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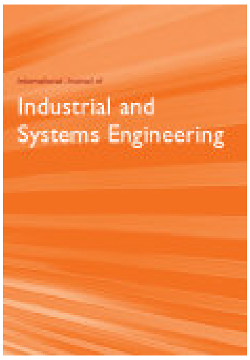

International Journal of Industrial and Systems Engineering

ISSN online: 1748-5045 - ISSN print: 1748-5037
https://www.inderscience.com/ijise

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DOI: 10.1504/IJISE.2021.10037223

Article History:

Received:	17 December 2020
Accepted:	26 February 2021
Published online:	20 January 2023

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Modelling of critical success factors for blockchain technology adoption readiness in the context of agri-food supply chain

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Abstract: The agri-food supply chain is continuously facing several challenges; the most severe are food quality and safety issues. These issues debilitate the performance of the supply chain and often harm the consumer's health. Therefore, there is an urgent need to address food quality and safety assurance in the supply chain. Blockchain technology (BCT) holds the potential to resolve these issues by enhancing security and transparency. The present study explores the critical success factors (CSFs) of BCT adoption readiness in the AFSC. Initially, CSFs are identified through a literature survey and finalised by experts' opinion. The finalised factors are prioritised using

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the fuzzy best-worst method, followed by sensitivity analysis. The results reflect that 'food quality control', 'provenance tracking and traceability', and 'partnership and trust' as the top three success factors. The study's findings will assist policymakers, managers, and practitioners in strategising the decision-making process while BCT dissemination.

Keywords: blockchain technology; agri-food supply chain; AFSC; fuzzy; best-worst method; BWM; trust.

Reference to this paper should be made as follows: Shardeo, V., Patil, A., Dwivedi, A. and Madaan, J. (2023) 'Modelling of critical success factors for blockchain technology adoption readiness in the context of agri-food supply chain', *Int. J. Industrial and Systems Engineering*, Vol. 43, No. 1, pp.80–102.

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1 Introduction

The global food supply chain has become more complex and interdependent because multiple stakeholders spread across the globe (Sage, 2013). With the increase in processed food consumption and enhanced consumer awareness for food quality and safety, consumers demand quality monitoring at every stage. This has pushed the agri-food supply chain (AFSC) to become more agile, transparent, efficient, secure and reliable (Aung and Chang, 2014; Monteiro et al., 2011; Tian, 2016). The AFSC comprises multiple stakeholders such as farmers, food processors, transporters, distributors, retailers, consumers, etc. This has generated employment, development, and gross domestic product for the country (Sabadin et al., 2020). A large number of workers are employed in performing a variety of tasks. In the context of the emerging economies, the proportion of workers engaged in AFSC is comparatively more and have a stark difference in their earning potential (Prajapati et al., 2020; Meena et al., 2019). The livelihood and prosperity of these workers depend on the proper and efficient functioning of AFSC. The AFSC struggles with numerous distinctive issues. Further, AFSC observes several counterfeit incidents causing a spillover effect on the economy (Bechtsis et al., 2019). Also, food loss along the supply chain is a challenging task. Food-borne disease is another global concern for AFSC, demanding the requirement to trace the product origin (Tse et al., 2017). The number of issues associated with AFSC engenders the need to adopt the potentially disruptive technologies as a potential solution. An effective tracing system can be seen as an effective solution to maintain the quality of agri-food products (Yadav et al., 2020). Also, it is evident that use of emerging information and communication technologies (ICTs) has created an opportunity to improve the organisational performance (Khan et al., 2020).

Recently, blockchain technology (BCT) has been reported to revolutionise the decision-making and several other aspects of the supply chain (Dolgui et al., 2020; Patil et al., 2020a). The BCT applications are implemented for the enhancement of trust, accountability, visibility, and traceability. In 2008, BCT emerged as a potential solution for eliminating the requirement for any third-party oversight on financial transactions (Seyedsayamdost and Vanderwal, 2020). BCT creates secure, immutable, decentralised and time-stamped ledgers that record transactions in the peer-to-peer network. The ledger exists as copies in the computer networks (Memon et al., 2019). In this ledger, data and information are captured in blocks. Several industries functional in varying domains have innovated applications adopting the ledger to resolve challenges. Some of the frequently used BCT applications in the supply chain domain utilise the feature of smart contracting.

Smart contracting can be defined as the blocks of a digitally stored and self-executable set of agreements among a group of stakeholders (Hofmann et al., 2018). Further, BCT is highly reliable and egalitarian technology (Seyedsayamdost and Vanderwal, 2020). Also, several benefits of BCT can be attributed to the open-source development of technology. BCT application comprises a wide range that includes scheduling, biometric identifications, governance, carbon pricing, cloud manufacturing, insurance claim process, etc. (Ivanov et al., 2018; Khaqqi et al., 2018; Li et al., 2018; Seyedsayamdost and Vanderwal, 2020).

Several studies are evident in the literature that endeavoured BCT adoption in organisations in the food supply chain domain. Köhler and Pizzol (2020) analysed the six case studies related to BCT application in AFSC. Similarly, Sander et al. (2018) evaluated the potential of a BCT-based transparency and traceability system. Walmart (2017) studied supply chain tracking and food traceability to enhance transparency and audibility. Also, Tse et al. (2017) discovered the application of BCT for information security in AFSC.

Despite several proposed BCT applications highlighted in the literature, a gap of scientific methodology driven study could develop the theoretical foundation for successful dissemination of BCT. Therefore, the present study objectives to identify the potential critical success factors (CSFs) of BCT adoption by utilising the multi-criteria decision-making (MCDM), fuzzy best-worst method (FBWM) approach. The present study contributes to the existing literature in two ways:

1 the study identifies potential CSFs of BCT adoption in AFSCs

2 the study models the identified CSFs and prioritise them in order of their influence.

The rest of this study is organised as follows. Section 2 describes the previous work and application of BCT in AFSC. Furthermore, Section 3 contains the research methodology. Section 4 discusses the results of the study. Section 6 will conclude the work.

