Robust framework to prioritize blockchain-based supply chain challenges: the fuzzy best-worst approach for multiple criteria decision-making

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Robust framework to prioritize blockchain-based supply chain challenges: the fuzzy best-worst approach for multiple criteria decision-making

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Abstract

Purpose – This study aims to identify and prioritize the challenges to adopting blockchain in supply chain management and to make its taxonomic model. Moreover, validate whether these challenging factors exist in the real world and, if they exist, then in what percentage.

Design/methodology/approach – This research adopted the fuzzy best-worst method (F-BWM), which integrates fuzzy set theory with the best-worst method to identify and prioritize the prominent challenges of the blockchain-based supply chain by developing a weighted multi-criteria model.

Findings – A total of 20 challenges (CH'S) were identified. Lack of storage capacity/scalability and lack of data privacy challenges were found as key challenges. The findings of this study will provide a robust framework of the challenges that will assist academic researchers and industry practitioners in considering the most significant category concerning their working area.

Practical implications – Blockchain provides the best solution for tracing and tracking where RFID has not succeeded. It can improve quality management in a supply chain network by improving standards and speeding up operations. For inventory management, blockchain provides transparency of documentation for both parties within no time.

Originality/value – To the best of the authors' knowledge, no previous research has adopted the fuzzy best-worst method to prioritize the identified challenges of blockchain implementation in the supply chain. Moreover, no study provides a taxonomic model for the challenges of implementing a blockchain-based supply chain.

Keywords Blockchain, Supply chain management, Challenges, Multiple criteria decision-making, Fuzzy best-worst method

Paper type Research paper

1. Introduction

The supply chain is a distribution network of goods and services. Many actors are involved, from raw materials procurement to the finished product, including manufacturers, suppliers, distributors, retailers, and end-users or customers (Abeyratne and Monfared, 2016). Currently, the supply chain is becoming more complicated due to market expansion. There is a high-quality demand and price war between the manufacturing and service sectors. It is challenging to achieve high quality and low prices without customer satisfaction. United Nations provides rights to customers about getting informed, maintaining protection, food safety, and a healthy environment (United Nations, 2016). It is the fundamental right of a customer to check the authority of the product/food. In the United States, 48 million cases are registered annually, and the reason behind them is contaminated food (Kowitt, 2015). Because there is no proper check and balance of the food chain once it is out of the market. Each year out of 420,000 cases, one of the 10,000 people is affected by food poisoning (WHO, 2015). In October 2017, 220 people got infected with outbreaks of strains of five types of Salmonella, and 68 cases got hospitalized; from New York City, one death was reported, and cases were linked to imported maradol papayas (Centre of Disease Control, 2017). Same as in September 2019, a total of 102 cases were registered with the epidemic strain of E.coli O157: H7, 10 people were infected by hemolytic uremic syndrome, and the reason behind this infection is food contaminated with E.coli O157: H7 (Centre of Disease Control, 2017). A 10% share of the pharmaceutical industry in developing and underdeveloped countries goes to fake drugs/ black markets (WHO, 2018). These counterfeit drugs put the patient's life in danger, resistance, and their anti-effects cause death (Mackey and Liang, 2011). In the pharmaceutical industry, anticancer drugs are provided at a high cost, have no authenticity, and time delay, providing a way to enter fake medicine into the market (Mackey and Nayyar, 2017).

In January 2014, around 33,840 pounds of Salmonella Heidelberg affected different chicken products recalled by Tyson Foods (Centre of Disease Control, 2017). In June 2019, King Arthur Flour recalled 14,218 cases of 5lb unbleached flour because of Escherichia coli bacteria (Food and Drug Administration, 2019). Just after six months, in December 2019, Nassau Candy Distributor recalled two lots of 7.5 OZ (212 g) of food and beverages snacks because they did not declare milk allergens, which may create an allergic reaction for customers (Food and Drug Administration, 2019). These things provide question marks on the sustainability of the supply chain as it is challenging to take sudden precautions after an incident happens. As stated above, these issues damage the customer's health and affect the business's reputation. The company loses its reputation by recalling its products because of negative rumors, dramatically reducing its market share (Viriyasitavat *et al.*, 2019).

Blockchain technology provides the best solution for tracing, tracking, making transactions transparent, durability, scalability, security, and reducing cost (Shoaib *et al.*, 2023). Blockchain technology is still in the experimental phase, so some issues exist regarding implementing a blockchain-based supply chain. Shoaib *et al.* (2020) mentioned that 35% of organizations do not adopt blockchain technology in the supply chain. As blockchain is one of the hot topics, our key motivation is to find out why organizations do not adopt blockchain technology. According to that, the proposed study tries to answer the following research questions:

RQ1. What are the challenges/obstacles mentioned in the prior literature?

RQ2. What are the most critical challenges (CCHs) identified using F-BWM?

RQ3. What would be the framework of challenges in adopting a blockchain-based supply chain?

Previous studies discussed the barriers/challenges in adopting the blockchain-based supply chain in various domains. Mendling *et al.* (2018) discussed challenges and opportunities related to blockchain for business process management. Queiroz and Wamba (2019) investigated drivers of blockchain technology with challenges in the USA and Indian markets by adopting two models. Zhou *et al.* (2020) discussed blockchain implementation's challenges and critical success factors for Singapore's maritime industry. Almutairi *et al.* (2022) and Yildizbasi (2021) mentioned challenges in renewable energy supply chain management and ranked them using a hybrid methodology. Panghal *et al.* (2023) categorized challenges into six key factors related to reverse logistics in the food processing industry. They performed EFA to categorize these factors. Rejeb *et al.* (2022) also investigated barriers to blockchain adoption in the circular economy. On the other hand, Govindan (2022) studied blockchain barriers from a circular manufacturing perspective.

In summary, many studies discussed blockchain-based challenges, but no one provides a holistic viewpoint of a blockchain-based supply chain. Previous studies mainly discussed challenges related to the applications of blockchain technology or challenges of the supply chain, but no one focused on the core application of blockchain technology adoption in the supply chain domain. The proposed study aims to identify and rank the critical barriers related to blockchain technology in general and the supply chain in particular. Moreover, no previous study has adopted F-BWM to rank the relative barriers associated with the blockchain-based supply chain. In addition, this paper also discusses the comparison of F-BWM results with F-AHP (fuzzy analytic hierarchy process) and F-ANP (fuzzy analytic network process) methods, to which the prior studies have not given much attention. Our fundamental motivation for adopting the fuzzy-based approach is that it can effectively resolve data uncertainty while solving real-life decision-making issues. During the evaluation, experts marked each criterion as per their knowledge and experience. However, due to data uncertainty, human knowledge is not always accurate when solving real-life decision-making issues. Due to that, the chances of human judgment errors increase, resulting in inaccurate outcomes. As a result, the fuzzy-based approach was used to resolve the decision-making data uncertainty problem to mitigate human judgment errors.

Literature (books, journals, conferences) was reviewed to determine the challenges in implementing a blockchain-based supply chain. Mainly these challenges were identified from the literature, including blockchain in general and supply chain in particular. The main contributions of this study are listed as follows:

(1) We provided a more detailed background on blockchain technology in general and its relation to the supply chain. Moreover, we have studied the prior literature and offer a comprehensive overview of the blockchain-based supply chain.

(2) We have identified the adoption challenges of blockchain technology in general and the supply chain in particular. Most of these challenges are system-related, and others are in the supply chain domain.

(3) We have conducted an empirical study with industrial practitioners and researchers to validate the identified challenges regarding the best and worst challenging factors.

(4) We built a robust framework after prioritizing the identified factors by using F-BWM. F-BWM is a practical approach to analyzing blockchain-based supply chain challenges, as it can quickly mitigate ambiguity and fuzziness during decision-making. This framework will guide researchers and industrial practitioners to consider these challenges before implementing a blockchain-based supply chain. Based on prior research, till now, no study has summarized the blockchain-based supply chain challenges in detail.

The rest of the paper is organized as follows. Section 2 provides the relative background of blockchain and the blockchain-based supply chain. Section 3 presents the research methodology in terms of five steps. Section 4, results and discussion, exhibits the outcomes of the proposed research. In addition, we discuss the prime challenges/obstacles in adopting a blockchain-based supply chain. Managerial and technical implications are given in Section 5. Section 6 concludes the paper.

