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Blockchain implementation for circular supply chain management: Evaluating critical success factors

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ABSTRACT

Blockchain technology implementation in a circular supply chain management (CSCM) context is an emerging topic that involves complex processes and diverse goals. This study aims to develop a framework that describes the main phases of Blockchain-enabled CSCM and evaluates the critical success factors of Blockchain implementation for CSCM. Further, we employed a combined analytical hierarchy process (AHP) and decision-making trial and evaluation laboratory (DEMATEL) method to explore the priorities and relationships of success factors using evaluations from academic and professional experts. The outcome of the AHP analysis shows that the success factors related to technology, such as technical capability, technological maturity, and technological feasibility, play critical roles in CSCM. Furthermore, the DEMATEL analysis suggests that knowledge training and data security should be regarded as essential causal factors influencing other factors. The results provide a possible path for determining critical success factors and facilitating Blockchain-enabled CSCM.

1. Introduction

With climate change and resource scarcity, circular supply chain management (CSCM) has received consistent attention from scholars and practitioners over the last few years (Gong, Jiang, & Jia, 2021; Govindan & Hasanagic, 2018; Jia, Gong, & Brown, 2019; Zheng, Li, Liu, Jia, & Leve, 2021). The term has been defined as "the coordinated forward and reverse supply chains via purposeful business ecosystem integration for value creation from products/services, by-products and useful waste flows through prolonged life cycles that improve the economic, social and environmental sustainability of organizations" (see Batista, Bourlakis, Smart, & Maull, 2018, p. 446). CSCM provides an opportunity for traditional supply chain management (SCM) transformation to optimize resource allocation and promote sustainable production and consumption through new business models based on circular economy ideas (Fehrer & Wieland, 2021; Ünal, Urbinati, Chiaroni, & Manzini, 2019). For instance, utilizing a multi-tiered supply chain structure helps improve resource utilization, overcome technical limitations, and understand consumption patterns (Tseng, Chiu, Liu, & Jantaralolica, 2020). Employing a CSCM strategy enhances the resilience and sustainability of automotive supply chains, and the primary resource requirements are reduced correspondingly (Baars, Domenech, Bleischwitz, Melin, & Heidrich, 2021). However, companies face several challenges, including financial viability, product complexity, management coordination, user behavior, and marketing competition when redesigning supply chains for the circular economy (Bressanelli, Perona, & Saccani, 2019; Zhu, Ziqi, Xiaowei, Fu, & Yuxi, 2022).

New technologies have been recognized as innovative approaches to meet these challenges and enhance the management of circular supply chains (CSCs) (Henry, Bauwens, Hekkert, & Kirchherr, 2020; Liu, Zhu, & Seuring, 2020). These new technologies for business model practices may involve the Internet of Things (Suppatvech, Godsell, & Day, 2019), Blockchain (Kouhizadeh, Zhu, & Sarkis, 2020), artificial intelligence (Benzidia, Makaoui, & Bentahar, 2021), 3D printing (Santander, Cruz Sanchez, Boudaoud, & Camargo, 2020), robotics, and automation (Sarc et al., 2019; Stackpole, 2020). They provide multiple solutions in digital information management, business process reengineering, and optimization strategy implementation, which facilitate a sustainable competitive advantage (Lahane, Kant, & Shankar, 2020; Nandi, Sarkis, Hervani,

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& Helms, 2021). Consistent with the technology acceptance model application (Albayati, Kim, & Rho, 2020), the implementation process of introducing new technologies into CSCM has become a complex system because of the participation and collaboration of multiple entities (Mangla et al., 2018). Hence, managers must promote the integration of business models and new technologies to meet customer expectations more efficiently and conveniently.

Ensuring SCM information trust is an increasingly urgent issue for establishing integration between new technologies and CSCs (Hastig & Sodhi, 2020; Mejías, Bellas, Pardo, & Paz, 2019). Blockchain technology, a shared and immutable ledger for recording transactions and tracking assets, is highly regarded as facilitating traceability in SCM (Sunny, Undralla, & Pillai, 2020). During the transition from a traditional supply chain to a CSC, managers promote various activities such as reverse logistics design, closed-loop supply chain design, industrial symbiosis collaboration, and green marketing strategy. Core information parameters, such as product demand, transaction price, delivery period, resource recycling rate, and greenhouse gas emissions, are certainly the focus of supply chain stakeholders (Zhu & Kouhizadeh, 2019). Specifically, Industry 4.0, traceability, and transparency may emerge as important aspects in designing circular Blockchain platforms in supply chains(Kouhizadeh, Saberi, & Sarkis, 2021; Saberi, Kouhizadeh, Sarkis, & Shen, 2019). Some industry sectors integrate the development of Blockchain technology and CSCs through specific business models coordinated by governments or academic institutions. Circularize, a Blockchain-enabled plastics recycling start-up, received support from the European Commission H2020 project (Konstantinov, 2019). The BASF, a global chemical multinational corporation, started an innovative pilot Blockchain project aimed at improving the circular economy and traceability of recycled plastics (Meischen, 2020). Accenture is working with Amazon Web Services, using services such as Amazon managed Blockchain to create a vision of the circular supply chain combining supply chain, Blockchain, identity, biometrics, and payment capabilities(Treat, 2018). In the farming example shown in Fig. 1, a farmer may produce about 500 pounds of fair-trade organic coffee a year and get around $1.30 a pound, or $650 a year, for coffee that can retail in the US for $20 a pound. Consumers who want to buy responsibly are often at a disadvantage and unable to see or influence an economic model that exacerbates income inequality. The solution provided by Accenture, with the help of Blockchain and artificial intelligence, offers full visibility of a supply chain from the producer to the consumer, and even beyond recycling and reuse.

Moreover, the academic community has an increased interest in research on Blockchain technology in SCM and CSCM contexts. Hastig and Sodhi (2020) investigated two industry cases and develop a hierarchy criteria system for implementing Blockchain for supply chain traceability to evaluate the critical success factors. Zhang, Zhong, Farooque, Kang, and Venkatesh (2020) established a framework to guide the implementation of Blockchain-based life cycle assessment. They provide a novel architecture that integrates Blockchain and big data analytics applications to discuss potential issues and policy implications. Esmaeilian, Sarkis, Lewis, and Behdad (2020) offered an overview of Blockchain technology and Industry 4.0 for facilitating CSCM implementation.

Furthermore, this research discusses the technological capabilities of Blockchain that can contribute to the development of a circular economy and relevant future research directions. To reduce package waste, Ajwani-Ramchandani et al. (2021) applied a case study to explore an approach that uses Blockchain and artificial intelligence. These latest studies present a significant discussion on related concerns and develop new avenues to explore the practice of implementing Blockchain for the supply chain circularly.

Although relevant research and practice are increasing gradually, the application and implementation of Blockchain-enabled CSCM continue to experience difficulties. Blockchain is still in the initial stages of technological development. Insufficient knowledge of the system architecture, technology implementation, and application scenarios affects CSCM managers (Saberi et al., 2019). Inconsistent communication between technical engineers and business managers is a common issue in the introduction of new technologies. On the CSCM side, their complex structure adds obstacles and barriers to enabling Blockchain technology (Wang, Han, & Beynon-Davies, 2019). The conflict among the multiple objectives of Blockchain-enabled CSCM also causes system risk (Tsao & Thanh, 2021). To the best of our knowledge, there has been limited research on the implementation of emerging Blockchain technologies for CSCM. The general criteria framework of Blockchain-technology-enabled CSCM has been insufficiently described. Furthermore, the critical success factors of Blockchain technology application CSCM have been rarely explored and evaluated. However, these concerns have not yet been addressed.

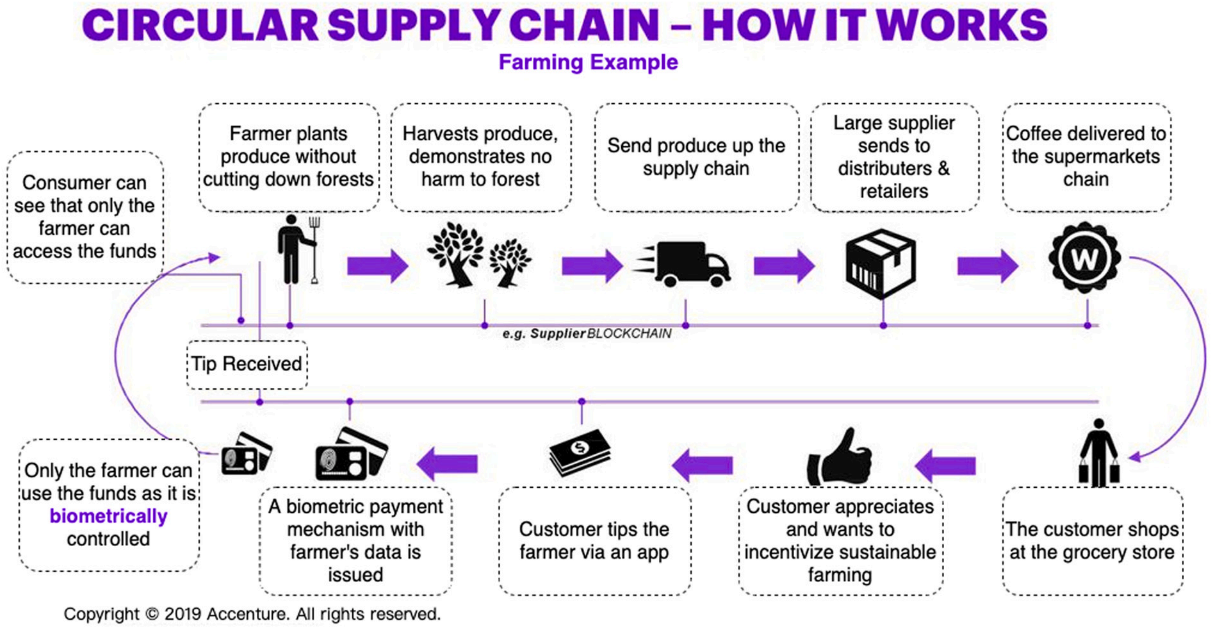

Fig. 1. Accenture's solution of Blockchain-enabled CSCM (Treat, 2018).

