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BLOCKCHAIN TECHNOLOGY IN SUPPLY CHAIN MANAGEMENT: PERFORMANCE AND RISK MANAGEMENT PERSPECTIVE

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ABSTRACT

Study 1

Blockchain technology (BT) in the supply chain/logistics has drawn much attention. Several benefits associated with the technology include cost-saving, sustainability enhancement, and economic viability. However, there are limited BT performance measurement models. The topic of the BT performance in supply chain management (SCM) is scattered across multiple disciplines. This study identifies different dimensions of BT performance and supports SCM managers to understand the systematic and holistic assessment of BT performance.

Study 2

The specific features of blockchain provide promise in managing supply chain risks. Given the growing research scrutiny in blockchain-based supply risk management, the development of a reliable and valid instrument to measure supply chain risk management is imperative. Nonetheless, no systematic research has been done to develop such an instrument. This study employs a comprehensive and rigorous procedure to develop a multifaceted measurement scale through an empirical analysis. We defined and operationalized the concept of blockchain-based supply chain risk management followed by validation and item measurement development.

Study 3

The supply chain management field is experimenting with the integration of blockchain, a cutting-edge and highly disruptive technology. However, blockchain research in supply chain risk is still nascent, especially the relationship between blockchain adoption and its impact on both risk management performance and supply chain competency. We aim to

investigate the potential influence of BT-based security management in mediating the effects of blockchain adoption on both risk management performance and firm performance. We plan to administer a survey to review the opinions and views of supply chain practitioners.

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PREFACE

This dissertation is written in manuscript form. Each chapter is written as a separate manuscript and prepared for publication separately in different operations and/or supply chain management journals; as such, they are formatted as required for submission to each journal.

Manuscript 1 was published by Emerald publishing 3 March 2021 in Industrial Management & Data Systems. Manuscript 2 is currently under review in the Production Planning & Control journal which is a part of the Taylor & Francis publishing group. Manuscript 3 is a future study description with an in-depth study plan.

Manuscript 1: Blockchain Performance in Supply Chain Management: Application in Blockchain Integration Companies

Manuscript 2: Evidence of Mitigating Supply Chain Risk Using Blockchain: Conceptualization, Scale Development, and Nomological Validity Test.

Manuscript 3: Blockchain Adoption and Its Impact on Risk Management Performance and Firm Performance

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MANUSCRIPT 1

Blockchain Performance in Supply Chain Management: Application in Blockchain Integration Companies

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Abstract

Purpose – Performance assessment of blockchain in the supply chain requires a systematic approach because of its interdisciplinary and multi-objective nature. Hence, four types of performance domains are identified, namely, environmental, economic, customer and information.

Design/methodology/approach – The following methodologies have been utilized: (1) literature review to find relevant factors, (2) factor analysis to validate factors, and (3) DEMATEL theory to find the cause-and-effect relationships amongst performance measures.

Findings – An integrated holistic performance assessment model incorporating the 4 criteria and 25 sub-criteria is applied.

Originality/value – This is the first paper to analyze blockchain performance in an industry setting.

Keywords - Blockchain, Blockchain performance, Blockchain supply chain, Distributed ledger, DEMATEL analysis

Paper type – Research paper

1. Introduction

Blockchain technology (BT) in the supply chain/logistics has drawn much attention. Continuous BT implementation in the supply chain/logistics worldwide is projected to grow, albeit it has overhyped enthusiasm (Bauer et al., 2020). Several benefits associated with the technology include cost-saving (Kshetri, 2019), sustainability enhancement (Saberi et al., 2019), and economic viability. For example, TEMCO partnering with Nenia, a producer/ retailer of eco-friendly organic products, linked all information from the initial production stage to the final delivery step in BT. Under the previous system, Nenia was not able to easily convey the eco-friendly image to customers. Therefore, TEMCO allows all supply chain partners to access each product's journey to the final customer to strengthen its value proposition.

However, a review of BT literature leads to the identification of the following gap. There are limited BT performance measurement models, especially in an industry setting. Because BT is new and its performance outcome is difficult to predict before implementation (Bai and Sarkis, 2020), many BT studies are presenting case applications of BT implementation. Researchers and studies have not systematically investigated performance measurement and the topic of the BT performance in supply chain management (SCM) is scattered across multiple disciplines. Without understanding the potential performance and its corresponding importance in business practices, the realization of value is deemed to fail.

The contribution of this study is to identify different dimensions of BT performance. It also supports SCM managers and decision-makers in understanding the systematic and holistic assessment of BT performance through the identification of criteria and sub-criteria in two phases: (1) a theoretical holistic BT-SCM framework and (2) its application in BT integration companies. The need, therefore, arises for a holistic approach model that can incorporate and integrate intangible and tangible criteria related to environmental, economics, customer, and information concepts. This study is unique in that it created such a model within the supply chain industry context. The proposed model can be hired and implemented by companies seeking BT implementation. This model allows supply chain organizations to assess their current BT performance, analyze causal relationships and prioritize sub-criteria. Addressing all performance measurements is practically infeasible. Thus, a decision-making approach may be suitable for evaluating the importance and ranking of various performance measures.

In line with the objective, we propose a hybrid model that combines factor analysis with the decision-making trial and evaluation laboratory (DEMATEL) method to conduct a comprehensive analysis in order to gain a complete understanding of BT performances. We conducted exploratory factor analysis (EFA) to identify the underlying relationships among variables. Subsequently, we used the decision-making approach which is appropriate for the ranking of each performance dimension. DEMATEL is selected because of its ability to identify important performance while visualizing the causal effect relationship of subsystems through a two-dimensional diagram. This paper is one of the first to investigate BT performances using BT experts.

The paper is structured as follows: Section 2 presents literature review on BT performances and identifies four dimensions. The research methodology is presented in section 3. Section 4 discusses theoretical, managerial, and practical implications of findings. Section 5 includes the conclusion and limitation of the study.

2. Background

2.1. Need for a holistic framework

This study proposed a holistic approach based on a systems theory perspective. Systems theory is an interaction between the activities of the organizations to achieve performance (Kazancoglu et al., 2018). Systems theory enables a holistic approach since it allows encompassing both the organizational level and supply chain level (Mele et al., 2010). Successful supply chain management involves enhancing both the performance of individual organizations and the overall supply chain (Gorane and Kant, 2015). Likewise, organizational activities in the BT-based supply chain such as procurement, inventory management, supplier and customer relationship management are interrelated to each other to enhance supply chain performance. We argue that values created from BT are related to the performance of both individual firms and the entire supply chain. Systems theory allows us to explore the impact of the BT application on business performance. First, the scope of the performance research should integrate and encompass intangible and tangible measures (McKinnon et al., 2015). Thus, this study reveals different indicators of the BT supply chain such as environmental, economic, customer and information. Second, we propose a systematic framework to assess BT SCM performance. This study, therefore, employs multiple levels such as main criteria and sub-criteria. To achieve a systematic BT supply chain performance, the proposed framework is constructed as a two-dimensional hierarchy that includes main criteria (i.e., the supply chain level) and sub-criteria (e.g., organizational level). Environmental, economic, customer, and information performances are identified as the main criteria for the BT supply chain performance assessment. This study investigates 4 main criteria and 25 sub-criteria to propose an assessment framework.

Hence, this study supports the understanding of systems theory within the holistic assessment of the BT-based supply chain.

2.2. System of systems (SoS) theory and BT supply chain performance

The BT-based supply chain can be used as an example of SoS as it consists of a number of autonomous and interdependent complex systems (Choi, 2018). An SoS is defined as a system that provides unique capabilities that none of the constituent systems (e.g., suppliers, customers, distributors) can accomplish on its own. A Constituent system can be a part of SoS (e.g., the supply chain). Each constituent system is a useful system by itself, developing its strategies, management objectives, and performances, but interacting within the system to provide unique capability (Henshaw, 2019). These complex constituents must function as an integrated metasystem to produce desirable results in performance to achieve a better output (Bourne et al., 2018). The success of a supply chain does not result from the aggregation of the individual constituent performances. Success relies on the integrated activities as well as the relationships among the constituents. A recent study is in favor of a more open and holistic approach that employs the principles of SoS (Choi, 2018). A BT-based supply chain provides a great context where the aforementioned attributes of SoS could transform how BT performance measurement is understood and practiced. In this section, we utilize the SoS theory to identify various performance measurements for blockchain technology, especially within the SCM context. Although SoS theory is a classical framework in engineering literature, it is an overlooked theory in supply chain management. The present study contributes to adopting the SoS theory to address performance measurements research. It can serve as an excellent theoretical backbone for performance analysis within the BT supply chain.

2.2.1. Environmental performance in the BT supply chain

Environmental performance refers to the benefits associated with a BT-based circular economy activity (Saberi et al., 2019). Reducing the environmental impact by minimizing waste, packaging and nonrenewable energies is an organizational responsibility. Goods and materials have plenty of opportunities to recover, reuse and recycle while the financial revenues generated from these activities are significant. Moreover, customers demand verification of specific products for sustainability and origins (Nikolakis et al., 2018; Kouhizadeh et al., 2020). This has put more pressure on organizations to accommodate sustainable strategies. Each constituent (e.g., suppliers, customers, distributors) uses BT as an instrument to accomplish sustainable environmental performance. Individual constituents are autonomous entities that use their strategies to achieve sustainable objectives. Different constituents have different sustainable objectives such as green value promotion, carbon footprint reduction, and resource conservation. These objectives of constituents have a great impact on the performance (Zhu and Mostafavi, 2014). BT is a solution to achieve such sustainable performances. For instance, BT plays an important role in sustainability by fostering collaboration between customers and organizations, helping organizations to improve their sourcing and recycling practices which enhance corporate environmental responsibility (Franca et al., 2020). BT-based life cycle assessment helps to design more sustainable products and provide data for green marketing (Kouhizadeh and Sarkis, 2018). BT offers environmental sustainability including renewable energy grids, sustainable food production, and e-waste monitoring. BT can reduce waste/emissions in the journey of products by applying low-carbon product design and production (Yadav and Singh, 2020). BT tracks the origins and movements of products and how it affects the environment (Adams et al., 2018). The BT-based energy-saving application reduces the amount of non-renewable energy resources (Sankaran, 2019). BT enhances traceability of the packaging process which contains a wide range of information (Gausdal et al., 2018). Ultimately, BT has the capability to interconnect all constituents, which results in overall environmental supply chain performance (i.e. SoS). Sustainable supply chain success relies on integrated performance measurement (Stank et al., 2001). Therefore, the system must track performance across the borders of external supply chain partners, measuring the overall sustainable supply chain. (see Table 1)

Table 1. Environmental performance

Type	**Sub-criteria**	**Definitions**	**Coded articles**
Environmental Performance	Green image/Green Marketing	BT based life cycle assessment helps to design more sustainable products and provide data for green marketing.	Saberi *et al*., 2019; Kouhizadeh *et al*., 2019 (1); Franca *et al*., 2019; Yadav and Singh, 2020; Pournader *et al*., 2020; Czachorowski *et al*., 2019; Kouhizadeh *et al*., 2019 (2); Lacity, 2018; Sankaran, 2019; Zhang *et al*., 2020; Teh *et al*., 2020
	Corporate environmental responsibility	BT offers environmental sustainability including renewable energy grids, sustainable food production, and e-waste monitoring.	Bai and Sarkis, 2020; Howson, 2020; Yadav and Singh, 2020; Orecchini *et al*., 2019; Montecchi *et al*., 2019; Hughes *et al*., 2019; Nikolakis *et al*., 2018; Verhoeven *et al*., 2018; Andoni *et al*., 2019; Wong *et al*., 2019; Chang *et al*., 2019; Murray *et al*., 2018; Roeck *et al*., 2020; Hald and Kirna, 2019
	Waste/emission reduction	BT can reduce waste/emissions in the journey of products by applying low-carbon product design and production.	Bai and Sarkis, 2020; Franca *et al*., 2019; Howson, 2020; Pournader *et al*., 2020; Czachorowski *et al*., 2019; Treiblmaier 2019; Manupati *et al*., 2020; Zhu *et al*., 2020; Tijan *et al*., 2019; Kouhizadeh *et al*., 2020
	Product lifecycle impact on environment	BT tracks the origins and movements of products and how it affects the environment.	Saberi *et al*., 2019; Kouhizadeh and Sarkis, 2018; Yadav and Singh, 2020; Kouhizadeh *et al*., 2019 (2); Abeyratne and Monfared, 2016; Wang *et al*., 2019; Babich and Hilary, 2019

	Non-renewable resources reduction	BT based energy-saving application reduces the amount of non-renewable energy consumed.	Kouhizadeh *et al*., 2019 (1); Yadav and Singh, 2020; Lacity, 2018; Andoni *et al*., 2019; Sankaran, 2019; Vaio and Varriale, 2020; Zhang *et al*., 2020; Fu *et al*., 2018
	Green packaging	The packaging of the final product which contains a wide variety of packaging processes requiring traceability. BT improves packaging processes.	Kouhizadeh *et al*., 2019 (1); Kouhizedeh and Sarkis, 2018; Teh *et al*., 2020; Behnke and Janssen, 2020; Fu *et al*., 2018
	Green supply chain	Environmentally concerned supply chain becomes popular due to its ability to provide economically, socially, and environmentally great solutions and maintains green supply chain.	Kouhizedeh and Sarkis, 2018; Kim and Shin, 2019; Gausdal *et al*., 2018; Tozanli *et al*., 2020

2.2.2. Economic performance in the blockchain technology supply chain

Economic performance refers to a measure of the benefit of adopting BT to improve operational efficiency or reduce costs. According to Carson et al. (2018), seventy percent of the value created in the BT-based supply chain is in cost reduction followed by revenue generation. The two most common operational initiatives that foster economic performance are profitability and cost reduction (Wamba et al., 2020). Individual constituents (e.g., suppliers, customers, distributors) can accomplish economic performance. Each constituent is an independent organization that adheres to its own economic objectives. Different constituents have different economic objectives such as operational costs reduction, inventory management improvement, and competitive advantage analysis. These constituent objectives have an impact on performance. BT is a key to fulfilling such economic performances. For example, BT is capable of achieving substantial cost savings in terms of operational efficiencies (Iansiti and Lakhani, 2017). Connecting supply chain-related organizations promote the integration of commodity, logistics, and information flows which reduce operating costs. BT can realize supply chain disintermediation in which fewer suppliers result in eliminating supply chain waste (Saberi et al., 2019). Also, advances in BT improve supply chain resilience by enhancing visibility, allowing a better prediction in the supply chain (Min, 2019). The technology can be applied to the inventory procurement and management of shipped goods (Martinez et al., 2019). In BT, the lead time information can be shared by each supplier and made available to a specific group of suppliers (Hald and Kinra, 2019). Thus, organizations can verify the validity of data stored in the BT (Longo et al., 2019). BT can identify recyclable components that can be reused or that need to be disposed of. Finally, BT can increase access to the pre-owned/secondary market. For example, Mercedes-Benz collaborates with PlatOn, a BT-based used car value platform company, to check the history and the value depreciation of used cars. Eventually, adopting BT has the potential to connect different constituent ledgers and maintain data integrity among multiple constituents. BT in the supply chain allows suppliers, manufacturers, transporters, and end-users to collect data, analyze trends and utilize a predictive monitoring process for overall economic performance. (see Table 2)

Table 2. Economic performance

Type	**Sub-criteria**	**Definitions**	**Coded articles**
	Reduce operational costs	BT links supply chain related organizations, facilitates the convergence of product flows, distribution, and information flows which reduce operational costs.	Saberi *et al*., 2019; Czachorowski *et al*., 2019; Irannezhad, 2018; Hughes *et al*., 2018; Andoni *et al*., 2019; Pan *et al*., 2020; Kim and Shin, 2019; Manupati *et al*., 2020; Schmidt and Wagner, 2019; Murray *et al*., 2018; Tozanli *et al*., 2020; Zhu and Kouhizadeh, 2019
	Reduce supply chain costs	BT can result in supply chain disintermediation where fewer tiers result in reducing waste in the supply chain.	Bai and Sarkis, 2020; Kshetri, 2018; Kamble *et al*., 2019; Howson, 2020; Korpela *et al*., 2017; Wang *et al*., 2019; Vaio and Varriale, 2020; Zhang *et al*., 2020; Karamchandani

Economic Performance			*et al*., 2020; Cole *et al*., 2019; Wamba *et al*., 2020
	Improve supply chain resilience	BT can benefit supply chain resilience by improving visibility, resulting in improved anticipation and adaptation capabilities.	Min, 2019; Kouhizedeh and Sarkis, 2018; Kouhizadeh *et al*., 2019 (2); Lacity, 2018; Hughes *et al*., 2018; Pettit *et al*., 2019; Kouhizadeh *et al*., 2020
	Improve inventory management	BT can help increase traceability of inventory, coupling with RFID technology.	Kamble *et al*., 2019; Yadav and Singh, 2020; Pournader *et al*., 2020; Babich and Hilary, 2019; Treiblmaier, 2019; Tijan *et al*., 2019; Ivanov *et al*., 2018; Martinez *et al*., 2019; Durach *et al*., 2020; Tozanli *et al*., 2020
	Reduce logistics costs	BTcan track shipments in global logistics operations. The shipment tracking capability of BT can reduce the risk of loss and damage during transit.	Kamble *et al*., 2019; Pournader *et al*., 2020; Irannezhad, 2018; Wang *et al*., 2019; Vaio and Varriale, 2020; Kurpjuweit *et al*., 2019; Durach *et al*., 2020
	Reduce lead time	The information about the lead time demand stored in BT can be shared among participants.	Bai and Sarkis, 2020; Kouhizedeh and Sarkis, 2018; Babich and Hilary, 2019; Wamba and Guthrie, 2020; Hald and Kirna, 2019; Longo *et al*., 2019
	Increase competitive advantage	BT can improve the organization and supply chain competitiveness.	Bai and Sarkis, 2020; Francisco and Swanson, 2018; Montecchi *et al*., 2019; Irannezhad, 2018; Wamba and Guthrie, 2020; Martinez *et al*., 2019
	Increase income through recycling	BT can easily identify components that can be reused or recycled, increasing organization revenue.	Saberi *et al*., 2019; Kouhizadeh *et al*., 2019 (1); Franca *et al*., 2019; Howson, 2020; Yadav and Singh, 2020; Czachorowski *et al*., 2019; Andoni *et al*., 2019; Zhang *et al*., 2020
	Increase access to preowned/secondary market	BT can provide a distributed platform for trading secondhand materials and products.	Kouhizadeh *et al*., 2019 (1); Kouhizedeh and Sarkis, 2018; Yadav and Singh, 2020; Kouhizadeh *et al*., 2019 (2); Babich and Hilary, 2019; Zhu *et al*., 2020; Abeyratne and Monfared, 2016; Tozanli *et al*., 2020