2. Relative background

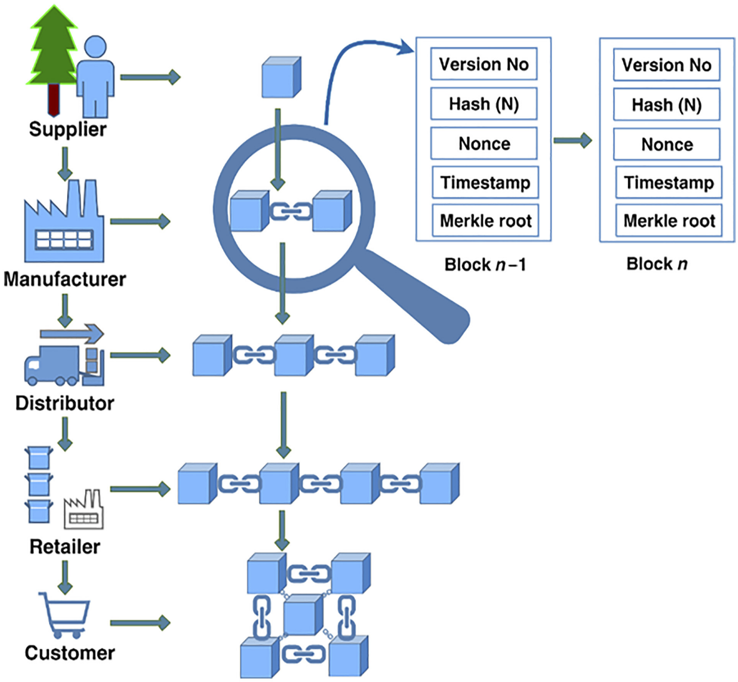
2.1 Blockchain

Blockchain is a decentralized and trustless peer-to-peer (P2P) technology introduced by Nakamoto (2008). It consists of a chronological chain of blocks with complete information and transaction details. The first block is called the genesis block, containing a "Header and Body" in which a list of transactions is recorded (Delmolino *et al.*, 2016). A new block is created for every new transaction that includes all the records related to the transaction and is then connected sidewise using a hash function. The next block is linked together using a previous block's hash to make a chain. Each block contains a unique number and hashtag, so each has its own identity. Blockchain technology eliminates center trust authority by using the "mining process" that ensures that the information added to the node is confirmed and secure (Tian, 2017).

Blockchain provides complete authentication to its user inside a chain to check data and add values. The immutability property can improve trust between two parties without the involvement of a middleman (Abeyratne and Monfared, 2016). Each block in a chain comprises a complete history of all transactions. Once a block is created, it cannot be deleted. Also, if one wants to make changes, one must generate a new block. Trust in the blockchain is an established protocol with the help of software known as a smart contract (Saberi *et al.*, 2019) that contains terms and conditions where both parties agree (Abeyratne and Monfared, 2016) and execute transactions upon verification of terms (Delmolino *et al.*, 2016). Blockchain networks can be classified into permission blockchain or permission-less blockchain/public blockchain. Parties can do transactions without authorization in a public (permission-less) blockchain. Whereas in permission blockchain, a user must have confirmation from the central agency/organization to make a transaction. This article mainly studies the public blockchain and its factors.

2.2 Blockchain-based supply chain

The supply chain is defined as the "flow of goods and services, starting from supplier, manufacturer, distributor retailer and ultimately to customers." Traceability in the supply chain cannot be enhanced by using RFID (Radio-Frequency Identification) integrating with other systems like GIS (Geographic Information System), WSN (Wireless Sensor Network), and GPS (Global Positioning System) (Tian, 2017). Blockchain is integrated with RFID, GIS, WSN, and GPS, which upload data to the cloud-based system every 10 s to trace the location and condition of goods (temperature and humidity for refrigerated goods). Blockchain also provides the best solution for refrigerated goods. Tracing the product reduces food waste and labor costs (Almutairi *et al.*, 2022) because it minimizes recalling the product as the process is streamlined. It also helps to track the carbon footprints and maintain the responsibilities of supply chain members. Transparency through blockchain promotes trust between two parties and enables them to make the right decisions for their future. Trust helps in setting goals and resolving problems related to tracking (Sahay, 2003). Nowadays, the manufacturing industries use blockchain to care for their supply chain as a decentralized system. Blockchain also helps collect the required information for each product's life cycle (Abeyratne and Monfared, 2016). The blockchain-based supply chain also facilitates improvement in inventory and warehousing as storekeepers can prepare themselves before the arrival of the new shipment (Zhao *et al.*, 2019). Figure 1 reveals a blockchain-based supply chain layout.



Source(s): Figure by authors

Figure 1. Blockchain-based supply chain layout

Although blockchain as a disruptive technology has many applications in the supply chain, it is still a big challenge as far as blockchain implementation in the supply chain is concerned. Implementation of successful blockchain technology is only possible if managers and industrial practitioners know about the challenges and plan to adopt a blockchain-based supply chain. Effective tracing of products and handling the supply chain through blockchain technology identifies blockchain challenges (Saberi *et al.*, 2019). This paper presents the challenges of adopting blockchain technology in the supply chain.

3. Research methodology

This study aims to identify and prioritize the challenges of the blockchain-based supply chain by using F-BWM. These factors will help scholars and industrial practitioners to understand and investigate supply chain activities using blockchain technology. In addition, an empirical study was conducted to check the validation of these challenging factors in real-world practice.

3.1 Fuzzy best-worst method

The best-worst method (BWM) introduced by Rezaei (2015) is a multi-criteria decision-making (MCDM) technique, in which the challenges are prioritized based on the pairwise comparison with the best and worst factors. BWM, compared to other MCDM techniques, e.g. the F-AHP and F-ANP, provides the best deviation of results, confirmation, and reliability (Bagheri *et al.*, 2022). It also provides better evaluations between the challenges and categories. The main advantage of the fuzzy best-worst method over fuzzy TOPSIS and fuzzy AHP is its utilization of a reduced pairwise comparison matrix. In other MCDM approaches, the pairwise comparison matrices rise with the increase in criteria. Due to the upsurge in the number of pairwise comparison matrices, the chances of errors will also increase as it will enhance the cognitive load of the experts. The fuzzy best-worst method uses fewer pairwise comparisons, producing more consistent results than fuzzy AHP and TOPSIS.

Integrating the fuzzy set theory with MCDM is strongly helpful in resolving the problems' fuzziness during decision-making. A triangular fuzzy number contains only three nodes which are lesser than trapezoidal or other fuzzy numbers. Most researchers use triangular fuzzy numbers because of their simplicity and calculation ease. So, due to its simplicity, we also utilized the triangular fuzzy numbers in the proposed research. Guo and Zhao (2017) developed the fuzzy-BWM to solve the decision-making data uncertainty problem. A triangular fuzzy number (TFN's) on the R set with the membership function $\mu_{\bar{s}}(x) : R \rightarrow [0, 1]$ is shown in Figure 2.

The membership function of $\bar{s}_j = (l_j, m_j, u_j)$ can be defined as

$$\mu_{\bar{s}}(x) = \left\{\frac{x-l}{m-l}, l \leq x \leq m;\ \frac{u-x}{u-m}, m \leq x \leq u;\ 0, otherwise\right\}. \tag{1}$$

where $l, m,$ and u defines the lower, medium, and upper values of s.

Let $X = (l_1, m_1, u_1)$ and $Y = (l_2, m_2, u_2)$ be the two TFNs. Then the operational laws of TFN's can be written as follows:

$$X(+)Y = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2). \tag{2}$$

$$X(-)Y = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2). \tag{3}$$

$$X(\times)Y = (l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2). \tag{4}$$

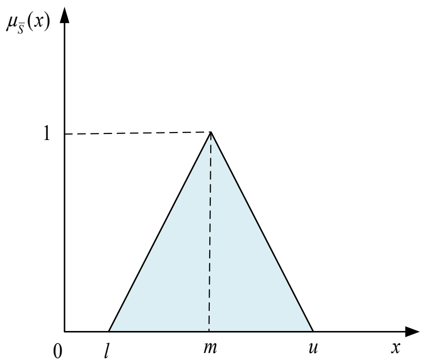
$$X(/)Y = (l_1, m_1, u_1)/(l_2, m_2, u_2) = (l_1/u_2, m_1/m_2, u_1/l_2). \tag{5}$$

$$\alpha X = \alpha(l_1, m_1, u_1) = (\alpha l_1, \alpha m_1, \alpha u_1). \tag{6}$$

where α be any constant, $\alpha > 0$

$$X^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{7}$$

The Graded-Mean-Integration-Representation (GMIR), denoted by $M(\bar{s}_j)$, can be calculated by using the formula below to de-fuzzify the TFNs:



Source(s): Ghoushchi *et al.*, 2019

Figure 2.
Membership function of TFN's

$$M(\bar{s}_j) = \frac{l_j + 4m_j + u_j}{6}. \tag{8}$$

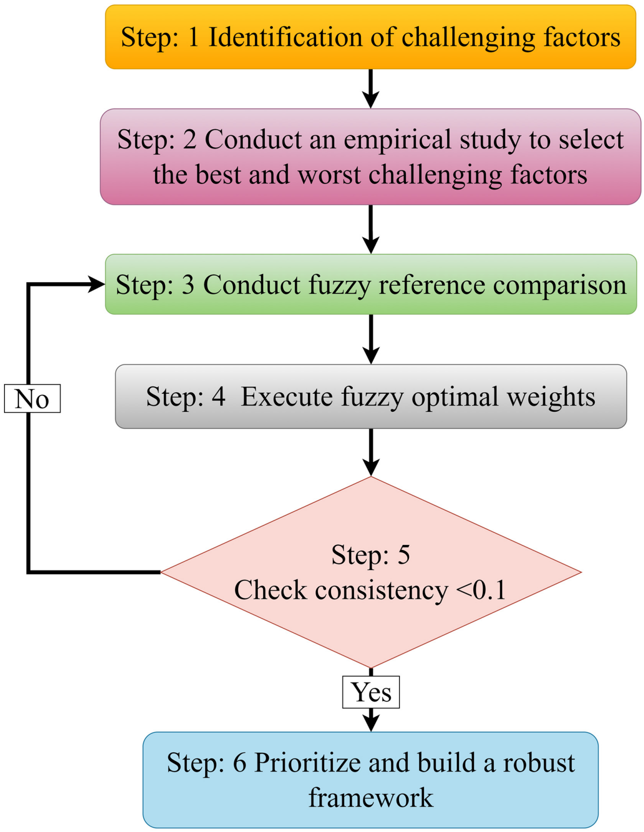
The above mentioned steps define the basic definitions associated with the usage of TFNs. The fuzzy best-worst method was carried out by adopting the following steps mentioned in Figure 3.

Step 1: Identification of challenging factors

This step identifies the main challenging factors that affect the decision-making process. In total, 20 factors were identified with the help of a comprehensive literature review that negatively influences the implementation of the blockchain-based supply chain. The identified challenges are mentioned in Table 1.

Step 2: Selecting the best and worst challenging factors

This step is the central part of the methodology in which the pilot survey was conducted to analyze the reference comparisons for the "best (the most favorable or important) vs others" and "others vs worst (the least favorable or important)" challenges. The respondents ranked the challenging factors (mentioned in Table 1) on a 0–5 linguistic scale, "Not Important (NI)," "Somewhat important (SW)," "Important (I)," "Very Important (VI)," and "Extremely



Source(s): Figure by authors

Figure 3.
Steps for adopting the fuzzy best-worst method

S.No	Challenges/obstacles	Reference
CH1	Challenge of information disclosure between partners in the supply chain	Karuppiah *et al.* (2023), Liu *et al.* (2021)
CH2	Interoperability challenges	Ismail *et al.* (2021)
CH3	Lack of new organizational policies for using technologies	Queiroz and Wamba (2019)
CH4	Lack of knowledge/skills	Karuppiah *et al.* (2023), Ratta *et al.* (2021)
CH5	Difficulty in changing organizational culture	Yaqoob *et al.* (2022)
CH6	Lack of management commitment	Queiroz and Wamba (2019)
CH7	Latency challenges/confirmation delay	Cao *et al.* (2019), Viriyasitavat *et al.* (2019)
CH8	Lack of storage capacity/scalability	Qureshi and Jiménez (2021)
CH9	Lack of communication and coordination	Liu *et al.* (2021)
CH10	Lack of governance/regulations	Boutkhoum *et al.* (2021)
CH11	Lack of standardization	Schmidt and Wagner (2019)
CH12	Cultural differences in supply chain partners	Saberi *et al.* (2019), Zhou *et al.* (2020)
CH13	Lack of security	Chang *et al.* (2020)
CH14	Access to technology/computer power	Queiroz and Wamba (2019), Chang *et al.* (2020)
CH15	Cost/energy consumption/funding challenges	Cao *et al.* (2019)
CH16	Lack of data privacy	Qureshi and Megías Jiménez (2021), Chang *et al.* (2020)
CH17	Lack of immutability of technology	Karuppiah *et al.* (2023), Liu *et al.* (2021)
CH18	Lack of performance/throughput	Yildizbasi (2021)
CH19	Risk challenges	Steiu (2020)
CH20	Lack of trust of external stakeholders	Viriyasitavat *et al.* (2019), Boutkhoum *et al.* (2021)

Source(s): Table by authors

Table 1. Challenges/obstacles mentioned in literature while adopting blockchain technology in the supply chain

Important (EI)" (Bagheri *et al.*, 2021; Shoaib *et al.*, 2022). Finally, the best and worst challenges were selected based on the survey's outcome.

Step 3: Conducting fuzzy reference comparison

In total, five industrial and three academic experts from the logistics and supply chain field, having experience of more than five years, were invited to perform the fuzzy reference comparisons based on the identified "best" and "worst" challenges with the help of the linguistic terms mentioned in Table 2.

Fuzzy best criterion "b" as compared with other criterion j, using TFN's $s_{bj}^{e} = \left(s_{bj}^{l}, s_{bj}^{m}, s_{bj}^{u}\right)$ where e denotes the number of experts. Judgment becomes nonfuzzy when $s_{bj}^{u} - s_{bj}^{l} = 0$, such that fuzzy best-to-best vector is $s_{bb} = (1, 1, 1)$. Same as determining others criteria j with worst criteria w, using TFNs $s_{jw}^{e} = \left(s_{jw}^{l}, s_{jw}^{m}, s_{jw}^{u}\right)$. $s_b = (s_{b1}, s_{b2}, s_{b3}, \ldots . s_{bn})$ and $s_w = (s_{1w}, s_{2w}, s_{3w}, \ldots . s_{nw})$ are the reference comparison of the "best" challenge with "others" and "all others" with "worst"

Linguistic variables	TFN's
Equally Important (EI)	(1, 1, 1)
Least Important (LI)	(0.667, 1, 1.5)
Strongly Important (SI)	(1.5, 2, 2.5)
Very Important (VI)	(2.5, 3, 3.5)
Absolutely Important (AI)	(3.5, 4, 4.5)

Source(s): Kumar *et al.* (2021)

Table 2. Linguistic variables and their TFN's

challenge, respectively. Here, $s = (l, m, u) = (\min l, GMm, \max u)$, where GM stands for the geometric mean and min and max for the lower and upper bounds of fuzzy numbers by experts for a precise reference comparison value.

Step 4: Executing fuzzy optimal weights

The fuzzy reference comparison will be reliable if the fuzzy reference comparison meets the two conditions $\frac{w_b}{w_j} = s_{bj}$ and $\frac{w_j}{w_w} = s_{jw}$, where w_b, w_w, and w_j be the TFNs weight for best criterion, worst criterion, and other's criteria j, respectively. The aim is to determine the fuzzy optimal weights by minimizing the objective function, such that the differences between $\frac{w_b}{w_j}$ and s_{bj} (TFNs for best); $\frac{w_j}{w_w}$ and s_{jw} (TFN's for worst) are minimized. The objective function ξ minimizes the absolute gap for the kth value. The constraints of the best and worst optimization problems are presented in eq. (9), which is limited to ξ. Eq. (10) defuzzify the triangular fuzzy number using GMIR, whose summation is equal to 1. The constraints for using GMIR, given in eq. (11-13), show the range and positive value of the absolute gap.

Fuzzy optimal weights $(w_1, w_2, w_3 \ldots w_n)$ can be calculated by minimizing the objective function ξ.

Min. ξ

Subject to:

$$\left| \frac{(l_b, m_b, u_b)}{(l_j, m_j, u_j)} - l_{bj}, m_{bj}, u_{bj}, \right| \leq (k^*, k^*, k^*,).$$
$$\left| \frac{(l_j, m_j, u_j)}{(l_w, m_w, u_w)} - l_{jw}, m_{jw}, u_{jw}, \right| \leq (k^*, k^*, k^*,). \tag{9}$$

$$\sum_{j=1}^{n} M(w_j) = 1 \tag{10}$$

$$l_j \geq 0 \tag{11}$$

$$l_j \leq m_j \leq u_j \tag{12}$$

$$j = 1, 2, 3, \ldots n \tag{13}$$

$s_{bj} = (l_{bj}, m_{bj}, u_{bj})$ and $s_{jw} = (l_{jw}, m_{jw}, u_{jw})$ are the aggregated "best" vs "others" and "others" vs "worst" reference comparisons, respectively. Whereas $w_b = (l_b, m_b, u_b)$ and $w_w = (l_w, m_w, u_w)$ are the best and worst fuzzy weights of the challenges. Where minimized objective function $\xi = (l^\xi, m^\xi, u^\xi)$; however $k^* \leq l^\xi$.