2 Literature review

The literature review is performed to explore the application of BCT in various domains, including AFSCs. The case studies, book chapters, along Scopus indexed journals are considered for conducting the research survey. From a methodological point of view, several studies have adopted the MCDM methodology to identify and prioritise the factors (Gholami and Seyyed-Esfahani, 2019; Mor et al., 2020; Sharma et al., 2020; Yadav et al., 2020). Based on these studies, the present study adopted FBWM to identify and prioritise the successful adoption of BCT in AFSC. The description of the methodology has been explained in a later section. Presently, the literature survey is presented in two sub-sections, namely, BCT adoption in AFSCs and CSFs of BCT adoption in AFSCs.

2.1 BCT adoption in AFSCs

BCT can be analysed based on two different aspects. One aspect is the distributed ledger, and the other is trust among the stakeholders (Hastig and Sodhi, 2019). The adoption and implementation of BCT are gradual in the supply chain domain (Hastig and Sodhi, 2019).

However, many organisations came forward with the adoption of BCT to improve their supply chain. The BCT has the potential to cater to the complexities and issues associated with AFSCs. This has been reported as a lack of trust among the AFSC stakeholders (Kamble et al., 2020). The lack of transparency and security are the two most important reasons for trust issues among these stakeholders. The BCT implies a promising solution to cater to the AFSCs issues such as visibility, transparency of the products, transaction settlement time, food safety, security, traceability, etc. Several researchers operational in the domain of AFSCs have proposed BCT-based solutions to improve the supply chain's performance.

Tse et al. (2017) introduced the application of BCT in terms of information security in the food supply chain. The study results suggest that the promotion for the adoption of BCT in AFSCs is to ensure food safety by tracking, monitoring and auditing the food-related information. Tian (2016) studied the utilisation of BCT and radio frequency information device (RFID) technology to ensure food safety effectively. Also, the study reflected the advantages and disadvantages of RFID and BCT technology-enabled traceability systems for the AFSC. Caro et al. (2018) integrated the internet of things (IoT) with BCT to make a fully decentralised traceability system for AFSC. The study defined a case, namely from-farm-to-fork, to assess the developed traceability system. The BCT is found promising to employ transparency within the system and to gain trust among the stakeholders of AFSCs. The case study by Kamath (2018) highlighted the opportunities of BCT deployment in the food sector. The study explored the BCT deployment by Walmart with a farm-to-table approach for increasing transparency and food safety. Walmart's two successful BCT-based pilot studies: pork in China and Mangoes in the USA proved that BCT adoption could be a revolutionary solution to cater to the food supply chain issues by providing an end-to-end traceability system. Shahid et al. (2020) proposed a system where all transactions are written on BCT to ensure a secure, efficient and reliable solution to AFSCs. Simulations and evaluations of smart contracts, along with security analyses, are presented in the study. The BCT enabled proposed system promises to cater to AFSCs issues by ensuring traceability, trust and delivery mechanism in AFSCs. A study focusing on BCT implementation in the food sector enhances trust among sellers and buyers (Shahid et al., 2020). The study proposed a blockchain-based reputation system in AFSCs that logs the seller's reviews and maintains the trust among the stakeholders. More studies are evident in literature that focused on BCT implementation as a solution approach to cater to food supply chain issues (Antonucci et al., 2019; Galvez et al., 2018; Salah et al., 2019; Zhao et al., 2019). Apart from the literature, various organisations have introduced the adoption of BCT in their organisations to leverage its benefits. For instance, Ford motor company and IBM Company have launched the BCT-based platform to trace the cobalt supply chain (Wolfson, 2019). Also, Pfizer and several other leading pharmaceutical companies have joined the working group's project Medileder, which uses BCT to trace the supplies of drugs with its potential users (Donovan, 2019). Walmart is leading in BCT applications for tracing and tracking its products (Dimitrov, 2020). To maintain the quality with an efficient tracing and tracking system, IBM Food Trust is working on BCT applications for the food supply chain and Walmart. The project provides the traceability of the food products to its customer to ensure their origin can be ensured (Chapman, 2020).

Based on the performed literature survey, it can be concluded that BCT has vast potential to transform the existing AFSC by providing transparency that can result in improving the supply chain performance. However, the domain of research is still in its nascent stage in the field of AFSC management. Also, there are scarce studies related to BCT adoption in the food supply chain (Ben-Daya et al., 2019; Kayikci et al., 2020; Dwivedi et al., 2020).

2.2 CSFs of BCT adoption in AFSCs

The CSFs of BCT adoption in AFSCs are identified from the literature survey. These potential factors drive organisations to adopt the BCT for improving their supply chains. The identified CSFs of BCT adoption in AFSC are presented in Table 1. A brief discussion of the CSFs is presented below.

2.2.1 Information transparency (CSF1)

The blockchain network generates an identical copy of a network that allows real-time inspection of the information. The information about the operation is visible to all blockchain network nodes, which brings transparency to the system (Feng et al., 2020). Such transparency is a crucial requirement for the existing AFSC system. Therefore, it is considered a potential success factor for BCT adoption.

2.2.2 Immutability (CSF2)

Immutability can be defined as something that cannot be changed over time. The decentralised nature of BCT reduces the chance of data manipulation and makes the network immutable (Kamble et al., 2020).

2.2.3 Transaction speed (CSF3)

Transaction speed is the ability of the technology to speed up the transactions within the system. The recording and approving of the transactions affect the whole process. BCT promises to accelerate the transaction speed that will reduce the lead time (Feng et al., 2020).

2.2.4 Technological readiness (CSF4)

Despite advantageous features of BCT, it possesses some limitations too. The BCT has been criticised for the degradation of transaction recording speed relative to the number of nodes (Zheng et al., 2019). Due to some limitations, organisations need to analyse whether the promising technology is required to cater to the issues. This requires technological maturity to adopt such promising technology (Hastig and Sodhi, 2019).

2.2.5 Anonymity and privacy (CSF5)

The BCT keeps the transactions visible to all nodes, but at the same time, it keeps each node anonymous. The participant's anonymity is ensured due to the BCT's cryptographic private key (Kamble et al., 2020). This act provides the privacy of the participant, which is one of the most attracting parts of BCT.