2.2.3. Customer performance in the blockchain technology supply chain

Customer performance is the perceived usefulness of BT, resulting in an attitude toward the product (Butz and Goodstein, 1996; Smith and Colgate, 2007). It entails customer satisfaction, customer confidence, customer interaction, and customer attitude toward green products/ processes. (Kibbeling et al., 2013; Flint et al., 2008). Each constituent (e.g., suppliers, customers, distributors) uses BT as a tool to meet customer needs. Individual constituents are autonomous entities that pursue their customer objectives. Each constituent has different customer objectives such as customer relationship management, customer loyalty, and customer retention. These constituent objectives can impact customer performance. BT is a device to achieve such customer performance. For example, BT can increase customer satisfaction and loyalty (Treiblmaier, 2019; Kouhizedeh and Sarkis, 2018; Kamble et al., 2019). BT is used to motivate customers by offering financial incentives in the form of cryptocurrency. As a result, more customers deposit recyclable items such as plastic, containers, and cans, which improves customer attitude toward green productions and processes (Saberi et al., 2019). In addition, the level of confidence increases with the transparent, verified, and immutable information from BT (Kouhizedeh and Sarkis, 2018). Being aware and confident of sustainable products can increase purchase intention. The transparency and traceability of BT substantially improve this confidence (Kouhizadeh et al., 2019a, b). Lastly, organizations can apply BT to build efficient relationships with customers, make business more transparent and sustainable and avoid frequent mistakes across the supply chain (Bai and Sarkis, 2020). Eventually, BT in the supply chain can interconnect all constituents which improve a customer's perception of benefits or quality of products. This improves overall customer performance in the supply chain. BT provides inherent promises to accomplish the goal (Kshetri, 2019). (see Table 3)

Table 3. Customer performance

Type	Sub-criteria	Definitions	Coded articles
Customer Performance	Customer satisfaction	Tracking goods through BT can improve the decision-making process for customers which satisfy their satisfaction.	Kouhizadeh *et al*., 2019 (1); Kamble *et al*., 2019; Yadav and Singh, 2020; Hughes *et al*., 2019; Nikolaskis *et al*., 2018; Vaio and Varriale, 2020; Teh *et al*., 2020; Tijan *et al*., 2019; Karamchandani *et al*., 2020; Durach *et al*., 2020
	Improve customer attitude toward green productions and processes	BT based energy saving management informs customers to use the product properly to reduce unnecessary energy consumption.	Franca *et al*., 2019; Kouhizedeh and Sarkis, 2018; Montecchi *et al*., 2019; Kouhizadeh *et al*., 2019 (2); Nikolaskis *et al*., 2018; Andoni *et al*., 2019; Zhang *et al*., 2020; Behnke and Janssen, 2020
	Improve customer confidence in brand	Tracking product components can provide consumers more confidence.	Kouhizadeh *et al*., 2019 (1); Bai and Sarkis, 2020; Yadav and Singh, 2020; Pournader *et al*., 2020; Hughes *et al*., 2019; Wang *et al*., 2019 (1); Vaio and Varriale, 2020; Litke *et al*., 2019; Queiroz and Wamba, 2019
	Improve customer relationship	BT, integrated with the supply chain, has the potential to transform the relationship between network members.	Howson, 2020; Montecchi *et al*., 2019; Lacity, 2018; Verhoeven *et al*., 2018; Andoni *et al*., 2019; Wamba and Guthrie, 2020; Morkunas *et al*., 2019; Karamchandani *et al*., 2020

2.2.4. Information performance in the blockchain technology supply chain

Information technology such as BT creates information performance (Korpela et al., 2017). BT can be used to collect information. If accumulated information can be shared across inter-organizations, it can serve as feedback to improve organizational capabilities and performances (Melville et al., 2004; Croom et al., 2007). Each constituent (e.g., suppliers, customers, distributors) may pursue different information objectives such as accumulation of the closed-loop process, product lifecycle, and internal knowledge. These constituent objectives have an impact on information performance. BT can act as a key to fulfilling such information performance. For instance, BT can track the product flow through reverse logistics systems. For instance, Hyundai Motor keeps track of the reverse supply chain (RSC) activities such as the history of recalled parts that can be resold. Moreover, tacit knowledge can be complemented with BT. The information value generated from BT remains in the organization's internal value chain (Martinez et al., 2019). These internal resources become important because it is the source of competitive advantage as well as being critical in daily operations. BT aggregates information about a product's journey from inception to recycling (Babich and Hilary, 2020) which can be managed in a closed-loop system (Sankaran, 2019). Finally, BT discloses the physical identities and habits of the customer. For instance, each customer order is recorded in a smart contract to understand customer preferences such as location or supplier preference based on the orders made previously (Litke et al., 2019). Eventually, BT integration has made it possible to obtain overall information performance from the supply chain network and share it with interconnected organizations (Kim and Shin, 2019). (see Table 4)

Table 4. Information performance

Type	Sub-criteria	Definitions	Coded articles
Information Performance	Forward supply chain processes	Supply chain members from upstream to downstream can access accurate and updated information about the products and inventory levels.	Saberi *et al.*, 2019; Min, 2019; Kouhizedeh and Sarkis, 2018; Howson, 2020; Yadav and Singh, 2020; Irannezhad, 2018; Wang *et al.*, 2019 (1); Pan *et al.*, 2020; Yang, 2019; Roeck *et al.*, 2020; Queiroz and Wamba, 2019
	Reverse supply chain processes	Every reverse supply chain transaction can be created/recorded in BT ledger that is traceable and immutable.	Saberi *et al.*, 2019; Kouhizadeh *et al.*, 2019 (1); Howson, 2020; Kouhizadeh *et al.*, 2019 (2); Wang *et al.*, 2019 (1); Babich and Hilary, 2019; Tozanli *et al.*, 2020; Zhu and Kouhizadeh, 2019
	Organizational internal/external knowledge/expertise	BT accelerates knowledge sharing and development. Shared knowledge, part of capabilities and value gaining, on a BT platform can advance organization's strategies, values, and cultures.	Kamble *et al.*, 2019; Pournader *et al.*, 2020; Czachorowski *et al.*, 2019; Kouhizadeh *et al.*, 2019 (2); Irannezhad, 2018; Verhoeven *et al.*, 2018; Sankaran, 2019; Wong *et al.*, 2019; Martinez *et al.*, 2019; Lambrou *et al.*, 2019; Cole *et al.*, 2019;
	Product life cycle information	Through BT based life cycle assessment, organizations are able to develop a comprehensive	Kouhizedeh and Sarkis, 2018; Montecchi *et al.*, 2019; Lacity, 2018; Hughes *et al.*, 2019; Vaio and Varriale, 2020; Schmidt and Wagner, 2019; Banarjee, 2018; Kurpjuweit *et*

		understanding of the product/service life cycle.	*al*., 2019; Litke *et al*., 2019; Azzi *et al*., 2019
	Consumer behavior	Each customer order in BT recognizes customer preferences such as location, area, or supplier preference based on the types of order made previously.	Bai and Sarkis, 2020; Franca *et al*., 2019; Kouhizedeh and Sarkis, 2018; Montecchi *et al*., 2019; Kouhizadeh *et al*., 2019 (2); Hughes *et al*., 2019; Babich and Hilary, 2019; Andoni *et al*., 2019; Martinez *et al*., 2019

3. Research Methodology

3.1. Survey method

3.1.1. Questionnaire development and pilot test

The questionnaire was developed in consultation with BT experts from both industry and academia. We integrated with the BT performances identified in the most recent literature. The performances were grouped into four dimensions. The list of performances and underlying manifestations were further refined and confirmed with the blockchain company CEOs and CFOs. The first draft version was reviewed by three operations management professors and the feedback was used to modify/rephrase certain questions and eliminate redundancies. Further, a pilot test using Q-sort was utilized to refine the questionnaire. Two independent rounds of Q-sorting were performed. To ensure domain and content validity, five pre-testers were used. First, all items were reordered, and the participants were asked to select an associated indicating variable for each domain. Experts are required to categorize the items between our initial thirty-two items with 70% as an acceptable ratio for content validity (Moore and Benbasat, 1991). In the second round, the same participants refined and eliminated scales, yielding twenty-five items across four domains. Results from the pretest were used to test the reliability of the questionnaire. The respondents from the BT industry (n = 32) were asked to evaluate the four BT performance dimensions on a five-point Likert scale (where "1" being not important at all and "5" being extremely important). The sample size should be four to five times the number of variables for exploratory factor analysis (Ngai et al., 2004). We achieved acceptable Cronbach's alpha of 0.6 as suggested by Naor et al. (2010).

3.1.2. Data collection and respondents' profile

Due to difficulty in obtaining survey data along with the likelihood of misunderstanding the survey contents, a balanced sample drawn from BT experts who specialize in BT implementation and supply chain management is preferable to a completely random sampling for the reasons stated. Convenience sampling is used in many manufacturing studies (Zhu and Sarkis, 2004; Kouhizadeh et al., 2020). They accessed a group of managers to complete the surveys. Thus, we selected a convenience sample of respondents who had BT project experience, implementation, and knowledge in a forward/reverse supply chain. (see Table 5)

Table 5. Descriptive summary

Blockchain Industry	Number of respondents	Percentage
Automobile	19	11.65%
Consumer apparel	12	7.36%
Energy	9	5.52%
Financial	7	4.29%
Food/beverage	9	5.52%
Healthcare	4	2.45%
Information technology	35	21.47%
Materials	15	9.20%
Retailing	19	11.65%
Transportation/logistics	12	7.36%
Blockchain lab	22	13.49%
Years		
1-5	48	29.44%
5-10	80	49.07%
10-20	31	19.01%
20 or more	4	2.45%
Employees		
1-10	15	9.20%
10- 50	22	13.49%
50-100	43	26.38%
100-300	32	19.63%

300 or more	51	31.28%
Title		
Assistant Manager	52	31.9%
Manager/Director	111	68.09%
Have knowledge/experience/implement BT		
Moderate to High	163	100%
Have forward/reverse supply chain experience/knowledge	163	100%

3.1.3. Principal component analysis (PCA) results and findings

The Bartlett's test of sphericity and the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy were used to access the appropriateness of the factor analysis. The test results of the KMO measure show that the compared value is 0.909, significantly exceeding the suggested minimum cutoff recommended of 0.6 required for accessing factor analysis (Hair et al., 2010). The Bartlett's test of sphericity is also significant ($p < 0.001$). Based on the above test results, it is evident that all factors are acceptable for applying factor analysis. Valid measures should have content validity, reliability, and unidimensionality. First, the content validity of the questionnaire in this study is all based on a thorough literature review and detailed discussion with three supply chain faculties who are familiar with BT, one BT startup CEO and one BT startup CFO. Second, a reliability test is utilized to check the overall consistency of a measure that should yield consistent results. The Cronbach's alpha value was used to test for reliability. The constructs were accepted if Cronbach's alpha value was greater than 0.6. The existing scale should have alpha higher than 0.7 while new scales developed should be above 0.6 (Naor et al., 2010). The Cronbach's alpha scores for newly constructed scales are as follows: environmental (α 5 0.853), economic (α 5 0.870), customer (α 5 0.736), information (0.823). As can be seen from Table 6, Cronbach's alpha values of the factors were well above the recommended cut-off value and ranged from 0.736 to 0.87. The results propose that the theoretical constructs demonstrate adequate psychometric properties. Third, unidimensionality was performed to test whether the individual items represent a single measure. PCA with varimax rotation was performed to evaluate unidimensionality. As a rule of thumb, the loading that underpins the correlation to the component should be greater than 0.4 (Kisperska and Swierczek, 2009). The PCA loadings are listed in Table 6. No item in our study had a loading of <0.4 and with all items loaded on the expected factors with eigenvalues greater than 1.00, the total variance explained was 60.00%. We further tested Harman's single factor test to identify common method variance. We examined the unrotated factor solution to determine the number of factors that are necessary to account for the variance in the variables. It is found that the unrotated factor solution shows no single factor dominant, which accounts for more than 50% of the variance, demonstrating the no significance of the issue of common method bias (Mitra and Datta, 2014). To test convergent validity, we investigated the AVE (average variance extracted) and CR (composite reliability). All AVE and CR values satisfied recommended cut-off value (AVE > 0.5, CR > 0.7) which satisfied convergent validity (see Table 6). We computed the square root of AVEs and compared the numbers with the correlations of each variable. As can be seen in Table 7, the values of diagonal values, the square root of AVEs, are greater than the correlation values which satisfied discriminant validity.

From the survey results, "green image and green packaging" have been observed as the most important factors in environmental performance. This means that BT-based solution provides effective sustainable practice such as recycling. Manufacturers can trace the source of their goods across the supply chain, ensuring that their products have been environmentally sourced. BT, therefore, helps in protecting the environment which has a positive effect on corporate image and firm value. BT also results in higher visibility in the sustainable attributes of packaging. BT could allow customers to track and trace exactly where their packaging comes from, placing a responsibility on food and beverage manufacturers to produce more sustainable packaging. “Increased access to a preowned market and improved inventory management” were found to be the most important factors in economic performance. Bosch, the German company, is using BT to eliminate the problems of used car fraud such as mileage, inspection history, and service history. Moreover, manufacturers are able to manage product origins, trace potential perishable goods and assess customer-level demand in real-time, allowing them to forecast demand accurately and plan to manufacture accordingly. “Improved customer relationship” is considered as the most important factor in customer performance. BT can be integrated with customer relationship management software which enables organizations to have verifiable records and restrict access from unwanted sources. As a result, CRM-related fraud may be minimized. “Organizational internal/external knowledge” is regarded as the dominant factor in information performance. It means that the tacit knowledge of BT can be retained in organizations and integrated into the manufacturing or service process. BT also allows trading partners to transfer business-relevant information or knowledge (e.g., about order).

Table 6. Results

No	Performance	Sub-Criteria	Item loading	Cronbach’s alpha	AVE	CR
1	Environment 1	Green image/marketing	0.803	.853	0.538	0.890
2	Environment 2	Corporate environment responsibility	0.715			
3	Environment 3	Waste/emission reduction	0.723			
4	Environment 4	Product lifecycle impact on environment	0.717			
5	Environment 5	Non-renewable resources reduction	0.628			
6	Environment 6	Green packaging	0.772			
7	Environment 7	Green supply chain	0.760			

8	Economic 1	Reduce operational costs	0.748	.870	0.5	0.897
9	Economic 2	Reduce supply chain costs	0.688			
10	Economic 3	Improve supply chain resilience	0.672			
11	Economic 4	Improve inventory management	0.724			
12	Economic 5	Reduce logistics costs	0.715			
13	Economic 6	Reduce lead time	0.676			
14	Economic 7	Increase competitive advantage	0.712			
15	Economic 8	Increase income through recycling	0.669			
16	Economic 9	Increase access to pre-owned/secondary market	0.712			
17	Customer 1	Improve Customer satisfaction	0.793	.736	0.56	0.837
18	Customer 2	Improve customer attitude toward green products/processes	0.766			
19	Customer 3	Improve customer confidence in brand/corporate image	0.722			
20	Customer 4	Improve customer relationship	0.721			
21	Information 1	Improve forward supply chain processes	0.886	.823	0.594	0.870
22	Information 2	Improve reversed supply chain processes	0.872			
23	Information 3	Organizational internal/external knowledge/expertise	0.648			
24	Information 4	Product lifecycle information	0.673			
25	Information 5	Customer behavior information	0.746			

Table 7. Discriminant validity

	Env	Econ	Cust	Info
Env	**0.733**			
Econ	0.701	**0.707**		
Cust	0.693	0.700	**0.748**	
Info	0.647	0.645	0.676	**0.771**

* Bold diagonal is square root of AVE > correlation

3.2 Decision making trial and evaluation laboratory (DEMATEL) method

Based on extracted performance factors, we applied the DEMATEL method to construct a cause-effect model for the performance of BT. Decision-making problems related to the complex system, particularly the evaluation given by experts or decision-makers on qualitative description of a certain object, are in linguistic expressions which makes further analysis difficult to comprehend. Therefore, we applied DEMATEL which can be implemented to measure ambiguous concepts associated with human subjective judgments

(Wu and Chang, 2015). The structural equation approach shows the interdependence relationships, the values of influential effect amongst factors, a causal-effect diagram, and the form of graphs to illustrate the importance of factors.

Step (1): Aggregate the average matrix using a pairwise matrix

Each respondent evaluates the direct influence between two factors using an integer scale of 0, 1, 2, 3 where 0 represents "no influence", "1 = low influence", "2 = medium influence" and "3 = high influence". The rationality of the evaluation scale of DEMATEL is the key to accurate decision-making. Experts tend to make linguistic judgments when assessing the influence relationships between factors due to the complex decision-making environment and the vagueness of inherent human thinking. The survey includes a pairwise comparison matrix of each BT performance. We aggregated experts' evaluation by computing the average scores and forming aggregate direct relationship matrices. Each element in the matrix, *Xij*, denotes the level of the influence of factor *i* on a factor *j*. The diagonal elements are set to zero for *i* = *j*, which shows no relationship between two factors. A general expression of a pairwise matrix is shown in eq (1).

$$X = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} x_{n2} & \dots & \dots & x_{nn} \end{bmatrix} \qquad \text{......eq (1)}$$

Step (2): Calculate the normalized initial direct-relation matrix

We normalized the aggregated relation matrix (*X*) above to compute the initial normalized influence matrix *D* by setting

$D = S * X$……………………………………………………………eq (2) where,

$S = \frac{1}{max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}}$ ……………………………………………………………………………eq (3)

Step (3): Compute the total relation matrix (T)

The total relation matrix can determine the relationship between factors using equation (4) below.

$$T = D(I - D)^{-1}$$

……………………………………………………………………………………………eq (4)

where I is the identity matrix.