As it is challenging to solve these equations with fuzzy numbers, so by using the operational laws of the TFNs, we converted these into a non-linear constrained problem with non-fuzzy numbers. In this, we have to minimize the k^*. Transformed inequalities for the "best challenge" are given below:

$$\begin{aligned} |l_b - (l_{bj} u_j)| &\leq (k^* u_j). \\ |m_b - (m_{bj} m_j)| &\leq (k^* m_j). \\ |u_b - (u_{bj} l_j)| &\leq (k^* l_j). \end{aligned} \tag{14}$$

Transformed inequalities for the "worst challenge" are given below:

$$\begin{aligned} |l_j - (l_{jw} u_w)| &\leq (k^* u_w). \\ |m_j - (m_{jw} m_w)| &\leq (k^* m_w). \\ |u_j - (u_{jw} l_w)| &\leq (k^* l_w). \end{aligned} \tag{15}$$

The remaining conditions will be the same to calculate the optimal values of the weights $(w_1, w_2, w_3 \ldots w_n)$.

Step 5: Determine the consistency ratio

The consistency of the formed pairwise comparisons can be checked by evaluating $s_{bj} \times s_{jw} = s_{bw}$, which is, in fact, not possible, so we propose an inequality function $s_{bj} \times s_{jw} \neq s_{bw}$, where s_{bj} is the relative fuzzy preference of the best criterion over j, s_{jw} is the relative fuzzy preference of the other criterion over the worst, and s_{bw} is the relative fuzzy preference of the best criterion over the worst. Moreover, there is a possibility for criterion j not to be completely reliable. Therefore, this step calculates the consistency ratio to check the degree of accurateness of formed pairwise comparisons.

To validate it, the fuzzy reference consistency ratio (CR) is calculated with the help of the below equation:

$$CR = \frac{\xi}{CI}. \tag{16}$$

where CI is the consistency index and defines as the "maximum possible inconsistency for any possible reference comparison input" (Ebrahimnejad and Amani, 2021).

The above inequality is converted into equality by introducing the ξ value, given in the equation below:

$$(s_{bj} - \xi) \times (s_{jw} - \xi) = (s_{bw} + \xi). \tag{17}$$

To maximize possible inconsistency value, we equate

$$s_{bj} = s_{jw} = s_{bw}.$$

Hence,

$$(s_{bw} - \xi) \times (s_{bw} - \xi) = (s_{bw} + \xi). \tag{18}$$

where the maximum likely fuzzy number "s_{bw}" is the same as the upper bounding value "u_{bw}" so, the above equation can be rewritten as follows:

$$(u_{bw} - \xi) \times (u_{bw} - \xi) = (u_{bw} + \xi). \tag{19}$$

After calculating the ξ value, the value of CI can be calculated for all linguistic variables. Lastly, fuzzy variables are again de-fuzzified to get weightage scores.

4. Results and discussion

This section presents the results obtained from the fuzzy best-worst method.

4.1 An empirical study to investigate challenging factors

Literature was reviewed to extract the prime indicators of a blockchain-based supply chain. To investigate the challenges in the real world, we conducted an online survey with blockchain practitioners and researchers and selected only those indicators that scored more than 50%. Finally, experts were invited for the final selection of indicators in the domain of blockchain-based supply chains. The survey link is given in the Appendix.

From Table 3, it is clear that most of the challenging factor's weights are greater than 2.5, which shows that most respondents agree to consider those as prime challenges for adopting the blockchain-based supply chain. CH8 "Lack of storage capacity/scalability" is observed as the most critical challenging factor in the empirical study having a value of 3.3. The result

Sr. No.	Challenging factors	Score
CH1	Challenge of information disclosure between partners in the supply chain	3.2
CH2	Interoperability challenges	3
CH3	Lack of new organizational policies for using technologies	2.55
CH4	Lack of knowledge/skills	2.85
CH5	Difficulty in changing organizational culture	2.65
CH6	Lack of management commitment	2.5
CH7	Latency challenges/confirmation delay	1.95
CH8	Lack of storage capacity/scalability	3.3
CH9	Lack of communication and coordination	2.5
CH10	Lack of governance/regulations	2.55
CH11	Lack of standardization	2.95
CH12	Cultural differences in supply chain partners	1.45
CH13	Lack of security	2.5
CH14	Access to technology/computer power	2.55
CH15	Cost/energy consumption/funding challenges	2.65
CH16	Lack of data privacy	2.7
CH17	Lack of immutability of technology	2.5
CH18	Lack of performance/throughput	3.2
CH19	Risk challenges	1.35
CH20	Lack of trust of external stakeholders	2.65

Source(s): Table by authors

Table 3. Scores of the challenging factors

further highlighted that CH18, “Lack of performance/throughput,” and CH1, “Challenge of information disclosure between partners in the supply chain,” is nominated as the second prime challenging factor having a score of 3.2. Similarly, CH2 “Interoperability challenges, 3”, CH11 “Lack of standardization, 2.95”, and CH4 “Lack of knowledge/skills, 2.85” are also ranked third, fourth, and fifth in survey results. CH19 “Risk challenges” got the lowest score of 1.35. Respondents might think there is no such risk related to adopting blockchain technology.

Best challenging factor (CH_b) = Lack of storage capacity/scalability.

Worst challenging factor (CH_w) = Risk challenges.

4.2 Fuzzy reference comparisons

Experts were involved in making reference comparisons based on the best and worst challenges. The questionnaire survey with complete detail related to the procedure was sent to the respondents through email. Experts ranked the challenges based on linguistic variables (defined in Table 2). Table 4 shows the aggregated values of the fuzzy reference comparison with CH8 (Lack of storage capacity/scalability) as the best challenging factor and CH19 (Risk challenges) as the worst challenging factor.

4.3 Final prioritization of challenging factors

This section illustrates the ranking of the prime factors that would make blockchain-based supply chains more challenging. Table 5 depicts the priority list of challenging factors. The triangular fuzzy weight values were initially obtained using LINGO 18.0 software. Later these fuzzy weight values were de-fuzzified using eq. (8) to get the crisp values to achieve the final ranking of challenging factors. The obtained ranking results will also help academic researchers and industrial practitioners to prioritize these factors while starting new projects (Kachouei *et al.,* 2020). According to the acquired results, CH8 (Lack of storage capacity/scalability) got the first ranking. CH16 (Lack of data privacy) came in second position with a

Challenges	"Best vs others" l_b	m_b	u_b	Challenges	"Others vs worst" l_w	m_w	u_w
CH1	1.5	1.685	2.5	CH1	2.5	3.265	4.5
CH2	0.667	1.46	2.5	CH2	1.5	2.98	4.5
CH3	1.5	2.697	4.5	CH3	0.667	1.542	3.5
CH4	1.5	1.675	2.5	CH4	2.5	2.68	4.5
CH5	1.5	2.475	4.5	CH5	1.5	2.663	3.5
CH6	2.5	2.854	4.5	CH6	0.667	1.587	4.5
CH7	1.5	3.652	4.5	CH7	0.667	1.398	4.5
CH8 (b)	1	1	1	CH8 (b)	3.5	4	4.5
CH9	0.667	2.694	3.5	CH9	2.5	3.65	4.5
CH10	1.5	1.764	2.5	CH10	3.5	3.68	4.5
CH11	1.5	2.857	3.5	CH11	2.5	3.89	4.5
CH12	3.5	4.245	4.5	CH12	0.667	1.65	3.5
CH13	0.667	1.537	2.5	CH13	3.5	4.12	4.5
CH14	1.5	2.354	3.5	CH14	2.5	3.685	4.5
CH15	1.5	1.613	2.5	CH15	3.5	3.87	4.5
CH16	0.667	1.758	2.5	CH16	3.5	3.675	4.5
CH17	1.5	2.435	3.5	CH17	1.5	1.97	4.5
CH18	0.667	1.675	3.5	CH18	1.5	2.64	4.5
CH19 (w)	3.5	4	4.5	CH19 (w)	1	1	1
CH20	1.5	1.768	2.5	CH20	1.5	3.16	4.5