2.2.6 Provenance tracking and traceability (CSF6)

Provenance tracking is required for most organisations to derive the value of the goods. A digital token within the BCT system could be used to accompany at each stage of value addition. This will ensure the proper tracking of goods at each stage while securing the information (Feng et al., 2020). Presently, the customers expect the live tracing of their products, and BCT offers such visibility, enhancing credibility (Shardeo et al., 2020b).

2.2.7 Agility and flexibility (CSF7)

The flexibility has enabled businesses to meet their customer expectations even during the disruptive environment. The advancements of ICTs have played an essential part in desiring flexibility for the firms (Shardeo et al., 2020a). The BCT and other technologies could provide firms with some degree of flexibility in a secured environment. Also, the adoption of BCT depends upon the culture of the organisation. The more flexible organisational culture will have more chances to adapt and vice-versa (Zīle and Strazdiņa, 2018). Thus, it qualifies as a CSF for BCT adoption in AFSCs.

2.2.8 Food quality control (CSF8)

The traceability system and immutability of BCT enable the food supply chain to maintain agri-food products' quality. A user can trace the processing conditions, including the mode of processing, equipment's used, etc. without the risk of information tampering (Feng et al., 2020). Such ability of BCT promises to provide better food quality control and enhances food safety.

2.2.9 Organisational readiness (CSF9)

The adoption of any technology leverages the existing resources and investment. Also, BCT is criticised due to scalability and power consumption (Hastig and Sodhi, 2019). Thus, organisational readiness is needed when an emerging technology such as BCT is supposed to be implemented. Therefore, organisational readiness can be seen as a CSF for BCT adoption.

2.2.10 Information security (CSF10)

Information security has always been a centre of discussion with respect to ICTs. The BCT can provide information security through its cryptographic nature (Hastig and Sodhi, 2019). Information security is a critical factor that can gain user trust and be treated as CSF for BCT adoption.

2.2.11 Partnership and trust (CSF11)

The decentralisation system of BCT ensures trust-building and removes the essence of measurement of trustworthiness among the members (Shardeo et al., 2020b). Also, the traceability system helps identify the no-tampering chain within the system, ensuring the evaluation capabilities (Feng et al., 2020). The tamper-proof system of BCT is promising to build trust among the business partners (Kamble et al., 2019).

2.2.12 System stability and scalability (CSF12)

The BCT holds the potential to integrate various stakeholders, irrespective of their size and scope. Thus, AFSC can efficiently utilise the BCT for integrating numerous stakeholders in a secure environment. Earlier, few concerns were explicitly raised to the stability of BCT. Despite criticism, BCT developers have improved their stability in recent years (Otte et al., 2020). Technology is now effectively utilised for recording transactions efficiently and securely in a scalable manner (Feng et al., 2020).

2.2.13 System and data reliability (CSF13)

In the present era of globalisation, the reliability of the data is must gain competitive advantages. The immutability and decentralised functionality of BCT ensure the reliability of the system and data. This can be a paradigm-changing solution for business firms (Feng et al., 2020).

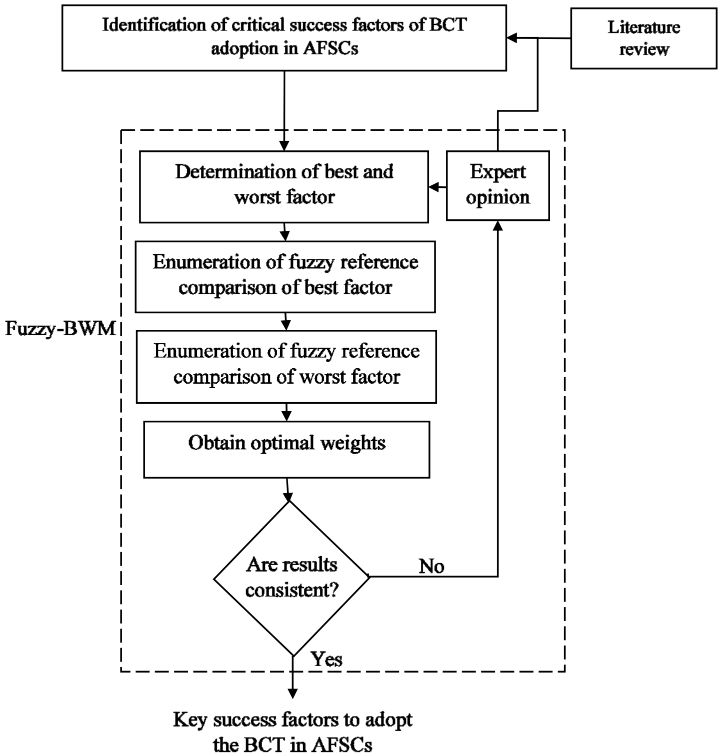
2.2.14 Technological feasibility (CSF14)

The BCT has advantages along with several limitations. It has been criticised due to its energy consumption, scalability issues, etc. Thus, the organisations are required to analyse whether they need BCT adoption or not. BCT adopters require assurance regarding the easy integration of BCT with the existing system. The developers must work on the integration aspects of BCT for successful dissemination (Hastig and Sodhi, 2019). This qualifies technological feasibility as a CSF for BCT adoption.

Table 1 Identified CSFs of BCT adoption in AFSC

Code	*Critical success factors*	*Source*
CSF1	Information transparency	Feng et al. (2020), Köhler and Pizzol (2020), Salah et al. (2019), Sander et al. (2018)
CSF2	Immutability	Kamble et al. (2020)
CSF3	Transaction speed	Feng et al. (2020)
CSF4	Technological readiness	Hastig and Sodhi (2019)
CSF5	Anonymity and privacy	Feng et al. (2020), Kamble et al. (2020)
CSF6	Provenance tracking and traceability	Feng et al. (2020), Kamble et al. (2020), Köhler and Pizzol (2020), Sander et al. (2018)
CSF7	Agility and flexibility	Zīle and Strazdiņa (2018)
CSF8	Food quality control	Feng et al. (2020)
CSF9	Organisational readiness	Hastig and Sodhi (2019)
CSF10	Information security	Feng et al. (2020), Hastig and Sodhi (2019)
CSF11	Partnership and trust	Hastig and Sodhi (2019), Köhler and Pizzol (2020), Sander et al. (2018)
CSF12	System stability and scalability	Feng et al. (2020), Otte et al. (2020)
CSF13	System and data reliability	Feng et al. (2020)
CSF14	Technological feasibility	Hastig and Sodhi (2019)

