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Removing Barriers to Blockchain use in Circular Food Supply Chains: Practitioner Views on Achieving Operational Effectiveness.

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Abstract:

The increasing demand for a sustainable, reliable and secure supply chain for food products has led to the application of digital technologies such as blockchain to improve operational effectiveness. The purpose of this paper is to investigate the integration barriers of Blockchain Technology (BCT) within Circular Food Supply Chains (CFSCs) towards firm's operational effectiveness through a multi-methodological process. Initially the integration barriers are identified through a review of literature and these risks are categorised, using evidence obtained by survey questionnaire completed by experts in the integrated research arena. A further quantified prioritisation of these barriers is made by utilizing a Fuzzy Delphi approach, validated by expert practitioners drawn from the food production and supply organizations. Finally, through semi-structured interviews with Blockchain and FSC experts, an examination of how the integration barriers affect operational effectiveness may be mitigated is provided. This paper concludes that the identified barriers to blockchain integration have real impact on the operational effectiveness of the firm that can only be clarified through industry wide standardised processes.

Keywords: Blockchain Technology, Food Supply Chain, Circular Economy, Operational Effectiveness, Digital Technology.

1. Introduction

From raw materials to the point of consumption, food goes through material selection, processing, production, sales and other interconnected links, which constitute the food supply chain (FSC). FSCs aim to manage the flow of goods and value along the supply chain in order to achieve low cost and cost-effectiveness (Folkerts and Koehorst, 1997; Baratsas, Pistikopoulos and Avraamidou, 2021). This concept has undergone rapid development within in the food industry over recent years, particularly in concert with rising interest related to concepts of Sustainable Supply Chain Management (SSCM) (He *et al.*, 2019) and Green Supply Chain (GSC) management (Kumar, Mangla, *et al.*, 2019). However, given the large number of stakeholders in the FSC, the often global distribution of stakeholders across diverse economies (Lu *et al.*, 2020), and the resulting complex interrelations of these networks, such factors make the information flow in the FSC disorganised and inefficient (Duan et al., 2020). Furthermore, it is suggested that the centralisation of modern FSC threatens the transparency and timeliness of information flow (Duan et al., 2020; Lambert and Cooper, 2000). Thus, possible problems include food quality problems, fraud in transactions, false production information (Jarka, 2019; Michalczyk, 2019; Prashanth et al., 2020). In addition, consumers' confidence with respect to food safety is fractured due to the series of incidences and scandals on food safety over the last few decades (Zhao *et al.*, 2019). These challenges can also lead to major food safety implications and risks, if not managed effectively (Lu *et al.*, 2020).

The requirement for transparency and efficiency of information flow as well as operational effectiveness has prompted the modern FSC industry to seek the latest solutions from the information technology sector (Jarka, 2019; Kolinski and Osmolski, 2019). As an important innovation of modern cryptography (Treiblmaier, 2018) blockchain technology (BCT) makes it possible to address the issues of information flow in the FSC in a secure fashion (Tian, 2016; Yildizbasi, 2021b). BCT is an open, distributed ledger that effectively records transactions between parties in a verifiable and traceable approach, while the ledger itself can be programmed to automatically trigger transactions (Casado-Vara et al. , 2018; Jarka, 2019).

Understanding the impact of this integration towards the operational effectiveness of the firms shall be explored in this study. Generally, firms within food supply chains are faced with competitive pressures to improve efficiency and productivity (Santa et al.,2014). The extant literature on operational effectiveness note that firms will need to respond to market change through the sustained improvement of their paradigms, practices, processes and their services (Tidd and Bessant, 2009; Santa, Hyland and Ferrer, 2014). According to (Porter and Siggelkow, 2008; Evans and Lindsay, 2011), operational effectiveness refers to the ability for firms to establish processes which are built on core internal capabilities that focuses on encouraging these firms to exceed customers' expectations. Within the OE literature, several general hypothesis has been established. These include the complementary nature of safety and operational effectiveness (Levine & Toffel, 2010; Lo et al., 2014), the direct relationship between technological innovation and operational effectiveness in achieving performance improvements (Santa, Hyland and Ferrer, 2014), as well as the contradictory perspectives of safety and operational effectiveness (Brenner et al. , 2004; Brown et al. , 2000). Important for food supply chain firms in attaining operational effectiveness include meeting cost, quality, reliability, flexibility and speed (Hill, 2005). These five performance dimensions allow the organisation to determine how it might add value at every stage of the service delivery process while meeting its own operational performance objectives (Rosenbusch et al. 2011). We note that there are relevant intersections of blockchain and operational effectiveness relevant in building a justification for this study. For instance, BCT constitutes smart technologies necessary for technological innovation effectiveness (Santa, Hyland and Ferrer, 2014; Tsang *et al.*, 2017). Reliability, flexibility and speed are also identified as BCT desirable properties (Nandi et al., 2020); these also constitute the five performance dimensions of operational effectiveness. We however note that there has been no study investigating BCT and operational effectiveness in the context of a firm.

This study examines the integration barriers of blockchain and the CE in food supply chain and their impact on operational effectiveness of the firms, drawing from both the academic literature and the perspective of experienced practitioners. Given the nascent state of blockchain technology and CE, to the best of our knowledge few studies present a comprehensive examination of the integration barriers of BCT *and* CE in food supply chains and their impact on FSC operational effectiveness. Managers need to establish a priority of these integration barriers in order to implement better blockchain-CFSC solutions and to enable implementation and operational effectiveness. Inspired by this need, this study aims to answer three research questions; (i) What are the key barriers to adopting blockchain and the CE in FSC? (ii) How are these barriers to be evaluated to determine their priority in efficient integration of BCT and CE in FSC? (iii) How do these barriers influence operational effectiveness? To answer these research questions, this uses several pathways. First, through existing literature, we distinguish the integration barriers in adopting BCT and CE in FSC. This study then uses a fuzzy Delphi approach validated through review by experts (Murray et al., 1985) in finalising the barriers. Finally, through semi-structured interviews with BCT in FSC experts, we examine how the integration barriers affect operational effectiveness in firm-actor in food supply chain. The remainder of the paper is organised as follows: Section 2 examines the relevant literature. The methodology is provided in Section 3. In Section 4, the results of the Fuzzy Delphi Modelling is presented. Discussions and implications on operational effectiveness are provided in Section 5. Finally, in Section 6 we summarise our contributions in the concluding section.

2. Literature Review

2.1 Blockchain Technology Barriers

The main feature of BCT is its decentralised network that consists of economic agents which agree about the true state of data (Catalini and Gans, 2016; Catalini, 2017). Its architecture offers users inherent characteristics such as transparency, robustness, auditability, interoperability, privacy and security (Greenspan, 2015; Catalini and Gans, 2016) amongst others. Research into the integrated area of blockchain and FSC have focused mainly from the perspective of its advantages. BCT use and barriers in healthcare have been examined by Tandon et al. (2020), finding that a need exists for a system of governance for the use of the technology in that sector. Wang et al. (2020) explores the use of Blockchain with circular supply chain management issues within the fashion industry. Wang et al. (2020) conclude that differences in organisational differences between supply chain partners and their IT systems along with government regulations act as barriers to Blockchain uptake within Apparel trade. Kouhizadeh et al. (2021) also find that technology barriers provide the greatest challenge to organisations is adopting Blockchain. One of the few studies to examine barriers to Blockchain encountered during the implementation phase is Öztürk and Yildizbaşi, (2020), who identify that technological transformation is especially challenging in the logistics sector. Callinan et al. (2022) explore the barriers and enablers of Blockchain use in the Fisheries supply chain. Several researchers have undertaken a review of blockchain-based applications in food supply chain. These include Duan et al. (2020) where the useful characteristics of BCT were identified as well as the challenges for adoption in FSC. We observe that some of these review studies focus on agricultural practices (Bermeo-Almeida *et al.*, 2018) and agri-supply chains (Yadav et al., 2020; Yadav et al. 2022; Khan et al. 2022; Khan, Kaushik et al. 2022; Dey and Shekhawat, 2021; Feng et al.2020; Leng, et al., 2018) and not primarily FSCs, but with similar advantages and challenges identified. In particular Khan, Kaushik et al. (2022) identify limited access to technology and lack of deployable frameworks as negative factors in food supply chains. Following this, Astill et al. (2019) in their review argue that BCT can be complemented with IoT solutions in order to efficiently enable transparency in FSCs. A number of papers identified in the review agreed with this suggestion (Powell et al. 2022; Baralla, et al. 2019; Kittipanyangam & Tan, 2020; Saberi, et al. 2019; Wognum, , 2011), with Wognum et al. (2011) arguing that this transparency include the sustainability, environmental and social dimensions of FSCs (Wognum *et al.*, 2011). Accordingly, Duan et al (Duan *et al.*, 2020) identifies transparency and efficiency from 25 reviewed papers as the main benefits blockchain implementation will bring to the FSC. The other benefits included information authenticity and sustainability which, according to (Tse *et al.*, 2018) and (Ge et al., 2017) advances the necessity for governments to improve their involvement in the monitoring and auditing of FSC in conjunction with identified stakeholders. We capture the integration barriers, categories and their brief description in Table 1. These categories were grouped using a three-step process:

authors' thorough examination of literature, ratified by the survey respondents and then the BCT experts.