Step (4): Determine the prominence and the net effects of factors

The sum of rows (n*1) and the sum of columns (1*n) are denoted as vector R and C within the total relation matrix T. The horizontal axis vector (R+ C) represents the degree of importance each factor holds. In a similar vein, the vertical axis ($R-C$) indicates factor criteria in a causal group. If the ($R-C$) is negative, the criteria are grouped into the effect group. Given t_{ij} is the comparison variable of the factor i on the factor j in the total matrix, T, where i,j = 1, 2, 3,…n, the row (R_i) and column (C_j) sum for each row i and column j can be obtained utilizing the following equations:

$R = [\sum_{i=1}^{n} t_{ij}]_{1*n} = [t_j]_{n*1}$ ……………………………………………………………eq (5)

$C = [\sum_{j=1}^{n} t_{ij}]_{1*n} = [t_j]_{n*1}$……………………………………………………………eq (6)

The overall prominence (P_i) indicates the total value that a factor influences on other factors and the value it is being influenced by. The net effect value (E_i) represents the difference between the impact that a factor has on other factors and the impact received by others. (P_i); (E_i) can be calculated using the following two equations below:

$P_i = (R + C \mid i = j)$………………………………………………………………...eq (7)

$E_i = (R - C \mid i = j)$ ....eq (8)

Step (5): Graphical representation

The last step is to graphically illustrate each factor of the computed prominence and net effect values on x and y axis. The x-axis shows the prominence value whereas the y-axis represents the net effect value of factors.

3.2.1 Application

The application used ten blockchain system-integration companies. The reason for selecting these companies is that panel groups had a significant level of knowledge/experience in blockchain and forward/reverse supply chain experience. They engaged in the implementation of BT, participated in a BT project, and monitored BT applications to protect valuable SCM information. The average work experience of BT panels was 13.4 years with an SD of 5.358 years Table 8 presents the respondent information and profiles. The survey design is to interpret the relationships among the performance categories. The major factors and subfactors are defined for survey participants. Respondents needed to read the definition of each factor and the subset definition of each factor before starting the survey. We utilized a linguistic scale (0 = no influence, 1 = low influence, 2 = medium influence, 3 = high influence) to convert the strength of the influence relationships.

Table 8. Respondent information

Respondent	Country	Position (title)	Department	BT experience	SCM experience
1	USA	Director	R&D	Run BT to protect SCM info	9 years
2	USA	Executive Vice President	Management	Implement BT in SCM	22 years
3	USA	Chief Executive Officer	IT department	Implement BT in SCM/RSC	5 years
4	USA	Supervisor	R&D lab	Participate in BT project	18 years

5	USA	Chief Information Officer	SCM Sales	BT system sales	15 years
6	USA	Director	IT department	Develop BT system	8 years
7	USA	Chief Technology Office	R&D/Sales/SCM	Implement BT in SCM/RSC	15 years
8	USA	Chief Information Officer	Marketing/Sales/ SCM	Implement/develop BT in SCM/RSC	15 years
9	South Korea	Blockchain startup CEO	Management	R&D, implementation	15 years
10	South Korea	Blockchain startup CFO	Blockchain Sales/Marketing	Sales implementation	6 years

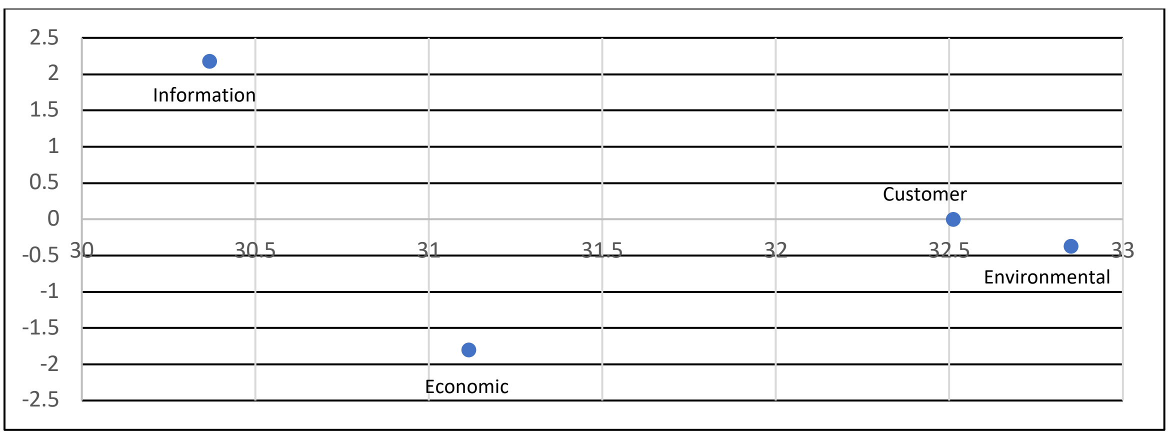
3.2.2 Application analysis and findings.

All average matrix A, normalized initial direct matrix D, and the total relation matrix T of four dimensions (environmental, economic, customer, information) are presented in the Table section. Based on the findings presented in Table 9 and Figure 1, the following major performances can be prioritized as follows: (1) environmental, (2) customer, (3) economics, and (4) information. Overall, we should consider both ($R+C$) and ($R-C$) ranking. The ($R+C$) score presents the relative significance of a value. The environment was found to be the most important enabler (R + C = 32.850), indicating that this dimension is the most essential dimension. Our findings support the claims made in the previous literature that the most promising feature of BT is in the triple bottom line of sustainability in the supply chain (Saberi et al., 2019). In the ($R-C$) ranking, information has the highest ranking, followed by the customer. The ($R-C$) score of economic is -1.805, the lowest value amongst effect factors means that it was obviously impacted by other factors. The net cause enablers were identified as customers and information. Because cause factors have an impact on the entire system, these criteria should be scrutinized. Amongst all factors in the cause group, information has the highest ($R - C$) score which means that information performance impacts more on the entire system than it receives from other factors. Besides, the degree of the influential impact of information is 16.274, which ranks first place among all factors. The value of accumulated information can be realized with BT which also influences customer relationships as well as organizational performance. The results also align with the previous study that shows how enhanced firm information affects customer relationships and organizational performance (Chuang and Lin, 2017).

Table 9. Overall performance

Dimensions	R	C	$P_i = R + C$ (prominence)	Rank ($R + C$)	$E_i = R - C$ (net effect)	Rank ($R - C$)
Environmental	16.237	16.613	32.850	1	-0.376	3
Economic	14.655	16.46	31.115	3	-1.805	4
Customer	16.256	16.255	32.511	2	0.001	2
Information	16.274	14.094	30.368	4	2.180	1

Figure 1. Cause and effect diagram

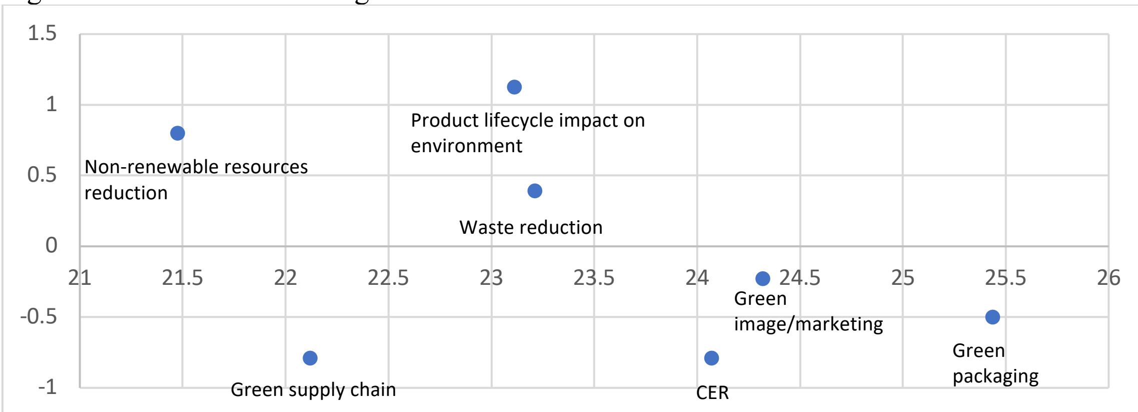


Environmental performance relationships appear in Table 10 and Figure 2. Expert results reveal green packaging, green image/marketing, and corporate environmental responsibility as the most prominent environmental performance. The results consist of the following sequence: (1) green packaging, (2) green image/marketing, (3) corporate environmental responsibility, (4) waste/emission reduction, (5) the product life cycle impact on the environment, (6) the green supply chain, and (7) nonrenewable resources reduction. Green packaging is the most important ($R + C = 25.436$). The results reveal that packaging can be reused and traced. BT traceability feature can monitor the recyclable packaging. The results empirically validate the findings of a previous study that recyclable packaging is monitored more effectively with the implementation of BT (Kouhizadeh and Sarkis, 2018). The net cause enablers are nonrenewable resources reduction, product life cycle impact on the environment, and waste/emission reduction. Based on the ($R - C$) values, we identified the net receiver values as follows: green image/ marketing, the green supply chain, corporate environmental responsibility, and green packaging. Within the cause group, the product lifecycle impact on the environment ($R - C$) is the most prominent factor which has more impact on the entire system. It implies that a BT-based product lifecycle management can enhance the green supply chain, green image/ marketing, environmental responsibility, and green packaging.

Table 10. Environmental performance

Dimensions	R	C	$P_i = R + C$ (prominence)	Rank ($R + C$)	$E_i = R - C$ (net effect)	Rank ($R - C$)
Green image/marketing	12.046	12.274	24.320	2	-0.228	4
Corporate environment responsibility	11.639	12.432	24.071	3	-0.793	7
Waste/emission reduction	11.800	11.41	23.210	4	0.39	3
Product lifecycle impact on environment	12.101	11.012	23.113	5	1.125	1
Non-renewable resources reduction	11.137	10.337	21.474	7	0.8	2
Green packaging	12.467	12.969	25.436	1	-0.502	5
Green supply chain	10.664	11.456	22.120	6	-0.792	6

Figure 2. Cause and effect diagram

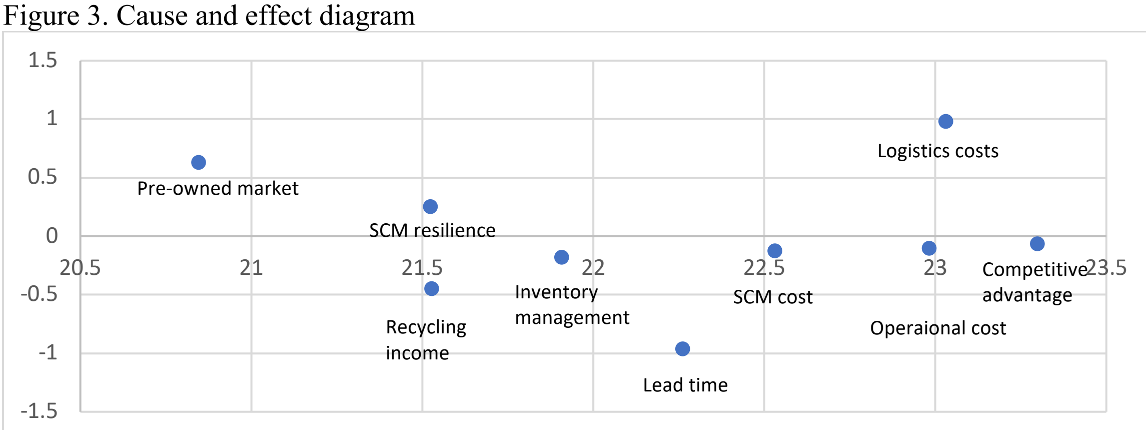


Net effects and overall prominence of economic performance appear in Table 11 and Figure 3. Based on the findings, the selected enablers are as follow: (1) competitive advantage, (2) logistics cost, (3) operational cost, (4) SCM cost, (5) lead time, (6) inventory management, (7) recycling income, (8) supply chain resilience and (9) access to the preowned market. The competitive advantage is the most important enabler ($R + C$ = 23.298). BT opens a gateway for gaining a competitive advantage. It is the driving force that keeps an organization ahead of its competitors. Whenever an organization embraces new technology, it aims to create or sustain a competitive advantage. The net cause enablers are logistics costs, SCM resilience, and preowned market. Recycling income, inventory management, lead time, SCM cost, operational cost, and competitive advantage are identified as the net receivers based on the $R - C$ value. For example, the waste collector uses BT to create a badge that identifies the ingredients of recyclable products thereby increasing the recovery rates. These recycled materials break down into pieces and resell for profit. The potential for operating cost reduction through logistics management is imperative because of a large portion of logistics costs.

Table 11. Economic performance

Dimensions	R	C	$P_i = R + C$ (prominence)	Rank $(R + C)$	$E_i = R - C$ (net effect)	Rank $(R - C)$
Reduce operational costs	11.439	11.542	22.981	3	-0.103	5
Reduce supply chain costs	11.205	11.326	22.531	4	-0.121	6
Improve supply chain resilience	10.890	10.641	21.523	8	0.257	3
Improve inventory management	10.866	11.041	21.907	6	-0.175	7
Reduce logistics costs	12.007	11.024	23.031	2	0.983	1
Reduce lead time	10.650	11.612	22.262	5	-0.962	9
Increase competitive advantage	11.618	11.680	23.298	1	-0.062	4
Increase income through recycling	10.540	10.988	21.528	7	-0.448	8
Increase access to pre-owned/ secondary market	10.738	10.107	20.845	9	0.631	2

Figure 3. Cause and effect diagram

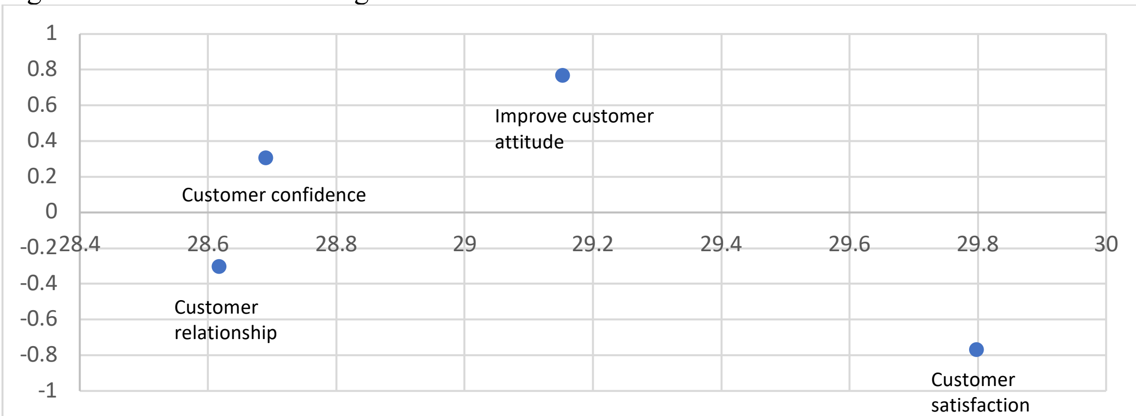


Based on the findings presented in Table 12 and Figure 4, the following major performances can be prioritized as follows: (1) customer satisfaction, (2) improved customer attitude toward green processes/products, (3) customer confidence, and (4) customer relationship. Overall, we should consider both (R + C) and (R – C) rankings. The (R + C) score presents the relative significance of a value. Customer satisfaction was found to be the most important enabler ($R + C = 29.798$), indicating that this dimension is the most essential dimension. Our findings support the claims made in the previous literature that the most promising feature of BT is in tracking goods which improves the decision-making process with the result being a more satisfying service for the end-user (Martinez et al., 2019). In the $(R - C)$ ranking, improved customer attitude toward green production/processes has the highest ranking, followed by customer confidence. The net cause enablers were identified as customer confidence and improved customer attitude toward green productions/processes. Amongst all factors in the cause group, improved customer attitude has the highest $(R - C)$ score which means that it impacts more on the entire system than it receives from other factors. For example, BT-based energy-saving management can inform customers to use the product properly to reduce unnecessary energy consumption which increases customer confidence, satisfaction, and relationship in terms of organizations' capability.

Table 12. Customer performance

Dimensions	R	C	$P_i = R + C$ (prominence)	Rank $(R + C)$	$E_i = R - C$ (net effect)	Rank $(R - C)$
Improve Customer satisfaction	14.515	15.283	29.798	1	-0.768	4
Improve customer attitude toward green products/processes	14.960	14.193	29.153	2	0.767	1
Improve customer confidence in brand/corporate image	14.498	14.192	28.690	3	0.306	2
Improve customer relationship	14.156	14.461	28.617	4	-0.305	3

Figure 4. Cause and effect diagram

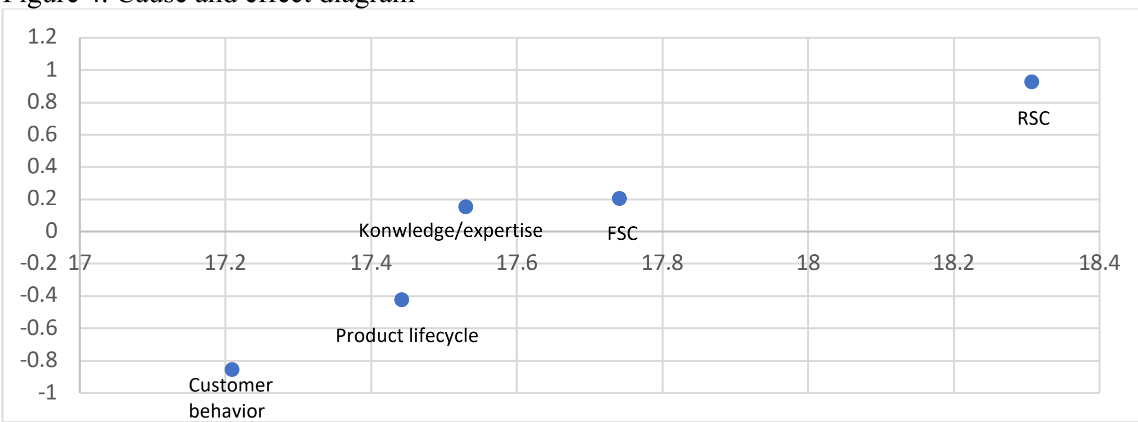


Net effects and overall prominence of information performance appear in Table 13 and Figure 5. Based on the findings, the following enablers are prioritized as follows: (1) reverse supply chain, (2) forward supply chain, (3) knowledge/expertise, (4) product life cycle, and (5) customer purchasing behavior. The reverse supply chain process information is the most important enabler (R + C = 23.298). Organizations must implement effective sustainability programs throughout product life cycles and govern proper disposal of products including recovery of raw materials. BT can identify visibility problems in collecting products from any stage of the reverse supply chain. Every reverse supply chain transaction can be recorded in the BT ledger and is traceable. Organizations can use BT to track returns. The return process is visible to customers, which increases consumer trust (Saberi et al., 2019). The net cause enablers are as follows: (1) the reverse supply chain process, (2) the forward supply chain process, and (3) knowledge and expertise. Product life cycle information and customer purchasing behavior are identified as the net receivers based on the R−C value.