Figure 1 Research methodology



3 Methodology

This is evident from the literature survey that the BCT has enormous potential to drive agri-food businesses by providing several benefits. Before adopting such potential technologies, one needs to be aware of their requirements. Organisations need to assess the several factors that affect BCT adoption in their organisation. Therefore, this study's main objective is to identify and assess the CSFs of BCT adoption in AFSC. The literature survey is performed to explore the CSFs of BCT adoption. Further, the identified CSFs are refined through experts' discussions for relevance. Finally, a list of 14 CSFs is identified and presented in Table 1. The identified CSFs are analysed and prioritised, adopting an integrated FBWM. The integrated methodology adopted in this study is similar (Moktadir et al., 2020; Patil et al., 2020b; Shardeo et al., 2020b). The adopted methodology has its advantages over other similar MCDM methodologies. One of the advantages is the reduction of pairwise comparison. The BWM methodology demands less pairwise comparison than different similar methodologies such as analytic hierarchy process (AHP) or analytic network process (ANP). Also, the integration of fuzzy logic will help cater to the ambiguities or fuzziness in the decision makers' opinion (Dwivedi et al., 2019; Dwivedi and Madaan, 2020). Therefore, the integrated methodology of fuzzy-BWM has been preferred over other MCDM methodologies. In the present study, initially, 13 experts are elected to conduct the pilot study to better understand the questionnaire design. After refinement of the questionnaire, an online questionnaire survey is circulated among the nine experts functional in different domains. In this study, the number of considered experts fulfils the BWM approach's requirement to provide consistent results (Rezaei, 2016). The detailed description of the experts considered in this study is presented in Table 2. The aggregation of the input data obtained from the experts is conducted by taking geometric mean instead of the simple mean. The purpose of using geometric mean is its accuracy in consensus representation of the experts (Saaty, 2008). The brief details of the research methodology adopted for this study are highlighted in Figure 1.

3.1 Description of fuzzy – best-worst method (FBWM)

Rezaei (2015) introduced the best-worst method to provide flexibility while conducting the pairwise comparison. It is considered an improved version of the AHP. It demands small pairwise comparison and maintains higher consistency than AHP (Moktadir et al., 2019; Patil et al., 2020a). The decision makers are asked to choose the best and worst criterion and then rate the best criterion over other criteria and other criteria over the worst criterion. As it considers the human subjective perceptions, it ordinarily has a property of vagueness and ambiguities. Therefore, Guo and Zhao (2017) introduced fuzzy BWM to tackle the vagueness and ambiguity in human perceptions. The basic steps of FBWM are described below:

Step 1 *Definition of a set of decision criteria:* In this step, a set of decision criteria $\{c_1, c_2, \ldots\ldots..c_n\}$ is defined for decision-making.

Step 2 *Identification of best and the worst criterion:* Experts are asked to identify the best and worst criterion.

Step 3 *Enumerate fuzzy reference comparison for the best criterion:* The best criterion's fuzzy preferences over all other criteria are established adopting linguistic terms and a set of transformations as reflected in Table 3. The fuzzy best-to-others vector is presented as $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2} \ldots \tilde{a}_{Bn})$ where $\tilde{a}_{Bj}$ depicts the fuzzy preference of the best criterion B over criteria j, ($j = 1, 2, \ldots.n$). Note that $\tilde{a}_{BB} = (1, 1, 1)$.

Step 4 *Enumerate fuzzy reference comparison for the worst criteria:* The fuzzy preferences of other criteria over the worst criterion are established adopting linguistic terms and a set of transformations as reflected in Table 3. The fuzzy membership function is reflected in Figure 2. The fuzzy worst-to-others vector is presented as $\tilde{A}_w = (\tilde{a}_{1w}, \tilde{a}_{2w} \ldots \tilde{a}_{nw})$ where $\tilde{a}_n$ depicts the fuzzy preference of the criteria j, ($j = 1, 2, \ldots n$) over the worst criterion w. Note that $\tilde{a}_{ww} = (1, 1, 1)$.

Step 5 *Estimate the optimal weights of the criteria* $(\overline{w}_1, \overline{w}_2, \ldots \overline{w}_n)$: Considering the fuzzy preferences $\tilde{a}_{Bj}$ and $\tilde{a}_{jW}$, the intention is to estimate the optimal weights that minimise the absolute maximum difference of the $\{| \overline{w}_B / \overline{w}_j - \tilde{a}_{Bj} |$ and $| \overline{w}_j / \overline{w}_W - \tilde{a}_{jW} |\}$. If $\overline{w}_j, \overline{w}_W$ and $\overline{w}_B$ are considered as fuzzy triangular numbers, we employ $\overline{w}_j = (l_j^w, m_j^w, u_j^w)$ to demonstrate the fuzzy weight of criteria *j*. With the assumption that the sum of weights is equal to one with non-negative constraints, the optimal weights can be achieved by solving the FBWM model reflected below (Guo and Zhao, 2017):

$$\min \max j \left\{ \left| \overline{w}_B / \overline{w}_j - \tilde{a}_{Bj} \right|, \left| \overline{w}_j / \overline{w}_W - \tilde{a}_{jW} \right| \right\},$$

subjected to:

$$\sum_{j=1}^{n} R\left(\overline{w}_j\right) = 1, \tag{1}$$

$$l_j^w \le m^w \le u_j^w \ \textit{for all } j$$

$$l_j^w \ge 0, \ \textit{for all } j$$

Model (1) can be further written as presented below:

$$\text{Min } \tilde{\xi}$$

subjected to:

$$\left| \overline{w}_B / \overline{w}_j - \tilde{a}_{Bj} \right| \le \tilde{\xi}, \ \textit{for all } j$$

$$\left| \overline{w}_j / \overline{w}_W - \tilde{a}_{jW} \right| \le \tilde{\xi}, \ \textit{for all } j \tag{2}$$