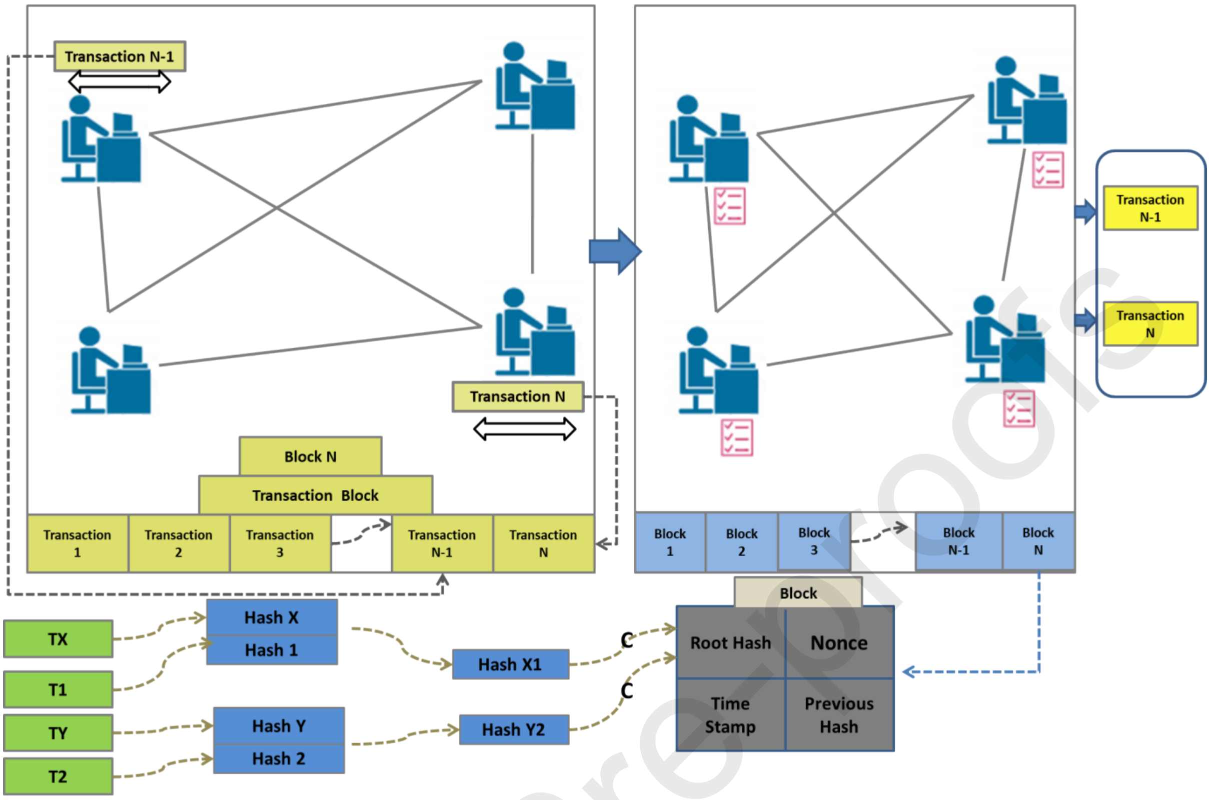

Figure. 1. Simplified overview of Blockchain System (Yildizbasi, 2021b)

A number of case study papers regarding conceptual ideas for blockchain in FSC are presented in the case of Walmart, where BCT was observed to have the capability of increasing WalMart's FSC efficiencies in either food flow, information flow or financial flow (Tan *et al.*, 2018b). Qualitative research undertaken by Saberi et al. (Saberi et al. , 2019) across 173 supply chain practitioners from the Association of Supply Chain Management (ASCM) show that, despite the advantages of BCT, the novelty of the technology makes it a risky proposition for adoption. Saberi et al. (2019) argue that a deeper understanding of the integration barriers is important for blockchain application in FSCs (Ge *et al.*, 2017).

2.2 Circular Food Supply Chain

The outcome on SCOPUS show that circular economy and FSC research is still limited, despite the wide acceptance of the symbiotic relationship of both areas. We argue that this slow uptake is primarily due to the fact that circular economy when considered within the context of years is an emerging research area (Bocken et al., 2017; Narayan & Tidström, 2020), as an input of "sustainability" and "food supply chain" returned 519 articles. While the integrated research area is nascent, several crucial outcomes have been made in available literature leading to a Gartner report to acknowledge that, "*the future of (food) supply chain is circular, not linear*" (Aronow et al,2018). Against this background, several authors attempt to synthesise this research area by arguing for the possibility of employing CE principles in finding solutions to perennial FSC issues such as high energy consumption, greenhouse gas (GHG) emissions and other related social, economic and environmental issues (Garnett, 2011; Zhu *et al.*, 2018). This possibility has given rise to sustainable food production research and policy framework that seeks to link environmental, economic and social issues in the FSC (Van Der Vorst et al., 2009). This singular policy framework to guide our understanding of circular economy and FSC research is paramount as we observe that papers identified in Table 1 have varied research directions. From Table 1 Farooque et al (2019) and van der Vorst et al. (2009), respectively explore circular FSCs utilising DEMATEL and discrete event simulation modelling to redesign food supply chain by including sustainability indicators. while Irani and Sharif explores the concept of food security (as an aspect of the FSC) and its impact on a circular economy (Irani and Sharif, 2018). Wognum et al. (2011) reports on an examination of the relationship between CE principles and food purchasing behaviour in Hungary, with the conclusion that, this application needs to be targeted to a “defined segment of the population” due to the complex nature of FSCs (Wognum et al., 2011). However, successful integration of CE and FSCs at macro, meso and micro-level is contingent upon identifying obstacles and barriers (Farooque et al., 2019; Ghisellini et al., 2016; Mathews & Tan, 2016; Zhijun & Nailing, 2007) in order to achieve cooperative circular supply chains.

Integration barriers impede the synthesis of blockchain and the circular economy in FSC. We identified these integration barriers and their key themes and methodology applied by reviewing 113 and excluded papers that did not focus on “barriers”, “risks”, “challenges”, “disadvantages” (see Table 1). The reviewed papers take different approach in identifying the integration challenges. For example, Kamilaris et al. (2019) in their paper examining the rise of BCT in FSCs and agriculture, match identified opportunities and potential benefits to challenges and barriers in attaining those benefits. Astill et al. (Astill et al., 2019) and Wognum et al. (Wognum et al., 2011) attempt to link the challenges to the social, environmental and economic perspective of FSCs. Govindan (Govindan, 2018) frames the targets, drivers and barriers in FSC with identified stakeholders operating in the FSC space. Others such as Tian (Tian, 2016) and Tse et al. (Tse et al., 2018) draw up the integration barriers from the traceability characteristic of BCT. Blockchain is a novel invention, just about a decade ago, and it reflects in the years of publication as seen in Table 1 and its sources. While BCT is maturing at a fast pace with real interest for both industry and academia, our table agrees with the observation of (Belchior et al., 2022) that applications have been largely focused on the areas of access control, public administration and performance of centralised systems. The next section examines the methodology we utilised to in answering the research questions and address the gap in research concerning the identification and removal of barriers to Blockchain use in circular food supply chains.

Table 1: Integration barriers and their brief description.

Category	Integration Barriers	Brief Description	Sources	Methodologies Applied in Sources	Key Themes in Sources
Security and Laws	Security (weaknesses and threats	Arising from information security, account/wallet security and cyber-related risks	(Reyna *et al.*, 2018), (Tan *et al.*, 2018b), (Kamilaris, Fonts and Prenafeta-Boldú, 2019), (Tseng *et al.*, 2019)	Qualitative thematic analysis; DEMATEL; case study approach	Blockchain, Food Supply Chain, Internet of Things (IoTs)
	Legal Issues and Regulatory compliance	Arising from right to audit, jurisdiction, policy design or implementation failure, regulatory risks, and potential breach of contract	(Farooque, Zhang and Liu, 2019)	Survey, DEMATEL	Circular Economy, Food Supply Chain
	Anonymity and data privacy	Arising from privacy protection, data privacy legislation, monitoring of metadata	(Baralla, Ibba, Marchesi, Tonelli, *et al.*, 2019); (Feng *et al.*, 2020)	Literature Review	Blockchain, Internet of Things, Food Supply Chain, Agri-Food
Funding	Costly new infrastructure	Arising from high infrastructure requirement and costs, i.e., new facilities, information technology installation.	(Andoni *et al.*, 2019), (Farooque, Zhang and Liu, 2019); (Kamilaris, Fonts and Prenafeta-Boldú, 2019); Öztürk and Yildizbaşi, 2020)	DEMATEL, interpretive structural modelling (ISM), analytic hierarchy process (AHP), analytic network process (ANP), structural equation modelling (SEM)	Food Supply Chain, Circular Economy, RFID
	High development costs for BCT	Arising from high labour/expertise costs of blockchain development, maintenance, and high insurance/risk coverage premiums.	(Baralla, Ibba, Marchesi, Tonelli, *et al.*, 2019)	Qualitative	Blockchain, Food Supply Chain
	High hardware and energy cost	Arising from high requirement for material, land, machine, and energy use for BCT validation/verification			
	Lack of investments funding	Arising from lack of/disruptions to investment funding, and budget constraints	(Kamilaris, Fonts and Prenafeta-Boldú, 2019)	Qualitative	Blockchain, Agri-food, Food Supply Chain
Technical	Consensus mechanism	Arising from required evaluation of the cryptographic protocol, and related framework, use case, and network participant requirements.	(Farooque, Zhang and Liu, 2019); (Duan *et al.*,	Content-analysis based literature review; DEMATEL;	Food Supply Chain, Circular Economy, Blockchain