Table 13. Information performance

Dimensions	R	C	$P_i = R + C$ (prominence)	Rank $(R + C)$	$E_i = R - C$ (net effect)	Rank $(R - C)$
Forward supply chain process	8.972	8.769	17.741	2	0.203	2
Reverse supply chain process	9.618	8.689	18.307	1	0.929	1
Organizational internal/external knowledge/expertise	8.833	8.697	17.530	3	0.154	3
Product lifecycle information	8.51	8.932	17.442	4	-0.422	4
Customer behavior	8.177	9.032	17.209	5	-0.855	5

Figure 4. Cause and effect diagram



4. Implication for theory and practice

4.1. Implication for theory

The proposed integrated framework provides a systematic tool to achieve the ultimate aims of BT-based supply chain performance. For scholars, there are key suggestions for BT-based supply chain implementation. Bai and Sarkis (2020) highlighted the critical lack of a holistic view of BT performance assessment in industry settings. Firstly, this study fills a gap with an integrated and holistic view of BT-based SCM performance assessment based on systems theory. The theoretical contribution of this study is to reveal the different indicators of BT performance measurements such as environmental, economics, customer, and information within the context of the supply chain. Therefore, this study supports the understanding of systems theory within the holistic assessment of BT-based performance.

Secondly, an SoS view of blockchain performance could also have significant implications. An SoS framework is proposed to provide a theoretical lens and methodological structure for integrative performance assessment. The SoS framework is based on the constituents and aggregation of performance in supply chain management. The performance of the constituents (e.g. suppliers, customers, distributors) within the supply chain has an emergent property which means it is inseparable from the operation of the supply chain as a whole (Bourne et al., 2018). Hence, the proposed theory facilitates considering interdependencies between constituents in a complex supply chain network. Further, the proposed framework can be used for the creation of an unexplored area of BT-based supply chain performance assessment. Lastly, we have further empirically tested the proposed model using data collected from multiple BT system integrators. To our knowledge, this is the first study focusing on BT integrators where an empirical study was conducted to investigate the performance assessment in the supply chain. Thus, we contribute to the literature by addressing the need to obtain a holistic understanding of the distinct relationships among four performance domains.

4.2 Implication for managers and practical implication

The four different domains investigated were initial and exploratory. We provided useful insights to supply chain managers and decision-makers. We identified twenty-five BT performance measurements based on a thorough literature review. We validated through pretesting of survey items using qualified experts with both blockchain implementation and supply chain experience. From the survey results, “Improved customer satisfaction” and “Improved customer relationship” have been observed as the most important BT performances. It means managers believe that technology is most effective in managing customer relationships. In addition, we performed exploratory factor analysis to extract factors for each dimension. We used four measurement dimensions as input in developing the DEMATEL ranking model. We also attempt to rank a given performance within an array of four domains. In summary, BT is most useful in managing environmental protection. This finding aligns with Saberi et al. (2019) in which tracking environmental conditions is a prominent application of BT. First, BT plays a vital role in managing green packaging. For example, Volkswagen uses VMware software to track and trace recycled packaging items based on the BT platform. In addition, BT can change the paradigm of conventional packaging which heavily relies on physical paperwork. It enables packages to communicate with customers and the supply chain. As technology continues adding more features such as serial numbers, barcodes, RFID, and QR code interconnection, it can convey authenticity. Secondly, the flow of reverse supply chain process information is a significant factor in information performance. BT enhances the flow of information in reverse logistics. It assists manufacturers in an understanding of the full life cycle of disposed of products. The environmental impact of materials requires verification and processing. The technology tracks refurbished and recycled electronic components throughout life cycles that store valuable information. BT makes reverse processes and systems more efficient, economical, and transparent (Kouhizadeh and Sarkis, 2018). Third, we have identified that customer satisfaction is a priority in the customer performance domains. BT can enhance customer satisfaction. Customers demand more sustainable practices when it comes to purchasing products. Consumers will purchase products with an improved sustainability footprint. Organizations with a poor sustainability reputation should embrace BT to enhance images of sustainability. The technology can detect, trace and recall products more efficiently when it integrates with the Internet of Things (IoT). It ensures customer satisfaction while eliminating reputational damage and operational losses. Lastly, the competitive advantage is the most notable aspect of economic performance. The competitive advantage is realized in an exchange relationship through the joint contribution of the supply chain partners. Once widely implemented across the industry, the technology can tackle data sharing problems resulting in easy data sharing. The holistic framework helps organizations (e.g., suppliers, customers, distributors) develop a road map. Practitioners could identify measurements (we recommended herein), rate their importance using the methodology we employed for rating importance, and construct a matrix to identify BT-based supply chain activities. Individual constituents (e.g., suppliers, customers, distributors) would have performance measurement needs that reflect the unique operations of their business. Thus, additional measurements may be desirable by each constituent and supply chain partner to complement their requirements. The proposed framework is an assessment tool for supply chain performance. The importance of metrics presented herein may not apply to all BT-based supply chains in all industries. We defined BT-based SCM performance and discussed the potential benefits. We illustrated a successful application of a newly developed concept at leading blockchain integration companies.

Appendix

Overall Performance

$$A = \begin{bmatrix} 0 & 2.5 & 2.5 & 2.1 \\ 2.4 & 0 & 2.2 & 1.6 \\ 2.5 & 2.4 & 0 & 2.2 \\ 2.4 & 2.3 & 2.4 & 0 \end{bmatrix} D = \begin{bmatrix} 0 & 0.342 & 0.342 & 0.288 \\ 0.392 & 0 & 0.301 & 0.219 \\ 0.342 & 0.329 & 0 & 0.301 \\ 0.329 & 0.315 & 0.329 & 0 \end{bmatrix}$$

$$T = D(I-D)^{-1} = \begin{bmatrix} 4.061 & 4.279 & 4.229 & 3.668 \\ 3.913 & 3.632 & 3.818 & 3.292 \\ 4.321 & 4.276 & 3.978 & 3.681 \\ 4.318 & 4.273 & 4.230 & 3.453 \end{bmatrix}$$

Environmental Performance

$$A = \begin{bmatrix} 0 & 2.5 & 2.1 & 2.3 & 1.7 & 2.6 & 2.0 \\ 2.3 & 0 & 2.3 & 2.1 & 2.0 & 1.9 & 2.1 \\ 2.3 & 2.5 & 0 & 1.9 & 1.7 & 2.5 & 2.0 \\ 2.7 & 2.5 & 1.7 & 0 & 2.0 & 2.3 & 2.1 \\ 1.9 & 2.0 & 2.1 & 2.1 & 0 & 1.8 & 2.2 \\ 2.4 & 2.2 & 2.0 & 1.8 & 2.0 & 0 & 2.1 \\ 1.9 & 2.0 & 2.2 & 1.7 & 1.7 & 2.0 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0.182 & 0.153 & 0.168 & 0.124 & 0.189 & 0.146 \\ 0.168 & 0 & 0.168 & 0.153 & 0.146 & 0.139 & 0.153 \\ 0.168 & 0.182 & 0 & 0.139 & 0.124 & 0.182 & 0.146 \\ 0.197 & 0.182 & 0.124 & 0 & 0.146 & 0.168 & 0.153 \\ 0.139 & 0.146 & 0.153 & 0.153 & 0 & 0.131 & 0.161 \\ 0.175 & 0.161 & 0.146 & 0.131 & 0.146 & 0 & 0.153 \\ 0.139 & 0.146 & 0.161 & 0.124 & 0.124 & 0.146 & 0 \end{bmatrix}$$

$$T = D(I-D)^{-1} = \begin{bmatrix} 1.703 & 1.879 & 1.715 & 1.668 & 1.545 & 1.820 & 1.716 \\ 1.788 & 1.666 & 1.673 & 1.606 & 1.512 & 1.726 & 1.668 \\ 1.812 & 1.844 & 1.550 & 1.615 & 1.515 & 1.781 & 1.683 \\ 1.878 & 1.889 & 1.703 & 1.535 & 1.569 & 1.814 & 1.731 \\ 1.695 & 1.721 & 1.596 & 1.542 & 1.325 & 1.651 & 1.607 \\ 1.769 & 1.779 & 1.634 & 1.568 & 1.492 & 2.580 & 1.645 \\ 1.629 & 1.654 & 1.539 & 1.460 & 1.379 & 1.597 & 1.406 \end{bmatrix}$$

Economic Performance

$$A = \begin{bmatrix} 0 & 2.5 & 2.0 & 2.3 & 2.4 & 2.1 & 2.3 & 1.9 & 1.8 \\ 2.3 & 0 & 2.0 & 2.2 & 2.5 & 2.3 & 2.1 & 1.9 & 1.6 \\ 2.2 & 2.3 & 0 & 2.0 & 2.0 & 2.0 & 2.2 & 2.0 & 1.7 \\ 2.2 & 2.3 & 2.1 & 0 & 1.8 & 2.2 & 2.0 & 2.1 & 1.7 \\ 2.6 & 2.3 & 2.1 & 2.4 & 0 & 2.6 & 2.3 & 2.0 & 2.0 \\ 2.1 & 2.4 & 1.9 & 1.9 & 2.1 & 0 & 1.9 & 1.8 & 1.9 \\ 2.2 & 2.0 & 2.1 & 1.9 & 2.0 & 2.5 & 0 & 2.6 & 2.4 \\ 2.1 & 1.7 & 1.7 & 1.7 & 2.1 & 2.0 & 2.5 & 0 & 2.0 \\ 1.8 & 1.6 & 2.1 & 2.3 & 1.7 & 1.9 & 2.5 & 2.3 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0.366 & 0.109 & 0.126 & 0.131 & 0.115 & 0.126 & 0.104 & 0.098 \\ 0.126 & 0 & 0.109 & 0.120 & 0.366 & 0.126 & 0.115 & 0.104 & 0.087 \\ 0.120 & 0.126 & 0 & 0.109 & 0.109 & 0.109 & 0.120 & 0.109 & 0.093 \\ 0.120 & 0.126 & 0.115 & 0 & 0.098 & 0.120 & 0.109 & 0.115 & 0.093 \\ 0.142 & 0.126 & 0.115 & 0.131 & 0 & 0.142 & 0.126 & 0.109 & 0.109 \\ 0.115 & 0.126 & 0.104 & 0.104 & 0.115 & 0 & 0.104 & 0.098 & 0.104 \\ 0.120 & 0.109 & 0.115 & 0.104 & 0.109 & 0.366 & 0 & 0.142 & 0.126 \\ 0.115 & 0.093 & 0.093 & 0.093 & 0.115 & 0.109 & 0.366 & 0 & 0.109 \\ 0.098 & 0.087 & 0.115 & 0.126 & 0.093 & 0.104 & 0.366 & 0.126 & 0 \end{bmatrix}$$

$$T = D(I-D)^{-1} = \begin{bmatrix} 1.224 & 1.321 & 1.225 & 1.282 & 1.285 & 1.334 & 1.349 & 1.258 & 1.161 \\ 1.311 & 1.177 & 1.202 & 1.254 & 1.265 & 1.318 & 1.315 & 1.234 & 1.129 \\ 1.272 & 1.255 & 1.073 & 1.212 & 1.211 & 1.270 & 1.285 & 1.207 & 1.105 \\ 1.269 & 1.252 & 1.173 & 1.111 & 1.200 & 1.276 & 1.274 & 1.209 & 1.102 \\ 1.408 & 1.372 & 1.286 & 1.344 & 1.227 & 1.417 & 1.410 & 1.320 & 1.223 \\ 1.242 & 1.234 & 1.143 & 1.184 & 1.191 & 1.146 & 1.246 & 1.173 & 1.091 \\ 1.349 & 1.317 & 1.247 & 1.282 & 1.285 & 1.369 & 1.258 & 1.307 & 1.204 \\ 1.230 & 1.191 & 1.123 & 1.163 & 1.179 & 1.233 & 1.261 & 1.074 & 1.086 \\ 1.237 & 1.207 & 1.161 & 1.209 & 1.181 & 1.249 & 1.282 & 1.206 & 1.006 \end{bmatrix}$$

Customer Performance

$$A = \begin{bmatrix} 0 & 2.5 & 2.4 & 2.0 \\ 2.5 & 0 & 2.0 & 2.7 \\ 2.4 & 2.3 & 0 & 2.2 \\ 2.5 & 1.9 & 2.3 & 0 \end{bmatrix} D = \begin{bmatrix} 0 & 0.338 & 0.324 & 0.270 \\ 0.338 & 0 & 0.270 & 0.365 \\ 0.324 & 0.311 & 0 & 0.297 \\ 0.338 & 0.257 & 0.311 & 0 \end{bmatrix}$$

$$T = D(I-D)^{-1} = \begin{bmatrix} 3.629 & 3.624 & 3.614 & 3.648 \\ 3.993 & 3.473 & 3.687 & 3.807 \\ 3.869 & 3.604 & 3.366 & 3.659 \\ 3.792 & 3.492 & 3.525 & 3.347 \end{bmatrix}$$

Information Performance

$$A = \begin{bmatrix} 0 & 2.4 & 2.0 & 2.0 & 2.1 \\ 2.3 & 0 & 2.2 & 2.5 & 2.3 \\ 2.1 & 1.8 & 0 & 2.4 & 2.1 \\ 2.1 & 2.0 & 1.8 & 0 & 2.1 \\ 1.8 & 2.0 & 2.2 & 1.6 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0.258 & 0.215 & 0.215 & 0.226 \\ 0.247 & 0 & 0.237 & 0.269 & 0.247 \\ 0.226 & 0.194 & 0 & 0.258 & 0.226 \\ 0.226 & 0.215 & 0.194 & 0 & 0.226 \\ 0.194 & 0.215 & 0.237 & 0.172 & 0 \end{bmatrix}$$

$$T = D(I - D)^{-1} = \begin{bmatrix} 1.636 & 1.826 & 1.798 & 1.843 & 1.869 \\ 1.951 & 1.737 & 1.928 & 1.998 & 2.004 \\ 1.794 & 1.758 & 1.594 & 1.845 & 1.842 \\ 1.735 & 1.715 & 1.699 & 1.579 & 1.782 \\ 1.653 & 1.653 & 1.669 & 1.667 & 1.535 \end{bmatrix}$$

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MANUSCRIPT 2

Evidence of Mitigating Supply Chain Risk Using Blockchain: Conceptualization, Scale Development, and Nomological Validity Test

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Abstract

The specific features of blockchain provide promise in managing supply chain risks. Given the growing research scrutiny in blockchain-based supply risk management, the development of a reliable and valid instrument to measure supply chain risk management is imperative. Nonetheless, no systematic research has been done to develop such an instrument. This study employs a comprehensive and rigorous procedure to develop a multifaceted measurement scale through an empirical analysis. We defined and operationalized the concept of blockchain-based supply chain risk management followed by validation and item measurement development. We employed both exploratory factor analysis and confirmatory factor analysis for scale development. Finally, a nomological model is theorized and tested to evaluate nomological validity. The findings present that blockchain-based supply chain risk management is a multidimensional construct, reflected in security risk management, operational risk management, information risk management, and financial risk management. Practitioners' guidance and suggestions are offered for risk management perspectives of blockchain.

Keyword: Blockchain, Blockchain supply risk management, Risk management, Scale development, Supply chain

1. Introduction

Blockchain technology (BT herein) in the supply chain has drawn much attention and its implementation is projected to grow. Samsung launches a BT to track imports and exports of shipments to work with 2500 suppliers around the world to reduce supply risks (Pederson et al., 2019). Secure information-sharing between supply chain partners facilitates real-time information sharing and reduces the risks in the supply chain (Lohmer et al., 2020). In addition, BT can increase visibility into the supply chain, reducing some types of supply risks (Babich and Hilary, 2020). As such, an understanding of how blockchain can manage supply chain risks has become an important topic for both academics and practitioners.

Risk management is a crucial topic in supply chain management. The organization's processes are exposed to different types of risks, such as fraud and violation. Effective risk management is essential to effective supply chain management. BT ensures the safety and authenticity of the data, reducing supply chain risks. By tracking products in the supply chain, organizations can mitigate their risk of legal liability around sourcing, customs, and other import regulations. In addition, BT helps predict many risks in the chain and lets all participants act accordingly.

Despite the potential risk management perspective of BT in the field of operations and supply chain management, it has received extremely limited attention in the OSCM literature, except few studies reporting a systematic review of literature reflecting on the drivers of BT adoption (Wamba et al., 2020), characteristics of BT (Cole et al., 2019), and barriers of adoption (Kouhizadeh et al., 2021). Empirical evidence on developing new models and tools to access several elements related to BT-based risk management is still scarce. Saberi et al. (2019) are also concerned the issue that BT improves supply chain risk requires further empirical investigation. While blockchain-based supply risk management may be the key to a firm's ability to manage supply chain risks, there is limited research on the topic. Prior to examining factors that contribute to the development of blockchain technology-based supply chain risk management (BT-SCRM herein), it is important to provide a unified definition of BT-SCRM. The aim of this paper is to address the following research questions:

- RQ1: Which aspects of supply chain risks are manageable when adopting blockchain technology in supply chain?
- RQ2: Can managing supply chain risks reduce the overall supply chain costs?

Thus, we address the gap related to the ambiguity surrounding the definitions and dimensions of BT-SCRM by employing a multidisciplinary literature review to gain an in-depth understanding of BT-SCRM. Additionally, an extensive instrument measurement is developed on the foundation of the risk management framework. We contribute to the blockchain and supply chain risk literature by defining, operationalizing, and validating BT-SCRM. In addition, a multi-agent technology model is proposed as the conceptual basis for the design of a BT-SCRM in the supply chain. Finally, we test whether managing supply chain risks using blockchain can reduce supply chain costs. Our study provides guidance to practitioners on blockchain based supply chain risk management at a practical level, and ways to reduce supply chain risks in uncertain environments.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical framework based on relevant literature. Section 3 explains the design of survey instruments as well as pilot-test procedures. Section 4 presents actual data sampling methods followed by data analyses and results in section 5. Section 6 discusses the result drawn from section 5. In sections 7, 8, and 9 concluding remarks are made, theoretical and practical implications are discussed, and limitations are outlined.