$$\sum_{j=1}^{n} R\left(\overline{w}_j\right) = 1,$$

$$l_j^w \le m^w \le u_j^w \ \textit{for all } j$$

$$l_j^w \ge 0, \ \textit{for all } j$$

where $\tilde{\xi} = (l^{\xi}, m^{\xi}, u^{\xi})$. Considering ($l^{\xi} \le m^{\xi} \le u^{\xi}$) with the assumption $\tilde{\xi}^* = (k^*, k^*, k^*)$, $k^* \le l^{\xi}$ model (2) is modified as presented below:

$$\min \tilde{\xi}$$

subjected to:

$$\left| \frac{l_B^w, m_B^w, u_B^w}{l_j^w, m_j^w, u_j^w} - \left(l_{Bj}, m_{Bj}, u_{Bj}\right) \right| \le \left(k^*, k^*, k^*\right)$$

$$\left| \frac{l_j^w, m_j^w, u_j^w}{l_W^w, m_W^w, u_W^w} - \left(l_{jW}, m_{jW}, u_{jW}\right) \right| \le \left(k^*, k^*, k^*\right) \tag{3}$$

$$\sum_{j=1}^{n} R\left(\overline{w}_j\right) = 1$$

$$l_j^w \ge 0, m^w \le u_j^w \ \textit{for all } j$$

$$l_j^w \ge 0, \ \textit{for all } j$$

By solving model (3), optimal weights can be obtained. After that, the graded mean integration representation (GMIR) is adopted to transform the fuzzy weight of criteria into crisp weights. The formula of GMIR is presented below:

$$R\left(\tilde{a}_i\right) = \frac{l_i + 4m_i + u_i}{6} \tag{4}$$

The consistency ratio (CR) is calculated to verify the consistency of the fuzzy comparison. A full consistency is observed in fuzzy pairwise comparison vector $\tilde{a}_{Bj} \times \tilde{a}_{jW} = \tilde{a}_{BW}$. In case where pairwise comparison vector $\tilde{a}_{Bj} \times \tilde{a}_{jW} \neq \tilde{a}_{BW}$, shows the occurrence of inconsistency. Inconsistency will attain its maximum value $\tilde{\xi}$ when both $\tilde{a}_{Bj}$ and $\tilde{a}_{jW}$ are equal to $\tilde{a}_{BW}$. Considering the occurrence of the greatest inequality, according to the equality relation, $\overline{w}_B / \overline{w}_j \times \overline{w}_j / \overline{w}_W = \overline{w}_{\dot{B}} / \overline{w}_W$ equation (5) obtained as presented below (Guo and Zhao, 2017):

$$\left(\tilde{a}_{BW} - \tilde{\xi}\right) \times \left(\tilde{a}_{BW} - \tilde{\xi}\right) = \left(\tilde{a}_{BW} + \tilde{\xi}\right) \quad (5)$$

Equation (5) can be further written as presented below:

$$\tilde{\xi}^2 - \left(1 + 2\tilde{a}_{BW}\right)\tilde{\xi} + \left(\tilde{a}_{BW}^2 - \tilde{a}_{BW}\right) = 0 \quad (6)$$

where $\overline{\xi} = (l^{\xi}, m^{\xi}, u^{\xi})$ and $\overline{a}_{BW} = (l_{BW}, m_{Bw}, u_{Bw})$. For $\overline{a}_{BW} = (l_{BW}, m_{Bw}, u_{Bw})$, the maximum fuzzy value cannot exceed 9/2. The upper bound $\tilde{u}_{BW}$ is used in the calculation for consistency index (CI), all the data associated with fuzzy triangular numbers $\tilde{a}_{BW}$ can utilise this CI; meanwhile, ξ, is represented as a crisp value of $\tilde{\xi}$. Equation (7) is measured to calculate the CR for all $\tilde{u}_{BW}$.

$$\xi^2 - \left(1 + 2u_{BW}\right)\xi + \left(u^2 - u_{BW}\right) = 0 \quad (7)$$

where $\tilde{u}_{BW} = 1, 3/2, 5/2, 7/2$ and $9/2$ respectively. Table 3 presents the CI for FBWM.

Table 2 Experts' description considered for this study

Experts	*Area of expertise*	*Designation*	*Years of experience*
Expert 1	Transport and logistics	General Manager	19 years
Expert 2	Food technology	Senior Manager	11 years
Expert 3	Food technology	Deputy Manager	14 years
Expert 4	Food safety	Senior Executive	13 years
Expert 5	Information technology	Senior Executive	9 years
Expert 6	Information technology	Senior Executive	11 years
Expert 7	Agri-food supply chain	Senior Researcher	8 years
Expert 8	Food technology	Associate Professor	13 years
Expert 9	Supply chain and logistics	Professor	27 years

Table 3 Linguistics scale and corresponding CI values for fuzzy BWM

Linguistic terms	a_{BW}	*CI*
Just equal (JE)	(1, 1, 1)	3.00
Equally important (EI)	(1/2, 1, 3/2)	3.80
Moderately important (MI)	(1, 3/2, 2)	4.56
Strongly important (SI)	(3/2, 2, 5/2)	5.29
Very strongly important (VSI)	(2, 5/2, 3)	6.00
Extremely important (EXI)	(5/2, 3, 7/2)	6.69

4 Results and discussion

In this study, an integrated FBWM approach is employed to prioritise the CSFs of BCT adoption in AFSCs. The detail of the experts considered is presented in the methodology section. Initially, the experts were asked to identify the best and worst CSF shown in Table 4. Later, the experts were asked to perform comparisons between the best CSF and all other identified CSFs and between other CSFs and worst CSF, respectively, using the linguistics fuzzy scale presented in Table 3. For instance, the pairwise comparison of expert one is shown in Table 5 and Table 6. Similarly, the comparisons have been conducted for each expert.