			2020); (Baralla, Ibba, Marchesi, Tornelli, *et al.*, 2019) (Khan et al., 2022)		
	Computing (Processing) Power	Arising from IT infrastructure requirements, e.g., networks, data centres, software, hardware, and related equipment	(Feng *et al.*, 2020)	Literature Review	Blockchain, Agri-Food
	Lack of consensus algorithm	Arising from lack of alignment between consensus algorithm security assumptions and actual requirements.	(Baralla, Ibba, Marchesi, Tonelli, *et al.*, 2019); (Andoni *et al.*, 2019)	Literature Review	Blockchain, Internet of Things, Food Supply Chain, Energy Sector
	Optimum platform/data-enabled infrastructure	Arising from technology optimisation challenges including speed, scalability, implementation, and selection, e.g., state-of-art BCT vs. new BCT development.	(Feng *et al.*, 2020) (Yadav et al. 2020)	Literature Review	Blockchain, Agri-food, Internet of Things
Functional	Unreliable Speed	Arising from inconsistency in the speed at which transactions can be completed, due to varied network and capabilities.	(Feng *et al.*, 2020)	Literature Review	Blockchain, Agri-Food
	Continuously expanding ledgers	Arising from the operational storage requirements associated with increasing numbers of nodes and ledgers being run in parallel.	(Patelli and Mandrioli, 2020); (Feng *et al.*, 2020)	Literature Review	Blockchain, Agri-Food
	Scalability barrier	Arising from congestion caused by increasing transactions that lead to slowing/decreased transaction rate; inability to escalate or track urgent transactions.	(Rana, Tricase and De Cesare, 2021)(Giungato *et al.*, 2017); (Baralla, Ibba, Marchesi, Tonelli, *et al.*, 2019); (Feng *et al.*, 2020); (Duan *et al.*, 2020); (Min, 2019), (Tayal *et al.*, 2021); (Behnke and Janssen, 2020); (Nurgazina *et al.*, 2021); (Kamilaris, Fonts and Prenafeta-Boldú, 2019)	Systematic Literature Review; Qualitative; PCA, TISM, MICMAC, Interviews	Blockchain, Food Supply Chain, IoT, Information Technology, Operation Management, DLTs

	Implementation interoperability	Arising from between-blockchain interoperability and communication expectations and requirements, i.e., integration with existing systems and app integration to allow transaction initiation and completion of other BCT networks.	(Nurgazina *et al.*, 2021)	Systematic Literature Review	Blockchain (Distributed Ledger technology), Food Supply Chain
Organisational	Organisational resistance	Arising from internal stakeholder lack of knowledge, lack of planning, lack of support, and/or other resistance to BCT adoption, i.e., can affect implementation success.	(Min, 2019); (Farooque, Zhang and Liu, 2019); (Kamilaris, Fonts and Prenafeta-Boldú, 2019) (Yadav et al., 2022)	Systematic literature review; DEMATEL;	Blockchain, Food supply chain, circular economy
	Lack of Expertise	Arising from lack of necessary technical knowledge or ability of participants across diverse supply chain	(Tan *et al.*, 2018a) (Yadav et al., 2020)	Thematic analysis, Case study	Blockchain, Food Supply Chain
	Changes in the ruling protocols	Arising from issues and/or misalignment of stakeholder and participant understanding	(Andoni *et al.*, 2019)	Systematic Literature Review	Blockchain, Energy Sector
	Lack of standardisation and flexibility	Arising from the lack of clear standards governing BCT offerings and use (e.g., cryptocurrencies, initial coin offerings, ICOs), and resulting investment uncertainty and risk.	(Andoni *et al.*, 2019); (Min, 2019) (Mangala et al. 2022)	Systematic Literature Review, Qualitative	Blockchain, Energy Sector, Supply Chain
Business Environment	Lack of change drivers (policies, taxation, rewards)	Arising from lack of supporting/enabling domestic policies and/or policy- based motivations for BCT adoption, e.g., taxation.	(Farooque, Zhang and Liu, 2019); Kamilaris et al., 2019)	DEMATEL, interpretive structural modelling (ISM), systematic literature review.	Food Supply Chain, Circular Economy, Blockchain
	Lack of competitive advantage	Arising from nascence of BCT, which limits confidence in, and perceived competitive advantage of BCT relative to incumbent systems and solutions.	(Andoni *et al.*, 2019)	Systematic Literature Review	Blockchain, Energy Sector
	Lack of proven commercial viability	Arising from lack of proven commercial viability, including funding and profitability challenges	(Andoni *et al.*, 2019)	Systematic literature review	Peer-to-peer (P2P) energy trading, Internet of Things
	Lack of Innovation and entrepreneurship	Arising from stagnation/delay of essential corresponding technological innovation, entrepreneurship, and leadership.	(Nurgazina *et al.*, 2021); (Kamilaris, Fonts and Prenafeta-Boldú, 2019)	Literature Review, Qualitative	Blockchain, Internet of Things, distributed ledger technologies, Sustainable Development Goals,

	Agri-food, Food Supply Chain

3. Methodology

3.1 Fuzzy theory

As shown in Figure 2 (adapted from Kumar et al., (2019) , we utilise a mixed method approach of fuzzy theory and semi-structured interview to assess the risks and determine their impact on operational effectiveness respectively. The overall method of this project is data processing method based on fuzzy theory. First, we identify and categorise integration barriers from literature as shown in Table 1. Secondly, we develop a survey questionnaire for identified barriers and this was sent to identify BCT experts. The researchers have good experience in developing survey questionnaire and also followed the questionnaire development protocol in several relevant publications (Yin, 2014; Kumar, Zavadskas, *et al.*, 2019) The respondents' data is shown in Table 2. Respondents were tasked in prioritising these barriers as well as validating the categories. The barriers to the application of BCT in the FSC are systematically analysed through the combination of fuzzy Delphi method and fuzzy Analytic Hierarchy Process (AHP). This analytical method, often used for order preference ranking (Lin et al. 2008; Bozdağ et al. 2003), has the following advantages (Cheng et al., 2009): first, data processing is simplified and the efficiency of data processing is improved by removing the barriers of low relevance; and second, the systematic conclusion is obtained, which is orderly and hierarchical. Analysis at both macro and micro levels are tallies for relevant industry to make accurate decisions. In addition Mangla et al.(2022) employs a Spherical Fuzzy Analytic Hierarchy Process (SF-AHP) approach to analyse blockchain implementation barriers for the supply of tea; SF-AHP is especially useful in tackling ambiguity faced when making distinctions between descriptive text with linguistic similarities.

3.2 Fuzzy Delphi method

Fuzzy Delphi method is an innovative method that integrates fuzzy set theory into traditional Delphi method (Cheng et al., 2009). The traditional Delphi method is a survey data analysis method. The introduction of fuzzy set theory can quantise subjective opinions into quantitative functions (Habibi et al., 2015). There have been successful cases of using fuzzy Delphi analysis for forecasting (Huang, Koopialipoor and Armaghani, 2020; Alharbi and Khalifa, 2021)(The detailed procedure of fuzzy Delphi method is given below (and summarised in Equation 1):

1. Decide analysis objectives through literature review and expert consultation.
2. Obtain expert opinions through questionnaires and represent the data using triangular fuzzy numbers:

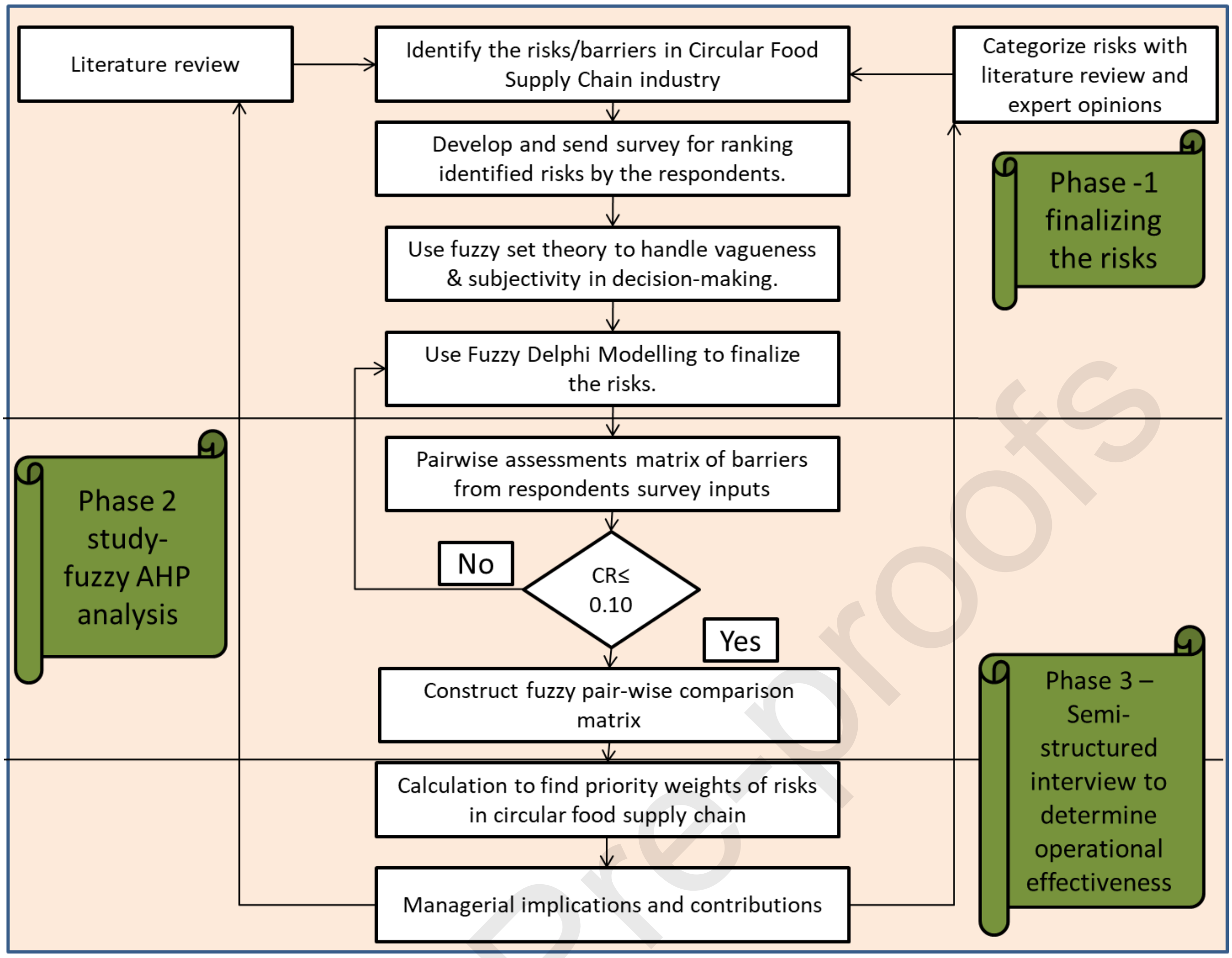

Figure 2: Research Framework

$$Z_{ij} = (l_{ij}, m_{ij}, u_{ij}) \quad (1)$$

Where i represents ith experts, j represents jth objectives, l represents the minimum expectation, m represents the mean expectation, u represents the maximum expectation. In general, the fuzzy triangular numbers depend on the original mark in the questionnaire, which is obtained by the corresponding relationship developed by the researcher.

The following equations (Equations 2-4) are used to obtain the fuzzy weight of each objective:

$$l_j = min\{l_{ij}\} \quad (2)$$

$$m_j = \frac{1}{n} * \sum_{i=1}^{n} m_{ij} \quad (3)$$

$$u_j = \max\{u_{ij}\} \quad (4)$$

Where i represents ith experts, j represents jth objectives, n represents the total number of experts. For example, the three expert opinions of a barrier are (0.3, 0.5, 0.7), (0.5, 0.7, 0.9), (0.7, 0.9, 1.0) respectively, then l_j, m_j, u_j are 0.3, 0.7, 0.87 respectively. The new fuzzy weight triangular number (0.3, 0.7, 0.87) will be used in Equation 5.

Defuzzification is carried out by taking the average value of fuzzy weight triangular number:

$$X_j = \frac{l_j + m_j + u_j}{3} \quad \textbf{(5)}$$

The final step is to set the appropriate threshold α for the project, if $X_j \geq \alpha$ then accept the barrier; if $X_j < \alpha$ then reject the barrier. The α here is determined by the researchers, depending on the project. According to the literature review, it is usually in the range of 0.5 to 0.7.

In some studies, the concepts of optimism and pessmisim can be introduced in order to obtain consensus due to huge divergence, Habibi, et al., (2015). This operation is done so we can calculate the arithmetic mean of the triangular fuzzy number of all expert opinions on a certain barrier. Each expert's opinion is then compared with the average and if the minimum expectation of the expert's opinion (the first digit of the fuzzy triangular number) is greater than the average of the maximum expectation, the expert is considered to be optimistic, However, if the maximum expectation is less than the average of the minimum expectation, this is regarded as pessimism. For example, the average value of the maximum expectation of the three groups of data: (0.1, 0.3, 0.5), (0, 0.1, 0.3), (0.7, 0.9, 1.0), is 0.6. However, since the minimum expectation of the third data 0.7 is greater than this average value, it is considered as "optimism" thus will be excluded.

3.2.1 Fuzzy analytic hierarchy process

As a powerful tool to deal with subjective fuzziness, a fuzzy analytic hierarchy process (AHP) can be used to achieve high decision reliability Öztürk and Yildizbaşi, 2020; Ayhan, 2013). Fuzzy AHP divides many elements into main categories and secondary sub-barriers, using triangular fuzzy numbers to build comparison matrices that calculate the relative importance. There are many successful cases of using fuzzy AHP to make decisions, i.e., solving the multi-target supplier selection problem (Arikan, 2013), food safety assurance (Hong et al . 2021; Lu *et al.*, 2020), and third party logistics decision problems (Soh, 2010). Fuzzy AHP method follows the procedure below:

All analysis objects are classified to form a hierarchical structure. The hierarchy consists of the main categories and sub-objects in each category, with the number of sub-objects equalised in each major category. For this work, the original comparison matrices with a certain scale are established by fuzzy calculation. According to the collected expert opinions, the original comparison matrices with a certain scale are established by fuzzy calculation. If there is no original comparative data, the fuzzy weight of each category can be obtained by using the fuzzy Delphi method to analyse the opinions of each expert with the main category as the minimum unit. Then by making a certain comparison standard, the weight of each main category is compared to get the comparison data matrix.

The following formulas (Equations 6 -9) are used to convert the original comparison matrix into fuzzy pairwise comparison matrix:

$$l_{ij} = \min\,(l_{ijk}) \quad \textbf{(6)}$$

$$m_{ij} = \frac{1}{k} * \sum_{k=1}^{n} (m_{ijk}) \quad \textbf{(7)}$$

$$u_{ij} = \max\,(u_{ijk}) \quad \textbf{(8)}$$

$$(\widetilde{x_{ij}}) = (l_{ij}, m_{ij}, u_{ij}) \quad \textbf{(9)}$$

Where i represents ith row, j represents jth column, k represents kth expert. This step is to process the data at the same position in all the expert opinion comparison matrix, and the resulting fuzzy triangular number is also at this position in the fuzzy pairwise comparison matrix. If the data compared by three experts on category 1 and category 2 are 1/5, 1, 7 respectively, then the final fuzzy triangular number $\widetilde{x_{ij}}$ is (1/5, 2.73, 7).

1. The global priority is calculated based on fuzzy numbers, and the result of the ith object is obtained by the following formula in Equation 10:

$$S_i = \sum_{j=1}^{k} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{k} M_{g_i}^{j}\right]^{-1} \quad \textbf{(10)}$$

   The above formula mainly consists of two parts, which can be computed by the following formula respectively:

$$\sum_{j=1}^{k} M_{g_i}^{j} = \left(\sum_{j=1}^{k} l_j, \sum_{j=1}^{k} m_j, \sum_{j=1}^{k} u_j\right) \quad \textbf{(11)}$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{k} M_{g_i}^{j}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \quad \textbf{(12)}$$

   Equation 11 represents the sum of the vectors in each row of the fuzzy pairwise comparison matrix, and Equation 12 represents the inverse operation of the sum of all the vectors in the matrix.

2. Next, we calculate and compare the degree of possibility of the two elements, using Equation 13:

$$V(M_2 \geq M_1) = \begin{cases} 1 & if\ q_2 \geq q_1 \\ 0 & if\ p_1 \geq r_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad \textbf{(13)}$$

   In general, the mean expectations are compared first, if the result matches the previous comparison symbol, then obtain the result of 1 directly. If not, use $\frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}$ to calculate.

3. The final priority weight is obtained by calculating the minimum value and matrix normalisation through Equations 14-16 :

$$A = \min\left[V(M \geq M_i)\right](i = 1,2,3,4,5) \quad \textbf{(14)}$$

$$W' = (d'(A_1), d'(A_2), d'(A_3), \ldots, d'(A_n))^T \quad \textbf{(15)}$$

$$W = (d(A_1), d(A_2), d(A_3), \ldots, d(A_n))^T \quad \textbf{(16)}$$

   In this step, the minimum expectation of each category's comparison data with other categories is extracted and used as the priority of this category. Then all the priorities are put into a vector and normalised.

4. These steps are repeated to calculate the priority of the sub-barriers in each category in turn, and finally get the weight of all barriers through the product of global priority and local priority.

$$Global\ priority = Category\ priority * Local\ priority \quad (17)$$

3.3 Choice of Experts

This study employs two qualitative methods to collect data. First, a structured questionnaire was designed and used as a survey to collect their informed opinions on blockchain and circular food supply chain through a Likert scale. While the term "survey" has been applied in several ways, it usually refers to the selection of a sample of people from a pre-established population, followed by the obtaining of data from these individuals (Gürdür, El-khoury and Törngren, 2019). A total of 33 blockchain experts in industry, academia and policymaking were identified on LinkedIn and contacted through emails and a discussion held on Zoom to determine their viability for the study. Attributes identified included experience in BCT applications, a working experience in supply chain, and familiarity with circular economy and/or sustainability adoption in industries and their availability to complete the survey questionnaire form. After these, a total of 16 respondents were selected and this is shown in Table 2. Fifteen (15) had over 5 years of relevant experience. The experts for the survey were chosen primarily due to their academic and industrial expertise in BCT and CFSC. Their profession ranged from academic researchers in universities to IT managers in consultancies and implementation consultants and managers in supply chain and procurement firms. Generally as seen in digital technologies-focused studies, these ones are agreed to have a detailed vision and knowledge of the study (Saunila *et al.*, 2019). 50% of the respondents had a PhD degree while the rest either had an MSc or an MBA, thus indicating the educational competence of the respondents. A direct link was sent to respondents by email and all responses were received within two weeks'. The results were used for the Fuzzy Delphi analysis.