Motivated by the above challenges and gaps, this study seeks to review the literature on Blockchain-enabled CSCM implementation and to design an approach to assess the critical success factors of project implementation through opinions from different professionals. By expanding the evaluation system of Hastig and Sodhi's (2020) research, we identified a hierarchy criteria system that includes success factors. Concurrently, we searched three streams of literature, namely, Blockchain technology, integration of Blockchain technology and CSCM, and CSCM, for criteria determination. An integrative implementation framework is developed for Blockchain-enabled CSCM. To the best of our knowledge, this study is the first to focus on evaluating the critical success factors of Blockchain-enabled CSCM. In this study, we aim to apply multi-criteria decision-making (MCDM) approaches utilizing a panoramic view to assist supply chain managers in implementing CSCM in the new emerging Blockchain technology context. This study integrates Hastig and Sodhi's (2020) recent work in Blockchain applications in supply chain traceability and works in circular management, such as Kouhizadeh et al. (2021) and Saberi et al. (2019). By contrast, this study does not intend to refine the content of Blockchain applications in supply chains or circular management. Instead, from an integrative perspective, this study seeks a close combination of the two and then explores how to improve the successful implementation of Blockchain-based circular supply chains. We use a combined analytical hierarchy process (AHP) and decision-making trial and evaluation laboratory (DEMATEL) (hereafter, AHP-DEMATEL) method to specify the weights and relationships of success factors for Blockchain technology-enabled circular supply chain management. Finally, relevant insights are revealed to help managers improve the efficiency of the implementation process. The research process is illustrated in Fig. 2.

The remainder of this paper is organized as follows. Section 2 reviews the literature and summarizes the relevant factors. The proposed methodology and the AHP-DEMATEL solution are described in Section 3. Section 4 presents the data collection and analysis. Section 5 presents a discussion and its implications. Finally, Section 6 presents the conclusions of this study and outlines the future research directions. Table A4 in the appendix includes the term explanations for all the abbreviations used in this study.

2. Literature review

2.1. Integrative framework

Blockchain technology and circular supply chains are two fundamental concepts of Blockchain-enabled circular supply chain management (Wang, Luo, Zhang, Tian, & Li, 2020). The external environment and internal factors of each organization change when applying Blockchain technology to enable circular supply chain management (Saberi et al., 2019). An integrative framework can identify various conceptualizations of these complex organizational activities (Eggert, Kleinaltenkamp, & Kashyap, 2019; Lemoine, Hartnell, & Leroy, 2019). Moreover, contingency theory is applied to identify important concepts and construct an integrative framework in the proposed literature review (Volberda, Van Der Weerdt, Verwaal, Stienstra, & Verdu, 2012). The idea of contingency theory has been adopted and examined in the research of new technologies, such as big data analysis and artificial intelligence pathway investigation (Boone, Hazen, Skipper, & Overstreet, 2018; Dubey et al., 2020).

Following Hastig and Sodhi (2020), we propose an integrative framework to conduct a literature review and analyze the vital criteria of Blockchain technology that enable CSCM, as shown in Fig. 3. Three stages, namely, Blockchain technology, integration, and CSCM, are described separately. Notably, we have embedded and highlighted the practice of CSCM in this framework. A subsequent literature review is conducted based on this framework.

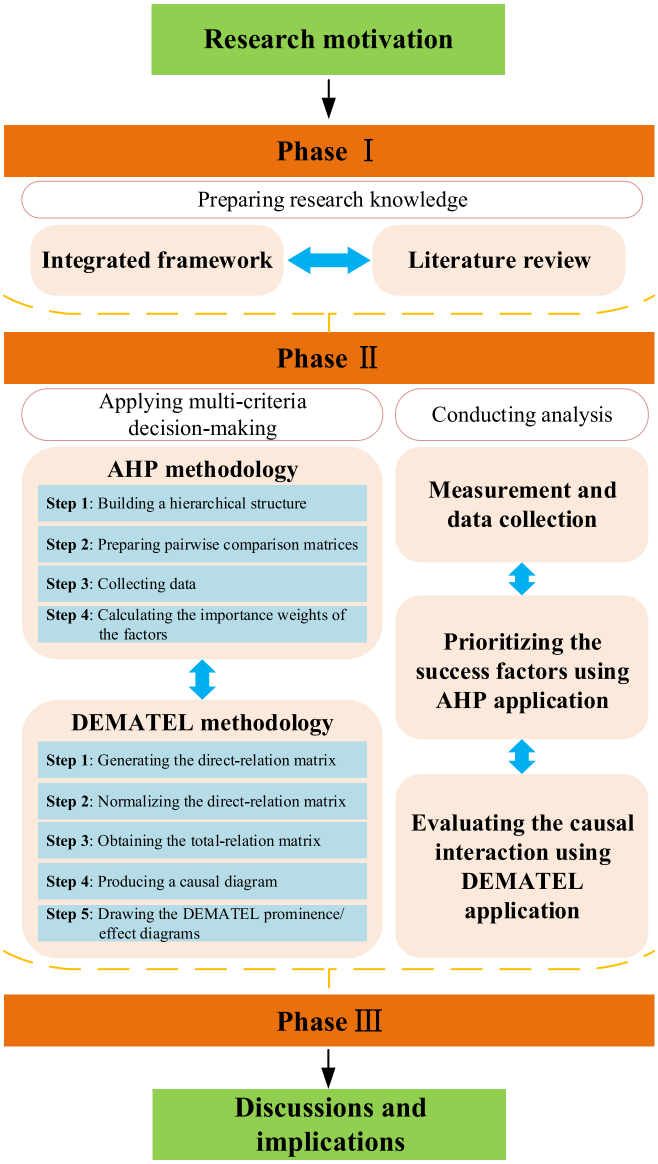

Fig. 2. A flow chart of the combined AHP-DEMATEL process.

2.2. Blockchain technology

Blockchain is gaining considerable attention in industries such as entertainment, retail, philanthropy, automotive, and healthcare (Cole, Stevenson, & Aitken, 2019; Liu, Liu, Mou, & Wang, 2020). Nakamoto (2008) published the fundamental paper on Blockchain technology, titled “Bitcoin: a peer-to-peer electronic cash system.” Thereafter, research into and applications of Blockchain have emerged in various areas (Pazaitis, de Filippi, & Kostakis, 2017; Saberi et al., 2019; Zhao, 2019). Blockchain technology, which provides a distributed platform for data recording and transactions, has become a prominent option for supply chain companies to implement informatization and digitization (Wang, Chen, & Xu, 2016).

Technological readiness forms the basis for Blockchain technology development and implementation (Hastig & Sodhi, 2020; Treiblmaier & Beck, 2018). In Hastig and Sodhi's (2020) framework, the criteria for technological readiness cover three success factors: a) *technology maturity*, b) *data security*, and c) *technical feasibility*. First, technological maturity includes application examples of emerging technologies, technical adaptability, infrastructure completeness, and other requirements. However, significant equipment investment and time-

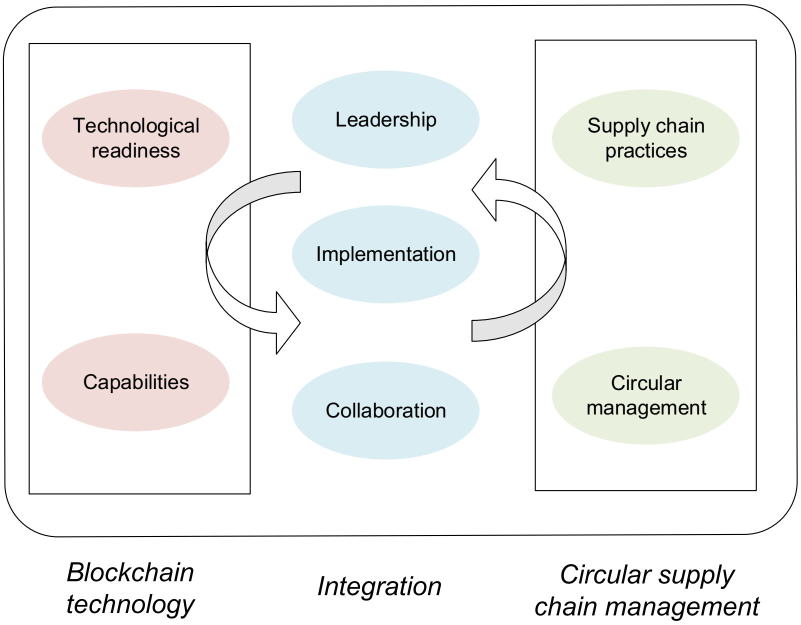

Fig. 3. Integrative framework of Blockchain implementation for CSCM.

consuming calculations restrict the promotion and application of Blockchain technology (Wang et al., 2016). Second, data security covers system vulnerabilities, user privacy, platform credibility, data credibility, and data governance. Effective data security is the premise for ensuring that transactions based on Blockchain technology are generally trusted (Esposito, de Santis, Tortora, Chang, & Choo, 2018). Third, operational cost analysis, energy consumption of hardware facilities, and hardware scalability are vital points of technical feasibility. Companies must measure both the cost-effectiveness and feasibility of implementing Blockchain technology (Chod, Trichakis, Tsoukalas, Aspegren, & Weber, 2020).