Table 4 The best and worst CSFs identified by experts (1–9)

Critical success factors (CSFs)	*Code*	*Best CSF*	*Worst CSF*
Information transparency	CSF1		
Immutability	CSF2		2, 5, 7
Transaction speed	CSF3		
Technological readiness	CSF4	4	
Anonymity and privacy	CSF5		3, 6, 9
Provenance tracking and traceability	CSF6	5, 9	
Agility and flexibility	CSF7		1
Food quality control	CSF8	2, 3, 6, 7, 8	
Organisational readiness	CSF9	1	
Information security	CSF10		
Partnership trust	CSF11		
System stability and scalability	CSF12		8
System and data reliability	CSF13		
Technological feasibility	CSF14		4

Table 5 Pairwise comparison between best and others CSF for Expert 1

Critical success factors (CSFs)	*Linguistic scale*	*Corresponding fuzzy numbers*
CSF9: Best CSF	JE	(1, 1, 1)
CSF1	SI	(3/2, 2, 5/2)
CSF2	SI	(3/2, 2, 5/2)
CSF3	MI	(1, 3/2, 2)
CSF4	MI	(1, 3/2, 2)
CSF5	SI	(3/2, 2, 5/2)
CSF6	EI	(1/2, 1, 3/2)
CSF7	EXI	(5/2, 3, 7/2)
CSF8	EI	(1/2, 1, 3/2)
CSF10	MI	(1, 3/2, 2)
CSF11	SI	(3/2, 2, 5/2)
CSF12	SI	(3/2, 2, 5/2)
CSF13	SI	(3/2, 2, 5/2)
CSF14	VSI	(2, 5/2, 3)

Further, the collected data is modelled as a nonlinear programming (NLP) problem using equations (2) and (3) as highlighted in the methodology section. The optimal fuzzy weights were attained after solving the model. The LINGO software (18.0.56) with Intel Core i3 7100U CPU 2.40 GHz and 8 GB of RAM is utilised to solve the NLP model. Using GMIR, the crisp values of optimal fuzzy weights are calculated and then aggregated using the geometric mean. Further, the consistency check is performed as per the equations (5-7), and results are found to be consistent. The potential CSFs, along with their optimal weights, are presented in Table 7.

Table 6 Pairwise comparison between others and worst CSF for Expert 1

Critical success factors (CSFs)	*Linguistic scale*	*Corresponding fuzzy numbers*
CSF7: Worst CSF	JE	(1, 1, 1)
CSF1	SI	(3/2, 2, 5/2)
CSF2	MI	(1, 3/2, 2)
CSF3	SI	(3/2, 2, 5/2)
CSF4	SI	(3/2, 2, 5/2)
CSF5	EI	(1/2, 1, 3/2)
CSF6	SI	(3/2, 2, 5/2)
CSF8	SI	(3/2, 2, 5/2)
CSF9	EXI	(5/2, 3, 7/2)
CSF10	MI	(1, 3/2, 2)
CSF11	SI	(3/2, 2, 5/2)
CSF12	VSI	(2, 5/2, 3)
CSF13	SI	(3/2, 2, 5/2)
CSF14	EI	(1/2, 1, 3/2)

Table 7 Optimal weights of CSFs of BCT adoption in AFSC (see online version for colours)

Code	*Critical success factors*	*Weights*	*Weights in %*	*Rank*
CSF1	Information transparency	0.06746	7.98%	4
CSF2	Immutability	0.04267	5.05%	13
CSF3	Transaction speed	0.06184	7.31%	7
CSF4	Technological readiness	0.05061	5.98%	10
CSF5	Anonymity and privacy	0.03725	4.40%	14
CSF6	Provenance tracking and traceability	0.08070	9.54%	2
CSF7	Agility and flexibility	0.05405	6.39%	9
CSF8	Food quality control	0.09792	11.58%	1
CSF9	Organisational readiness	0.06405	7.57%	5
CSF10	Information security	0.06293	7.44%	6
CSF11	Partnership trust	0.07310	8.64%	3
CSF12	System stability and scalability	0.04554	5.38%	12
CSF13	System and data reliability	0.04740	5.60%	11
CSF14	Technological feasibility	0.06026	7.12%	8
	ksi value	0.55855		

Notes: The colour intensity represents the weights of the corresponding CSFs. Red to Green represents the weights in decreasing order respectively.

The FBWM exercise indicates that food quality control (CSF8) received the first rank, followed by provenance tracking and traceability (CSF6) and partnership trust (CSF11). These three CSFs account for 29.76% weightage out of the 14 potential CSFs. High influence is given to these three customer-centric CSFs, indicating that BCT developers need to focus on developing the customer-focused application. The nascent stage of BCT innovation is focused more on the software development process and feature development without considering the practical feasibility and consumers need. However, an integrated solution that can add value to the AFSC needs to be developed for successful and industry-wide adoption. Mainly, Information transparency (CSF1), organisation readiness (CSF9), information security (CSF10) and transaction speed (CSF3) are the CSFs that received the fourth, fifth, sixth and seventh rank. A key insight that can be derived from these results because AFSC decision makers need to focus on designing and implementing policies that can work towards operation improvement using BCT.

Several potential benefits of BCT adoption are suggested in the literature. This multitude of benefits sometimes results in confusion and uncertainty regarding the realised benefits of the technology. Without having the realisation of the benefits of BCT technology, effective implementation is impossible. At this stage, developers and AFSC stakeholders should understand the needs and requirements of each other. Since the technology is in the nascent stage, and this is the right time to address the complexities of BCT disseminations.

The results derived from this study reflect the key benefits required to be focused on the development and implementation of BCT in AFSC. The most influential CSF 'food quality control (CSF8)' is the permanent cause of concerns for the FSC stakeholders. In combination with the IoT, BCT holds the potential to revolutionise the food traceability system. As a result, it prevents the adultery of food and ensuring suitable stock-keeping conditions. Also, consumers in food supply chains are more concerned about ethical production methods (Francisco and Swanson, 2018). The satisfaction of these consumers requires a robust product provenance system. The BCT can enable the firms to facilitate the food provenance system (Kayikci et al., 2020). However, one of the experts highlighted the potential issue of tempering when the physical world and the digital world interact. Thus, researchers are required to develop more innovative solutions to make the system fail-safe. Partnership and trust appear to be one of the most pursued benefits of BCT in AFSC. This outcome is an extension to the study that validates that BCT is positively linked to trust and collaboration (Dubey et al., 2020). Information transparency appears to be in the fourth position, as highlighted in the performed analysis. India has varying policies across states and requires a comprehensive assessment before interventions (Bhatnagar and Bolia, 2019). Further, the stakeholders of AFSC have a stark economic difference. Several participants are involved in earning much less than their counterparts in other countries between producers to consumers. This is mainly attributed to corruptions and leakages. Information transparency, along with product tracking and traceability, can insure justified earning to each stakeholder.

