. The most important factor is the sub-criteria with the highest upper bound. The results will be very similar if we sort them according to the lower bound. So, it is possible to analyze the results since there is no inconsistency. Table 18 shows the sub-criteria sorted by interval weights.

The method results reveal that the first and third influential sub-criteria for decision-making comes from the emerging nature of BTs. The cost-effective transition plan (TS1) is the most weighted sub-criterion. Due to the lack of competition between suppliers and the novelty of such platforms, decision-makers are concerned about the high implementation costs. The results of this study are consistent with the argument made by Dutta (2021) about possible high implementation costs. There is a concern that there might be a situation where the costs of implementing such a platform would outweigh its benefits. A similar rationale can be applied to the third relevant sub-criterion, Previous experiments deploying the platform to the sector (PR3). This shows that decision-makers do not understand the costs and risks of implementing BT. Identifying best practices and estimating budgets and results is crucial. Therefore, it is clear that they are very risk-averse in this period and are trying to avoid possible costs associated with failures.

The second (SC5), fourth (SC1), and fifth (SC2) most weighted sub-criteria are tied to SC-related characteristics, including customer-specific traceability feature (SC3), improving the traceability of cargo (SC1) and improving the traceability of inventory (SC2). It indicates that traceability is a major concern for decision-makers in subsidized settings.

Security (TC3) is the sixth important factor in preventing data breaches, protecting documents from cyber-attacks, and keeping the system active. Interactivity with current platforms (TS4), Customer-specific traceability feature (SC3), Fraud traceability (SC8), Privacy of customers (TC6), and Performance efficiency (TC2) are in the next levels of importance.

Community activity (PR2) is the least relevant factor to the decision makers, suggesting they prefer to outsource maintenance to the provider rather than hire in-house experts. Property tokenizing (SC9) and Integration with financing institutions, banks, and insurance (SC7) have little importance for decision-makers which shows that their focus is not on the side operations of SCs and are more interested in logistic-related activities. The comparison of importance levels within the main criteria level is intriguing. Comparing the SC feature to all of the criteria, the weight assigned to Supply chain operational features (i.e. $\sum_{i=1}^{10} \mathrm{SC_i}$) is approximately 52%. Hence, it can be deduced that decision-makers, in this case, are concerned with features that ensure a healthy flow of cargo from the producers to the final consumers. This is closely related to a natural instinct in the subsidized food industry to track the products to distribute the subsidized resources fairly. 18.9% of the weight is allocated to the popularity and support activities of the provider, making it the least weighted criterion.

One of the problems with MCDM methods is that the preferences of experts influence them. In the proposed approach, two parameters ϑ and θ are valued based on the experts' opinions. As mentioned, θ and ϑ represent the optimism level of the decision-makers and the strategy weight for the maximum group utility, respectively. An optimistic decision-maker considers values greater than 0.5 for θ, while a pessimism decision-maker should assign values less than 0.5 to this parameter. On the other hand, if values greater than 0.5

Table 18
Sub-criteria sorted by their interval weights.

Sub-criteria	w_i^L	w_i^U	Rank
TS1	0.059225	0.080176	1
SC5	0.0591	0.080004	2
PR3	0.058357	0.078982	3
SC1	0.052341	0.073026	4
SC2	0.052341	0.073026	4
TC3	0.052265	0.072908	5
TS4	0.045996	0.066734	6
SC3	0.045871	0.066562	7
SC8	0.045871	0.066562	7
TC6	0.045545	0.065969	8
TC2	0.039079	0.05951	9
SC6	0.032806	0.053288	10
PR4	0.032193	0.052186	11
TC1	0.026056	0.04628	12
TS2	0.019498	0.03959	13
TS3	0.019498	0.03959	13
SC4	0.019457	0.039505	14
PR1	0.019212	0.039	15
SC10	0.012782	0.032614	16
TC5	0.012782	0.032575	17
TC4	0.006596	0.026402	18
SC7	0	0.019631	19
SC9	0	0.019631	19
PR2	0	0.01938	20

Table 19
The sensitivity analysis of parameters ϑ and θ.