Next, semi-structured interviews were conducted as the second qualitative method used to validate the survey data and provide new and more detailed data on the impact of operational effectiveness on BCT-CFSC integration. As the area of BCT is still emergent, experts with more operational and senior job titles were targeted for this interviews. These 6 experts were different from the expert respondents who supported with the survey response as we wanted to eliminate bias in responses (Saunila *et al.*, 2019; Erasmus *et al.*, 2020). All 6 experts were involved in the modelling and implementing of executable BCT in food supply chain industries. These experts had risen in the ranks of BCT implementation and had worked across several nations and continents, hence could provide a very rich source of data. While the respondents were encouraged to freely speak about the research question, the average response time for these experts was 45 minutes. Table 3 gives a summary of the description of the 6 experts. Similar integration studies use 3 experts (Yildizbasi, 2021a) and 7 experts (Singh *et al.*, 2020) for studies on blockchain and renewable energy integration and circular economy and mining sector integration barrier studies respectively. As precedent has been set in studies investigating blockchain integration, we argue that this justifies our use of 6 experts as our sample population. All the experts used in the interviews have had experience in the food supply chain industry.

Table 2: Background of experts involved in the survey

Respondents Code	Years of BCT Experience (Including Research)	Position	Industry	Qualification	Primary location of business	Gender	Age
R1	8	Senior Researcher	Operations Management	PhD	United Kingdom	Male	38
R2	10	IT Manager	IT Consultancy	MSc	United Kingdom	Male	34
R3	21	General Manager	IT Consultancy	MBA, BTech	India	Male	40
R4	13	Lecturer	Academia	PhD	India	Female	36
R5	9	Senior Researcher	Academia	PhD	United Kingdom	Male	41
R6	2	Lecturer	Academia	PhD	India	Male	31
R7	19	Lecturer/ IT Consultant	Academia/ Civil Service	PhD	India	Male	43
R8	5	Research Fellow	Academia	PhD	United Kingdom	Male	32
R9	15	IT Consultant	"Big 4"	MSc	India	Male	39
R10	7	Researcher	Academia	Mtech	Pakistan	Male	30
R11	6	Researcher/ Consultant	IT Consultancy	MSc	United States	Female	29
R12	12	Research Fellow	Academia	PhD	United Kingdom	Male	32
R13	8	General Manager	Food Supply Chain	PhD	United Kingdom	Male	38
R14	8	Consultant	Supply Chain & procurement	MBA, MSc	Colombia	Female	29
R15	23	Manager	Procurement & Supply Chain	MBA	United Kingdom	Female	33
R16	20	Researcher	Academia	MSc (Logistics)	Portugal	Female	46

Table 3: List of BCT Experts for Semi-Structured Interview

Experts Code	Years of BCT Experience (Including Research)	Position/Job Title	Industry	Highest Degree Earned	Primary Business Location	International Business?	Interview Duration
A	19	Professor/CEO	Academia/ Food Supply Chain Entrepreneur	PhD	United Kingdom	Yes	44 mins
B	13	Senior Researcher/ Business Analyst	Academia/ Consultancy	PhD	Denmark	Yes	51 mins
C	9	Director	Blockchain Consultancy (Food Supply Chain)	MBA	United Kingdom, Nigeria	Yes	1 hr 6 mins
D	17	Principal Consultant/Executive Director	"Big 4"/ Tech Consultancy for Food Supply Chain (Asia Division)	MSc	India	Yes	50 mins
E	7	Chief Technological Officer/ Director	Software Consultancy (Food Supply Chain, Finance)	MSc	India	Yes	44 mins
F	5 (25 years in Finance & Treasury)	Principal Founder & CEO	Agricultural/ Food Supply Chain Consultancy	MSc	United Kingdom	Yes	51 mins

4. Results

4.1 Fuzzy Delphi

Twenty-five barriers to blockchain and circular economy in the FSC were proposed in the initial literature research and discussion (summarised in Table 1). To explore the importance of these barriers and their relevance to the subject, 16 expert respondents were invited to fill out questionnaires. These experts are people working in blockchain-related industries or research areas. The Table 4 shows the scales represented by marks 1-7 in the questionnaire, and the fuzzy numbers are assigned according to the importance of the representatives (Habibi, Firouzi, Sarafrazi, 2015), so that the data can be sorted out and fuzzified after data collection.

Table 4: Fuzzy Numbers after Data Collection

Option	Representation	Fuzzy number
1	Very Low Significance	(0,0,0.1)
2	Low Significance	(0,0.1,0.3)
3	Medium Low Significance	(0.1,0.3,0.5)
4	Medium Significance	(0.3,0.5,0.7)
5	Medium High Significance	(0.5,0.7,0.9)
6	High Significance	(0.7,0.9,1.0)
7	Very High Significance	(0.9,1.0,1.0)

Based on the data obtained from the questionnaire, the fuzzy Delphi method is used to process the data to get the results of the first phase. Different from the conventional fuzzy Delphi method, this study introduces the concepts of optimism and pessimism to deal with extreme opinions which leads to a more consensual view (Habibi, Firouzi, Sarafrazi, 2015). Once an expert's lower bound of a barrier was bigger than the average upper bound, his opinion would be regarded as over optimistic and neglected. Similarly, when an expert's upper bound of a barrier was smaller than the average lower bound, his opinion would be regarded as over pessimistic and neglected. Compared with the average upper and lower bounds in Table 5, the opinions of experts who were considered optimistic and pessimistic are listed in the Table 6:

Table 5: Mean fuzzy number

Barriers	l (mean)	m (mean)	u (mean)
1	0.51	0.69	0.84
2	0.33	0.51	0.70
3	0.54	0.73	0.88
4	0.60	0.79	0.92
5	0.63	0.79	0.91
6	0.48	0.64	0.77
7	0.51	0.70	0.86
8	0.44	0.64	0.81
9	0.54	0.73	0.87
10	0.56	0.74	0.88
11	0.57	0.73	0.85
12	0.55	0.71	0.88
13	0.44	0.63	0.76
14	0.49	0.66	0.81
15	0.38	0.58	0.76
16	0.44	0.63	0.81
17	0.48	0.66	0.82
18	0.46	0.65	0.81
19	0.46	0.63	0.78
20	0.41	0.59	0.75
21	0.49	0.68	0.83
22	0.33	0.49	0.64
23	0.54	0.72	0.85
24	0.51	0.69	0.83
25	0.54	0.73	0.88

Table 6: Expect Opinions (Optimism and Pessimism)

Optimism	Pessimism
6-3, 6-4, 6-8, 6-14, 6-15, 13-2, 13-4, 13-6, 19-3, 19-4, 19-6, 20-3, 20-4, 22-3, 22-4, 22-16	1-15, 4-14, 5-14, 6-9, 7-2, 11-15, 13-12, 13-12, 13-15, 14-12, 14-16, 16-12, 17-2, 18-2, 19-5, 20-5, 20-8, 22-14, 23-5, 24-9

Where 6-3 represents the third expert's opinion on barrier 6.

According to experts' suggestions and research requirements of this project, the threshold value of the Fuzzy Delphi method was determined to be 0.55, and only two barriers with low correlation were excluded and twenty-three barriers were retained to ensure the data richness and reliability of subsequent studies. Table 7, shows the threshold for rejecting barriers. A defuzzification value less than a threshold value indicates that the priority of the barrier is low and should be rejected.

Table 7: Threshold value of the Fuzzy Delphi method

Barriers	l (mean)	m (mean)	u (mean)	lower boundary	Fuzzy mean	Upper boundary	Defuzzification	Threshold	R/S?
1	0.51	0.69	0.84	0.10	0.73	1.00	0.67	0.55	Seleted
2	**0.33**	**0.51**	**0.70**	**0.00**	**0.51**	**1.00**	**0.51**	**0.55**	**Rejected**
3	0.54	0.73	0.88	0.10	0.73	1.00	0.67	0.55	Seleted
4	0.60	0.79	0.92	0.30	0.82	1.00	0.76	0.55	Seleted
5	0.63	0.79	0.91	0.30	0.83	1.00	0.77	0.55	Seleted
6	0.48	0.64	0.77	0.10	0.52	1.00	0.55	0.55	Seleted
7	0.51	0.70	0.86	0.10	0.74	1.00	0.68	0.55	Seleted
8	0.44	0.64	0.81	0.10	0.64	1.00	0.61	0.55	Seleted
9	0.54	0.73	0.87	0.30	0.73	1.00	0.70	0.55	Seleted
10	0.56	0.74	0.88	0.10	0.74	1.00	0.68	0.55	Seleted
11	0.57	0.73	0.85	0.10	0.78	1.00	0.70	0.55	Seleted
12	0.55	0.71	0.88	0.10	0.73	1.00	0.67	0.55	Seleted
13	0.44	0.63	0.76	0.10	0.63	1.00	0.60	0.55	Seleted
14	0.49	0.66	0.81	0.10	0.74	1.00	0.68	0.55	Seleted
15	0.38	0.58	0.76	0.00	0.58	1.00	0.55	0.55	Seleted
16	0.44	0.63	0.81	0.10	0.67	1.00	0.63	0.55	Seleted
17	0.48	0.66	0.82	0.10	0.70	1.00	0.65	0.55	Seleted
18	0.46	0.65	0.81	0.10	0.69	1.00	0.64	0.55	Seleted
19	0.46	0.63	0.78	0.10	0.58	1.00	0.57	0.55	Seleted
20	0.41	0.59	0.75	0.10	0.60	1.00	0.58	0.55	Seleted
21	0.49	0.68	0.83	0.10	0.68	1.00	0.64	0.55	Seleted
22	**0.33**	**0.49**	**0.64**	**0.00**	**0.40**	**0.90**	**0.42**	**0.55**	**Rejected**
23	0.54	0.72	0.85	0.10	0.76	1.00	0.69	0.55	Seleted
24	0.51	0.69	0.83	0.10	0.73	1.00	0.67	0.55	Seleted
25	0.54	0.73	0.88	0.10	0.73	1.00	0.67	0.55	Seleted

ii. Fuzzy AHP

The priority ranking of the 23 retained barriers was obtained by using fuzzy AHP method, and these were classified according to the literature review and expert opinions. The final barrier categories include: Security and laws (SL), Funding (FD), Technical (T), Functional (FT), Organizational (O), Business environment (BE). The specific classification criteria and the sub-barriers included in each category are shown in the **Table 8**.