The potential insights derived from the study indicate the contribution of BCT towards enhancing trust, agility, flexibility and transparency in AFSC. The BCT can help improve the performance of AFSC and further improve the health of the stakeholders involved. Considering the criticality of AFSC and ripple effects, suitable development and dissemination of BCT is a must. This study contributes to the theoretical foundation for BCT dissemination in the AFSC.

Table 8 Changes in weights of CSFs through sensitivity analysis

	Normal	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
	0.09792	0.02000	0.04000	0.06000	0.08000
CSF1	0.06746	0.07345	0.07191	0.07037	0.06883
CSF2	0.04267	0.04867	0.04713	0.04559	0.04405
CSF3	0.06184	0.06783	0.06629	0.06475	0.06321
CSF4	0.05061	0.05661	0.05507	0.05353	0.05199
CSF5	0.03725	0.04325	0.04171	0.04017	0.03863
CSF6	0.08070	0.08670	0.08516	0.08362	0.08208
CSF7	0.05405	0.06004	0.05850	0.05696	0.05543
CSF8	0.09792	0.02000	0.04000	0.06000	0.08000
CSF9	0.06405	0.07004	0.06850	0.06696	0.06542
CSF10	0.06293	0.06892	0.06738	0.06584	0.06430
CSF11	0.07310	0.07910	0.07756	0.07602	0.07448
CSF12	0.04554	0.05153	0.04999	0.04845	0.04691
CSF13	0.04740	0.05339	0.05185	0.05031	0.04877
CSF14	0.06026	0.06625	0.06471	0.06318	0.06164
	Scenario 5	*Scenario 6*	*Scenario 7*	*Scenario 8*	*Scenario 9*
	0.10000	0.12000	0.14000	0.16000	0.18000
CSF1	0.06730	0.06576	0.06422	0.06268	0.06114
CSF2	0.04251	0.04098	0.03944	0.03790	0.03636
CSF3	0.06168	0.06014	0.05860	0.05706	0.05552
CSF4	0.05045	0.04891	0.04738	0.04584	0.04430
CSF5	0.03709	0.03556	0.03402	0.03248	0.03094
CSF6	0.08054	0.07901	0.07747	0.07593	0.07439
CSF7	0.05389	0.05235	0.05081	0.04927	0.04773
CSF8	0.10000	0.12000	0.14000	0.16000	0.18000
CSF9	0.06389	0.06235	0.06081	0.05927	0.05773
CSF10	0.06277	0.06123	0.05969	0.05815	0.05661
CSF11	0.07294	0.07140	0.06987	0.06833	0.06679
CSF12	0.04538	0.04384	0.04230	0.04076	0.03922
CSF13	0.04724	0.04570	0.04416	0.04262	0.04108
CSF14	0.06010	0.05856	0.05702	0.05548	0.05394

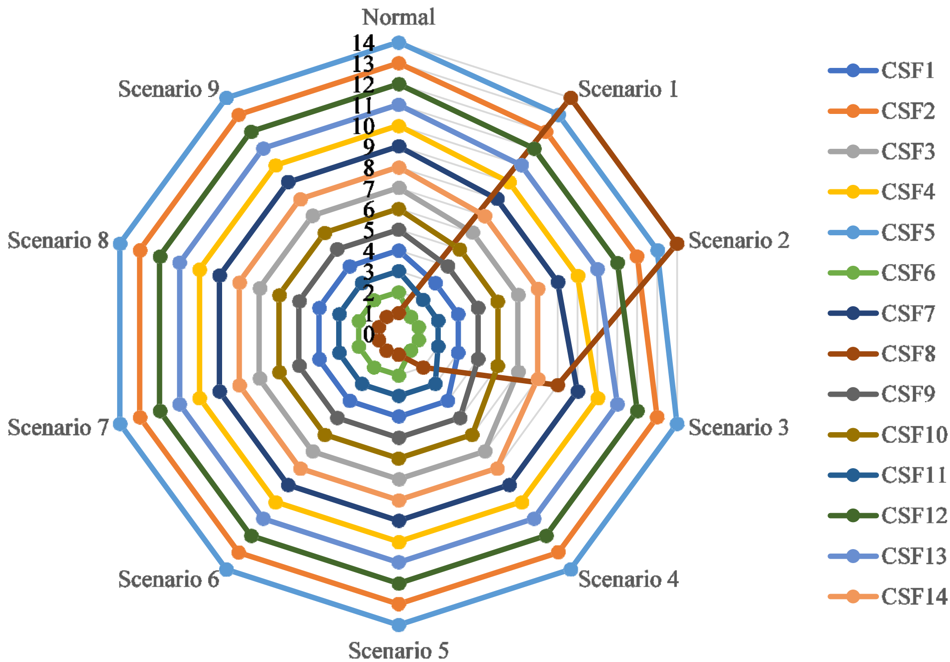
In the present study, sensitivity analysis is performed to check the proposed model's viability and robustness (Prakash and Barua, 2015; Shardeo et al., 2020b). Sensitivity analysis is performed after the determination of the optimal solution as a post-optimality test. The topmost ranked CSF's weight varies from 0.02 to 0.18, with an increment of 0.02 and nine different scenarios are articulated. In each scenario, with the change in weight of the topmost ranked CSF, the weights of the other CSFs vary accordingly. The change in weights of other CSFs corresponding to top-ranked CSF changes (CSF 8 in our case) is shown in Table 8. The resultant change in the ranking of the CSFs is shown in

Table 9. The variations in the ranking for the CSFs are shown in Figure 2. Figure 2 and Table 9 highlight that food quality control (CSF8) ranking occupies the first position for all the scenarios where the value is greater than 0.08. The anonymity and privacy (CSF5) is at the last position for all scenarios where the value is greater than 0.04. Whereas, in the scenarios with the weights of food quality control (CSF8) lower than 0.08 and 0.06, the ranking of top-ranked and bottom-ranked CSF varies, respectively. The study results reflect that the model is unbiased and has robustness as food quality control (CSF8) is ranked at the top and anonymity and privacy (CSF5) at the bottom in most of the build scenarios.