2. Literature Review

The present study draws on the literature of both supply chain risk management (SCRM) and blockchain technology (BT). Risk management is referred to as the identification and analysis of risks. The main concept of supply chain risk management (SCRM) is characterized by a cross-organizational endeavor aiming to identify and reduce the risk of supply chain-related issues. (Thun and Hoenig, 2011). For the intended results of SCRM, prior studies either emphasize the strengthening of the positive characteristics of the supply chain or the mitigation of negative risk effects (Baryannis et al., 2019). It covers the broad macro dimensions of operational risk, financial risk, information risk, and security risk (Tang, 2006; Voss and Williams, 2013). These four complementary parts of the SCRM concept are comprehensively addressed in the study when developing and validating the BT-SCRM scale. Supply chain professionals often need to identify such potential supply chain risks. Blockchain can mitigate such risks associated with supply chain management including vulnerability, intermediary interventions, and uncertainty (Min, 2019). Prior to integrating the concept of SCRM into BT, it is necessary to delve into the crux of these two concepts.

2.1.Supply chain risk management

Supply chain risk is interpreted as the likelihood and unexpected macro/micro-level events that adversely affect any part of the supply chain (Ho et al., 2015). Yang and Wei (2013) defined supply chain security risk as to the application of technologies to protect supply chain assets such as equipment, products, personnel, and facilities from theft and to prevent unauthorized people from entering into the supply chain. Supply chain security risk management facilitates international trade by improving customs clearance efficiency, reducing transit time, and increasing operational efficiency. It also helps to predict the movement of goods, reduce lead-time, reduce the time taken to release cargo by customs, decrease the number of customs inspections and waiting times at borders (Zailani et al., 2015).

Operational risk is about supply-demand and results from inadequate or failed processes (Lockamy and McCormack, 2010). The variation in a supply chain includes all factors affecting the flow of goods across the supply chain (Ju¨ttner et al., 2003). In a supply chain, the variations are raised from three sides: suppliers' performance, customer's demand, and internal production processes of the focal firm. Chen et al. (2012) defined supply chain operational risk as demand risk, supply risk, and process risk. Demand risk is defined as the deviation of the forecasted demand from actual demand. Large variations in order changes make it more difficult for manufacturers to forecast the demand. The mismatch between the actual orders and forecast would harm the efficiency of the supply chain. For instance, if the forecast is higher than the actual demand, it may result in excess inventory, obsolescence, inefficient capacity utilization (Sodhi and Lee, 2007). If the forecast is less than actual demand, it may result in shortages and failure to serve the customer. Thus, demand risk is a major threat for the supply chain to serve its customer. Supplier risk is the deviations in the inbound supply in terms of quantity, quality, and time that may result in incomplete orders (Kumar et al., 2010). Inconsistency in the supply side makes a focal firm unpredictable and increases supply risk. Inconsistent supply lead-time increases the forecast error. The inability of suppliers to deliver the required components or products can have detrimental effects on the supply chain's ability. Supply risk also has detrimental effects on outbound logistics which may have a negative impact on supply chain performance.

Financial risk is the uncertainty of cash flows between organizations, the incurrence of expenses, and settlements (Ho et al., 2015). Tang and Musa (2011) defined supply chain financial risk as a failure of the payment schedule, letter of credit, timely payment of bills, bankruptcy, supplier's contract, and credit terms. Financial supply chain risk involves the inability to settle payments and improper investment. The common risks are price/cost risk, exchange rate risk, financial handling, and financial strength of supply chain partners. Research on exchange rate risk can be found in Goh et al. (2007). The exchange rate has been a major hurdle that influences on firm's after-tax profit. Price and cost risk can be strongly related to the exchange rate (Papadakis, 2006). Kerr (2006) discusses the risk arising from financial handling and practice. For example, an increasing quantity and velocity of payment can complicate the financial flow and need urgent attention. Hendricks and Singhal (2005) study financial flow vulnerability and the long-term effect of supply chain disruptions with a focus on the financial strength of supply chain partners. Their empirical study also shows that this type of risk can be evaluated based on the evidence of increasing equity risk, financial leverage, and asset risk.

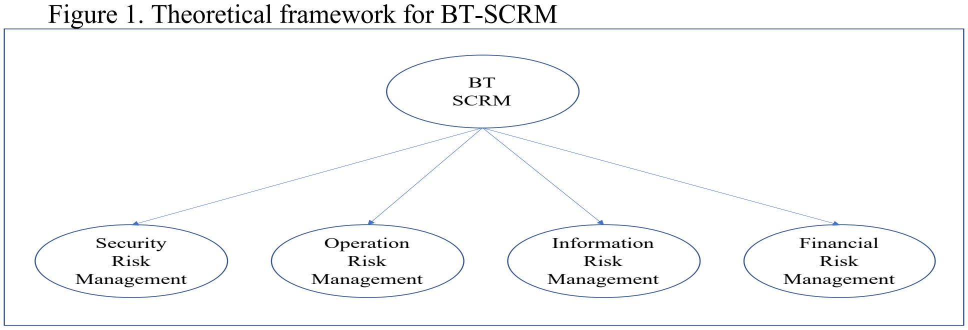
Information risks are classified as information accuracy risk, information system security risk, and intellectual property risk (Ho et al., 2015). The risk of information accuracy may be caused by information accessibility, data accuracy, and information efficiency. Inaccurate information can affect decision-making in the supply chain. The threats of information system security can occur externally by hackers and natural disasters (Faisal et al., 2007). Intellectual property risk is associated with increasing information flow in supply chain networks and the inability to protect information sharing, for instance, trade secret exposure (Barry, 2004).

2.2.Multi-agent technology conceptual model

The use of a multi-agent technology framework can be an alternative conceptual model for supply chain risk management in the blockchain context. Supply chain risk management involves several entities interacting with each other, each with different conflicting requirements (Baryannis et al., 2019). As such, constructive collaboration among supply chain partners is crucial to reduce risks (Hallikas et al., 2004). In the multi-agent technology model, an agent is an individual entity that is autonomous to accomplish its objectives through the axiom of coordination and communication with other agents (Giannakis and Louis, 2011). These agents interact with other inter-organizations to solve problems and to support risk management. Similarly, blockchain technology also contains individual agents (i.e., blockchain nodes such as supplier, buyer, manufacturer). Each agent is a useful system, developing its strategies, management objective, and risk management but interacting within the system to provide unique capability (Hong and Hales, 2021). These complex agents must function as an integrated metasystem to reduce risks to achieve a better output. Within this paradigm, the management of supply chain risks will mitigate by several autonomous decision-making entities (blockchain nodes) in the system. In this paper, a multi-agent technology framework is proposed as the conceptual basis for the design of a BT-SCRM, facilitating collaborative disruption risk management in a supply chain network. The multi-agent technology-based blockchain is the most promising technology for the effective management of supply chain risks under high levels of uncertainty. Through its capability, blockchain technology can demonstrate the proactive and autonomous behavior of the participating agents in mitigating risk and rectifying supply chain disruptions. The role of blockchain risk management software is to initiate the necessary coordination among the agents when a risk through a potential disruption is identified or the overall operational performance.

2.3.Blockchain technology in the context of supply chain risk management

Figure 1. Theoretical framework for BT-SCRM



2.3.1. BT-based security risk management

In this paper, we derived a conceptual framework based on the existing literature which highlights the potential risk management perspectives provided by blockchain (see figure 1). BT-based security risk management is the process of reducing any residual security-related risks in a supply chain. BT eliminates the cost of organizational data from security breaches. BT can be paired with a radio frequency identification system (RFID) that can perceive the risk of potential security breaches. Thus, the entire supply chain can share information regarding inventory without the risk of a data breach (Min, 2019; Tapscott, 2017; Gurtu and Johny, 2019). In addition, transactions are executed through consensus protocols among multiple parties involved, the risk of dealing with unknown parties is reduced, thus reducing invisible risks (Kumar et al., 2020). In BT, a smart contract is a computerized program to replace the needs of a conventional contract. It usually includes contract conditions, rules, and penalties that apply to all supply chain partners in the particular transaction. It provides better security and lower transaction costs. (Dutta et al., 2020). Contractual fraud would be easily detected and prevented by incorporating the Internet of Things (IoT) into BT, thus making the supply chain more resilient (Li et al., 2021; Lohmer et al., 2020). Also, it eliminates the product labeling practices currently used for cross-border trade, reducing the risk of counterfeit transactions (Yang, 2019).

BT tracks a wider range of logistics partners such as shippers, ocean freight forwarders, carriers, and port operators, making it possible to monitor and track goods more thoroughly. It records all the steps of delivery, ensures the traceability of the information, and reduces the risk of false claims and packet loss (Yang, 2019). Shipping tracking devices such as tags or sensors are subjected to cloning. The BT-based product management system allows proving the uniqueness of RFID shipping tag-attached products for the supply chain (Azzi et al., 2019). In addition, the BT solution impacts the operations of the firm's customer order management processes by granting access rights for viewing and accessing information (Martinez et al., 2019). Order processing is characterized by several actions involved in the customer fulfillment process. Orders from customers are received, processed, and finally delivered to final destinations. As such, BT provides online shipment tracking information to all stakeholders during the distribution, expediting supply chain order processes (Hastig and Sodhi, 2020; Ar et al., 2020). Lastly, cybercrime leads to data breaches, financial crimes, and internet protocol security risks. BT-based data integrity and security can protect against fraud and cybercrime. BT also has no single point of failure, so it is more resistant to attack (Wang et al., 2019). (see table 1)

Table 1. BT-based security management

Item	Definition	Citation
SR1	Preventing security breaches in supply chain	Min, 2019
SR2	Reducing hidden, invisible risks that cannot be easily detected by a limited number of participants (e.g., seller, buyer, financial institutions) in supply chain activities	Tapscott, 2017
SR3	Reducing the risk of contract life cycle due to Smart Contract which automates self-verifying/self-executing agreement	Gurtu and Johny, 2019
SR4	Detecting and preventing contractual fraud when Blockchain based Smart Contract incorporates the Internet of Things (IoT)	Kumar et al., 2020
SR5	Tracing the origin of an asset which prevents the transaction of fake or counterfeit assets	Dutta et al., 2020
SR6	Reducing the risk of loss and damage during transit due to the shipment (e.g., asset) tracking capability of Blockchain	Li et al., 2021
SR7	Making difficult for anyone to tamper with shipping labels and misplace shipments during transit due to Blockchain's resilience on cryptographic signatures	Lohmer et al., 2020 CS Yang, 2019 Azzi et al., 2019
SR8	Reducing the risk of fulfillment error due to visibility of the order fulfillment process	Martinez et al., 2019
SR9	Expediting order fulfillment processes throughout the supply chain with paperless and easy-to-access customer records	Hastig and Sodhi, 2020
SR10	Mitigating the risk of cybercrime and hacking due to the immutable nature of Blockchain	Ar et al., 2020 Wang et al., 2019

2.3.2. BT-based operation risk management

BT-based operation risk management is characterized as identifying and assessing the consequences of operational-related risks. Employing blockchain can reduce the probability of or losses associated with process risks, supply-side risks, and customer-side risks. It is widely known that BT can improve operational efficiency. For instance, hard copies are required for cross-border transportation, so there may be delays and losses in transition. BT can be used to develop digital solutions and could enhance the ability to share transaction records in real-time to improve operational process efficiency (Lim et al., 2021). Wu et al. (2021) investigate the impact of BT on the exporting firm's performance under the demand volatility risk. The result shows that BT could shorten supplier delivery lead time and reduce export costs. Ho et al. (2021) address the key research question on implementing blockchain through private chain code to enhance traceability and trackability for consistent inventory management. In addition, BT provides an accurate method to measure product quality. For instance, a manufacturing process can be adjusted when real-time monitoring discovers defects in production. The IoT could be coupled with BT to provide data security which improves the quality of parts produced. This improvement is due to multiple validation checks from other nodes in the blockchain network (Gurtu and Johny, 2019). The on-time delivery rate is used to measure the ability of suppliers to deliver orders on time. A high level of on-time delivery rate is an important index to measure sustainable organizations. For instance, fresh food products are prone to a short life cycle, decay over time, and fluctuating temperatures. Therefore, it requires strict temperature control and on-time delivery during transit. BT can track the entire cold supply chain in which suppliers are able to deliver as promised (Tian et al., 2021). In a conventional transaction, customers either use the planning schedule transaction (e.g., EDI, ERP) or the shipping schedule transaction. As data sharing is limited to these options, there is no real-time integration and data must be exchanged several times. The BT-based real-time data sharing across the supply chain enables a robust consensus-driven forecast, thereby improving order demand volume consistency from customers (Banerjee, 2018). Customers want real-time information on shipment, lead time, and invoices when an order is placed. BT is synchronized with the ERP systems which provide visibility into order and inventory status, thereby meeting nominated delivery lead time (Banerjee, 2018). Also, end customers sometimes fail to provide demand forecasting data accurately to the logistics providers. Accurate forecasting is essential for upstream supply chain planning and execution. Therefore, if downstream supply chains are willing to share their forecast of expected purchases, organizations can incorporate this knowledge into the demand and forecast model. The key to solving demand forecasting problems is to improve data integration from downstream. BT provides the solution for organizations to do so with optimal privacy and without losing any proprietary data (Subramanian et al., 2020). (see table 2)

Table 2. BT-based operational risk management

Item	Definition	Citation
OR1	Improving process efficiency (ex: poorly designed operations create unnecessarily slow processes which threaten the company's ability to achieve business objectives)	Lim et al., 2021
OR2	Meeting our required delivery lead times consistently from our suppliers	Wu et al., 2021
OR3	Meeting our inventory/volume requirements consistently from our suppliers	Ho et al., 2021
OR4	Meeting our quality specification requirements consistently from our suppliers	Gurtu and Johny, 2019
OR5	Suppliers deliver our orders as promised (e.g., service level)	Tian et al., 2020
OR6	Consistently meeting our overall requirements from our suppliers	Tian et al., 2020
OR7	In blockchain supply chain, orders from our customers are consistent with their forecasted demand volume	Benerjee, 2018
OR8	In blockchain supply chain, orders from our customers are consistent with their nominated delivery lead time	Benerjee, 2018
OR9	In blockchain supply chain, customers provide reliable forecasted demands	Benerjee, 2018
OR10	In blockchain supply chain, customers commit to demand forecasts	Subramania et al., 2020
OR11	In blockchain supply chain, customers' actual demands are consistent with our forecast	Subramania et al., 2020

2.3.3. BT-based information risk management

We define BT-based information risk management as preventing risk from malicious supply chain members, for instance, motivation to steal proprietary data or destroy an organization's operations. The source of information risk may include leaking vital information to competitors and hacking weak security members in the supply chain (Manuj et al., 2008). In contrast to conventional traceability technologies, BT helps to manage the supply chain information risk. BT is a novel technology that benefits from controlling and collecting supply chain risk information (Fan et al., 2020). BT offers protection from counterfeit products entering the supply chain. When paired with Near Field Communication (NFC) and IoT technologies, BT provides the consumer to access a product’s entire history and contribute to its verifiable history by scanning product tags (Danese et al., 2021). BT ensures a distributed database with information sharing ability among all parties. It is a decentralized database that makes sharing information more secure and transparent. BT also offers a solution to multinational information sharing, helping supply chain partners with security and collaboration (Mangla et al., 2021). A centralized server is vulnerable to single-point attacks and malicious insider attacks. The data stored in an organization’s internal system may be at risk of being leaked by malicious insiders to other organizations. BT is resilient to a single point of failure and insider attacks in the decentralized based system (Shi et al., 2020). Additionally, BT eliminates the supply chain risks caused by information asymmetry and incompleteness. It improves the supply chain response speed and decision accuracy (Rao et al., 2021). In terms of identity protection, BT can potentially eliminate the need for intermediaries and allow individuals control over their digital identities. With users’ digital identities cryptographically stored directly on a blockchain within an internet browser, users would no longer need to provide sensitive data to any third party (Hald and Kinra, 2019). BT platform can be paired with real-time sensors to prevent security vulnerabilities and attacks in systems, including malicious code injection, and malware installation (Etemadi et al., 2021). For instance, attackers may spoof and enter the network by bypassing the rules. If attackers spoof IP addresses of trusted IoT devices, then these addresses will not be considered a trusted list in the smart contract. Thus, organizations use a distributed solution to overcome problems associated with IP spoofing during the DDoS attack (Singh et al., 2020; Kurpjuweit et al., 2021). Lastly, the supply chain could be at risk of data leakage from participants. For instance, a retailer sharing its sales data with its supplier fears that the supplier may leak the information to the competitors. However, BT could avoid data leakage among unauthorized members in the supply chain (Wang et al., 2021). (see table 3)

Table 3. BT-based information risk management

Item	Definition	Citation
IR1	Collecting supply chain risk information periodically	Fan et al., 2020
IR2	Identifying counterfeit products	Danese et al., 2021
IR3	Verifying disturbance to the flow of the product information	Mangla et al., 2021
IR4	Reducing the likelihood of poor information sharing	Mangla et al., 2021
IR5	Reducing data exposure risk: a significant exposure of sensitive data entrusted to the company	Shi et al., 2020
IR6	Reducing external data risk: Interruption of external data availability or quality of external data significantly impairs the value of company	Fu et al., 2019
IR7	Mitigating Supply chain information asymmetry/incompleteness	Rao et al., 2021
IR8	Tracking information which eliminates fraud and manipulation	Hald and Kinra, 2019
IR9	Protecting information stored on the servers against identity theft	Etemadi et al., 2021
IR10	Preventing installation of malware code on a server for malicious activities	Singh et al., 2019
IR11	Identifying IP spoofing (false source IP address) and forgery attack	Kurpjuweit et al., 2021
IR12	Avoiding data leakage among unauthorized members in the supply chain	Wang et al., 2021