Capability is another widely valued criterion. It refers to the technical resources and competencies a company needs to carry out its operational activities (Pan, Pan, Song, Ai, & Ming, 2020). Within Hastig and Sodhi's (2020) framework, the criteria for capabilities contain three success factors: a) *technical capability*, b) *organizational readiness*, and c) *other capabilities for bringing about change*. Technical capability refers to the ability to deploy information technology and the skills required to operate information systems. The insufficient capability to apply Blockchain technology often prevents enterprises from conducting business based on Blockchain (Morkunas, Paschen, & Boon, 2019; Pan et al., 2020). Second, technical knowledge reserves, information system project management levels, and technical team composition are the core concepts of organizational readiness. Uslay and Yeniyurt (2018) investigate the positive role of technology experts in Blockchain implementation. Clohessy and Acton (2019) explore the impact of organizational factors on Blockchain adoption. Finally, operating conditions, cash flow, and investment sustainability are also important factors for enterprises to deal with technological changes (Esposito et al., 2018; Pan et al., 2020).

2.3. *Circular supply chain management*

Hastig and Sodhi (2020) pointed out supply chain practice as one criterion for Blockchain implementation. In the context of Blockchain implementation, information capture and the operations model are argued to be success factors driving supply chain practices. Information capture involves timely and accurate data processing, supply chain performance capture, and maintenance of the information infrastructure (Zhu & Kouhizadeh, 2019). Efficient data storage, processing, and timely data sharing can help improve supply chain performance, particularly traceability (Gaur & Gaiha, 2020). Well-practiced operational models of data management and information maintenance among suppliers and partners may greatly promote Blockchain implementation in supply chain practices (Agrawal, Kumar, Pal, Wang, & Chen, 2021). In addition, knowledge training, which includes skills, guidance, and failure correction, is also important (Chang et al., 2020) and has been listed as another success factor in supply chain practice.

The goal of this study is to explore the success factors of Blockchain implementation in CSCM. We selected circular management practices on the CSCM side as a criterion. (Geng, Mansouri, Aktas, and Yen (2017) developed a conceptual framework that characterizes the drivers and barriers to the adoption of green supply chain management practices. Kouhizadeh et al. (2020) introduced several cases, describe the implementation method of a circular economy based on Blockchain technology, and explored how Blockchain technology promotes the realization of a circular economy. Ajwani-Ramchandani, Figueira, Torres de Oliveira, and Jha (2021) analyzed two cases in India to illustrate the specific practices and impacts of using Blockchain in a circular economy. These results demonstrate the importance of the circular approach. Quintana-Garca, Benavides-Chicón, and Marchante-Lara (2021) tested a set of hypotheses in panel data of European manufacturing companies for a period of ten years to gain further knowledge regarding the impact of strategies oriented to green supply chain management on a firm's corporate reputation.

Moreover, several studies have shown that information disclosure is another success factor of Blockchain technology in cycle management. Circular management requires that all kinds of information in the supply chain, such as corporate responsibility, carbon emissions, and pollutant emissions, be disclosed in a timely manner (Cui & Leonas, 2020). Once the Blockchain mechanism is adopted, the content of information disclosure about CSCM cannot be tampered with (Dutta, Choi, Somani, & Butala, 2020).

2.4. *Integration of Blockchain technology and CSCM*

Integration has become an important practice in modern supply chain management(Liu, Wei, Ke, Wei, & Hua, 2016; Queiroz, Telles, & Bonilla, 2019; Wang, Jia, Schoenherr, Gong, & Chen, 2020). Practically, the process of Blockchain technology that promotes CSC management involves the integration of the two approaches (Saberi et al., 2019). For example, Wang et al. (2019) conducted a systematic review to analyze how Blockchain may influence future supply chain practices and policies.

Hastig and Sodhi (2020) emphasized the function of leadership. Leadership, both inside and outside stakeholders, is crucial for Blockchain's implementation in the supply chain (Kouhizadeh et al., 2021). Leadership promotes partner membership within the supply chain and helps firms seek support from outside technology and resources (Chen, Li, & Zhang, 2021; Jeppsson & Olsson, 2017). Leadership provides a strong driving force for the smooth implementation of SMEs' Blockchain projects (Britchenko, Cherniavska, & Cherniavskyi, 2018).

Hastig and Sodhi (2020) introduced three success factors of collaboration: a) *goal alignment*, b) *partnership trust*, and c) *stakeholder participation*. First, goal alignment includes information sharing, management of conflicting objectives, common standards of product production, and collaboration of management processes. Goal alignment guarantees the integration of Blockchain technology implementation (Sheel & Nath, 2019). Second, the concept of partnership trust may include information exchange, proper authorization, and process transparency mechanisms. Howson (2020) investigated Blockchain technology's application to enhance the role of trust in marine conservation and fisheries SCM. Third, stakeholders are a comprehensive concept that includes supply chain operators, participants, governments, and other organizations and their cultures. Stakeholder participation in the implementation phase plays a vital role in CSCM development (Rane, Thakker, & Kant, 2020).

Implementation is the core link in the integration of Blockchain technology and CSCM. To ensure that the effective integration of Blockchain and CSCM plays an active role in a complex CSC, all types of resources focus on this link (Esmaeilian et al., 2020; Hastig & Sodhi, 2020; Lumineau, Wang, & Schilke, 2021). The novelty of Blockchain technology and the complexity of CSCM make it time-consuming and laborious to import Blockchain technology into CSCM. Hardware, human resources, and power require financial support (De Angelis, Howard, & Miemczyk, 2018). Blockchain implementation in CSCM is also influenced by government policies, particularly in developing countries. The Chinese government announced that Blockchain would be included in the new infrastructure strategy (Ølnes, Ubacht, & Janssen, 2017). In addition, similar to other information technologies, Blockchain's implementation inevitably encounters various risks. The complexity of CSCM makes risk management more urgent (Drljevic, Aranda, & Stantchev, 2020). Thus, we argue that implementation is an essential criterion in the integration of Blockchain and CSCM. According to the literature, there are three success factors corresponding to the implementation criteria: a) *cost control*, b) *government policies*, and c) *risk management*.

2.5. Criteria and success factors system

Following the structure of Fig. 3 and the content of the literature review, we list the criteria and success factor system to empirically evaluate the success factors of Blockchain implementation for circular supply chain management, as shown in Table 1 and Table 2. Correspondingly, the codes and literature sources for the criteria and success factors are listed.

Specifically, Table 1 shows the criteria system for Blockchain-enabled CSCM. The three primary criteria are “Blockchain technology (C1),” “Integration(C2),” and “Circular supply chain(C3).” “Blockchain technology(C1)” mainly covers criteria on the technology side, which are “Technological readiness(C11)” and “Capabilities(C12).” “Integration(C2)” mainly covers criteria for the integration of Blockchain technology and the circular supply chain, which are “Leadership(C21),” “Collaboration(C22),” and “Implementation(C23).” “Circular supply chain(C3)” mainly covers criteria on the circular supply chain practices, which are “Supply chain practices(C31)” and “Circular management (C32).” Table 2 presents the success factor system for Blockchain-enabled CSCM corresponding to the criteria system in Table 1.

Table 1
Criteria system for Blockchain-enabled CSCM.

Criteria	Code	sub-criteria	Code	Reference-Author (year)
Blockchain technology	C1	Technological readiness	C11	Hastig and Sodhi (2020); Treiblmaier and Beck (2018)
		Capabilities	C12	Hastig and Sodhi (2020); Pan et al. (2020)
Integration of Blockchain technology and CSCM	C2	Leadership	C21	Hastig and Sodhi (2020); Pan et al. (2020); Kouhizadeh et al. (2021)
		Collaboration	C22	Hastig and Sodhi (2020); Pan et al. (2020); Lumineau et al. (2021); Saberi et al. (2019)
		Implementation	C23	Hastig and Sodhi (2020); Pan et al. (2020); Lumineau et al. (2021); Esmaeilian et al. (2020)
CSCM	C3	Supply chain practices	C31	Hastig and Sodhi (2020); Kouhizadeh et al. (2020); Saberi et al. (2019)
		Circular management	C32	Kouhizadeh et al. (2021); Saberi et al. (2019)

3. Research methodology

To achieve the objectives of this research, a combined AHP-DEMATEL approach is used as the analytical technique. This technique has the advantage of quantifying the subjective judgments of experts in a manner that can be measured and evaluated (Büyüközkan & Güleryüz, 2016; Tseng, 2011). We jointly apply the AHP and DEMATEL methods because a single method is not sufficient for a complete and correct analysis of the problem in this study.