Source(s): Table by authors

Table 4.
Aggregated reference comparison values

Sr. No.	Challenging factors	l_j	m_j	u_j	Crisp weight	Ranking
CH1	Challenge of information disclosure between partners in the supply chain	0.023	0.035	0.085	0.041	12
CH2	Interoperability challenges	0.045	0.055	0.096	0.060	7
CH3	Lack of new organizational policies for using technologies	0.016	0.023	0.042	0.025	15
CH4	Lack of knowledge/skills	0.04	0.04	0.097	0.050	9
CH5	Difficulty in changing organizational culture	0.015	0.018	0.038	0.021	17
CH6	Lack of management commitment	0.014	0.015	0.034	0.018	18
CH7	Latency challenges/confirmation delay	0.014	0.018	0.052	0.023	16
CH8	Lack of storage capacity/scalability	0.115	0.12	0.126	0.120	1
CH9	Lack of communication and coordination	0.024	0.028	0.031	0.028	14
CH10	Lack of governance/regulations	0.069	0.079	0.089	0.079	6
CH11	Lack of standardization	0.035	0.049	0.06	0.049	10
CH12	Cultural differences in supply chain partners	0.012	0.016	0.018	0.016	19
CH13	Lack of security	0.113	0.113	0.113	0.113	3
CH14	Access to technology/computer power	0.046	0.055	0.067	0.056	8
CH15	Cost/energy consumption/funding challenges	0.088	0.091	0.097	0.092	4
CH16	Lack of data privacy	0.111	0.114	0.139	0.118	2
CH17	Lack of immutability of technology	0.028	0.034	0.053	0.036	13
CH18	Lack of performance/throughput	0.069	0.079	0.13	0.086	5
CH19	Risk challenges	0.011	0.013	0.019	0.014	20
CH20	Lack of trust of external stakeholders	0.031	0.043	0.068	0.045	11

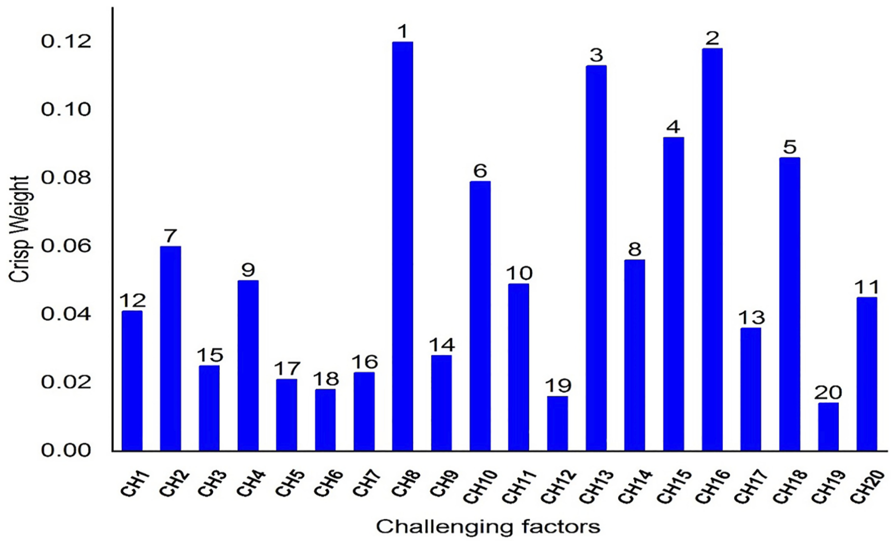
Source(s): Table by authors

Table 5.
Prioritization of challenging factors

weightage of 0.118. Whereas CH13 (Lack of security), CH15 (Cost/energy consumption/ funding challenges), and CH18 (Lack of performance/throughput) ranked third, fourth, and fifth in challenging factors. Figure 4 shows the ranking and crisp weight values of challenging factors.

The consistency ratio was calculated using the consistency index (CI) value of 8.04 from Table 6 (Bagheri *et al.*, 2020). The consistency ratio value is found to be 0.087 $<$ 0.1. As our value is less than the threshold value, this shows that our results are accurate and ready for discussion.

CH8 (Lack of storage capacity/scalability, 0.12) was considered a prime challenge for adopting a blockchain-based supply chain, as a large amount of data is required for processing and transaction purposes. When it comes to scaling and managing a high volume of transactions, blockchain technology is still in its infancy and is widely regarded as unreliable (Yli-Huumo *et al.*, 2016). Bitcoin's "bloat" problem, caused by the network's ever-increasing block size and number, poses a storage challenge for the real-time processing of massive amounts of data (Liu *et al.*, 2022). Supply chain networks involve a large amount of financial data related to different processes and practices. As a result, there is a need for developments in the infrastructure of storage management and cloud computing. Meanwhile, because of the limited size of the blocks, many minor transactions may be held up because minor transactions favor those with a higher transaction fee. Too large block sizes also decrease the speed of tractions. Hence, this will affect the performance of a public blockchain



Source(s): Figure by authors

Figure 4. Ranking and crisp weight values of challenging factors

Linguistic terms	EI	LI	SI	VI	AI
s_{bw}	(1, 1, 1)	(0.667, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
CI	3	3.80	5.29	6.69	8.04

Source(s): Kumar *et al.* (2021)

Table 6. Consistency index for F-BWM

for the supply chain and make it impractical for widespread use, making it one of the main challenges for blockchain implementation (Koteska *et al.*, 2017).

CH16 (Lack of data privacy, 0.118) was presented as a second key obstacle in implementing a blockchain-based supply chain. The participants who belong to the blockchain network can check all the information on a blockchain, leading to a data privacy issue (Kosba *et al.*, 2016). CH13 (Lack of security) was also labeled as a challenge having a value of 0.113. Mougayar (2016) mentioned that data security is also a big issue when adopting blockchain technology. In the Bitcoin network, this arises because of hackers and 51% attack (Lim *et al.*, 2014). CH15 (Cost/energy consumption/funding challenges, 0.092) was presented as a key obstacle in implementing a blockchain-based supply chain. Yli-Huumo *et al.* (2016) stated that during transactions, when blockchain becomes more complicated, it requires more computer power to verify these blocks. A large amount of electricity is consumed in the "mining process" and in "peer-to-peer" communication, which results in extra cost/energy. Implementing the SSCM strategy requires the development of supply chain infrastructure, systems and processes, which may increase the costs of operations.

Moreover, blockchain-based supply chain projects can be expensive to implement, and securing funding can be challenging, especially for small and medium-sized businesses. Companies mostly fail to implement blockchain-based supply chain practices because of budgetary constraints or high infrastructure costs (Hader *et al.*, 2022). According to research findings of Wang *et al.* (2022) on procurement procedures in the UK public sector, a lack of funds is one of the biggest obstacles to environmentally friendly purchasing. Because of the low initial investment, consumers are more likely to buy low-quality and environmentally unfriendly products.

CH18 (Lack of performance/throughput, 0.086) was also described as a challenge (Almutairi *et al.*, 2022). Throughput issues define the volume of transactions. Bitcoin net processes three to twenty transactions per second and a theoretical current maximum of seven transactions. When the number of blockchain transactions per second approaches the level mentioned above, the network's throughput will require enhancement; otherwise, this will be a challenge for supply chain partners.

CH10 (Lack of governance/regulations) was also nominated as a hurdle in primary studies, having a crisp weight of 0.079. Lucena *et al.* (2018) highlighted that lack of governance as its "legal values" is also a challenge for using blockchain technology. Adoption of blockchain technology means achieving sustainability and advanced technology-supporting mechanisms. However, the lack of appropriate policy and industry willingness to direct and support safe practices is also one of the main obstacles to adopting blockchain technology (Mangla *et al.*, 2022). There is a lack of clarity in governmental regulations and laws about using blockchain technology. Several governments' unfriendly policies regarding Bitcoin cause concern for markets and organizations because it dramatically impacts the widespread adoption of blockchain technology in the business sector (Mougayar, 2016).

CH14 (Access to technology/computer power) got a value of 0.056. Almutairi *et al.* (2022) stated that adopting blockchain is also challenging for supply chain participants. Limited access to communication technology lengthens the time it takes for manufacturers to contact retailers. To improve communication, these producers will often need additional people in a central location with access to technology. The data collection process may also benefit from technological capabilities. Yet, a lack of technical skills and access to technology presents a significant barrier at that point in the supply chain.

New information technology tools are required to implement blockchain technology and collect data for supply chain management (such as the Internet of things). However, Hader *et al.* (2022) pointed out that this can be difficult for some businesses in the supply chain. To maximize the cost savings potential of an integrated supply chain, all participants in the chain must have access to the relevant data (Ali and Shoaib, 2023). Therefore, the implementation of blockchain technology is hindered by the lack of accessible technology needed to obtain real-time data in a supply chain.