2.3.4. BT-based financial risk management

BT-based financial risk management is defined as managing supply chain financial risk using blockchain. The visibility feature of BT facilitates easier and lower-cost audits of financial transactions (Kumar et al., 2020). BT reduces transactional complexity, information asymmetry, and contractual incompleteness. Supply chain risks decrease due to traceability and openness of transaction and agreement records. Therefore, the technology reduces costs for gathering, drafting/negotiating contracts, and monitoring agreements (Schmidt and Wagner, 2019; Akter et al., 2020). BT has the potential to bring digital trust to the procurement payment. In a traditional supply chain, there is a pay gap between the actual delivery of the product, the generation of the invoice, and the final payment settlement. BT, however, helps organizations reduce this delayed payment by integrating digital payment contracts that flow across supply chain networks (Kamble et al., 2019). Moving centralized finance capital across the border often encounters friction and delay as it ties to specific geographic locations with flat currencies. In contrast, BT-based finance allows borderless financing because of unrestricted geographic location. (Chen and Bellavitis, 2020). Moreover, the benefit of BT is the integrity of a non-repudiable log of transparent transactions. The tamper-proof log of transaction history is especially helpful for auditing purposes. Its advantage is for the entire audit trail and the document flow (Pedersen et al., 2019). BT is used to build a supply chain financial platform to solve inefficient information sharing. The technical characteristic of the BT brings convenience to auditing and supervision, which controls the risk of the supply chain platform (Du et al., 2020). Duplicate and erroneous payments are problems in the supply chain because of human error. For instance, duplicate invoices might have different dates or different invoice numbers. This can happen when suppliers send both a paper and an electronic invoice after having not paid by the agreed-upon date. With BT, data cannot differ across databases because there is a single record. This reduces the risk of duplicate or tempered payment and makes the data itself much more reliable (Gaur and Gaiha, 2020; Sternberg et al., 2021). In a cross-border transaction, the credit evaluation of supply partners is the hurdle to completing the transaction. In BT, however, consumer credit data such as username, user address, credit score, number of purchases, and transaction list are included to manage credit-related transactions (Liu and Li, 2020). Incorrect and forged documents could increase the risk of non-existing collateral or the incorrect amount of financing from the bank. If, however, all relevant parties are registered into BT, the information is available to the parties involved. Therefore, the financing party could confirm the authenticity of the documents and the purchasers (Chen et al., 2020). Lastly, blockchain currency can act as an alternative payment method for customers. For instance, international payments or exchanges can be made at a much lower rate with cryptocurrency. Suppose an American organization's income is in U.S. dollars. However, the Korean supplier wants to be paid in Korean won. Conventionally, American organizations must exchange USD for KRW before making the payment. As the payment can take several days to settle, the USD-KRW exchange rate can fluctuate while the payment is in transit, causing losses for one or the other party. However, if both parties agree that the payment is made in Bitcoin, a fast settlement can significantly reduce the risk of adverse exchange rate movements (Durach et al., 2021). (see table 4)

Table 4. BT-based financial risk management

Item	Definition	Citation
FR1	Making useful for payment audits (e.g., freight payment audits, international payment audits) due to the secure nature of Blockchain	Kumar et al., 2020
FR2	Reducing transaction costs in supply chain	Schmidt and Wagner, 2019
FR3	Minimizing the risk associated with procurement payment	Akter et al., 2020
FR4	Reducing the cost of processing cross border payments (fast and simplified)	Kamble et al., 2019
FR5	Ease of availability and accessibility of the information stored for the audit	Chen and Bellavitis, 2020
FR6	Verifying financing information used in order process	Pederson et al., 2019
FR7	Enabling the real-time transfer of funds with minimal fees in supply chain transaction	Du et al., 2020
FR8	Minimizing the risk of duplicate payment in supply chain transaction	Gaur and Gaiha, 2020
FR9	Managing credit-related transaction details in supply chain	Sternberg et al., 2021
FR10	Minimizing the risk of incorrect amount of financing caused by forged documents	Liu and Li, 2020
FR11	Minimizing the risk of non-existing collateral from the bank caused by incorrect documents	Chen et al., 2020
FR12	Managing currency exchange rate risk in the supply chain	Durach et al., 2021

3. Development of a research instrument for BT-SCRM

Blockchain and SCRM may have been among the leading concerns in recent years, but the studies that focus on BT-SCRM remain inadequate. Therefore, we argue that an organization can strengthen its ability to carry out its strategic plan by implementing blockchain to manage risks consistently and holistically. This section examines different BT-SCRM constructs developed and proposes a theoretical framework based on the holistic risk categorization structure in figure 1.

3.1. Defining the domain of Blockchain-based supply chain risk management

Notwithstanding its limitations, prior studies have provided us with a theoretical and operational basis for the conceptualization of blockchain-based supply chain risk management. Therefore, we define blockchain-based supply chain risk management as an inter-organizational collaborative endeavor by implementing blockchain risk management strategies. It can identify (Ivanov et al., 2019), evaluate (Saberi et al.,2019), mitigate (De Giovanni, 2020), and monitor (Rogerson and Parry, 2020) unexpected conditions, which may adversely impact the supply chain network. We also maintain that BT-SCRM is a multifaceted concept with four risk management dimensions, enhancing risk management processes highlighted by several studies. The first dimension of BT-SCRM is Blockchain-based security risk management, defined here as the process of identifying, analyzing, evaluating, and monitoring any residual security-related risks in the supply chain using blockchain. The second dimension is Blockchain-based operations risk management. We define BT-based operation risk management as identifying and assessing the consequences of operational-related risks and employing blockchain to reduce the probability of losses associated with process risks, supply-side risks, and customer-side risks. BT-based information risk management, the third dimension, refers to managing supply chain financial risk, which threatens the entire supply chain financial flow by adopting blockchain. Finally, BT-based financial risk management represents managing supply chain financial risk, which threatens the supply chain financial flow by adopting blockchain.

3.2. Design of research instrument for BT-SCRM

Scale development followed procedures recommended by Churchill (1979) and Dillman, (2007). Each dimension of the second-order construct was measured using multi-item scales to increase reliability, improve validity, reduce measurement error, and assure variability among the survey respondents. Based on the rigorous literature review, we generated an initial pool of 45 items to reflect each domain of the BT-SCRM dimensions. Table (1-4) presents the list of security risk management (10 items), operation risk management (11 items), information risk management (12 items), and financial risk management (12 items) respectively. These items helped us in designing a preliminary questionnaire based on the research purpose of the present study. Once the survey items were determined, the procedures suggested by Dillman (2007) for survey design were employed. We presented the initial questionnaire to four experts comprising two blockchain researchers, one startup blockchain company CEO, and one startup blockchain R&D manager. We sought their opinions about the adequate and appropriate coverage of each BT-SCRM item. After the review, we rephrased a few items for ease of understanding. The entire procedure eventually helped us achieve the content validity of the questionnaire. The questionnaire includes three sections. The first section of the questionnaire contains three screening questions (a. level of experience/knowledge in blockchain, b. level of supply chain experience, c. define blockchain supply chain) to measure respondents' blockchain knowledge (see appendix 2). Screening questions helped us to either qualify or disqualify respondents from taking the survey further, depending on how they answered. The second section is about the demographic information of the respondents. The third section includes questions about respondents' perception of the level of BT-SCRM. We estimated all variables through respondents' perceptual evaluation on a 7-point Likert scale (1: not at all, 7=completely).

3.3. Item sorting of BT-SCRM and pilot-test

We pretested the scale items to increase reliability, decrease measurement error, and improve the validity of the construct measurement (Ruel et al., 2021). A Q-sorting method was employed to achieve these goals. This method was essential because the instrument we developed for measuring BT-SCRM was rather new, and its measurement scales were not yet well established or validated. To do so, we developed an instrument that includes three parts: a construct description, a random item list, and an item sorting instruction. First, the construct description explains the concept of four component factors of the BT-SCRM. The random item list of the 45 initial items was recast in the form of a single sentence. The sorting instructions then asked the respondents to read the construct definition and group them within four dimensions according to the definitions. Three pre-testers were used in the first rounds, comprising of one blockchain faculty, one blockchain company CEO, and one blockchain company senior developer who possesses reliable sources of information. We re-ordered the items randomly and asked the panels to choose an associated indicator variable. Panels are also required to categorize the questionnaire items among four-constructs with 70% agreement as to the acceptable rate for verified measures (Moore and Benbasat, 1991). Item placement ratios were used to access the content validity of the measurement items and the initial reliability of the proposed constructs. We computed respondents' responses using the frequency and all placement ratios of items within each target construct far exceeded the recommended level of 70% (i.e., SR=90%, OR=87%, IR=91%, FR=88%). We confirmed the adequacy of each scale item for capturing the factor components of the BT-SCRM scale. As a result, we deemed no further analysis was necessary for item refinement or rephrasing and adopted all forty-five items as measures of associated constructs (see table 5). Consequently, the resultant questionnaire was pretested using a random sample of supply chain managers with blockchain experience. During the spring of 2021, the survey was distributed to IT and supply chain personnel through Qualtrics. Prior to conducting the large-scale survey, we carried out a pilot test to check and refine the measurement items. This pilot test was conducted among 152 supply chain managers through convenience sampling. These respondents were asked to indicate the extent to which they agreed with each item. The result of the pilot-test indicated that KMO sampling adequacy (>0.9), Cronbach alpha (>0.8), and total variance explained (>0.6) far exceeds the recommended level which was considered acceptable for exhibiting content validity. Eventually, all items were adopted for the final model testing.

Table 5. Item sorting

	SR	OR	IR	FR
Respondent 1	9	10	11	12
Respondent 2	10	9	12	11
Respondent 3	8	10	10	9
Total Score	90%	87%	91%	88%

Notes: each cell shows the number of items correctly sorted into each construct

4. Data collection and sampling for the final model

The unit of analysis in the research was the organization, and the preferred target respondents were mid-level, senior level, and the chief executive level with in-depth knowledge on blockchain and supply chain. Data were gathered using a nonexperimental survey methodology (Gligor et al., 2013). The potential source of participants was selected from the panel members of SurveyMonkey, a large third-party marketing firm that specializes in survey data collection. During the spring of 2021, the survey was administered to 445 possible respondents in India (1. primary role in the organization: supply manager, president/CEO/chairperson, middle management, CFO, senior manager, project manager, chief technical officer, director; 2. field of expertise: procurement, operations, technology development software, technology implementation, technology development hardware; 3. professional position in company: director/manager; 4. industry sector: agriculture, banking, financial, IT, healthcare, manufacturing, pharmaceutical, retail, transportation, apparel, shipping, distribution, and automotive). SurveyMonkey utilizes regular benchmarking surveys to make sure all members are adequately representative of the population based on a random sample selection (Schniederjans and Hales, 2016). Potential respondents were prequalified using the screening test procedure. Screening tests were given prior to taking the actual survey. Screening tests were comprised of the level of blockchain experience, the level of supply chain experience, and define blockchain technology in the supply chain. Following the prequalified procedures, a total of 204 responses were received for a response rate of 45.8%. No reminder was sent to the SurveyMonkey panel members because of the initial high response rate. The demographic information for the final respondents is presented in table 6. We tested non-response bias for statistically significant differences between the earlier and the later waves of returned survey (Moon et al., 2012). We adopted a t-test to observe the mean differences among the 45 scales between the two groups. The results showed no significant difference at the 0.05 level, suggesting that the non-response bias did not exist.

5. Data analysis and results

5.1. Demographic profile

As shown in SIC code description table 6, respondent's organizations represent diverse industries. This classification system ensures results will be comparable to other international blockchain studies. The SIC chosen for the survey is a well representative sample of blockchain industries. Although there is a high concentration of IT organizations, these companies represent a significant part of Blockchain technology development. However, this high representation of a key group has led to the underrepresentation of other industries. Nonetheless, if the sample includes at least one industry from each of the SIC codes, it is considered as a representative sample of the industrial profile (Marshall et al., 2015). The demographic profile includes respondents' affiliation to organization type, years of operation, number of employees, and their position in the organization.

Table 6. Respondent demographic

SIC Description/SIC Code	Respondents	Percentage
Energy (oil, gas, non-renewable)/22	2	0.9%
Materials (chemical, packaging, metal)/32	6	2.9%
Transportation (airline, marine, road/rail)/48-49	1	0.5%
Automobile (auto components, automobiles)/33	7	3.4%
Retailing (suppliers, distributors, etc.)/44-45	7	3.4%
Consumer durable & Apparel (apparel, wine, luxury)/31	11	5.4%
Food/beverage products/72	8	3.9%
Healthcare (healthcare equipment, pharmaceutical, biotech)/62	2	0.9%
Financial (insurance, bank, capital)/52	8	3.9%
Information technology (IT service, electronic)/51	152	74.5%
Organization Years		
0-5 years	6	2.9%
5-9 years	57	27.9%
10-14 years	75	36.8%
More than 15 years	66	32.4%
Employees		
Less than 100	4	2.0%
100-249	29	14.2%
250-500	69	33.8%
Greater than 500	102	50%
Title		
Junior manager	3	1.5%
Middle manager	68	33.3%
Senior manager/director	97	47.5%
CEO/COO/CFO	36	17.6%
BT/SCM experience		
Blockchain – Moderate to high Have supply chain experience/knowledge	204	100%

5.2. Model specification and purification

To develop a reliable, valid, and parsimonious scale for BT-SCRM, we specified and purified the measurement models for each component factor. We conducted an exploratory factor analysis to ensure the unidimensionality of the constructs. We eliminated items based on the following criteria suggested by Ruel et al. (2021); items whose factor loading was less than 0.6, and items that showed a high cross-loading. A high cross-loading might be attributed to a statistical artifact.

As a result, we removed violating items to improve the chi-square value with caution. In the removal process, we scrutinized the concept and nature of each of the problematic items. We deleted them one by one according to the magnitude of the factor. After evaluating each factor construct individually, several items did not have adequate loadings and had significant cross-loadings. Therefore, we eliminated 14-items for the final analysis. Consequently, the number of items was reduced to 31, ending with 8 items for SR, 8 items for OR, 7 items for IR, and 8 items for FR. We conducted principal component extraction with varimax rotation. The results indicated that the 31 items projected four identified factors. In fact, this purification process made the structure of the component factors cleaner and simpler. The final sample explained 60.00% of the total variance for a KMO sampling adequacy of 0.951. In addition, the scale obtained a highly satisfactory Cronbach alpha of 0.976. The results confirm the overall reliability of the BT-SCRM survey items.

5.3. Scale characteristics

As shown in table 8, the mean values of the 31 measurement items ranged from 5.431 to 5.86, standard deviation from 1.067 to 1.325, and inter-item correlations from 0.265 to 0.628. Considering the results of the mean values, we found that the most important item within SR dimension was SR8 (mean=5.726, SD=1.167), implying that BT may reduce the risk of fulfillment error due to visibility among parties involved in the transaction. The key item in OR dimension was OR8 (mean=5.696, SD=1.067), suggesting that BT can realize the customer's nominated delivery lead time. For IR measurement item, the most important item was IR9 (mean=5.863, SD=1.074). This suggests that BT can protect supply chain information stored on the servers against identity theft. The most important indicator in FR was FR1 (mean=5.721, SD=1.076) which suggests that BT makes useful for payment auditing. Blockchain will allow auditors to access information in real-time and conduct online assessments throughout the period under audit instantly.

5.4. Validation of component factors

We conducted a series of validation tests for unidimensionality, reliability, convergent validity, discriminant validity, and nomological validity to examine the properties of the four component factors of the BT-SCRM. The results of tests should be satisfied to achieve overall construct validity (Hair et al., 2006).

Table 7. Inter-item correlations

Inter-item correlations and convergent validity

Items	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR10	OR1	OR2	OR3	OR5	OR6	OR8	OR10	OR11	IR2	IR7	IR8	IR9	IR10	IR11	IR12	FR1	FR2	FR4	FR6	FR8	FR10	FR11	FR12
SR2	1																														
SR3	.544**	1																													
SR4	.558**	.403**	1																												
SR5	.510**	.456**	.509**	1																											
SR6	.454**	.478**	.460**	.451**	1																										
SR7	.487**	.536**	.469**	.454**	.429**	1																									
SR8	.471**	.508**	.407**	.486**	.531**	.494**	1																								
SR10	.539**	.483**	.545**	.505**	.404**	.567**	.500**	1																							
OR1	.444**	.441**	.363**	.442**	.389**	.457**	.396**	.426**	1																						
OR2	.412**	.401**	.400**	.388**	.351**	.383**	.468**	.417**	.587**	1																					
OR3	.437**	.366**	.373**	.483**	.323**	.358**	.366**	.384**	.552**	.527**	1																				
OR5	.460**	.447**	.451**	.464**	.475**	.460**	.365**	.406**	.452**	.528**	.540**	1																			
OR6	.418**	.408**	.421**	.379**	.475**	.424**	.405**	.434**	.483**	.447**	.507**	.597**	1																		
OR8	.385**	.359**	.389**	.390**	.334**	.369**	.419**	.459**	.512**	.434**	.485**	.382**	.520**	1																	
OR10	.425**	.454**	.361**	.416**	.404**	.487**	.393**	.439**	.471**	.469**	.515**	.574**	.520**	.502**	1																
OR11	.506**	.447**	.401**	.409**	.455**	.470**	.484**	.444**	.469**	.489**	.448**	.595**	.580**	.493**	.589**	1															
IR2	.361**	.346**	.386**	.343**	.363**	.432**	.346**	.350**	.453**	.454**	.481**	.463**	.421**	.535**	.508**	.471**	1														
IR7	.484**	.477**	.544**	.471**	.416**	.462**	.454**	.524**	.394**	.452**	.498**	.405**	.425**	.525**	.469**	.463**	.480**	1													
IR8	.431**	.467**	.355**	.445**	.466**	.412**	.383**	.472**	.374**	.341**	.482**	.519**	.474**	.459**	.466**	.548**	.466**	.480**	1												
IR9	.285**	.436**	.312**	.369**	.368**	.424**	.449**	.455**	.347**	.384**	.342**	.384**	.405**	.441**	.531**	.447**	.444**	.432**	.478**	1											
IR10	.371**	.445**	.289**	.330**	.450**	.459**	.439**	.423**	.412**	.398**	.462**	.539**	.531**	.478**	.536**	.559**	.388**	.418**	.528**	.550**	1										
IR11	.477**	.531**	.388**	.356**	.407**	.518**	.438**	.533**	.346**	.320**	.408**	.415**	.447**	.364**	.484**	.522**	.419**	.491**	.486**	.477**	.459**	1									
IR12	.544**	.498**	.594**	.505**	.538**	.530**	.492**	.585**	.501**	.451**	.481**	.518**	.469**	.437**	.445**	.463**	.435**	.628**	.505**	.419**	.415**	.596**	1								
FR1	.405**	.421**	.412**	.356**	.385**	.483**	.421**	.474**	.605**	.584**	.505**	.523**	.466**	.535**	.522**	.566**	.562**	.518**	.493**	.508**	.468**	.423**	.557**	1							
FR2	.433**	.329**	.395**	.426**	.395**	.466**	.266**	.382**	.424**	.398**	.426**	.480**	.385**	.410**	.523**	.459**	.523**	.444**	.462**	.367**	.465**	.417**	.477**	.435**	1						
FR4	.404**	.346**	.476**	.353**	.339**	.426**	.298**	.435**	.399**	.314**	.369**	.461**	.453**	.491**	.464**	.516**	.496**	.528**	.447**	.366**	.373**	.398**	.522**	.461**	.555**	1					
FR6	.480**	.455**	.510**	.429**	.409**	.422**	.374**	.351**	.443**	.419**	.507**	.551**	.521**	.554**	.568**	.510**	.505**	.481**	.550**	.450**	.496**	.447**	.529**	.537**	.472**	.512**	1				
FR8	.439**	.448**	.440**	.510**	.410**	.492**	.347**	.354**	.484**	.422**	.492**	.476**	.450**	.531**	.523**	.540**	.558**	.432**	.464**	.412**	.489**	.498**	.478**	.501**	.676**	.589**	.564**	1			
FR10	.401**	.347**	.397**	.396**	.419**	.468**	.421**	.373**	.499**	.490**	.493**	.464**	.377**	.426**	.436**	.478**	.471**	.487**	.452**	.428**	.397**	.382**	.561**	.506**	.514**	.462**	.560**	.552**	1		
FR11	.423**	.375**	.265**	.300**	.308**	.467**	.391**	.455**	.350**	.302**	.443**	.385**	.375**	.447**	.440**	.528**	.488**	.414**	.506**	.427**	.443**	.509**	.445**	.423**	.486**	.494**	.431**	.530**	.543**	1	
FR12	.500**	.394**	.480**	.451**	.370**	.554**	.445**	.450**	.456**	.390**	.451**	.418**	.401**	.384**	.514**	.522**	.452**	.422**	.479**	.395**	.510**	.453**	.475**	.463**	.554**	.520**	.539**	.591**	.526**	.508**	1

5.4.1. Testing for unidimensionality

Unidimensionality is defined as a measure of a single attribute, construct, and an underlying set of items (Koufteros, 1999). A justification for accessing unidimensionality is to see how well the identified survey items reflect their respective latent variables. This procedure is required in a validation process and should be conducted prior to conducting other tests (Garver and Mentzer, 1999). We tested the unidimensionality of each component factor assessing the Cronbach alpha scores, the item-total correlations, and the results of the exploratory factor analysis (EFA) using varimax rotation. In table 8, all Cronbach's alpha values far exceed the cut-off recommended value of 0.7 and all item-to-total correlations are greater than the cut-off value of 0.4. For the EFA, the results show that the factor loadings of respective component factors are well above 0.7. The total cumulative variance is 60.00%. All of these properties demonstrate strong evidence of factor unidimensionality of the BT-SCRM. The results of this composite measurement were used to establish construct reliability and the remaining measure of validity. We further tested Harman's single factor test to identify common method bias. We examined the unrotated factor solution to determine the number of factors that are necessary to account for the variance in the variables. It is found that the unrotated factor solutions show no single factor dominant, which accounts for more than 50% of the variance, demonstrating the non-significance of the issue of common method bias.