As a well-established MCDM methodology, the AHP has been used by supply chain management (SCM) scholars to structure and evaluate a number of defined successful factors for SCM (Saaty, 1987). And, the AHP is often applied by decision-makers to effectively incorporate numerous factors in solving complex problems. However, decision-makers may ignore the interdependencies among success factors when capturing success factors directly by using AHP. DEMATEL can evaluate the complex interrelationships among factors by classifying them into cause-and-effect clusters (Gandhi, Mangla, Kumar, & Kumar, 2016), which leads to a hierarchical structure for effective solutions (Yang, Shieh, Leu, & Tzeng, 2008). Furthermore, focusing only on DEMATEL might lead to a passive position because it is not clear which success factors are more critical, resources could be wrongly allocated consequently (Chen, Lien, & Tzeng, 2010; Tzeng, Chiang, & Li, 2007).

To effectively incorporate numerous factors in solving complex problems, decision-makers often apply MCDM methodologies and structural modeling approaches. According to Kumar et al. (2017), MCDM models are designed to evaluate alternatives for a small group of experts to help them make decisions involving multiple criteria and alternatives. As a well-established MCDM approach, AHP has been applied by SCM scholars to structure and evaluate a number of defined successful factors for SCM (Wu, Tseng, Chiu, & Lim, 2017). DEMATEL has also been applied in studies related to SCM such as success factor analysis (Gandhi et al., 2016) and Blockchain adoption (Biswas & Gupta, 2019). The AHP-DEMATEL technique has been widely used in the literature on circular supply chains (e.g., (Biswas & Gupta, 2019; Gandhi et al., 2016)). The aim of this study is to develop a framework that

Table 2
Success factor system for Blockchain-enabled CSCM.

sub-criteria	Code	Success factors	Code	Reference-Author (year)
Technological readiness	C11	Technology maturity	C111	Wang et al. (2016)
		Data security	C112	Esposito et al. (2018)
		Technological feasibility	C113	Chod et al. (2020)
Capabilities	C12	Technical capability	C121	Morkunas et al. (2019)
		Organizational readiness	C122	Clohessy and Acton (2019); Uslay and Yeniyurt (2018)
		Other capabilities for change	C123	Esposito et al. (2018); Pan et al. (2020)
Leadership	C21	Internal leadership within firm	C211	Jeppsson and Olsson (2017); Chen et al. (2021)
		External leadership with stakeholders and in supply chain	C212	Jeppsson and Olsson (2017), Chen et al. (2021)
Collaboration	C22	Goal alignment	C221	Sheel and Nath (2019)
		Partnership trust	C222	Howson (2020)
		Stakeholder buy-in	C223	Rane et al. (2020)
Implementation	C23	Cost control	C231	De Angelis et al. (2018)
		Government policies	C232	Ølnes et al. (2017)
		Risk management	C233	Drljevic et al. (2020)
Supply chain practices	C31	Information capture	C311	Gaur and Gaiha (2020); Zhu and Kouhizadeh (2019)
		Operational model	C312	Agrawal et al. (2021)
		Knowledge training	C313	Chang et al. (2020)
Circular management	C32	Circular approach	C321	Ajwani-Ramchandani, Figueira, Torres de Oliveira, and Jha (2021); Kouhizadeh et al. (2020)
		Information disclosure	C322	Cui and Leonas (2020); Dutta et al. (2020)

Table 3
Significance of scores in AHP.

Score	Definition
1	Item *i* and item *j* are of equal importance.
3	Item *i* is weakly more important than item *j*.
5	Item *i* is strongly more important than item *j*.
7	Item *i* is very strongly more important than item *j*.
9	Item *i* is absolutely more important than item *j*.
2, 4, 6, 8	Intermediate values between the two adjacent judgments.

describes the main phases of Blockchain technology-enabled CSCM and evaluate the complex relationships among success factors. Therefore, the AHP-DEMATEL method is employed to fulfill the goals.

3.1. AHP methodology

AHP is a multi-criteria, multilevel decision model that develops priority weights for items based on decision-makers' professional evaluations (Wu et al., 2017). For the purpose of this study, we also adopt AHP to evaluate the success factors consisting of the goal, strategic factors, criteria, and sub-criteria discussed earlier. A systematic approach consisting of four steps is followed.

Step 1: *Building a hierarchical structure*. This step involves formulating an appropriate hierarchy of the AHP model, consisting of the goal, strategic factors, criteria, sub-criteria, and alternatives.

Step 2: *Preparing pairwise comparison matrices*. To develop priority weights for items, our participants were asked to complete a pairwise comparison based on two items at a time.

Step 3: *Collecting data*. The AHP data collection procedure described by Vidal Vieira, Ramos Toso, da Silva, and Cabral Ribeiro (2017) was adopted in this study. Thus, a structured group (see Table 3) encounters the review problems, discusses the factors/items at hand (a leader is in charge of asking questions, and making interpretations or explanations), and votes on factors/items based on a pairwise comparison table. The participants were also instructed to use the following nine-point scale system to assign their judgments: We select a numerical value A_{ij} when comparing items *i* and *j*, where $i, j=1,2,\ldots, n$. Further, $A_{ij}=1$ for all $i=j$. If $A_{ij}=y$, then $A_{ji}=1/y$.

Step 4:*Calculating the importance weights of the factors*. The consistency ratio $CR = CI/RI$ was also calculated to ensure consistency of the pairwise assessment, where $CI = \frac{(\lambda_{max}-n)}{(n-1)}$, λ_{max} is the maximum average value, and *RI* indicates the value of a random consistency index depending on the value of (*n*). To ensure that the results obtained are consistent, the *CR* value should be less than 0.10 (Madaan & Mangla, 2015).

3.2. DEMATEL methodology

DEMATEL explores the causal dependency structure among a set of identified factors and utilizes pairwise comparisons to visualize the direct and indirect relationships among these factors. DEMATEL is a good methodology for studying MM. Causal relationships are difficult to capture through other methodologies, particularly techniques that focus on correlation, such as multivariate regression analysis. DEMATEL is valuable for exploring research questions regarding significance and causation. This methodology helps to structure the causal relationships among the identified barriers and identify each barrier's prominence (Kaur, Sidhu, Awasthi, Chauhan, & Goyal, 2018).

Incompatible with AHP, DEMATEL is a constructive modeling technique that can be used to explore the interdependence among the barriers of a system through a causal diagram. The causal diagram based on digraphs presents a canonical understanding of the contextual relationships and the influence of barriers (Kumar & Dixit, 2018). The detailed procedure of this methodology is summarized in the following steps.

Step 1: *Generating the direct-relation matrix*. First, measuring the relationship between the criteria requires that the comparison scale be designed at five levels: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), and 4 (very strong influence). Next, the experts made sets of pairwise comparisons in terms of the influence and direction between the criteria. Specifically, the entry a_{ij} indicates the degree to which the expert conceives that criterion *i* affects criterion *j*. Then, as a result of these evaluations, the initial data can be obtained as a direct-relation matrix, which is an $n \times n$ matrix *A*, where a_{ij} is denoted as the degree to which criterion *i* affects criterion *j* as aforementioned.

Step 2: *Normalizing the direct-relation matrix*. Based on direct-relation matrix *A*, the normalized direct-relation matrix $N = k \cdot A$, where $k = \frac{1}{max\left(\sum_{j=1}^{N} a_{ij}\right)}, i,j = 1,2,\ldots,n.$

Step 3: *Obtaining the total-relation matrix*. Once the normalized direct-relation matrix *N* is obtained, the total-relation matrix $T = N + N^2 + N^3 + \ldots = \sum_{i=1}^{\infty} N^i = N(I - N)^{-1}$, where *I* denotes the identity matrix.

Step 4: *Producing a causal diagram*. Given the total relation matrix $T = (t_{ij})_{n\times n}$, the sum of rows and the sum of columns are denoted separately as vectors *D* and *C* through $D = (\sum_{j=1}^{n} t_{ij})_{n\times 1} = (t_{i\cdot})_{n\times 1}$ and $C = (\sum_{j=1}^{n} t_{ij})_{n\times 1} = (t_{i\cdot})_{n\times 1}$, respectively, where $i, j=1,2,\ldots, n$. Subsequently, the horizontal axis vector $(D + C)$ named “Prominence” is created by adding *D* to *C*, which is the general naming rule of DEMATEL methodology(Gül, 2020; Tseng, 2009), This vector reveals the importance of the criterion. Similarly, the vertical axis $(D - C)$ named “Relation” is created by subtracting D from C, which may divide criteria into cause-and-effect groups. Generally, when $(D - C)$ is positive, the criterion belongs to the causal group. Otherwise, if $(D - C)$ is negative, then the criterion belongs to the effect group. Therefore, a causal diagram can be acquired by mapping the dataset of $(D + C, D - C)$. This provides valuable insights for decision-making.