Table 9 Variations in rankings of CSFs through sensitivity analysis

	Normal	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
CSF1	4	3	3	3	4
CSF2	13	12	12	13	13
CSF3	7	6	6	6	7
CSF4	10	9	9	10	10
CSF5	14	13	13	14	14
CSF6	2	1	1	1	1
CSF7	9	8	8	9	9
CSF8	1	14	14	8	2
CSF9	5	4	4	4	5
CSF10	6	5	5	5	6
CSF11	3	2	2	2	3
CSF12	12	11	11	12	12
CSF13	11	10	10	11	11
CSF14	8	7	7	7	8
CSF1	4	4	4	4	4
CSF2	13	13	13	13	13
CSF3	7	7	7	7	7
CSF4	10	10	10	10	10
CSF5	14	14	14	14	14
CSF6	2	2	2	2	2
CSF7	9	9	9	9	9
CSF8	1	1	1	1	1
CSF9	5	5	5	5	5
CSF10	6	6	6	6	6
CSF11	3	3	3	3	3
CSF12	12	12	12	12	12
CSF13	11	11	11	11	11
CSF14	8	8	8	8	8

Figure 2 Ranking of CSFs through sensitivity analysis (see online version for colours)



5 Managerial implications

With the adoption of new technology, every manager counter's key questions are 'where to start? The next question is, 'Stakeholders level of readiness for BCT'? In the initial years, interest in BCT was primarily driven by promised improvements and innovation. However, practical applications require a logical and methodologically established theoretical foundation. This foundation must address the probable complications and shape a smooth transition to new technology. The present study attempts to develop the theory for a practical approach to BCT dissemination in FSC.

The managers can utilise the outcomes of this study in the implementation phase of BCT adoption. The producers can substantially be incentivised by adopting BCT. This study exposes the potential of BCT for improving the health and economic circumstances of millions of poor farmers. Further, government and regulatory body can utilise the outcomes of this study for framing the policies. BCT holds the potential to transform the agriculture sector and, in extension lifestyle of millions engaged in agriculture sectors. For successful dissemination of BCT in AFSC, BCT developers and academicians are required to address the highlighted issues in this study. The application developers are required to design the application features while considering the literacy level of each stakeholder. Further, applications are required to be both user and customer-centric. The division between the physical world and the digital world can be bridged by integrating IoT with BCT. However, the required Infrastructure, energy and technological readiness can only be insured with collaborative work among several stakeholders. Further, consumers will have a critical role in BCT dissemination. Thus, awareness and sensitisation of AFSC stakeholders are a must for full utilisation of this potentially disruptive technology.

In this study, several valuable insights were derived for the AFSC managers. One expert suggested enhancing the focus of AFSC stakeholders towards sensitisation of regulatory and intermediary body. This step will ensure the reach of anticipated expectations from the BCT implementation. Also, BCT developers and AFSC stakeholders need to work on the development of supporting Infrastructure. This Infrastructure will strengthen the AFSC and might result in more flexibility and resiliency as a side product. The critical infrastructures that need to be focused on are the robust IT network and innovative hardware development. The hardware development process needs to consider the role of the IoT, artificial intelligence (AI) and cloud computing. Also, the AFSC stakeholders need to engage the government for positive policy support. Government contributions for successful BCT implementation include regulatory and infrastructure support. A positive regulator environment is essential for successful BCT implementation. Other regulators such as quality certification organisation are required to be integrated with the BCT network. Also, BCT developers need to engage with the small producer and incorporate their concerns in the application development process. Flexible integration of small but large in number producers will bring a positive perception of BCT. This can assist in converging the society-wide support for BCT.

From the perspective of BCT maturity, CSF identification and prioritisation extends the readiness of FSC stakeholders. Consideration of identified CSF can bridge the gap between practitioners and developers. This provides stability to the BCT adoption and prepares the stakeholders for risk associated with technology adoption. The framework extracted from the study provides a common ground for practitioners, developers and researchers to ponder upon during the planning and development stage of the BCT adoption process. A knowledge base can be developed around the proposed CSF framework. This knowledge base can assist the managers in BCT implementation in AFSC.

6 Conclusions and future research directions

In the emerging economies, where producers suffer due to ambiguities in the food supply chain, reduction in the cost of financial transaction and immutable records can benefit the poor farmers. The BCT promises to cater to such real-world problems by providing security and transparency. This study identified and prioritised the CSFs of BCT adoption in AFSC. In the study, 14 CSFs for BCT adoption are identified through a literature survey. Further, identified CSFs were refined and finalised in consultation with the experts' opinion. Later, fuzzy-BWM, which can reduce the comparisons and consider the ambiguities and vagueness of human subjective judgements, has been employed to prioritise the CSFs based on their degree of influence. Sensitivity analysis is performed that ensures the viability and robustness of the proposed model. The present study addresses BCT adoption in AFSC, initiating a theoretical foundation for BCT dissemination. This domain has observed relatively limited attention. The study propagates several strategic measures for AFSC stakeholders to explore and implement.

This study discusses a sensitive and critical issue of poor farmers' incomes and the effect of BCT adoption on their economic situation. These aspects of BCT implementation had not been discussed earlier. Improvement of farmers' situation can be the critical tool for BCT dissemination. While developers are primarily focused on the technical aspects of BCT, several practical aspects remain unexplored. The study narrowed to this critical issue and proposed insights around AFSC stakeholders. Several practical and policy-related interventions were also proposed in the study, supporting AFSC stakeholders in the BCT implementation process. Lastly, the adoption of BCT has several social, economic and operational consequences for FSC in developing economies. The proposed framework provides valuable knowledge to FSC stakeholders and enhances their readiness.

The study has some limitations. The data obtained for the study is based on experts functional in their specific domain. Further, experts from diversified fields are invited to participate in the study for improving the accuracy of the results. Also, the inter-relationship among the CSFs can be considered as a future research direction. Future researchers must explore and validate the results of this study using quantitative methods in the practical field scenario. Also, the researchers need to access the integration of BCT with the IoT, AI and cloud computing. An established theoretical foundation is essential for making the AFSC more resilient, flexible and efficient.

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