Table 8. Descriptive statistic, alpha, EFA

KMO Sampling Adequacy (0.951, $P > 0.001$)						
Scale/Item	Mean	SD	Item-to-total correlation	Cronbach Alpha	Item Loadings	Total Variance Explained (Cumulative)
Security Risk Management				0.883		16.59%
SR2	5.582	1.182	0.656		0.771	

SR3	5.647	1.107	0.633		0.742	
SR4	5.583	1.270	0.619		0.732	
SR5	5.534	1.292	0.621		0.735	
SR6	5.637	1.181	0.603		0.703	
SR7	5.451	1.325	0.674		0.748	
SR8	5.726	1.167	0.612		0.740	
SR10	5.564	1.287	0.659		0.768	
Operation Risk Management						
OR1	5.686	1.114	0.647		0.746	
OR2	5.662	1.118	0.618		0.739	
OR3	5.529	1.217	0.653	0.892	0.756	32.16%
OR5	5.613	1.137	0.689		0.776	
OR6	5.632	1.139	0.659		0.772	
OR8	5.696	1.067	0.651		0.710	
OR10	5.583	1.178	0.701		0.770	
OR11	5.618	1.069	0.722		0.774	
Information Risk Management						
IR2	5.549	1.192	0.649		0.691	
IR7	5.529	1.176	0.686		0.760	
IR8	5.789	1.105	0.674	0.863	0.761	47.08%
IR9	5.863	1.074	0.606		0.728	
IR10	5.750	1.192	0.654		0.720	
IR11	5.558	1.276	0.651		0.759	
IR12	5.667	1.135	0.736		0.776	
Financial Risk Management						
FR1	5.721	1.076	0.703		0.704	
FR2	5.569	1.298	0.654		0.775	
FR4	5.534	1.176	0.644		0.755	
FR6	5.647	1.142	0.707	0.896	0.758	60.00%
FR8	5.431	1.301	0.716		0.829	
FR10	5.647	1.084	0.666		0.766	
FR11	5.662	1.219	0.625		0.722	
FR12	5.657	1.212	0.686		0.775	

5.4.2. Testing for reliability

Reliability is the degree to which measures yield consistent results (Hatcher and O'Rourke, 2013). The most common reliability tests are composite reliability (CR) and average variance extracted (AVE) estimates to confirm the scale reliability based on the two following formulas (Fornell and Larcker, 1981).

$$CR = \frac{(\Sigma\lambda)^2}{[\Sigma\lambda^2 + \Sigma(1-\lambda^2)]}$$

$$AVE = \frac{\Sigma\lambda^2}{[\Sigma\lambda^2 + \Sigma(1-\lambda^2)]}$$

where $1 - \lambda^2$ is the error variance associated with each observed variable and λ is the standardized loadings for each observed variable. As a rule of thumb, composite reliability presents the internal consistency in a set of constructs while the average variance extracted estimates the overall amount of variance in the indicators explained by the latent variables. A CR value greater than 0.7 and an AVE greater than 0.5 indicate good reliability for a construct. As shown in table 9, all values for CR and AVE exceed the recommended threshold, indicating that each component is reliable for test-retest reliability.

5.4.3. Testing for convergent validity

Convergent validity refers to whether items comprising a scale behave as if they are measuring one common construct (Dubey et al., 2019). Convergent validity can be examined using several different methods. First, we compared correlations at the item level as shown in table 7. If the lowest correlation of a particular item within each component factor is significant at $p < 0.01$, convergent validity is established. The results show that the correlation of each item in each factor is all greater than the recommended cut-off of 0.4 and is significant at the 0.01 level. Second, we checked the parameter estimated and the overall fit indices of each item. As shown in table 8, the regression weights of all items range from 0.601 to 0.739, satisfying the recommended threshold of 0.5. Third, a series of goodness-of-fit indices, namely X^2/df, IFI, TLI, and CFI is greater than the threshold level of 0.9 while RMR, RMSEA is lower than 0.08 (Hair et al., 2006). The results indicate strong evidence for the existence of convergent validity. All observed indicators are a good representation of their respective latent construct.

Table 9. Measurement properties of the component factors

Component/item	Regression weight Parameter (λ)	CR	AVE	Model summary and fit indices
SR2	0.657			
SR3	0.635			
SR4	0.636			
SR5	0.627	0.908	0.552	
SR6	0.601			
SR7	0.685			
SR8	0.613			
SR10	0.676			
OR1	0.643			
OR2	0.613			
OR3	0.664			
OR5	0.695	0.915	0.571	
OR6	0.667			
OR8	0.671			$\mathcal{X}^2/df$ = 1.713 IFI = 0.917 TLI = 0.907 CFI = 0.916 RMR = 0.068 RMSEA = 0.06
OR10	0.718			
OR11	0.736			
IR2	0.664			
IR7	0.691			
IR8	0.694			
IR9	0.618	0.896	0.552	
IR10	0.671			
IR11	0.670			
IR12	0.738			
FR1	0.709			
FR2	0.672			
FR3	0.668			
FR6	0.736	0.917	0.580	
FR8	0.739			
FR10	0.681			
FR11	0.656			
FR12	0.705			

Threshold CR (> .70), AVE (>0.50)

5.4.4. Testing for discriminant validity and nomological validity

Discriminant validity refers to the degree to which a dimension in a theoretical system differs from other dimensions in the same system (Churchill, 1979). First, the initial EFA results already established the evidence for discriminant validity. In addition, we examined the discriminant validity by comparing the square root of AVE of each construct with the correlation between constructs. To demonstrate an appropriate level of validity, each individual square root of AVE should exceed the correlation between constructs. The results provide support for discriminant validity, as each square root AVE exceeds the correlation between construct pairs. Moreover, a nomological test determines whether the correlation between each pair of constructs in the measurement model is significant and positive (Das, 2017). The correlation between each pair of construct measures has been shown in the off-diagonal elements of table 10 along with their respective *p*-values. It is observed that all 6 inter-construct correlations are significant at $p < 0.001$. It can be concluded that all inter-construct correlations are significant and positive. This ensures that nomological validity exists on the scale of BT-SCRM.

Table 10. Discriminant/nomological validity

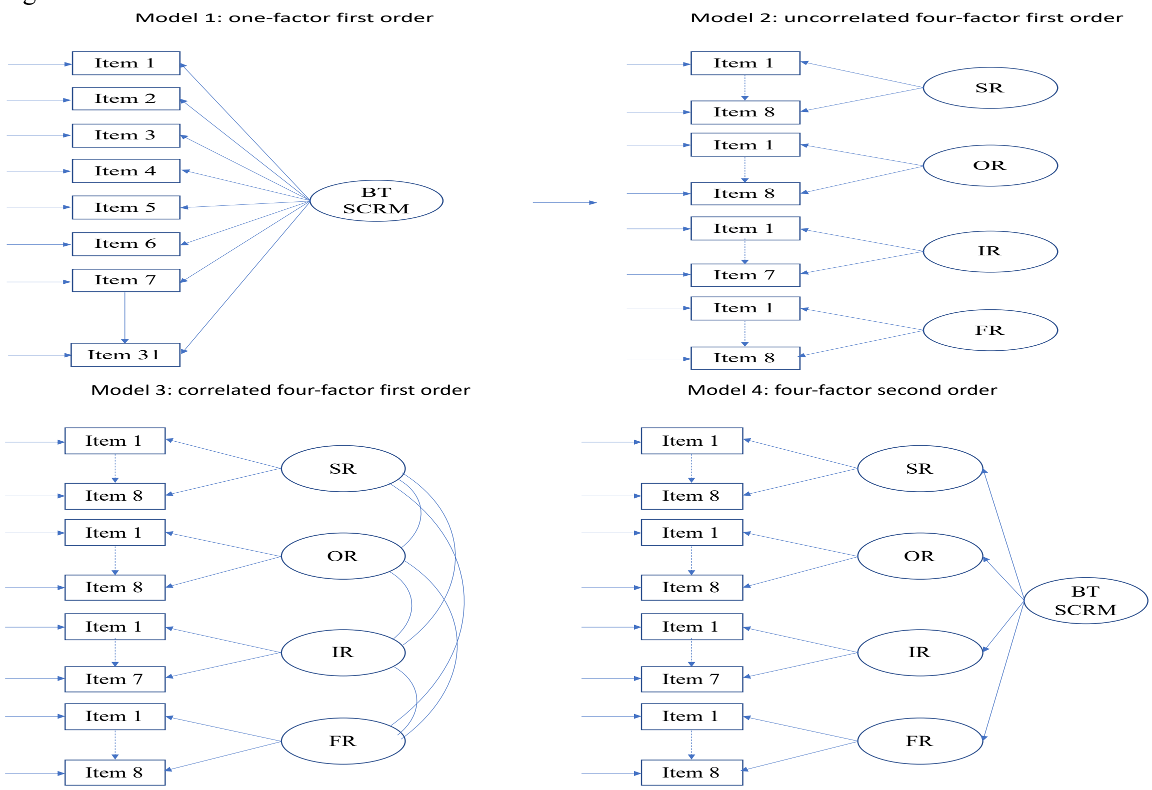
Construct	SR	OR	IR	FR
SR	***0.743***			
OR	0.664 (***)	***0.756***		
IR	0.630 (***)	0.647 (***)	***0.743***	
FR	0.652 (***)	0.651 (***)	0.660 (***)	***0.762***

*Bold italic= square root of AVE, *** $P < 0.001$

5.4.5. Developing and testing overall measurement model for BT-SCRM

Based on our theorization, four risk managements are a priori factors of the BT-SCRM. We tested if these reflect the dimensions and form a high-order factor in four steps. To achieve the purpose of proposing a reliable and valid measurement for BT-SCRM, we set up four alternative competing models as shown in figure 2 based on the approach suggested by Xia and Lee (2005). We examined each model using confirmatory factor analysis (CFA) in structural equation modeling. The four models are as follows: (1) a model in which the measures are loaded onto a single first-order factor, (2) a model in which the measures are loaded onto four uncorrelated first-order factors, (3) a model in which the measures are loaded onto four correlated first-order factors, and (4) a model in which the four factors are loaded onto a second-order factor of BT-SCRM.

Figure 2. Alternative models for CFA



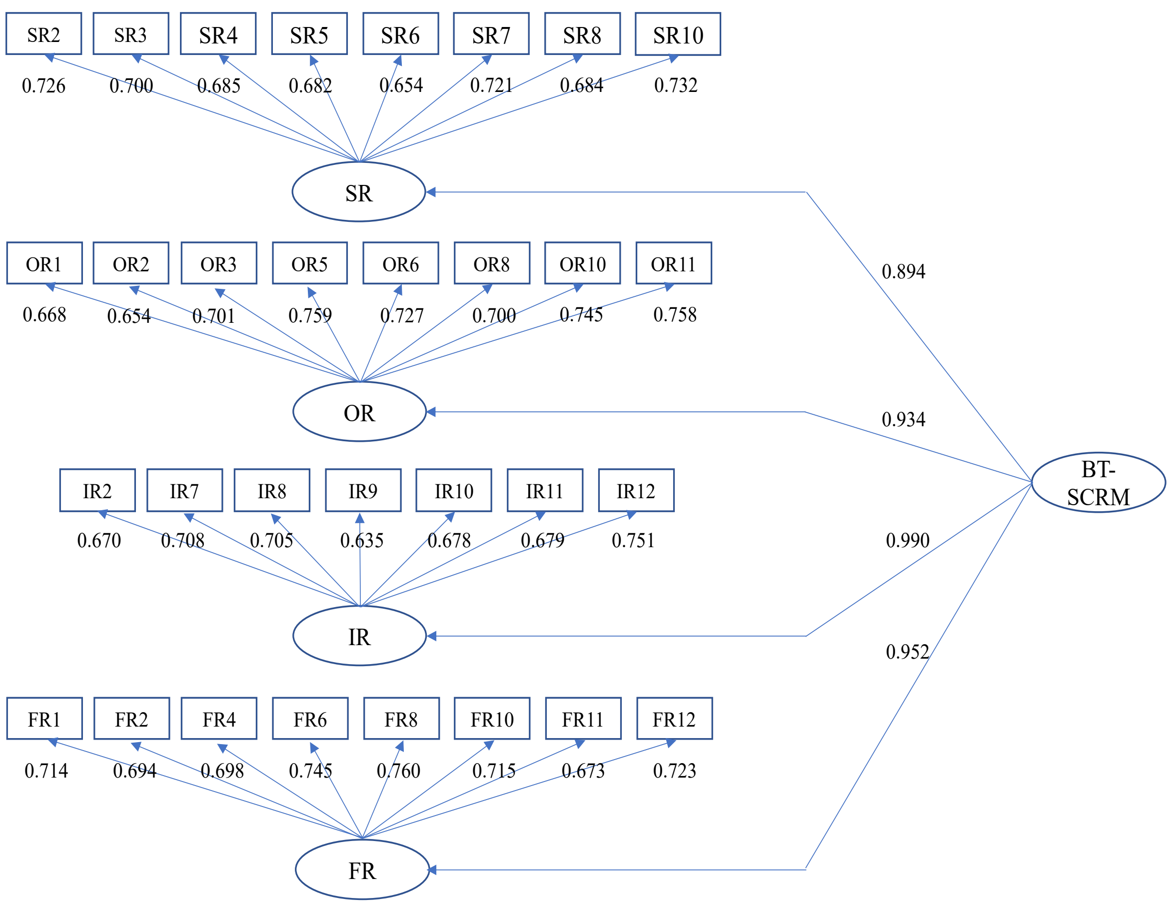
The results of these four competing models are shown in table 11. All models are acceptable because most fit indices satisfy the threshold criteria. For the one-factor first model, the normed χ^2/df is 1.713, well below 3.00. In addition, IFI (0.917), TLI (0.907), and CFI (0.916) are well above 0.9 threshold while RMR (0.068) and RMSEA (0.06) are below 0.08. For the uncorrelated four-factor first order model, we followed the analysis suggested by Swafford et al., (2006) which requires checking all measurement models. This ensures that parameter estimates exhibit the correct sign and size and are consistent with the underlying theory. All four models exhibit acceptable fit with a $\chi^2/df < 3.0$, IFI > 0.9, TLI > 0.9, CFI > 0.9, RMR < 0.08, and RMSEA < 0.08, thus indicating that the data acceptably fits the model. For the correlated four-factor first-order model, all four constructs are correlated, and all the model summary statistics and the goodness-of-fit indices suggest a good model fit. The χ^2/df normed is below 3.00 (p <0.001) while IFI (0.918), TLI (0.910), and CFI (0.918) are well above 0.9. RMR (0.065) and RMSEA (0.59) are below recommended cut-off value 0.8. We concluded that the four proposed factors fit the collected data well and could represent the scale of BT-SCRM. In the previous discussion, SR, OR, IR, and FR are specified as a priori factors of BT-SCRM. In the first model SR, OR, IR, and FR are correlated measurement factors for BT-SCRM. Alternatively, BT-SCRM may be operationalized as a second-order factor, where the four factors are governed by a higher-order factor. Moreover, the theory suggests that the correlations among first-order constructs can be more effectively explained by a higher-order factor. Therefore, an additional analysis is required for the second-order factor. An important note is that the higher-order factor is the theoretical explanation for the covariation of the first-order constructs (Segars and Grover, 1999). Thus, the second-order factor model may not have an improved fit as compared to the correlated first-order model. As shown in table 11, the overall goodness-of-fit indices indicate that the second-order model is still acceptable although it slightly underperformed in comparison to the first correlated model. An examination of the second-order model of the BT-SCRM construct reveals that all the standardized coefficient estimates exceed 0.9 which describes the significant relationships of the four factors on the higher-order construct of BT-SCRM. Therefore, BT-SCRM practice can be acceptably conceptualized as a second-order multidimensional construct consisting of SR, OR, IR, and FR.