Step 5: *Drawing the DEMATEL prominence/effect diagrams*. This involves mapping relationships above a threshold value. The last step is the graphical representation of each factor of the calculated prominence and net effect values on a two-dimensional axis. The x-axis represents the prominence value and the y-axis represents the net effect value of the factors. Directed arrows capture the interrelationships between the barriers. To clarify the visualization, we defined a threshold that sets the cut-off point for the relationships between factors. Therefore, those values in the total relation matrix that are greater than the threshold would depict the arrows in the final DEMATEL diagrams. The threshold value θ is calculated as $(mean(T) + SD_T)$ (Fu, Zhu, & Sarkis, 2012), where the average of all t_{ij} values within the total relationship matrix is $mean$ (T), and the standard deviation of all t_{ij} values is SD_T. The values of t_{ij} are greater than θ, indicating a significant relationship between the two factors, corresponding to the arrows in the DEMATEL diagrams. Values above the thresholds are highlighted in each of the relation matrices.

4. Data collection and analysis

4.1. Measurement and data collection

After building the criteria hierarchy for Blockchain implementation in CSCM, the next phase is measurement and data collection. The collection process was divided into two parts: 1) collecting the data for the AHP analysis and 2) collecting the data for DEMATEL analysis. Data collection for both sides involved forming a team of experts in Blockchain and CSCM, who were invited to participate in this survey. We invited 30 experts, 18 of whom participated, including nine academics and nine practitioners. The academics in the team were researchers who were active in Blockchain and/or CSCM. The average work experience of the academics was 12.44 years, with a standard deviation of 7.41 years. Practitioners were mainly in manufacturing and high-tech industries and were positioned in management or technical departments. Practitioners own 9.89 years of work experience on average, with a standard deviation of 4.98 years. All experts on the team had an acceptable level of knowledge of Blockchain and CSCM. Before formally filling in the questionnaires, we trained them on the background knowledge of Blockchain and CSCM and introduced the research background of this study. Table 4 presents the information and profiles of the expert teams. The questionnaires used for data collection are provided in the Appendix.

As explained in Section 3, every expert assigned pairwise comparisons to the criteria and sub-criteria for the AHP data acquisition. These pairwise comparisons data were translated into the corresponding pairwise comparison judgment matrices (PCJMs). Additionally, we asked experts to evaluate the influence of each criterion or sub-criteria on each other to generate direct-relation matrices (DRMs). As suggested by Kumar et al. (2017) and Wu et al. (2017), in AHP analysis, the geometric mean approach was used to combine the individual PCJMs to obtain the consensus PCJMs for the entire team. In line with the typical method of DEMATEL analysis, the arithmetic approach is used to combine the individual DRMs to obtain consensus DRMs for the entire team.

Next, using the AHP technique, the success factors of Blockchain implementation for CSCM were prioritized. This prioritization would help evolve the short-term success of Blockchain implementation strategies. Then, the DEMATEL technique was used to analyze the causal interaction among the success factors of Blockchain implementations for CSCM. This would help determine the long-term success of Blockchain implementation strategies.

Table 4
Expert team's information and profiles.

No.	Academic/ Practitioner	Department	Position	Year of Work Experience
1	Academic	School of Fintech	Assistant Professor	2
2	Academic	School of Management	Assistant Professor	3
3	Academic	School of Business Administration	Professor	20
4	Academic	School of Fintech	Associate Professor	14
5	Academic	School of Computer Science	Associate Professor	19
6	Academic	School of Business	Associate Professor	15
7	Academic	School of Business	Assistant Professor	2
8	Academic	School of Business	Assistant Professor	20
9	Academic	School of Business	Professor	17
10	Practitioner	Warehousing	Project Manager	4
11	Practitioner	Production and Planning	Vice General Manager	15
12	Practitioner	Research and Development	Senior Engineer	16
13	Practitioner	Product development	Project Manager	8
14	Practitioner	Research and Development	Testing Engineer	2
15	Practitioner	Research and Development	Manager	12
16	Practitioner	Marketing	Manager	5
17	Practitioner	Quality control	Manager	15
18	Practitioner	Purchasing	Manager	12

4.2. Prioritizing the success factors using AHP application

In line with Kumar et al. (2017) and Wu et al. (2017), the PCJMs obtained from 18 experts during the measurement and data collection phases were combined using the geometric mean approach at each hierarchy level. The goal is to form corresponding consensus PCJMs. Each matrix was then translated into the corresponding enormous eigenvalue problem and was solved to find the normalized and unique priority weights for each criterion, as shown in Tables 5-7. As shown in each matrix, the consistency ratio (CR) is well below the rule-of-thumb value of CR. Typically, the rule-of-thumb value of CR was set to 0.1(Sedghiyan et al., 2021). This implies that the experts were consistent in providing pairwise comparison judgments.

After calculating the global weights of each success factor in Table 8, we rearranged them in descending order of priority. The three success factors related to technology are the top three most important: technical capability (0.1334), technology maturity (0.19), and technological feasibility (0.1016). All three factors weighed more than 0.1, whereas the others weighed less than 0.1. This implies that the main factor influencing the implementation of Blockchain in CSCM is technical. Specifically, firms' technical capabilities are the most critical factors, reflecting that experts generally believe improving technical capability is a crucial link for firms to apply Blockchain in CSCM. Experts are more optimistic about organizational factors. Instead, stakeholder buy-in

Table 5
Pairwise comparison judgment matrices of Blockchain implementation in CSCM problem(First-level criteria).

Goal	C1	C2	C3	Local weights
C1	1	3 1/2	2	0.5693
C2	2/7	1	1 1/7	0.2051
C3	1/2	7/8	1	0.2256
			CR=	0.0548

Table 6

Pairwise comparison judgment matrices of Blockchain implementation in CSCM problem(Second-level criteria).

Goal	C1	C2	C3	Local weights
C1	1	3 1/2	2	0.5693
C2	2/7	1	1 1/7	0.2051
C3	1/2	7/8	1	0.2256
			CR=	0.0548
C1	C11	C12		Local weights
C11	1	1 1/4		0.5531
C12	4/5	1		0.4469
			CR=	N/A[1]
C2	C21	C22	C23	Local weights
C21	1	3	1 2/3	0.5245
C22	1/3	1	1	0.2199
C23	3/5	1	1	0.2556
			CR=	0.0425
C3	C31	C32		Local weights
C31	1	2 1/5		0.6878
C32	4/9	1		0.3122
			CR=	N/A[1]

[1] Not applicable.

Table 7

Pairwise comparison judgment matrices of Blockchain implementation in CSCM problem(Success factors).

C11	C111	C112	C113	Local weights
C111	1	1 1/5	1 1/4	0.3809
C112	5/6	1	6/7	0.2963
C113	4/5	1 1/6	1	0.3228
			CR=	0.0035
C12	C121	C122	C123	Local weights
C121	1	2 2/7	2 2/9	0.5243
C122	4/9	1	1 8/9	0.2869
C123	4/9	1/2	1	0.1888
			CR=	0.0474
C21	C211	C212		Local weights
C211	1	2 1/5		0.6874
C212	1/2	1		0.3126
			CR=	N/A[1]
C22	C221	C222	C223	Local weights
C221	1	1 2/3	1 2/5	0.4329
C222	3/5	1	1 1/3	0.3018
C223	5/7	3/4	1	0.2653
			CR=	0.0240
C23	C231	C232	C233	Local weights
C231	1	3/5	5/6	0.2458
C232	1 2/3	1	2 7/9	0.5186
C233	1 1/5	1/3	1	0.2356
			CR=	0.0515
C31	C311	C312	C313	Local weights
C311	1	6/7	7/8	0.2966
C312	1 1/6	1	2	0.4306
C313	1 1/7	1/2	1	0.2728
			CR=	0.0483
C32	C321	C322		Local weights
C321	1	1 5/8		0.6184
C322	5/8	1		0.3816
			CR=	N/A[1]

[1] Not applicable.

(0.0120), risk management (0.0124), and cost control (0.0129) were ranked the least essential success factors. This is related to the cost advantage of Blockchain and the security that decentralization brings.

As mentioned earlier, an AHP model that includes all success factors, criteria, and sub-criteria and their priority weights can be used for prioritization or importance sequencing. In Section 4.3, we further analyze the causal relationships among various factors using the DEMATEL method.

Table 8

Composite priority weights for success factors of Blockchain implementation in CSCM.

Criteria	Local weights	sub-criteria	Local weights	Success factors	Local weights	Global weights
C1	0.5693	C11	0.5531	C111	0.3809	0.1199
				C112	0.2963	0.0933
				C113	0.3228	0.1016
		C12	0.4469	C121	0.5243	0.1334
				C122	0.2869	0.0730
				C123	0.1888	0.0480
C2	0.2051	C21	0.5245	C211	0.6874	0.0739
				C212	0.3126	0.0336
		C22	0.2199	C221	0.4329	0.0195
				C222	0.3018	0.0136
				C223	0.2653	0.0120
		C23	0.2556	C231	0.2458	0.0129
				C232	0.5186	0.0272
				C233	0.2356	0.0124
C3	0.2256	C31	0.6878	C311	0.2966	0.0460
				C312	0.4306	0.0668
				C313	0.2728	0.0423
		C32	0.3122	C321	0.6184	0.0436
				C322	0.3816	0.0269

4.3. *Evaluating the causal interaction using DEMATEL application*

To evaluate the causal interaction among the listed criteria and success factors related to the adoption of Blockchain in CSCM, we applied the DEMATEL methodology, following the steps stated in Subsection 3.2. This approach helps scrutinize the cause-and-effect relationships among success factors, which are represented in causal relationship maps.