Table 8: classification criteria and the sub-categories of the 23 retained barriers

Barrier Category	Criteria	Sub-barriers
Security and laws (SL):	**Information security, privacy protection and related laws and regulatory issues**	Security (weaknesses and threats)
		Legal issues and Regulatory compliance
		Anonymity and data privacy
Funding (FD):	**The cost on information technology and infrastructure needed to build the blockchain**	Requiring costly new infrastructure
		High development costs for blockchain technologies
		High hardware and energy cost
		Lack of investments funding
Technical (T):	**Key technical problems for the implementation of blockchain technology**	Consensus mechanism
		Computing (Processing) Power
		Lack of consensus algorithm
		Optimum platform/data-enabled infrastructure

Functional (FT):	**The functional defects caused by the nature of blockchain technology itself**	Unreliable Speed
		Continuously expanding ledgers
		Scalability barrier
		Implementation interoperability
Organizational (O):	**As a matter of cooperative relationships between different organizations that share information**	Organisational resistance
		Lack of Expertise
		Changes in the ruling protocols
		Lack of standardisation and flexibility
Business environment (BE):	**Macro commercial environment and market environment in a certain sense**	Lack of change drivers (policies, taxation, rewards)
		Lack of competitive advantage
		Lack of proven commercial viability
		Lack of Innovation and entrepreneurship

Table 9: Fuzzy comparison matrix

	SL	FD	T	FT	O	BE
SL	(1.00,1.00,1.00)	(0.14,2.54,7.00)	(0.14,2.77,7.00)	(0.14,2.08,7.00)	(0.14,2.11,7.00)	(0.14,2.21,7.00)
FD	(0.14,2.32,7.00)	(1.00,1.00,1.00)	(0.14,2.75,7.00)	(0.14,2.19,7.00)	(0.14,2.56,7.00)	(0.14,2.11,7.00)
T	(0.14,2.68,7.00)	(0.14,2.03,7.00)	(1.00,1.00,1.00)	(0.14,2.42,7.00)	(0.14,1.97,7.00)	(0.14,1.93,7.00)
FT	(0.14,2.62,7.00)	(0.14,2.55,7.00)	(0.14,3.40,7.00)	(1.00,1.00,1.00)	(0.14,2.52,7.00)	(0.14,2.58,7.00)
O	(0.14,2.87,7.00)	(0.14,2.69,7.00)	(0.14,3.21,7.00)	(0.14,2.78,7.00)	(1.00,1.00,1.00)	(0.14,2.48,7.00)
BE	(0.14,2.05,7.00)	(0.14,2.71,7.00)	(0.14,3.25,7.00)	(0.14,2.24,7.00)	(0.14,2.69,7.00)	(1.00,1.00,1.00)

The fuzzy comparison matrix is obtained by taking the arithmetic average of the fuzzy numbers corresponding to the opinions of all experts in each category which is shown in Table 9. This matrix indicates the relative priority of each category in experts' opinion.

Equations (10)-(16) is used to defuzzify the fuzzy comparison matrix to get the priority of the category which is shown in **Table 10**:

Table 10: Category priority

Category	Weight	Ranking
SL	0.166	5
FD	0.167	4
T	0.160	6
FT	0.169	2
O	0.171	1
BE	0.167	3

The local priorities of sub-barriers in each directory are calculated with the same process, and the global priority of each sub-barriers is obtained by using (17) as shown in Table 11:

Table 11: Final results

Category	Sub-barriers	Category priority	Local priority	Local ranking	Global priority	Global ranking
SL	5	0.166	0.354	1	0.0441	2
	6	0.166	0.316	3	0.0393	22
	7	0.166	0.330	2	0.0411	15
FD	17	0.167	0.252	2	0.0421	10
	18	0.167	0.244	4	0.0407	18
	19	0.167	0.247	3	0.0412	14
	24	0.167	0.257	1	0.0429	5
T	8	0.160	0.249	3	0.0398	21
	12	0.160	0.263	1	0.0421	11
	13	0.160	0.252	2	0.0403	20
	15	0.160	0.236	4	0.0378	23
FT	1	0.169	0.251	3	0.0424	9
	3	0.169	0.256	1	0.0433	3
	14	0.169	0.253	2	0.0428	6
	20	0.169	0.240	4	0.0406	19
O	4	0.171	0.258	1	0.0441	1
	9	0.171	0.250	3	0.0428	7
	10	0.171	0.253	2	0.0433	4
	16	0.171	0.239	4	0.0409	17
BE	11	0.167	0.255	1	0.0426	8
	21	0.167	0.245	4	0.0409	16
	23	0.167	0.251	2	0.0419	12
	25	0.167	0.249	3	0.0416	13

The results show that the ranked priority difference is very small. Overall, the results identified organizational issues as the most important barriers to blockchain adoption in the FSC, and technological barriers (T) remained the lowest-weighted category. The ranking of functional (FT) category and business environment (BE) category were often relatively high, and in some cases had only a small priority differential. Although the gap between barriers is small, the results reflect to some extent the priorities among the barriers. In the discussion, researchers will focus on the reasons for this small priority gap.

4.2 Detailed Survey Results and Discussion

To further explore and explain the relevance and importance of the different BCT barrier categories, interviews with six experts, (distinct from Table 2) were conducted to clarify perspectives and reflect on category ranking results. These experts were selected primarily based on their organisational experiences as they would be ideal in assessing the operational effectiveness of these barriers on circular supply chain firms (shown in Table 3).

As the most heavily weighted category, the 'Organizational' (O) barriers reinforces the critical role of BCT as an information-sharing structure that allows all members to share and consult information rapidly, thus forming a superior organization composed of various stakeholders. To ensure the interests of all members in this organization, reasonable rules, structure and consensus are necessary (Duan et al., 2020). However, from the view of practitioners, this requirement has not yet been practically realized:

"…there are quite a few alliances of a few industry players [who have] come together and said "this is what we want to do", but the [Blockchain] ecosystem definitely has not consolidated… standardization [of practices and processes] is really important, but I don't think the industry is there yet." (Practitioner-Expert A).

Similarly, Practitioner-Expert F observed: "…there are several bodies looking at ways to create a standard. It's just that it's still siloed in some ways… [across] the academics, the entrepreneurial, and the corporate." Within the organizational barrier category, the sub-barrier 'Lack of standardisation and flexibility' occupy the most important position, followed by the sub-barrier 'Organisational resistance'. Due to the complexity in FSC, there will be resistances in the establishment of organisational standards in terms of using blockchain technologies to form a superior organisation (Behnke and Janssen, 2020). Per the view of one practitioner:

"What is the standard I have to follow? What standard [do] I have to follow so that a trust can be generated? [These] standards are the acceptable standard by the fact that everybody can agree to it, and that the community developed it, and have brought it into the ecosystem right." (Practitioner-Expert D).

BCT requires a shared standard information platform, which means that all stakeholders are required to build and join the platform with the same standards (Behnke and Janssen, 2020). However, again, from the view of practitioners, there is a lag in the realization of this potential:

"…blockchain is not about "me", it's about "us" where "us" involves other participants. So, unless you get all those participants, your ability to succeed is limited. [Companies] need like 50 participants or more to join hands together…it takes time." (Practitioner-Expert E).

The category 'Functional issues' (FT) ranked second, and ensuring that BCT works correctly and achieves its intended function is a high priority. A recurring concern of practitioners is whether the functional performance of the blockchain is necessary for the business:

> *"…there is a notion that blockchain technology has the answer for everything, [but] that's not the case. Yes, [BCT] has some specific feature which no other technology can provide. But individual businesses need to understand whether that is something that is actually important and valuable for the business, or not."* (Practitioner-Expert B).

The two most important of the sub-barriers: '*Implementation interoperability*', '*Unreliable Speed'* illustrate the advantages of blockchain functionality: interoperability and fast access (Golosova & Romanovs, 2018). Interoperability enables rapid data exchange and sharing through protocols. The efficiency of information flow between blocks reflects the efficiency of the whole blockchain to some extent, and the operation of information stored in different blocks helps stakeholders to obtain and process the information needed to achieve the purpose quickly. However, due to the huge amount of computation, high redundancy of network structure (Ezaki et al., 2022), difficulty in node capacity expansion and other problems of BCT, its running speed is unstable and vulnerable. Per one practitioner's view:

> "*…to actually have the full possibility of the supply chain, you have to have everything from end to end, on one blockchain, right? I'm talking like from the farm down to the shipping companies all the way down to the people that will provide and process the manifest on the ship to those who clear it through custom and the custom agent then to the warehouse then it's distribution down to local stores and super markets…it's monumental. So, the question, now you will start asking yourself is the juice worth the squeeze? What [is] the problem here [we are] actually trying to solve, [are they] trying to kill a fly with a sledgehammer…?"* (Practitioner-Expert B).