CH7 (Latency challenges/confirmation delay) acquired a weightage of 0.023. Latency is related to the time needed to add data to the blockchain and is one of the critical challenges for adopting blockchain technology (Koteska *et al.*, 2017). It takes more time on a block to achieve security efficiency because it has to outweigh the cost of double-spending attacks. When money is spent more than once without any problems, this is known as double spending (Liu *et al.*, 2022). Every Bitcoin transaction added to the blockchain is checked to ensure the amount used has not been spent twice (Omar *et al.*, 2022). Because of this, latency is currently a significant problem in the blockchain. Bitcoin transaction blocks take 10 min to complete one transaction, whereas the processing time for VISA is only one second (Yli-Huumo *et al.*, 2016).

CH1 (Challenge of information disclosure between partners in the supply chain, 0.041) is also considered an obstacle to adopting a blockchain-based supply chain. Blockchain technology provides help in sharing information. When applied to a supply chain, blockchain technology could improve the flow of information between all parties. It is essential to have transparent and verifiable information to achieve sustainable performance (Yousefi and Tosarkani, 2022). However, some businesses may view their information as a source of competitive advantage and be hesitant to disclose it (Jiang *et al.*, 2022), while some partners' unwillingness to share information could prevent them from reaping the full benefits of adopting blockchain technology and prevent its effective implementation.

Immutability in blockchain arises while making the data entry to blockchain reverse by removing mistakes (Bloomberg, 2018). Risk challenges occur with the loss or damage of the node's private key or when a user cannot use the block (Li *et al.*, 2021). The interoperability issue creates a hurdle in adopting blockchain technology in which one user from one blockchain can get complete information while the other user from another blockchain has a slight excess (Deichler, 2017). This issue is mainly because of "orphaned forks" within two blockchains (Schatsky *et al.*, 2018). CH17 (Lack of immutability of technology, 0.036), CH19 (Risk challenges, 0.014), and CH2 (Interoperability challenge, 0.06) are also a challenge for the issues described above.

CH3 (Lack of new organizational policies for using technologies, 0.025), CH5 (Difficulty in changing organizational culture, 0.021), and CH6 (Lack of management commitment, 0.018) were also considered to be key challenges within an organization. As far as new technology is concerned, the lack of organizational policy is also a barrier. Implementing successful blockchain technology would be challenging because of the lack of new organizational policies (Saberi *et al.*, 2019). Organizations want to make their supply chain network more sustainable by implementing new technologies according to their goals (Ali *et al.*, 2022), but it is often hampered by employees' emotional and behavioral problems (Mangla *et al.*, 2022). In addition, CH9 (Lack of communication and coordination, 0.028) and CH12 (Cultural differences in supply chain partners, 0.016) were also mentioned as obstacles within the supply chain partners. Managers may encounter resistance due to negative perceptions, hesitation about adopting new things, and difficulties adjusting to new company culture.

4.4 Comparative analysis

This section compares the proposed method outcomes with other MCDM methods to ensure the reliability of the final results. In this regard, the final ranking results from the F-BWM are compared with other popular methods like the F-AHP and F-ANP. The outcomes of the comparison are depicted in Figure 5. Interestingly, our proposed methodology yields consistent rankings for the most challenging factors across all MCDM methods. For example, the challenging factors, CH8 and CH16, are still ranked as first and second in all the methods.

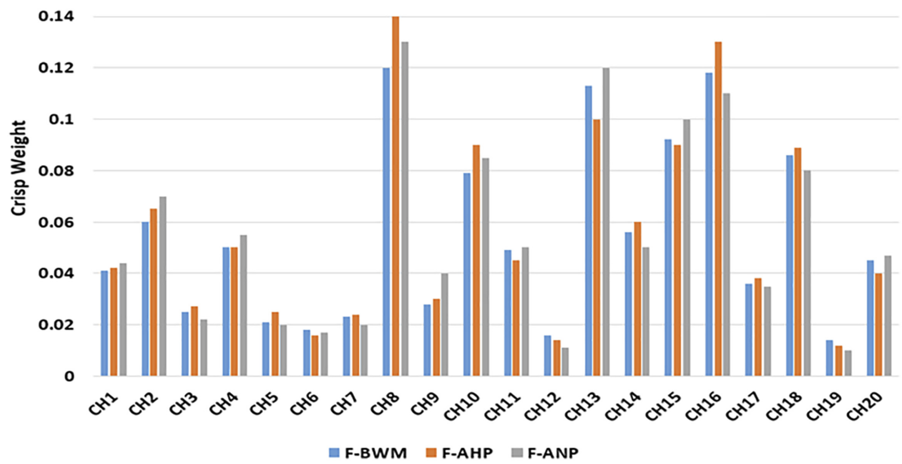


Figure 5. Comparison of different MCDM techniques

Source(s): Figure by authors

However, the proposed F-BWM produces a more consistent final solution as it utilizes lesser pairwise comparisons than the F-AHP and F-ANP methods. Using lesser pairwise comparisons lessens the confusion of experts during decision-making, which boosts their confidence and directly leads to a more consistent final solution. Due to this fact, we can conclude that the proposed method produces more precise results than the F-AHP and F-ANP methods.

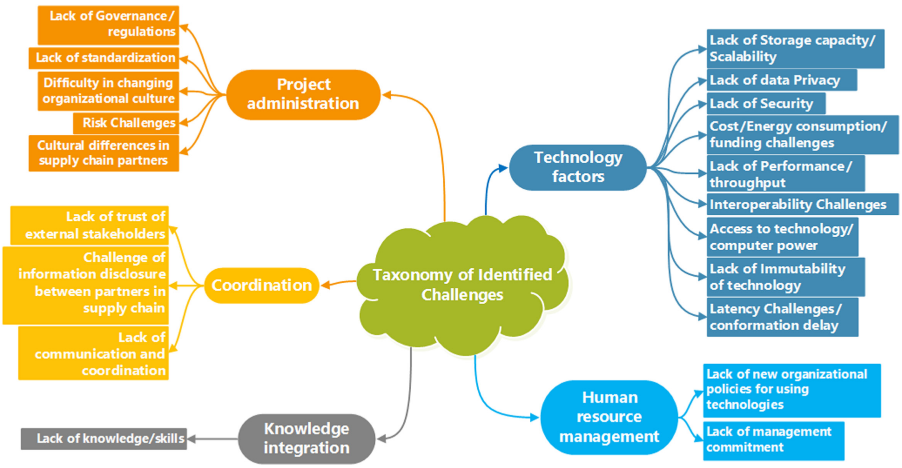
4.5 Robust framework

Challenging factors were further mapped into five categories (i.e., "project administration," "coordination," "human resource management," "knowledge integration," and "technology factor"). All authors categorized the challenges based on their experience and understanding. The "Technology factor" category is considered a prime category among others. We believe that a given framework of challenges will provide a better understanding of blockchain-based supply chain activities. Furthermore, categorizing factors will also assist researchers and industrial practitioners in deliberating the suitable category for using blockchain technology. The taxonomy of challenging factors is given below in Figure 6.

This study provides a framework for a blockchain-based supply chain that shows the key categories. These factors will assist a body of knowledge for researchers and industrial practitioners working in that domain. It will also help the project management team focus on the most significant categories based on obstacles they face while adopting the blockchain-based supply chain.

5. Managerial and technical implications

In this paper, we tried to develop a model to understand the adoption of a blockchain-based supply chain. This model will help research scholars and industrial practitioners better understand their projects and provide a guideline for future work. Blockchain provides many implications in technology, management, knowledge integration, coordination, and project administration. Compared with RFID, blockchain offers the best solution for tracing and tracking. In quality management, blockchain improves standards and increases the speed of operations in a supply chain network. It also provides transparency of documentation for



Source(s): Figure by authors

Figure 6.
Classification of the identified challenges into categories

inventory management. This saves not only both parties' time but also transaction and labor costs.

Furthermore, it provides sustainability (social, economic, and environmental) within a supply chain network. For small networks, blockchain motivates manufacturers to deliver their products wherever they want without any complexity and provides customers with authentication of products' origin. Now, managers have to check whether their organization needs blockchain and, if it does, how they will get maximum competitive advantage from this.

6. Conclusion

The growing number of supply chain activities motivates us to investigate the factors that could negatively impact implementing the blockchain-based supply chain. F-BWM was applied to prioritize the total of 20 challenges that were identified using a comprehensive literature review. An empirical study was conducted to validate challenges in the real world. "Lack of storage capacity/scalability" and "Lack of data privacy" were found to be the prime challenges. Finally, the identified challenges' weight values were also compared with others MCDM approaches to check the validity of the final results produced by the F-BWM. The outcomes of the comparative analysis show that the proposed method produces accurate results. We believe that the anticipated challenging factors and their categories will help academic scholars and industrial practitioners to focus on these areas while adopting the blockchain-based supply chain.