First, by collecting data from the expert team, we obtained the direct relationship matrix (A) of the success factors by taking the average of the scores of the experts (Table A1). Then, the corresponding normalized direct relation matrix (N) (Table A2) and total relation matrix (T) (Table A3) were calculated. After that, the dataset ($D_i + C_i$, $D_i - C_i$) was calculated, and a Cartesian coordinate system was created according to Step 4 in Section 3.2. As stated in step 5 of Section 3.2, we took $\theta = mean$ (T) + SD_T as the threshold value (i.e., the effect of any factor less than this value is negligible). Thus, θ=0.339 + 0.067=0.406.

The values of ($D_i + C_i$)(i.e., prominence) specify the overall effect of each success factor in the factoring system hierarchy. This represents the center of the factors. Specifically, the higher the value of a success factor (i.e., positioned toward the right in Fig. 2), the more substantial is the

Table 9

Prominence and net effect values for success factors.

Success factors	Code	D_i	C_i	$D_i + C_i$	$D_i - C_i$
Technology maturity	C111	7.486	4.959	12.446	2.527
Data security	C112	6.598	5.539	12.136	1.059
Technological feasibility	C113	6.906	5.484	12.390	1.423
Technical capability	C121	7.479	5.518	12.997	1.961
Organizational readiness	C122	6.156	6.629	12.785	−0.472
Other capacities for change	C123	6.461	7.210	13.671	−0.750
Internal leadership within firm	C211	5.664	6.612	12.275	−0.948
External leadership with Stakeholders and in CSCM	C212	5.638	6.603	12.241	−0.966
Goal alignment	C221	5.799	6.993	12.793	−1.194
Partnership trust	C222	5.586	7.370	12.956	−1.784
Stakeholder buy-in	C223	5.886	6.438	12.324	−0.551
Cost control	C231	6.132	3.804	9.935	2.328
Government policies	C232	6.436	6.937	13.373	−0.500
Risk management	C233	6.633	6.783	13.416	−0.151
Information capture	C311	6.224	8.085	14.309	−1.861
Operational model	C312	7.158	5.241	12.399	1.917
Knowledge training	C313	7.069	7.964	15.033	−0.895
Circular approach	C321	6.863	7.964	14.827	−1.101
Information disclosure	C322	6.362	7.902	14.265	−1.540

contribution of that factor to the successful implementation of Blockchain in CSCM. From Table 9, we can see that knowledge training (C313) is the most crucial success factor because it obtains the highest $(D_i + C_i)$ value; that is, 15.033. By contrast, the cost control (C231) is evaluated to be the least, as it obtains the lowest $(D_i + C_i)$ value; that is, 9.935.

Likewise, the "relation" values (i.e., $D_i - C_i$) are used to categorize the success factors into cause-and-effect groups depending on their obtained values in the total relationship matrix; that is, the positive (net cause) and negative (net receive) values attained. The values of $(D_i + C_i)$ indicate that the higher the value, the stronger the influence on the successful implementation of Blockchain in CSCM (that is, position upward in Fig. 4). Causal factors are sorted by the net effect (i.e., $D_i - C_i$) for the influence of Blockchain's successful implementation in CSCM as follows: technology maturity (C111), cost control (C231), technical capability (C121), operational model (C312), technological feasibility (C113), and data security (C112). This can be applied to the development of long-term measures. Factors with negative values are called effect factors (EFs). These are categorized as risk management (C233), organizational readiness (C122), government policies (C232), stakeholder buy-in (C223), other capacities for change (C123), knowledge training (C313), internal leadership within the firm (C211), external leadership with stakeholders and in CSCM (C212), circular approach (C321), goal alignment (C221), information disclosure (C322), partnership trust (C222), and information capture (C311). The effect factors are influenced by causal factors, which lead to Blockchain's successful implementation in CSCM. A causal effect map of the success factors is shown in Fig. 4. Similarly, an analysis of the success factors was performed.

To sum up, the main results of AHP and DEMATEL analysis effectively respond to the evaluation of critical success factors of Blockchain-enabled CSCM. Specifically, first, based on the assessment results of the AHP method, success factors related to technology (i.e., C111, C113, and C121) as well as the "knowledge training" (C313) are regarded as essential factors. Second, based on relationships of success factors derived by DEMATEL analysis, success factors related to technology (i.e., C111, C113, and C121) also play critical roles in influencing other factors. Among them, "Technology maturity" (C111) plays the most critical role as a causal factor, followed by "technical capability" (C121) and "technological feasibility" (C113). Also, "data security" (C112) is also an important causal factor related to technology. Last, based on relationships of success factors derived further by DEMATEL analysis, "Operational model" (C312) and "cost control" (C231) are also primary causal factors in addition to factors related to technology. Among them, the operational mode reflects the degree of decentralized supply chain information, the standardization, and the informatization of the supply chain operation process, while the cost control reflects the input cost of the implementation process of the integration of Blockchain technology and CSCM.

5. Discussion and implications

Along with prioritizing the success factors and evaluating the causal interaction, this study provides evidence of the theoretical and managerial implications of implementing Blockchain in CSCM, which is discussed further below.

5.1. Theoretical implications

This work has several theoretical implications. For one thing, consistent with the technology acceptance model (Davis, 1989), the findings highlight the critical role of technology and knowledge-related factors in implementing Blockchain in CSCM. The results strongly support the view that technological maturity, technological feasibility, and technical capability are essential factors. Knowledge is also often considered a strategic resource for an organization and is more important than traditional resources such as capital and land (e.g., Hansen, Nohria, and Tierney (1999)). The results also support the view that enterprise knowledge training is critical for the implementation of Blockchain in CSCM. This study responds to the call of scholars to

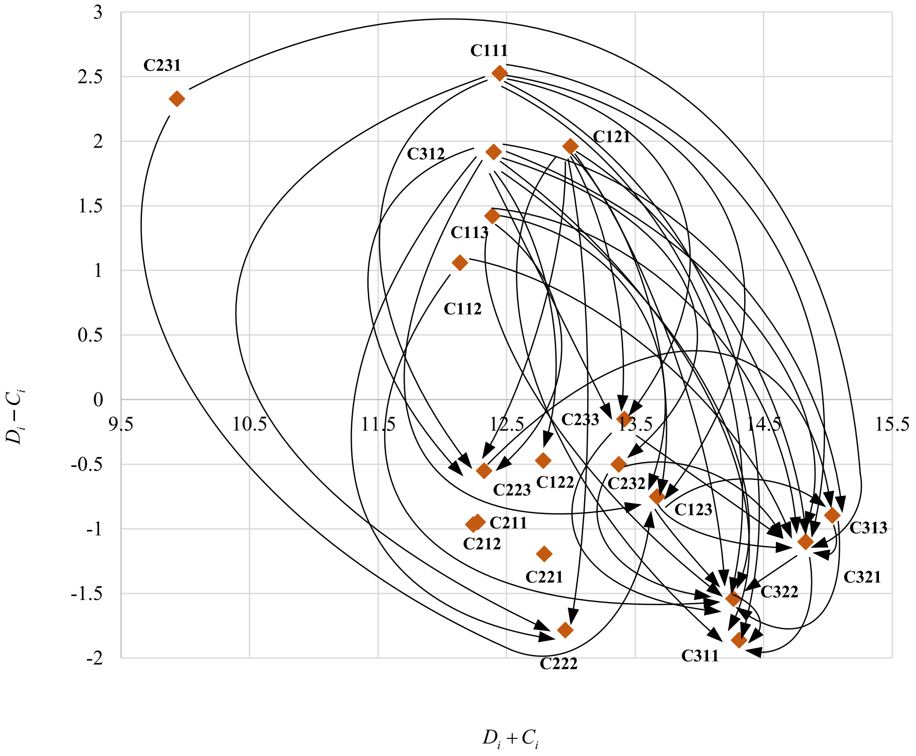

Fig. 4. DEMATEL success factors relationships for Blockchain implementation in CSCM.

emphasize the need to study the relationship between Blockchain technology application capability and knowledge management capability (e.g., Irannezhad, Shokouhyar, Ahmadi, and Papageorgiou (2021); Ostern, Holotiuk, and Moormann (2021)). These findings highlight the importance of technology readiness and knowledge training. For another, from a contingency theory perspective (Lawrence & Lorsch, 1967), the relationship among the success factors of Blockchain implementation in CSCM is outlined. Our analysis found that a firm's technological maturity, technological feasibility, and technical capability are critical to the impact of other factors. According to the technology-organization-environment perspective (Tornatzky, Fleischer, & Chakrabarti, 1990), technology is one of the three main factors influencing the adoption of new technologies by enterprises. The technological context includes the characteristics and availability of technological innovation. Moreover, the technical elements include the basic challenges faced by Blockchain technology, such as security, accessibility, and immaturity. Our findings highlight that a technical factor is not the only factor of superior importance. Technical factors affect other factors in particular. Contrary to the previous study by Gökalp, Gökalp, and Çoban's (2020), environmental factors are more significant than other factors. This study responds to the call of scholars who stress the need to provide empirical evidence to suggest which factor is more critical (Sternberg, Hofmann, & Roeck, 2021), and the need for a survey of differing viewpoints of a number of experts in various fields (Ghode, Yadav, Jain, & Soni, 2020).