Per the fuzzy Delphi and AHP analyses, the category '*business environment'* (BE) ranked in third place, reflecting influence at the macro level. Practitioners view this category as far more important, relatively:

> *"…the business environment is probably the biggest risk, as much as it could benefit everyone. [Blockchains] run the risk of it been hijacked by a group of actors who may dictate who gets what, who does what, who has access to what. Operationally you need access to your data to be able to innovate, to be able to prove it. So, what happen*
>
> *s when you don't easily have access to your own data you generate that could quickly help you make informed decision from the business decision, and inform analytical, what happens."* (Practitioner-Expert C).

Political and macro factors, such as policy, taxes, and appropriations, are important drivers for the adoption of BCT in the FSC. China has pushed information technology to the level of national policy to boost development, and this has gained many achievements (Liu et al. , 2020). The barriers 'Lack of change drivers (taxation, policies)', and 'Lack of proven commercial viability' occupy top priority ranking within the BE category. In the initial stage of exploration, appropriate tax cuts, appropriations, and policy support includes talent introduction, can greatly mitigate barriers and reduce risks and lay a solid foundation for the birth of a mature system. However, from the practitioner perspective, government policies and adoption practices may also create new challenges:

> *"…[some] countries are committed to specific policies and specific laws that are making It difficult for [blockchain] to achieve its purposes. For example, Blockchain for financial transactions. They are happy to allow Blockchains to exist for every other thing but not for financial transactions. So that is a barrier… if Blockchain can be used for every other business but is not permitted to get into the financial market because of a desire to maintain control."* (Practitioner-Expert E).

More recent events have also shifted behaviours and perceptions that will affect whether and how BCT is implemented: *"…the [global COVID-19] pandemic is an external strife that has created a need for better trust, and this is why we see increased interest and understanding of the critical need for trust systems*." (Practitioner-Expert F).

Alongside 'Business environment', 'Funding issues' (FD) was identified as an important barrier category in the fuzzy Delphi and AHP analyses due to the fact that BCT relies heavily on infrastructure and advanced information technology (Kumar, et al., 2020; Duan and Zhang, 2020; Liu et al. , 2020). Whether from the perspective of hardware or software, extensive construction fund requirements, place a heavy burden on some small and micro industries (Hackius and Petersen, 2017; Golosova and Romanovs, 2018). Lack of investments funding for profit-driven investors' is ranked first as it is the foundation of all the sub-barriers associated with high costs. As noted by Practitioner-Expert F,

"…there's a lot of investment [in BCT]. But it's not investment [that] start-ups can easily access… unless they're in capital markets." Added to this, "*…the majority of the food [industry] are not doing traceability so much as they are doing credit… working with smallholder famers to provide credit or access to market."* (Practitioner-Expert F).

For emerging industries, a stable profit-driven investor is often the main source of capital in the early stage and the guarantee of the successful construction of blockchain network. However, practitioners reflect on the primary source of funding for blockchain adoption and implementation, noting an interesting trend:

> *"…if you look at blockchain funding you see that individual funding is coming in, and groups are putting up money creating new networks, but I don't see institution funding coming in that speed, it is there but it is not to that extent. I don't see institutions -- big institutions -- adopting and putting money, except maybe some small projects. No big investments by big institutions."* (Practitioner-Expert D).

Further explaining this challenge, several practitioners noted the compounding issue of trade-offs and uncertainty captured by the low-ranked three sub-barriers of 'High development costs', 'High hardware and energy cost' and 'Costly new infrastructure'. These sub-barriers are essentially similar and are the necessary costs of building a blockchain network, including infrastructure, energy consumption, computation consumption (Golosova and Romanovs, 2018) and so on. From the practitioner's perspectives:

> *"…even though [blockchain] is solving a problem in terms of securing the chain and ensuring traceability from the origin of the produce to the table, you are passing on extra cost [to every node in the network, whether small farmer or large logistics firm] to buy fuel in the generator, to keep [the Blockchain] on and maintain it… it's a trade-off of cost vs. benefit and value. Is it necessary? If you are asking me, no. But…if [a company] wants to do it, sure -- and eventually somebody will have to pick up the price tag along the line. That's going to be either on the supplier, or the farmer, or the consumers like you and I. Somebody has to pick up the price tag along the way."* (Practitioner-Expert C).

'*Security and laws'* (SL) category ranked fifth in the fuzzy Delphi and AHP analyses. BCT involves information security and privacy issues. Since the information is stored in the ledger, it can be freely viewed by the parties in the blockchain network. Per Practitioner-Expert B: *"…when it comes to looking at the operational effectiveness, yes, security is a major challenge in the blockchain industry, largely related to the ethics, and how we are going to measure, monitor, and benchmark."*. As a result, information security and prevention of leakage have become important issues, such as how to set up the principles of access to information and how to formulate relevant rules to manage such information (Kamilaris, Fonts and Prenafeta-Boldú, 2019; Duan *et al.*, 2020). 'Security (weaknesses and threats)' as the first ranked sub-barriers, emphasise the information security and the importance of preventing the occurrence of related threats. In practice, 'trust' – of suppliers and all network nodes – is highlighted as being critically important:

> *"I need to have trust that the suppliers there are really trustful, the information they entered on the ledger, meaning the ledger entry, corresponds to this pack of coffee and this pack of coffee was really sourced without children slavery, [etc.] So, if they lie, I have no means to validate the physical data; I can't travel to Columbia, I can't travel to Kenya."* (Practitioner-Expert A); and:

> *"…private corporate organizations…may invest in the farmers to bring visibility to them and to gain data insight. In return, the farmers gain the structural position …trust is an important factor because that establishes credibility that your document, your proof of ownership, is properly*

> *recorded on the database and that the system can't be manipulated."* (Practitioner-Expert D).

There is also a real and practical cost associated with failed trust and credibility:

> *"…assuming that all the information [on the blockchain] is truthful, then the risks is actually are low. Operational efficiency increases as a result of smart contracts and automation. But, the problem has been shifted – it is no longer a technical issue affecting operational efficiency, but a problem of provenance verification. For this, we have no technical solution."* (Practitioner-Expert A).

Improper use of BCT can affect the security of the chains: *"…it's nearly impossible to modify that data, and that is the protection we get from blockchain. However, we lose that protection if we reduce the number of nodes you can play with, for example, by making the blockchain private."*

Challenges related to regulation, compliance, and basic standardization also persist for BCT affecting implementation and the achievement of operational efficiencies, as Practitioner-Expert F noted:

> *"…one needs to step back and say, how long have we had this? [General Data Protection Regulation] GDPR is an issue, but it's not only a blockchain issue – it's a normal database issue. Until we have digital identity with the ability amass people's private information, we're going to continue to have this issue."*

Specific to FSC,

> *"…in the food industry [supply chain] contracts are usually extended from the buyer to the seller, not from the seller to the buyer; this means that conventionally the obligations [such as due care] are usually driven much more buy the buyer than the seller. In the agricultural environment, very few commodities had the ability to actually dictate how things are done, except in the very big markets like palm oil…until [smart contracts executed via BCT] are recognized in the court of law as a means of enacting commerce somebody can go back and say "I didn't agree to this" and "I don't want to do this".* (Practitioner-Expert F).

The 'Technical issues' (T) was ranked as the lowest barrier category within each of the fuzzy Delphi and AHP analyses. Fundamentally, as noted by Practitioner-Expert F, the focus is on delivering what the clients ask for: *"…if we deliver what the clients ask, then it's functional, and it works*." However, this tends to lead to high levels of customization for each distinct client, and thus affects the longer-term scalability of BCT innovations: *"…the next step is to build a more modular system that [can be] more scalable and more industrial."*

The application of blockchain needs a lot of advanced technology support, including algorithm, optimal operating platform, and powerful computing power (Golosova and Romanovs, 2018). In addition, its own technical features should also be noted, such as the establishment of consensus mechanism. 'Optimum platform/data-enabled infrastructure' and 'Computing (Processing) Power' are listed top priority in this category. As information technology, its application is based on powerful and thorough algorithms, and requires a certain scale of computers and servers to provide computing power (Golosova and Romanovs, 2018). These barriers can be linked in part to 'Funding' issues, and it is this technical requirement that leads to the high demand for capital. Per Practitioner-Expert B:

> *"…the actual thing I have to think about is the…energy consumption when it comes to blockchain technology. If you factor in a developing or underdeveloped country where a farmer doesn't even have a cell phone. They certainly don't even have any access to technology or internet. Is this a good idea if you cannot reach your audience? I would argue that might actually defeat the purpose of the whole thing."*