In the future, we will try to identify some more challenges and their categories. Furthermore, a case study will be planned to validate the framework of identified challenges. In conclusion, we believe this study provides better positive support to investigate and resolve problems related to adopting a blockchain-based supply chain.

References

Abeyratne, S.A. and Monfared, R.P. (2016), "Blockchain ready manufacturing supply chain using distributed ledger", *International Journal of Research in Engineering Technology*, Vol. 5 No. 9, pp. 1-10.

Ali, H. and Shoaib, M. (2023), "A comprehensive literature review on green supply chain management: recent advances and potential research directions", *International Journal of Supply and Operations Management*, Vol. 10 No. 1, pp. 57-75.

Ali, H., Zhang, J., Liu, S. and Shoaib, M. (2022), "An integrated decision-making approach for global supplier selection and order allocation to create an environment-friendly supply chain", *Kybernetes*, doi: 10.1108/K-10-2021-1046.

Almutairi, K., Hosseini Dehshiri, S.J., Hosseini Dehshiri, S.S., Hoa, A.X., Arockia Dhanraj, J., Mostafaeipour, A. and Techato, K. (2022), "Blockchain technology application challenges in renewable energy supply chain management", *Environmental Science and Pollution Research*. doi: 10.1007/s11356-021-18311-7.

Bagheri, M., Ebrahimnejad, A., Razavyan, S., Lotfi, F.H. and Malekmohammadi, N. (2020), "Solving the fully fuzzy multi-objective transportation problem based on the common set of weights in DEA", *Journal of Intelligent and Fuzzy Systems*, Vol. 39 No. 3, pp. 3099-3124.

Bagheri, M., Ebrahimnejad, A., Razavyan, S., Lotfi, F.H. and Malekmohammadi, N. (2021), "Solving fuzzy multi-objective shortest path problem based on data envelopment analysis approach", *Complex and Intelligent Systems*, Vol. 7, pp. 725-740.

Bagheri, M., Ebrahimnejad, A., Razavyan, S., Lotfi, F.H. and Malekmohammadi, N. (2022), "Fuzzy arithmetic DEA approach for fuzzy multi-objective transportation problem", *Operational Research*, Vol. 22, pp. 1479-1509, doi: 10.1007/s12351-020-00592-4.

Bloomberg, J. (2018), "Eight reasons to be skeptical about blockchain", available at: https://www.forbes.com/sites/jasonbloomberg//05/31/eight-reasonsto-be-skeptical-about-blockchain

Boutkhoum, O., Hanine, M., Nabil, M., El-Barakaz, F., Lee, E., Rustam, F. and Ashraf, I. (2021), "Analysis and evaluation of barriers influencing blockchain implementation in Moroccan sustainable supply chain management: an integrated IFAHP-DEMATEL framework", *Mathematics*, Vol. 9 No. 14, p. 1601.

Cao, B., Li, Y., Zhang, L., Zhang, L., Mumtaz, S., Zhou, Z. and Peng, M. (2019), "When Internet of Things meets blockchain: challenges in distributed consensus", *IEEE Network*, Vol. 33 No. 6, pp. 133-139.

Centre of Disease Control (2017), "Centre of disease control and prevention", available at: https://www.cdc.gov/outbreaks/

Chang, V., Baudier, P., Zhang, H., Xu, Q., Zhang, J. and Arami, M. (2020), "How blockchain can impact financial services–the overview, challenges and recommendations from expert interviewees", *Technological Forecasting and Social Change*, Vol. 158, 120166.

Deichler, A. (2017), "Interoperability: the holy grail of blockchain", Association for Financial Professionals. Blog, available at: https://www.afponline.org/ideas-inspiration/topics/articles/Details/interoperability-the-holy-grail-of-blockchain

Delmolino, K., Arnett, M., Kosba, A., Miller, A. and Shi, E. (2016), "Step by step towards creating a safe smart contract: lessons and insights from a cryptocurrency lab", *Financial Cryptography and Data Security*, Vol. 9604, pp. 79-94.

Ebrahimnejad, A. and Amani, N. (2021), "Fuzzy data envelopment analysis in the presence of undesirable outputs with ideal points", *Complex and Intelligent Systems*, Vol. 7 No. 1, pp. 379-400.

Food and Drug Administration (2019), "Food and drug administration", available at: https://www.fda.gov/

Govindan, K. (2022), "Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: a circular manufacturing perspective", *Business Strategy and the Environment*, Vol. 31 No. 8, pp. 3769-3785, doi: 10.1002/bse.3031.

Guo, S. and Zhao, H. (2017), "Fuzzy best-worst multi-criteria decision-making method and its applications", *Knowledge-Based Systems*, Vol. 121, pp. 23-31.

Hader, M., Tchoffa, D., El Mhamedi, A., Ghodous, P., Dolgui, A. and Abouabdellah, A. (2022), "Applying integrated Blockchain and Big Data technologies to improve supply chain traceability and information sharing in the textile sector", *Journal of Industrial Information Integration*, Vol. 28, 100345.

Ismail, L., Materwala, H. and Hennebelle, A. (2021), "A scoping review of integrated Blockchain-Cloud (BcC) architecture for healthcare: applications, challenges and solutions", *Sensors*, Vol. 21 No. 11, p. 3753.

Jiang, R., Kang, Y., Liu, Y., Liang, Z., Duan, Y., Sun, Y. and Liu, J. (2022), "A trust transitivity model of small and medium-sized manufacturing enterprises under blockchain-based supply chain finance", *International Journal of Production Economics*, Vol. 247, 108469.

Kachouei, M., Ebrahimnejad, A. and Bagherzadeh-Valami, H. (2020), "A common-weights approach for efficiency evaluation in fuzzy data envelopment analysis with undesirable outputs: application in banking industry", *Journal of Intelligent and Fuzzy Systems*, Vol. 39 No. 5, pp. 7705-7722.

Karuppiah, K., Sankaranarayanan, B. and Ali, S.M. (2023), "A decision-aid model for evaluating challenges to blockchain adoption in supply chains", *International Journal of Logistics Research and Applications*, Vol. 26 No. 3, pp. 257-278, doi: 10.1080/13675567.2021.1947999.

Kosba, A., Miller, A., Shi, E., Wen, Z. and Papamanthou, C. (2016), "Hawk: the blockchain model of cryptography and privacy-preserving smart contracts", *2016 IEEE Symposium on Security and Privacy (SP)*, San Jose, CA, USA, IEEE. doi: 10.1109/SP.2016.55.

Koteska, B., Karafiloski, E. and Mishev, A. (2017), "Blockchain implementation quality challenges: a literature", *6th Workshop of Software Quality, Analysis, Monitoring, Improvement, and Applications, Belgrade, Serbia*, Vol. 1938, p. 8.

Kowitt, B. (2015), "Health food contamination", available at: https://fortune.com/2015/09/25/food-industry-contamination/

Kumar, A., Mangla, S.K., Kumar, P. and Song, M. (2021), "Mitigate risks in perishable food supply chains: learning from COVID-19", *Technological Forecasting and Social Change*, Vol. 166, 120643.

Li, H., Xiao, F., Yin, L. and Wu, F. (2021), "Application of blockchain technology in energy trading: a review", *Frontiers in Energy Research*, Vol. 9, 671133.

Lim, I.-K., Kim, Y.-H., Lee, J.-G., Lee, J.-P., Nam-Gung, H. and Lee, J.-K. (2014), "The analysis and counter measures on security breach of bitcoin", *Computational Science and Its Applications*, Vol. 8582, pp. 720-732.

Liu, P., Hendalianpour, A., Hamzehlou, M., Feylizadeh, M.R. and Razmi, J. (2021), "Identify and rank the challenges of implementing sustainable supply chain blockchain technology using the bayesian best worst method", *Technological and Economic Development of Economy*, Vol. 27 No. 3, pp. 656-680.

Liu, Y., Zhou, Z., Yang, Y. and Ma, Y. (2022), "Verifying the smart contracts of the port supply chain system based on probabilistic model checking", *Systems*, Vol. 10 No. 1, p. 19.

Lucena, P., Binotto, A.P.D., Momo, F.D.S. and Kim, H. (2018), "A case study for grain quality assurance tracking based on a blockchain business network", *Proceedings of the Symposium on Foundations and Applications of Blockchain (FAB 18)*, March 9, 2018, Los Angeles, California, USA, doi: 10.48550/arXiv.1803.07877.

Mackey, T.K. and Liang, B.A. (2011), "The global counterfeit drug trade: patient safety and public health risks", *Journal of Pharmaceutical Sciences*, Vol. 100 No. 11, pp. 4571-4579.