From the perspective of circular supply chain management, our findings also suggest that technological maturity could promote integration, such as partnership trust, stakeholder buy-in, and risk management. Additionally, it can promote a circular supply chain style, information capture, and information disclosure. This finding is consistent with prior studies suggesting that Blockchain technology bridged trust, traceability, and transparency in CSCM (e.g., Centobelli, Cerchione, Del Vecchio, Oropallo, and Secundo (2021)). The current study is consistent with previous literature, which emphasizes that firms focus too much on the adoption stage and too little on other functions, such as the connection between successful Blockchain technology and the three components of circular elements (environmental, social, and economic sustainability) (Di Vaio & Varriale, 2020; Kajikawa, 2008). The results clarify the relationship between technology maturity, integration factors, and circular supply chain levels.

Finally, it is interesting to note that the results of our study suggest that circular supply chain management and integration can facilitate the adoption of Blockchain technology. Specifically, based on the relationships among success factors for Blockchain implementation in CSCM, the operation mode of the circular supply chain and cost control of integration are also the main factors involved in this. Operation mode reflects the degree of decentralized supply chain information, standardization, and informatization of the supply chain operation process, whereas cost control reflects the input cost of the implementation process of the two-chain integration. This finding is consistent with previous studies showing that the adoption of Blockchain technology in supply chains requires standardization (Morkunas et al., 2019), organizational collaboration (Lumineau et al., 2021), and the willingness to invest in new, unproven, and high-cost technologies (Öztürk & Yildizbasi, 2020). In contrast to previous studies, this study further clarifies the promotion mechanism of circular supply chain management and integration in the implementation of Blockchain technology adoption, namely, strengthening the management of operational models and cost control.

5.2. Managerial contributions

This study generates several managerial contributions as well. Our results support a firm's CSCM managers (or CEOs) in gaining a richer understanding of their plans to implement Blockchain in the supply chain. Blockchain technology is not sufficiently mature (Yu, Lin, & Tang, 2018), and there is a lack of existing technical infrastructure (Niranjanamurthy, Nithya, & Jagannatha, 2019). Existing systems may be barriers to implementing Blockchain technology (Scott, Loonam, & Kumar, 2017). Thus, performance and scalability pose challenges for the implementation of Blockchain in the supply chain (Vukolić, 2016). Our research provides strategic managers with a complete framework and evidence for managing Blockchain implementation in CSCM. From the perspective of supply chain members, Blockchain is a very complex technology, and many people do not know its intricacies and ramifications (Hunhevicz & Hall, 2020). This also makes it difficult for the entire supply chain to adopt the technology because it includes many new terms such as public key, private key, and cryptography. In addition, the lack of trained human resources in Blockchain technology is another important difficulty in the integration of Blockchain technology and CSCM (Öztürk & Yildizbasi, 2020). Therefore, we encourage strategic managers to emphasize the role of knowledge training in supply chain management.

Furthermore, a firm's environment, health, and safety (EHS) managers are often responsible for executing strategic decisions in circular management. The results of this study guide enterprise EHS and supply chain managers to implement Blockchain in CSCM in an integrated manner. Our findings suggest that the implementation of Blockchain technology in CSCM also requires additional attention to cost control, especially the choice of the circular method (i.e., the company plans to implement innovative practices in CSCM with Blockchain technology) and other transformative capacities such as dynamic operation ability, financial liquidity, investment strength, and financing channels. Moreover, the results also suggest that technological maturity could indirectly promote circular approaches and information disclosure, enriching EHS managers' tools to improve the performance of circular management throughout the supply chain.

6. Conclusions and limitations

Blockchain is gaining considerable attention in CSCM (Centobelli et al., 2021; Paul, Islam, Mondal, & Rakshit, 2022). The purpose of this study is to explore the priorities of success factors in the implementation of Blockchain-enabled CSCM and uncover the relationships among these success factors. To achieve this goal, an integrative framework and a multi-attribute combination decision-making method combining the AHP and DEMATEL techniques were designed. Specifically, based on the framework of Hastig and Sodhi (2020), as well as the literature surveys, a hierarchy system of success factors was identified, including criteria, sub-criteria, and success factors. The framework extracted from their research helps to identify the sub-criteria of technological readiness, capabilities, leadership, and collaboration. We then extend the sub-criteria to Blockchain technology, integration of Blockchain technology and CSCM, and CSCM. The proposed integrative framework and AHP-DEMATEL analysis improve the current understanding of Blockchain-enabled CSCM.

Our findings demonstrate that technology-related success factors (i.e., technical capability, technology maturity, and technological feasibility) play a critical role in the implementation of Blockchain-enabled CSCM. In addition, knowledge training and data security should be regarded as essential causal factors influencing other factors. Thus, technological factors not only largely determine the implementation of Blockchain in CSCM but also influence other success factors to a large extent. Then, we also give the corresponding theoretical implications and management contributions. This work helps broaden the academic discussion of Blockchain-enabled CSCM in industrial marketing and business-to-business marketing research.

Despite its valuable results for managers, this study faces a few limitations. First, the AHP method and the DEMATEL approach integrate the opinions of experts from many fields. Therefore, there are limitations regarding generalization. Although experts come from academia and industry, not all fields have been represented. Individuals from different areas may have their preferences for Blockchain research. Future research should include more experts with broader experience in Blockchain research and implementation. This work considers the characteristics and processing capabilities of AHP and DEMATEL technology, and the corresponding data collection and analysis results are accepted by representative industry experts and relevant scholars within a certain range. Second, the multi-criteria decision method is employed to extract the expert judgment and, thus, the causal relationship among the success factors of Blockchain applied to CSCM to build the corresponding weight system. However, future research needs to verify through empirical studies whether these can play a practical guiding role in integrating Blockchain and circular supply chains. Real and detailed Blockchain implementation data might be a good source of information to verify its effectiveness for practical use.

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Declarations of interest

None.

Appendix A. Appendices

- Table A1 Direct relation matrix (A) for success factors
- Table A2 Normalized direct relation matrix (N) for success factors
- Table A3 Total relationship matrix (T) for success factors
- Table A4 List of abbreviations

Table A1

Direct relation matrix (A) for success factors.

	C111	C112	C113	C121	C122	C123	C211	C212	C221	C222	C223	C231	C232	C233	C311	C312	C313	C321	C322
C111	0	3.333	3.200	3.000	1.800	2.667	1.800	1.733	1.333	1.533	1.533	2.533	0.800	2.533	2.133	2.667	2.000	3.000	2.667
C112	2.200	0	2.400	2.333	1.733	2.200	1.600	1.133	1.333	2.000	1.800	1.733	1.067	2.800	2.533	2.067	1.333	2.333	2.867
C113	2.733	2.333	0	2.600	1.867	2.200	1.733	1.467	1.600	1.800	2.000	2.000	1.267	2.067	2.333	2.600	1.467	2.733	2.333
C121	2.800	2.867	3.267	0	2.267	2.933	1.600	1.467	1.600	1.733	1.867	2.333	0.867	2.133	2.333	2.600	1.533	3.333	2.800
C122	1.333	1.333	1.467	1.667	0	2.600	2.133	1.933	1.800	2.133	2.000	1.733	0.800	2.133	2.000	2.467	1.800	2.000	2.067
C123	1.600	1.333	1.600	1.933	2.133	0	2.133	2.200	1.933	2.333	2.467	2.000	1.200	2.133	1.600	2.600	1.400	2.667	1.867
C211	0.667	0.800	0.733	0.867	2.467	2.133	0	2.000	2.133	2.333	2.267	1.467	0.867	2.133	1.800	2.600	1.467	2.133	2.067
C212	0.667	1.000	1.000	0.800	2.067	1.800	1.933	0	2.200	2.533	2.600	1.533	1.533	1.800	1.733	2.200	1.467	1.933	2.067
C221	0.800	0.867	0.933	1.000	2.400	1.933	2.267	2.267	0.067	2.933	2.867	1.667	1.067	1.800	1.467	2.333	1.333	2.000	1.867
C222	0.600	0.667	0.800	0.933	1.800	1.800	2.200	2.467	2.867	0	3.000	1.467	0.933	1.733	1.667	2.400	1.333	1.933	2.067
C223	0.733	0.800	1.000	1.000	1.933	2.067	2.200	2.400	2.533	2.800	0	2.000	1.733	1.667	1.667	2.400	1.467	1.867	2.067
C231	1.333	1.200	1.400	1.400	1.667	1.800	1.800	1.800	1.600	1.333	1.600	0	0.867	2.067	2.400	3.200	1.933	2.933	2.667
C232	1.733	1.667	1.400	1.467	1.667	1.933	1.600	2.000	1.800	1.267	2.533	1.933	0	1.933	1.867	2.267	2.133	2.867	2.733
C233	1.467	2.267	2.000	1.667	1.800	2.067	1.933	1.800	1.933	2.000	2.400	2.333	1.333	0	1.800	2.467	1.333	2.467	3.000
C311	1.333	1.733	1.467	1.467	1.600	1.933	2.000	1.800	1.933	2.000	2.133	2.000	1.000	2.133	0	2.333	1.600	2.333	3.000
C312	1.333	1.733	1.600	1.667	2.467	2.200	2.400	2.467	2.533	2.333	2.600	2.667	1.067	2.533	2.400	0	2.000	2.933	2.400
C313	2.267	2.267	2.267	2.400	2.400	2.667	1.867	1.800	2.067	2.067	1.800	2.000	0.867	2.067	2.267	2.267	0	2.400	2.533
C321	2.133	2.200	2.067	2.600	1.933	2.467	2.000	1.867	1.733	1.800	1.800	1.867	1.333	2.200	2.400	2.800	1.333	0	2.533
C322	1.533	2.067	1.600	1.400	1.800	2.067	2.133	1.933	2.200	2.400	2.533	1.667	1.333	1.933	2.467	2.000	1.467	2.200	0

Table A2

Normalized direct relation matrix (N) for success factors.