We capture the "operational effectiveness" views from the 6 expert respondents in Figure 5. The practitioners were exposed to the definition of "Operational Effectiveness" from Evans and Lindsay (2011) and Porter (1996) which deals with establishing the core capabilities within organisations, improvements, measurements, and exceeding customer expectations. While practitioners agreed with is definition, there was a consensus of operational effectiveness as very important for firm-actors in circular food supply chains. According to a respondent, the knowledge of these risks can either slow or improve operation effectiveness. Their views support the literature perspective where, according to Porter (1996) and Santa et al, (2014), a better use of resources (or understanding of the degree of the risks) can enable the organisation to "eliminate waste, reduce costs and adapt more relevant technologies, thereby outperforming their competitors. However, practitioners noted that for these risks to be useful in circular supply chains, several variables need to be considered:

> *"When I am talking about operational effectiveness, I am speaking about making it measurable, creating relevant industry benchmarks, and correctly defining BCT as a technology that isn't a solution, but can lead to a solution depending on its application"* Per Practitioner-Expert B

Furthermore, there was consensus that the emergent nature of BCT would imply that operational effectiveness would have to be redefined to fit the challenges of BCT implementation. The "sustainability" concerns of BCT mining was identified as required in such a definition as the "destructive technology" potentials of BCT is required to support CFSC managers' decision making for BCT adoption. This position is corroborated with Practitioner Expert C who cautioned that a refusal to acknowledge the implications of these risks on operational effectiveness may lead to the sustainable challenges managers have faced with similar technologies:

> *"Is there actually a need for Blockchain? And food supply chain? Because where problem is, some of these problems you've highlighted here is similar in any industries in terms of digital transformation generally. Blockchain technology is just another strain of technology. Clarifying what operational effectiveness is for these risks must establish industry standards, so we are not replicating what existing technology can do" (Practitioner Expert C)*

This clarity is essential for CFSCs firms if they are to reduce potential costs inherent with new technologies. As argued by (Jamieson and Hyland, 2004), there is a very high failure rate experienced in the implementation of new and expansive innovative technological projects, if they do not succeed in delivering the promised outcomes. (This is why several Experts suggested that Blockchain must be identified to solve more localised problems for actors in the FSC, if the FSC will be circular and will meet the needs of smaller stakeholders). Jamieson and Hyland (2004) further suggest that it is difficult to know the real failure rate of new innovation technologies, as it could be larger than reported by firms. As a consequence, Santa et al (2014) suggests that it is necessary to define and gain a comprehensive set of measures that enables the proper identification of the new technologies as well as the improvements in performance after the implementation of technologies such as BCT. This is an important feedback for managers and decision makers within the CFSC ecosystem. Finally, we capture further barriers identified from the semi-structured interviews with experts (shown in Table 8). These new barriers while not captured in the literature, are vital in achieving operational effectiveness for FSC managers.

Table 8: New Barriers and their Potential Mitigation.

Barrier to Blockchain Integration	**Reason for Barrier**
Trust issues relating to a lack of standards regarding Blockchain use	No set of national or international standards exist for unified Blockchain use. Some managers lack experience and understanding of Blockchain and therefore do not trust the technology.
Poor general understanding of what Blockchain can and cannot do (combating the 'silver bullet' solution myth – the assumption that Blockchain can resolve all information security problems)	The general lack of understanding regarding Blockchain can also lead to problems in identify how the technology can be used within Food and other sector supply chains. Uncertainty is also fostered by generic beliefs of Blockchain being a solution to all SCM problems.
Scale of integrating all links in the supply chain is too great	There is a fear that the cost of implementing Blockchain in a supply chain will be too high.
Concerns relating to Blockchain ownership and possibility of 3rd party hijacking	Lack of trust issues may extend to the nature of Blockchain as it is delivered as a distrusted 3rd party hosted application. Concerns exist about the ability of cyber hackers to take over an existing chain.
Costs of implementation – especially for SME supply chain participants	There is also the question of who pays for this technology introduction and operation in terms of SME partners, who may struggle to afford the implementation of Blockchain in their operation?
How do you verify suppliers outside your home country in the supply chain - trust and provenance issues still exist, even with Blockchain	Blockchain may not address pre-existing concerns about trust and provenance of supply within existing chains.
Energy consumption of Blockchain processing infrastructure is too high	Blockchain infrastructure and in particular server farms have high energy needs and may make significant contributions to carbon emissions in their operation.

5. Study Limitations, Conclusion and Future Research Agenda

The methodology of this study was limited by the sample size and the distribution of the original opinions of the experts. It can be observed that the difference between each category and the difference between each sub-barrier in the category is relatively small,. The main problems and limits lie in the AHP method. Since there are experts who hold almost opposite opinions on every barrier in original questionnaire data, the maximum and minimum values in the computation are very similar. In this work, the opinions of 16 experts were used to obtain accurate conclusion from the survey results. However, the experts responses were more divergent than expected, due to each distinct experience. These experts have different work and educational backgrounds, some are practitioners, some are related researchers. This may cause experts to have different views when thinking about problems, and they may get different answers when looking at problems from the perspective of research or practical work. We attempt to mitigate this limitation by introducing 6 new experts for the analysis of operational effectiveness with respect to the identified risks.

From practitioner feedback it is apparent that the study of contemporary BCT applications is somewhat limited by the nascence of the technology, as well as its continuous iteration and innovation. Table 9 summarises the main research gaps identified from the analysis of both literature and the views of the expert panel:

Table 9: Research Gaps identified for BCT-CFSC integration study

Barrier to Blockchain Integration	**Research Gap to be Addressed**
Lack of a framework to decide when a supply chain should (or should not) migrate to Blockchain use	A framework needs to be developed to allow organisations to evaluate the state of their supply chains and assess at what point a switch to Blockchain would provide a net benefit (cost/benefit analysis for Blockchain in Food SCM) Studies are needed to examine the use of alternative SCM security solutions from both the cryptocurrency/distributed ledger area and the Artificial Intelligence field (then comparison with Blockchain may be made)
Current Blockchain knowledge by supply chain/organisation managers is poor	Education programmes need to be produced, along with communication about technology use and potential relevance to different sectors of the economy
Energy consumption of Blockchain infrastructure is too high and speed of software execution is too slow	Development of processing optimisation in software code and hardware infrastructure. Development of research to minimise energy needs and emissions from server farms.
Investment requirements and ownership of Blockchain ‘roll out’ within a supply chain	Development of an analytics based cost/benefit framework for the evaluation of Blockchain in a given SCM

	Methodology and process development to support Blockchain roll out programmes Studies into join ventures and large organisation investment programmes and vehicles targeted at investing in SME supply chain partners IT infrastructure
Trust and provenance issues still exist even with Blockchain use and the technology is more associated with the protection of services rather than goods	Integrated studies into the development and linkage with IoT technologies to verify origin, quality and safety through SCM transit of food products; with Blockchain as just one of multiple verification technologies and stages. Linking digital technology with physical objects/products in transit – studies involving RFID (Radio Frequency Identification) tagging and IoT technologies beyond this such as distributed Edge processing.
Lack of internationally recognised standards for Blockchain use regarding data needs and privacy protection – especially the integration of differing national GDPR requirements (or lack of)	Studies into the development of an international minimal acceptable set of parameters for trans-national supply chains. Investigation into the need for international standards development (e.g. ISO) or a validating body for standards.

The FSC is closely related to human daily life and provides the necessary food for human survival. It is this close relationship that makes any problems in the FSC immediately spread to people. The complex interrelation in the FSC and numerous stakeholders make the information flow inefficient. Once there is a problem in a certain link, it is impossible to respond quickly and the relevant information cannot be traced efficiently. To solve the problem of information flow and invocation, BCT has been introduced into the FSC to facilitate the rapid and transparent flow of information. This project focuses on the barriers encountered by the application of BCT in the FSC, and tries to use scientific computation to reveal the importance of these barriers, so as to provide a reference for industrial practical applications. The main contributions of this paper include:

1. According to the preliminary investigation and literature review, the barriers that may be related to the introduction blockchain were determined. Combined with the expert opinions, the barriers with low correlation were eliminated by the fuzzy Delphi method to obtain the list of barriers to the application of blockchain technology in the FSC.

2. According to expert opinions and literature review, all barriers were reasonably classified, including six categories: Security and laws (SL), Funding (FD), Technical issues (T), Functionality (FT), Organisational issues (O), Business environment (BE). Then fuzzy analytic hierarchy process was used to identify the priority of all categories and sub-barriers.
3. The final priority ranking of categories is: (1) Organisational-(2) Functional-(3) Business Environment-(4) Funding-(5) Security and Laws-(6) Technical. The results show that organizational issues are considered to be the most significant barriers to the introduction of BCT, despite divergence in expert experiences and opinions.
4. A brief analysis of all barriers and categories is made. We find that while the barriers can influence BCT and circular food supply chain integration, their individual impacts are not as significant in weighting and degree. Generally, they are varied and should be given holistic consideration by implementation managers.
5. Finally, clarification of the importance of these identified barriers with respect to operational effectiveness of firms within CFSCs ecosystem is crucial for effective deployment of BCT in circular food supply chains.

Our findings provide a nascent measurement and understanding for empirical work and a foundation for industrial applications for blockchain technology in circular food supply chains. As BCT is still an emerging digital technology whose application has largely been focused on the financial and gaming industries, food supply chain practitioners have been very limited knowledge of how best to deploy the technology. Furthermore, operations management (OM) and other academics and practitioners are turning their attention to the BCT related areas of visibility, transparency and traceability in their supply chain (Sodhi and Tang, 2019; Hastig and Sodhi, 2020). Taking this into consideration and the findings in this paper we strongly suggest that future research agenda should focus on removing the barriers identified in Table 5 and exploring the suggested mitigations, in addition to the gaps identified in Table 6.

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