Mackey, T.K. and Nayyar, G. (2017), "A review of existing and emerging digital technologies to combat the global trade in fake medicines", *Expert Opinion on Drug Safety*, Vol. 16, pp. 587-602.

Mangla, S.K., Kazançoğlu, Y., Yıldızbaşı, A., Öztürk, C. and Çalık, A. (2022), "A conceptual framework for blockchain-based sustainable supply chain and evaluating implementation barriers: a case of the tea supply chain", *Business Strategy and the Environment*, Vol. 31 No. 8, pp. 3693-3716, doi: 10.1002/bse.3027.

Mendling, J., Weber, I., Aalst, W.V.D., Brocke, J.V., Cabanillas, C., Daniel, F., Debois, S., Ciccio, C.D., Dumas, M., Dustdar, S. and Gal, A. (2018), "Blockchains for business process management-challenges and opportunities", *ACM Transactions on Management Information Systems (TMIS)*, Vol. 9 No. 1, pp. 1-16.

Mougayar, W. (2016), "The business blockchain: promise, practice, and application of the next internet technology", available at: https://publicism.info/business/blockchain/index.html

Nakamoto, S. (2008), "Bitcoin: a peer-to-peer electronic cash system", available at: http://bitcoin.org/bitcoin.pdf

Omar, I.A., Debe, M., Jayaraman, R., Salah, K., Omar, M. and Arshad, J. (2022), "Blockchain-based supply chain traceability for COVID-19 personal protective equipment", *Computers and Industrial Engineering*, Vol. 167, 107995.

Panghal, A., Manoram, S., Mor, R.S. and Vern, P. (2023), "Adoption challenges of blockchain technology for reverse logistics in the food processing industry", *Supply Chain Forum: An International Journal*, Vol. 24 No. 1, pp. 7-16, doi: 10.1080/16258312.2022.2090852.

Queiroz, M.M. and Wamba, S.F. (2019), "Blockchain adoption challenges in supply chain: an empirical investigation of the main drivers in India and the USA", *International Journal of Information Management*, Vol. 46, pp. 70-82.

Qureshi, A. and Megías Jiménez, D. (2021), "Blockchain-based multimedia content protection: review and open challenges", *Applied Sciences*, Vol. 11 No. 1, p. 1.

Ratta, P., Kaur, A., Sharma, S., Shabaz, M. and Dhiman, G. (2021), "Application of blockchain and internet of things in healthcare and medical sector: applications, challenges, and future perspectives", *Journal of Food Quality*, Vol. 2021, 7608296.

Rejeb, A., Rejeb, K., Keogh, J.G. and Zailani, S. (2022), "Barriers to blockchain adoption in the circular economy: a fuzzy delphi and best-worst approach", *Sustainability*, Vol. 14 No. 6, p. 3611.

Rezaei, J. (2015), "Best-worst multi-criteria decision-making method", *Omega*, Vol. 53, pp. 49-57.

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L. (2019), "Blockchain technology and its relationships to sustainable supply chain management", *International Journal of Production Research*, Vol. 57, pp. 2117-2135.

Sahay, B.S. (2003), "Understanding trust in supply chain relationships", *Industrial Management and Data Systems*, Vol. 103 No. 8, pp. 553-563.

Schatsky, D., Arora, A. and Dongre, A. (2018), "Blockchain and the five vectors of progress", available at: https://www2.deloitte.com/insights/us/en/focus/signalsfor-strategists/value-of-blockchain-applications-interoperability.html

Schmidt, C.G. and Wagner, S.M. (2019), "Blockchain and supply chain relations: a transaction cost theory perspective", *Journal of Purchasing and Supply Management*, Vol. 25 No. 4, 100552.

Shoaib, M., Lim, M.K. and Wang, C. (2020), "An integrated framework to prioritize blockchain-based supply chain success factors", *Industrial Management and Data Systems*, Vol. 120 No. 11, pp. 2103-2131.

Shoaib, M., Zhang, S. and Ali, H. (2022), "Assessment of sustainable green logistics enablers: a robust framework using fuzzy DEMATEL and ISM approach", *International Journal of Environmental Science and Technology*. doi: 10.1007/s13762-022-04709-4.

Shoaib, M., Zhang, S. and Ali, H. (2023), "A bibliometric study on blockchain-based supply chain: a theme analysis, adopted methodologies, and future research agenda", *Environmental Science and Pollution Research*, Vol. 30, pp. 14029-14049, doi: 10.1007/s11356-022-24844-2.

Steiu, M.-F. (2020), "Blockchain in education: opportunities, applications, and challenges", *First Monday*, Vol. 25 No. 9, p. 10654, doi: 10.5210/fm.v25i9.10654.

Tian, F. (2017), "A supply chain traceability system for food safety based on HACCP, blockchain and internet of things", *2017 International conference on service systems and service management*, Dalian, China, IEEE. doi: 10.1109/ICSSSM.2017.7996119.

United Nations (2016), "United Nations guidelines for consumer protection", available at: https://digitallibrary.un.org/record/3929030?ln=en

Viriyasitavat, W., Anuphaptrirong, T. and Hoonsopon, D. (2019), "When blockchain meets internet of things: characteristics, challenges, and business opportunities", *Journal of Industrial Information Integration*, Vol. 15, pp. 21-28.

Wang, L., Luo, X.R., Lee, F. and Benitez, J. (2022), "Value creation in blockchain-driven supply chain finance", *Information and Management*, Vol. 59 No. 7, 103510.

WHO (2015), "Who estimates of the global burden of foodborne diseases?", available at: https://apps.who.int/iris/handle/10665/199350

WHO (2018), "Antimicrobial resistance and primary health care", available at: https://apps.who.int/iris/h&le/10665/326454

Yaqoob, I., Salah, K., Jayaraman, R. and Al-Hammadi, Y. (2022), "Blockchain for healthcare data management: opportunities, challenges, and future recommendations", *Neural Computing and Applications*, Vol. 34, pp. 11475-11490, doi: 10.1007/s00521-020-05519-w.

Yildizbasi, A. (2021), "Blockchain and renewable energy: integration challenges in circular economy era", *Renewable Energy*, Vol. 176, pp. 183-197.

Yli-Huumo, J., Ko, D., Choi, S., Park, S. and Smolander, K. (2016), "Where is current research on blockchain technology? A systematic review", *PloS ONE*, Vol. 11 No. 10, 163477.

Yousefi, S. and Tosarkani, B.M. (2022), "An analytical approach for evaluating the impact of blockchain technology on sustainable supply chain performance", *International Journal of Production Economics*, Vol. 246, 108429.

Zhao, X., Liu, N., Zhao, S., Wu, J., Zhang, K. and Zhang, R. (2019), "Research on the work-rest scheduling in the manual order picking systems to consider human factors", *Journal of Systems Science and Systems Engineering*, Vol. 28 No. 3, pp. 344-355.

Zhou, Y., Soh, Y.S., Loh, H.S. and Yuen, K.F. (2020), "The key challenges and critical success factors of blockchain implementation: policy implications for Singapore's maritime industry", *Marine Policy*, Vol. 122, 104265.

Further reading

Dutta, P., Choi, T.M., Somani, S. and Butala, R. (2020), "Blockchain technology in supply chain operations: applications, challenges and research opportunities", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 142, 102067.

Ghoushchi, S.J., Yousefi, S. and Khazaeili, M. (2019), "An extended FMEA approach based on the Z-MOORA and fuzzy BWM for prioritization of failures", *Applied Soft Computing*, Vol. 81, 105505.

Kouhizadeh, M., Saberi, S. and Sarkis, J. (2021), "Blockchain technology and the sustainable supply chain: theoretically exploring adoption barriers", *International Journal of Production Economics*, Vol. 231, 107831.

Pelissari, R., Khan, S.A. and Ben-Amor, S. (2022), "Application of multi-criteria decision-making methods in sustainable manufacturing management: a systematic literature review and analysis of the prospects", *International Journal of Information Technology and Decision Making*, Vol. 21 No. 2, pp. 493-515.

Xu, X., Pautasso, C., Zhu, L., Gramoli, V., Ponomarev, A., Tran, A.B. and Chen, S. (2016), "The blockchain as a software connector", *2016 13th Working IEEE/IFIP Conference on Software Architecture (WICSA)*, Venice, Italy, pp. 182-191, IEEE.

(The Appendix follows overleaf)

Appendix

Primary survey link

(1) https://forms.gle/UChSMwGFq32ePomn7

Secondary survey link

(1) https://forms.gle/SSrgSBQFuTDvosHp7