	C111	C112	C113	C121	C122	C123	C211	C212	C221	C222	C223	C231	C232	C233	C311	C312	C313	C321	C322
C111	0	0.083	0.079	0.074	0.045	0.066	0.045	0.043	0.033	0.038	0.038	0.063	0.020	0.063	0.053	0.066	0.050	0.074	0.066
C112	0.055	0	0.060	0.058	0.043	0.055	0.040	0.028	0.033	0.050	0.045	0.043	0.026	0.069	0.063	0.051	0.033	0.058	0.071
C113	0.068	0.058	0	0.064	0.046	0.055	0.043	0.036	0.040	0.045	0.050	0.050	0.031	0.051	0.058	0.064	0.036	0.068	0.058
C121	0.069	0.071	0.081	0	0.056	0.073	0.040	0.036	0.040	0.043	0.046	0.058	0.021	0.053	0.058	0.064	0.038	0.083	0.069
C122	0.033	0.033	0.036	0.041	0	0.064	0.053	0.048	0.045	0.053	0.050	0.043	0.020	0.053	0.050	0.061	0.045	0.050	0.051
C123	0.040	0.033	0.040	0.048	0.053	0	0.053	0.055	0.048	0.058	0.061	0.050	0.030	0.053	0.040	0.064	0.035	0.066	0.046
C211	0.017	0.020	0.018	0.021	0.061	0.053	0	0.050	0.053	0.058	0.056	0.036	0.021	0.053	0.045	0.064	0.036	0.053	0.051
C212	0.017	0.025	0.025	0.020	0.051	0.045	0.048	0	0.055	0.063	0.064	0.038	0.038	0.045	0.043	0.055	0.036	0.048	0.051
C221	0.020	0.021	0.023	0.025	0.060	0.048	0.056	0.056	0.002	0.073	0.071	0.041	0.026	0.045	0.036	0.058	0.033	0.050	0.046
C222	0.015	0.017	0.020	0.023	0.045	0.045	0.055	0.061	0.071	0	0.074	0.036	0.023	0.043	0.041	0.060	0.033	0.048	0.051
C223	0.018	0.020	0.025	0.025	0.048	0.051	0.055	0.060	0.063	0.069	0	0.050	0.043	0.041	0.041	0.060	0.036	0.046	0.051
C231	0.033	0.030	0.035	0.035	0.041	0.045	0.045	0.045	0.040	0.033	0.040	0	0.021	0.051	0.060	0.079	0.048	0.073	0.066
C232	0.043	0.041	0.035	0.036	0.041	0.048	0.040	0.050	0.045	0.031	0.063	0.048	0	0.048	0.046	0.056	0.053	0.071	0.068
C233	0.036	0.056	0.050	0.041	0.045	0.051	0.048	0.045	0.048	0.050	0.060	0.058	0.033	0	0.045	0.061	0.033	0.061	0.074
C311	0.033	0.043	0.036	0.036	0.040	0.048	0.050	0.045	0.048	0.050	0.053	0.050	0.025	0.053	0	0.058	0.040	0.058	0.074
C312	0.033	0.043	0.040	0.041	0.061	0.055	0.060	0.061	0.063	0.058	0.064	0.066	0.026	0.063	0.060	0	0.050	0.073	0.060
C313	0.056	0.056	0.056	0.060	0.060	0.066	0.046	0.045	0.051	0.051	0.045	0.050	0.021	0.051	0.056	0.056	0	0.060	0.063
C321	0.053	0.055	0.051	0.064	0.048	0.061	0.050	0.046	0.043	0.045	0.045	0.046	0.033	0.055	0.060	0.069	0.033	0	0.063
C322	0.038	0.051	0.040	0.035	0.045	0.051	0.053	0.048	0.055	0.060	0.063	0.041	0.033	0.048	0.061	0.050	0.036	0.055	0

Table A3
Total relationship matrix (T) for success factors.

	C111	C112	C113	C121	C122	C123	C211	C212	C221	C222	C223	C231	C232	C233	C311	C312	C313	C321	C322
C111	0.267	0.375	0.369	0.367	0.396	0.447	0.394	0.384	0.383	0.409	0.428	0.403	0.222	0.430	0.413	0.493	0.326	0.495	0.484
C112	0.286	0.262	0.315	0.315	0.352	0.391	0.349	0.331	0.342	0.375	0.388	0.344	0.204	0.391	0.378	0.428	0.278	0.429	0.438
C113	0.309	0.329	0.272	0.334	0.370	0.407	0.366	0.352	0.362	0.386	0.409	0.364	0.217	0.390	0.389	0.458	0.293	0.456	0.444
C121	0.332	0.364	0.370	0.297	0.406	0.453	0.390	0.378	0.389	0.413	0.435	0.398	0.224	0.420	0.417	0.491	0.315	0.502	0.486
C122	0.248	0.274	0.274	0.280	0.291	0.376	0.341	0.330	0.333	0.358	0.371	0.323	0.186	0.354	0.344	0.412	0.272	0.396	0.394
C123	0.265	0.285	0.289	0.298	0.355	0.331	0.355	0.350	0.350	0.377	0.397	0.343	0.204	0.369	0.350	0.433	0.274	0.428	0.407
C211	0.214	0.240	0.236	0.241	0.326	0.340	0.268	0.310	0.318	0.339	0.352	0.294	0.175	0.329	0.315	0.386	0.246	0.369	0.366
C212	0.213	0.243	0.241	0.239	0.315	0.331	0.312	0.261	0.319	0.342	0.358	0.294	0.190	0.320	0.312	0.376	0.245	0.363	0.364
C221	0.221	0.246	0.245	0.249	0.330	0.342	0.327	0.322	0.276	0.359	0.373	0.304	0.183	0.328	0.314	0.388	0.248	0.374	0.369
C222	0.209	0.233	0.234	0.239	0.307	0.328	0.316	0.317	0.332	0.281	0.365	0.290	0.175	0.316	0.308	0.377	0.240	0.360	0.361
C223	0.223	0.248	0.250	0.252	0.324	0.349	0.330	0.329	0.338	0.360	0.311	0.316	0.201	0.329	0.323	0.395	0.254	0.376	0.378
C231	0.248	0.271	0.273	0.274	0.329	0.357	0.332	0.325	0.327	0.338	0.360	0.281	0.187	0.352	0.353	0.427	0.274	0.415	0.407
C232	0.268	0.293	0.285	0.288	0.343	0.376	0.341	0.344	0.345	0.351	0.397	0.341	0.175	0.363	0.355	0.423	0.290	0.431	0.426
C233	0.269	0.314	0.305	0.300	0.355	0.389	0.358	0.348	0.358	0.378	0.404	0.358	0.212	0.327	0.363	0.439	0.279	0.433	0.442
C311	0.251	0.286	0.277	0.279	0.332	0.365	0.341	0.330	0.339	0.358	0.377	0.332	0.193	0.357	0.301	0.413	0.270	0.407	0.419
C312	0.283	0.321	0.316	0.319	0.396	0.418	0.394	0.388	0.396	0.412	0.437	0.389	0.220	0.412	0.401	0.412	0.314	0.472	0.458
C313	0.304	0.333	0.330	0.335	0.390	0.425	0.377	0.368	0.381	0.401	0.413	0.371	0.212	0.398	0.395	0.460	0.263	0.457	0.457
C321	0.293	0.323	0.317	0.331	0.370	0.410	0.370	0.360	0.364	0.384	0.403	0.359	0.218	0.391	0.388	0.460	0.288	0.390	0.445
C322	0.260	0.298	0.285	0.282	0.343	0.375	0.350	0.339	0.352	0.374	0.394	0.331	0.205	0.359	0.364	0.413	0.272	0.411	0.357

Table A4
List of abbreviations.

Abbreviation	Explanation
CSC	circular supply chain
CSCM	circular supply chain management
AHP	analytical hierarchy process
DEMATEL	decision-making trial and evaluation laboratory
SCM	supply chain management
MCDM	multi-criteria decision-making
PCJMs	pairwise comparison judgment matrices
DRMs	direct-relation matrices
CR	consistency ratio

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indmarman.2022.02.009.

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