Scenario	ϑ	θ	Results
SC1	0.4	0.4	Platform1 > Platform2 > Platform3 > Platform5 > Platform4
SC2	0.4	0.5	Platform1 > Platform2 > Platform3 > Platform4 > Platform5
SC3	0.4	0.6	Platform1 > Platform2 > Platform3 > Platform4 > Platform5
SC4	0.5	0.4	Platform1 > Platform3 > Platform2 > Platform4 > Platform5
SC5 (main problem)	0.5	0.5	Platform1 > Platform3 > Platform2 > Platform4 > Platform5
SC6	0.5	0.6	Platform1 > Platform3 > Platform4 > Platform2 > Platform5
SC7	0.6	0.4	Platform1 > Platform5 > Platform3 > Platform2 > Platform4
SC8	0.6	0.5	Platform1 > Platform5 > Platform3 > Platform2 > Platform4
SC9	0.6	0.6	Platform3 > Platform4 > Platform1 > Platform2 > Platform5

are considered for ϑ, it means that the decision is based on voting by a majority, and if the decision is based on veto compromise, the value of ϑ should be less than 0.5. The decision-maker considering the value of 0.5 for this parameter, is looking for a consensus solution. Now, this question arises to what extent do experts' preferences affect the ranking of platforms? To answer this question, we define scenarios based on changes in ϑ and θ values and rank platforms based on these scenarios. For this purpose, nine scenarios are defined. These scenarios and their results are shown in Table 19.

The results obtained from the sensitivity analysis of parameters θ and ϑ show that Platform 1 has better performance in all scenarios except scenario 9 compared to other platforms (See Table 19). Therefore, choosing Platform 1 as an efficient platform is a reliable decision.

6. Managerial implications

This paper develops a practical MCDM-based framework for prioritizing BT platforms in food SC. A literature review shows that some researchers have previously used MCDM methods to evaluate BT platforms in various fields. Still, this paper first develops an efficient hybrid approach that can weigh intertwined criteria in a network with a hierarchical structure and rank BT platforms under uncertainty. In addition, this is the first paper to evaluate BT platforms in subsidized food SC. This paper applies the proposed approach to evaluate 5 BT-based platforms used in food supply chains. According to the results, Platform 1 is the most desired platform by decision-makers in 8 out of 9 scenarios. It indicates that Platform 1 is justified for them. TS4, TC3, SC1, SC2, PR3, SC5, and TS1 accounted for more than 50% of the overall weight of the criteria. Platform 1 outperformed the other platforms in six out of these seven criteria. This approach can be used as a decision support system to help the Ministry of Industry, Mines, and Trade managers choose the best BT platform according to their conditions and limitations.

Besides considering strength and influence intensity, this approach suits problems with a hierarchical structure. Moreover, unlike other structural models, the intertwined nature of the components does not impose significant complexity on the problem. Considering the flexibility of the approach presented in this research, it can also be applied to other areas, such as supplier selection, organization ranking, and project selection.

7. Conclusion

Countries with a protectionist approach to food security subsidize low-income groups' access to strategic food items like wheat. Agricultural subsidized prices, however, can differ significantly from equilibrium market prices, especially during difficult economic times. Some might use the subsidized price to fraudulently resell the product at a market price. As a result, the authorities need to implement real-time tracking systems that monitor all stages of SC, from the supply sources to the final shipment stage. This problem can be overcome by using BT-IoT platforms. If this is the case, how do you choose a BT platform that is appropriate for this purpose? Based on a review of the existing literature, this paper identifies a set of decision criteria related to popularity and support, transition simplicity, SC features, and technical issues. In this paper, for the first time, a novel approach is presented to evaluate and rank BT platforms in food SC by combining the interval WINGS method and interval VIKOR technique. Considering the interrelatedness and hierarchy of the evaluation factors, using structural models to evaluate them is beneficial. The interval WINGS method evaluates the evaluation criteria and their sub-criteria. The interval VIKOR method has also been applied to rank BT platforms under uncertainty using several factors, including experts' preferences.

The results showed that transition simplicity has the most weighted sub-criteria. The cost-effective transition plan, verifiable record of transactions among parties (supplier, distributors, retailers), previous experiments in deploying the platform to the sector, improving the traceability of inventory, improving the traceability of cargo, and interactivity with current account for more than 50% of the weight of sub-criteria that influence decision-making.

Similar to other research, our study faced some limitations. This study does not discuss blockchain's potential role in SC sustainability. Reports on the environment, society, and governance (ESG) are becoming significant in the stock market. For instance, as part of the European Green Deal, all large companies and listed companies are required by EU law to disclose information on their risks and opportunities related to social and environmental issues to assist all stakeholders in assessing the sustainability performance of businesses. By tracking the ESG indicators through sustainable product information (like recycling and carbon emissions) and participant sustainability conditions visible, the characteristics of BT platforms can be taken advantage of as a trustworthy and agreedupon platform among all internal and external stakeholders and authorities. We propose to examine this issue in future research. Moreover, most MCDM methods that consider criteria dependencies only consider situations with positive effects. However, both positive and negative impacts exist simultaneously in the real world. To manage food SCs, we propose using a method that can handle both.

Declaration of Competing Interest

The above authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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