Table 11. Model fit test-four alternative models

	X^2/df	IFI	TLI	CFI	RMR	RMSEA
One-factor first order	1.713***	0.917	0.907	0.916	0.068	0.060
Uncorrelated first order (SR)	1.593***	0.982	0.975	0.982	0.050	0.054
Uncorrelated first order (OR)	1.337***	0.992	0.987	0.992	0.039	0.041
Uncorrelated first order (IR)	1.141***	0.991	0.984	0.991	0.039	0.045
Uncorrelated first order (FR)	1.455***	0.988	0.983	0.988	0.042	0.047
Correlated four-factor first order	1.709***	0.918	0.910	0.918	0.065	0.590
Four-factor second order	1.720***	0.917	0.908	0.916	0.066	0.060

****p < 0.001, ** p < 0.01, *p < 0.05*

Fig. 3. Second-Order CFA Results

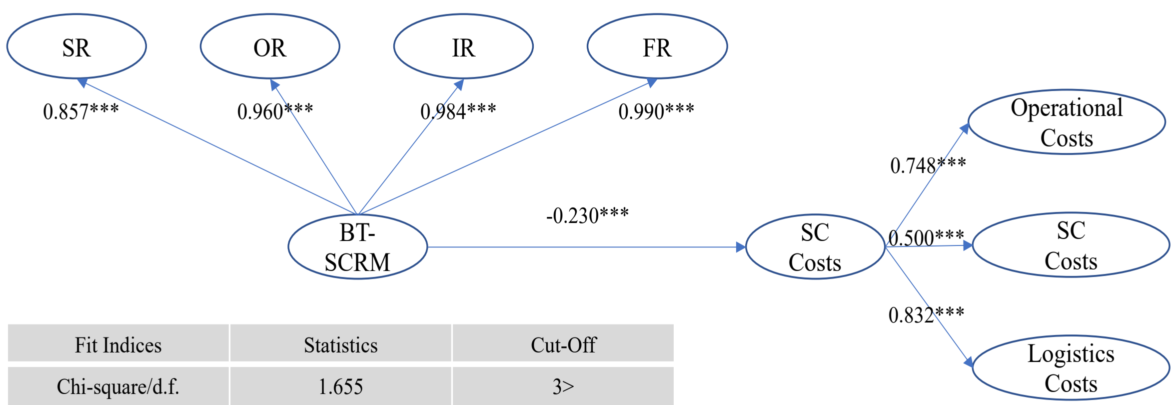


6. Result discussion and findings

This study contributes to theory building by addressing the ambiguity regarding the concepts and dimensions of BT-SCRM. This study expands on Min (2019) and Gurtu and Johny's (2019) conceptual work by fully examining the multidimensionality. SR, OR, IR, and FR were examined as potential blockchain-based supply chain risk management dimensions. The scale we developed adds to the body of knowledge by identifying key dimensions required for advancing BT-SCRM. To the best of our knowledge, the present study is the first to develop a systematic and empirical method to confirm reliable and validated scale instruments for BT-SCRM. Thus, we added empirical evidence to the conceptual notion of blockchain-based risk management. Also, we introduced a rigorously developed and validated scale. The multidisciplinary literature review indicated these constructs as potential dimensions and the results provided sufficient evidence to consider four dimensions as distinct constructs. In addition, we developed a hierarchical model in which the validated measurement scale is a second-order construct containing four unidimensional constructs. The existence of the second-order model suggests that blockchain-based risk management is comprised of a multifaceted and interactive process rather than a single dimension.

The proposed scale of BT-SCRM was examined by testing the relationship with a related outcome construct: supply chain costs. Blockchain can reduce costs primarily through disintermediation. Our rationales are underpinned by the opportunity to lower overall costs such as supply chain costs, logistics costs, and operational costs (Hong and Hales, 2021; Cole et al., 2019; Kurpjuweit et al., 2021). Foremost, risk management should lead to the desired cost savings. Total supply chain costs are important outcomes that need to be measured to ascertain the effectiveness of a risk management strategy (Manuj and Mentzer, 2008). We, therefore, posit the following hypothesis H1: managing supply chain risks using blockchain reduces supply chain costs. We collected data using a sample of 164 supply chain experts to conduct the analysis of the proposed model. Figure 4 exhibits the model, fit indices, and path coefficient. The fit indices of the proposed model are acceptable with $\mathcal{X}^2/df$ = 1. 655, SRMR = 0.071, IFI = 0.9, TLI = 0.89, CFI = 0.9, and RMSEA = 0.064. (see fig. 4). As theorized, BT-SCRM is significant and negatively related to costs, providing support for the nomological validity of the scale. We can conclude that blockchain manages supply chain risks which result in cost reduction. Our result aligns with previous preposition studies with concrete empirical evidence. Therefore, organizations may reduce the supply chain risks associated with trading partners and overall trading costs.

Figure 4. Research model



Fit Indices	Statistics	Cut-Off
Chi-square/d.f.	1.655	3>
SRMR	0.071	0.08>
IFI	0.900	0.9<
TLI	0.890	0.9<
CFI	0.900	0.9<
RMSEA	0.064	0.08>
N=164		

For organizations hesitant to implement BT, this measurement instrument could be used as a self-diagnostic tool to identify areas that require specific risk management. Our effort to develop such a scale and instrument will facilitate future research particularly in developing usable hypotheses and testing empirical results in blockchain supply chain risk field. Therefore, this study adds to the body of knowledge regarding BT-SCRM, giving other researchers a valuable tool to measure the supply chain risk management in various aspects of an organization. We believe that future qualitative and quantitative research that collects data from different supply chain members will provide more robust results. Future studies may extend on this initial construct and find the scale to be of use.

7. Theoretical implications

The development of BT-SCRM represents a crucial step toward further theoretical advancement. We theoretically develop and empirically proves the value of supply chain risk management in the BT context. With newly validated measurement scales, it is now possible to further examine the effects of various antecedents (e.g., blockchain adoption, consequent (e.g., blockchain performance), and contingency factors (e.g., supply chain integration). We can better understand how supply chain risks may be reduced and how blockchain technology can improve overall performance in future studies. Although the multi-agent conceptual model is a classical framework in engineering literature, it is an overlooked theory in supply chain management. The present study contributes to adopting the multi-agent framework to address supply chain risks management using blockchain. It can serve as an excellent theoretical backbone for risk analysis within the BT-SCRM.

The framework proposed provides a theoretical lens and methodological structure for integrative supply chain risk assessment. The proposed framework is a tool for the creation of an unexplored area of BT-SCRM. Thus, we contribute to the literature by addressing the need to obtain a holistic understanding of four supply chain risks.

8. Managerial implications

This study is useful for managers trying to identify different types of risk management capabilities of blockchain. The measurement scales developed are widely applicable to supply chain industries. Based on the validated measure of this study, BT enables supply chain organizations to track and monitor their overall risks. Supply chain managers can use the comprehensive list of dimensions explored in this study to determine what aspects of their supply chain operations risks can be mitigated to enhance the entire supply chain. We proved that BT is a novel technology, and it has a potential benefit for exploring and controlling supply chain risks. For instance, Amazon Managed Blockchain can predict supply chain risk from planning and execution system data, along with risk from external data sources (Kastelein, 2019). It can provide a decision support platform to mitigate the overall risk in the supply chain at scale and speed. An organization's processes are usually exposed to different types of risks discussed above. Effective risk management programs are essential to effective supply chain management. BT may help reduce many risks in the chain and allow all participants to act appropriately. Once managers identify risks associated with any one of the four dimensions, corrective actions may be taken to reduce or eliminate these vulnerabilities by adopting a comprehensive blockchain system in the supply chain network. However, blockchain adoption may vary by organization, even within the same industry. Traditional risks along with new risks will continue to emerge as adoption increases. It is paramount that risk management is effectively coupled with comprehensive cyber protections to secure the important resources.

9. Limitations and Future Studies

As with any exploratory study, BT-SCRM research is still in its nascent stage of development which may bring some redundancies in pre-existing concepts. Building a measurement scale enables us to consider, specify, and examine key elements of theoretical concepts. However, this is a dynamic process, and we expect that the scale may change as blockchain technology progresses. A few items dropped were of interest to the readers but did not survive rigorous statistical analysis. It is plausible that such items should be revisited in other contexts and future research may investigate such possibilities.

Appendix 1.

Evaluate to what extend blockchain could manage the following risks (0=not at all, 7=completely)	
*Items retained	
Security Risk Management	**Items**
*SR2	Reducing hidden, invisible risks that cannot be easily detected by a limited number of participants (e.g., seller, buyer, financial institutions) in supply chain activities
*SR3	Reducing the risk of contract life cycle due to Smart Contract which automates self-verifying/self-executing agreement
*SR4	Detecting and preventing contractual fraud when Blockchain based Smart Contract incorporates the Internet of Things (IoT)
*SR5	Tracing the origin of an asset which prevents the transaction of fake or counterfeit assets
*SR6	Reducing the risk of loss and damage during transit due to the shipment (e.g., asset) tracking capability of Blockchain
*SR7	Making difficult for anyone to tamper with shipping labels and misplace shipments during transit due to Blockchain's resilience on cryptographic signatures
*SR8	Reducing the risk of fulfillment error due to visibility of the order fulfillment process
*SR10	Mitigating the risk of cybercrime and hacking due to the immutable nature of Blockchain
Operation Risk Management	**Items**
*OR1	Improving process efficiency (ex: poorly designed operations create unnecessarily slow processes which threatens the company ability to achieve business objectives)
*OR2	Meeting our required delivery lead times consistently from our suppliers
*OR3	Meeting our inventory/volume requirements consistently from our suppliers
*OR5	Suppliers deliver our orders as promised (e.g., service level)
*OR6	Consistently meeting our overall requirements from our suppliers
*OR8	In blockchain supply chain, orders from our customers are consistent with their nominated delivery lead time
*OR10	In blockchain supply chain, customers commit to demand forecasts
*OR11	In blockchain supply chain, customers' actual demands are consistent with our forecast
Information Risk Management	**Items**
*IR2	Identifying counterfeit products
*IR7	Mitigating Supply chain information asymmetry/incompleteness
*IR8	Tracking information which eliminates fraud and manipulation
*IR9	Protecting information stored on the servers against identity theft
*IR10	Preventing installation of malware code on a server for malicious activities
*IR11	Identifying IP spoofing and forgery attack
*IR12	Avoiding data leakage among unauthorized members in the supply chain
Financial Risk Management	**Items**
*FR1	Making useful for payment audits (e.g., freight payment audits, international payment audits) due to the secure nature of Blockchain
*FR2	Reducing transaction costs in supply chain
*FR4	Reducing the cost of processing cross border payments (fast and simplified)
*FR6	Verifying financing information used in order process
*FR8	Minimizing the risk of double payment in supply chain transaction
*FR10	Minimizing the risk of incorrect amount of financing caused by forged documents
*FR11	Minimizing the risk of non-existing collateral from the bank caused by incorrect documents
*FR12	Managing currency exchange rate risk in the supply chain

Appendix 2.

Q1. How do you measure your knowledge on supply chain Blockchain technology?	
1	Have no knowledge
2	Have a low level of knowledge
3	Have a moderate level of knowledge
4	Have a high level of knowledge
Q2. Do you have experience/knowledge in supply chain?	
1	Yes
2	No
Q3. What is the definition of blockchain technology in supply chain?	
1	Distributed ledger linked in a peer-to-peer network.
2	Enterprise resource planning to integrate management of main business processes.
3	Electronic interchange of business information using a standardized format.

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MANUSCRIPT 3

Blockchain Adoption and Its Impact on Risk Management Performance and Firm Performance

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Abstract

The supply chain management field is experimenting with the integration of blockchain, a cutting-edge and highly disruptive technology. However, blockchain research in supply chain risk is still nascent, especially the relationship between blockchain adoption and its impact on both risk management performance and supply chain competency. We aim to investigate the potential influence of BT-based security management in mediating the effects of blockchain adoption on both risk management performance and firm performance. We plan to administer a survey in order to review the opinions and views of supply chain practitioners.

1. Introduction

Blockchain technology allows the digitization of decentralized business models through the "implementation of autonomous trust controls for decentralized systems" (Gartner, 2019). Blockchain technology has the potential to transform many SCM business models, enhance end-to-end supply chain risks and thus improve supply chain performance. Because of the blockchain tamper-proof characteristics, the level of blockchain adoption is expected to increase significantly to enhance supply chain performance. Amongst other advantages, blockchain can mitigate supply chain problems (e.g., supply chain risks, supply chain visibility), and enhance the traceability of operations (Helo and Shamsuzzoha, 2020). While these recent trends have emphasized blockchain benefits in the SCM, effective applications of the technology are still in a nascent stage. Prior studies have not contributed to the blockchain as an enabler of supply chain risk management and overall performance. We, therefore, aim to bridge the knowledge gap identified in the literature.

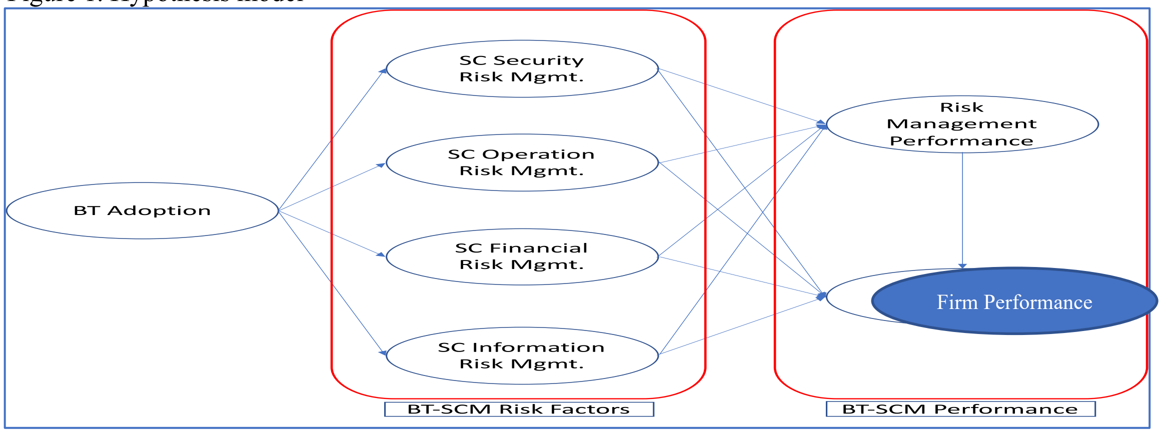
This study seeks to examine blockchain adoption and its influence on supply chain risk management and performance. To answer these questions, the model will be tested using data in India and US. The findings of this study enrich the literature in logistics/SCM and emerging blockchain literature. The rest of the paper is organized as follows. In section 2, constructs of interest are presented based on a theoretical foundation, which leads to the hypothesis formulation. In section 3 and 4, the description of the methodology is presented, followed by possible implications.

2. Literature Review

2.1. Theoretical background: technology adoption model

In this study, we plan to adopt an approach that is centered on blockchain adoption. This means that we provide the post-adoption blockchain benefits. We lay the groundwork for the literature on technology adoption (Warshaw and Davis, 1985). Davis (1989) presented two basic constructs that predict technology adoption and usage at the individual level. These two constructs are known as key elements of the technology acceptance model (TAM). These basic constructs are perceived usefulness (PU) and perceived ease of use (PEOU). Moreover, the unified theory of acceptance and use of technology (UTAUT) is a part of a theory that explains performance expectancy. Based on two characteristics, we propose a model that captures blockchain adoption and the impacts of blockchain on supply chain risk management and performance.

Figure 1. Hypothesis model



2.2. Blockchain adoption and BT-based blockchain risk management

Blockchain remains a significant technology that organizations have to develop, implement, and manage. It can help integrate different business partners in the supply chain, contributing to a more reliable environment (Angelis et al., 2019). With BT, organizations can achieve meaningful performance improvement in the supply chain network (Kshetri, 2018), bringing in more transparency. The numerous benefits of blockchain to monitor supply chain activities include mitigation of compliance risk, cost-efficient delivery of products, and coordination between partners. Organizations can mitigate their risk of legal liability around sourcing, customs, and other import regulations. Blockchain manages supply chain security which is the effort to reduce the risk of both external and internal threats such as terrorism, piracy, and theft. BT-based operation risk management is characterized as identifying and assessing the consequences of operational-related risks. Employing blockchain can reduce the probability of or losses associated with process risks, supply-side risks, and customer-side risks. It is widely known that BT can improve operational efficiency. For instance, hard copies are required for cross-border transportation, so there may be delays and losses in transition. In contrast to conventional traceability technologies, BT helps to manage the supply chain information risk. BT is a novel technology that benefits from controlling and collecting supply chain risk information (Fan et al., 2020). BT offers protection from counterfeit products entering the supply chain. The visibility feature of BT facilitates easier and lower-cost audits of financial transactions (Kumar et al., 2020). BT reduces transactional complexity, information asymmetry, and contractual incompleteness. Supply chain risks decrease due to traceability and openness of transaction and agreement records.

Therefore, we posit the following hypotheses:

H1a: Blockchain adoption in the supply chain has a positive impact on security risk management.

H1b: Blockchain adoption in the supply chain has a positive impact on information risk management.

H1c: Blockchain adoption in the supply chain has a positive impact on operational risk management.

H1d: Blockchain adoption in the supply chain has a positive impact on financial risk management.

2.3. BT-based blockchain risk management and risk management performance

The increasing complex supply chains and uncertain environment make organizations vulnerable to risks and disruptions (Bode and Wagner, 2015). The extant literature recognizes the contribution of SCRM to an organization's performance through lowering operational loss, fast response, and prevention of disruptions in supply chains (Manuj et al., 2014). In this study, we focus on four key performance indicators: quality, delivery, flexibility, and customer service (Rho et al., 2001). Blockchain-based supply chain risk management provides the ability to identify and mitigate potential risks factors in the supply chain and aids to reduce errors (Munir et al., 2020). BT-SCRM can detect potential threats which can be acted upon resulting in increased accuracy in forecasting and reducing the delivery time. It also improves flexibility performance in terms of downstream and upstream supply chain risks. Finally, customer service can be achieved by preventing the possible failure of products and materials (Zsidisin et al., 2013). Therefore, we posit the following hypothesis.

H2a: BT-based security risk management has a positive impact on risk management performance.

H2b: BT-based operational risk management has a positive impact on risk management performance.

H2c: BT-based information risk management has a positive impact on risk management performance.

H2d: BT-based financial risk management has a positive impact on risk management performance.

2.4. Risk management performance and firm performance

Both theories and business cases indicate that risk management performance is positively related to the firm performance (Jun and Rowley, 2014). For instance, the ability to confront to opportunities and threats in the environment helps firms satisfy customers' requirements under market uncertainty and, in turn, increases firms' market share and growth. A greater risk management ability can help organizations mitigate the adverse impact of supply chain vulnerability, which will reduce costs and lead to better financial performance. For instance, both ship owners and cargo insurers can use blockchain based insurance as a risk control measure to improve firm performance under risk and uncertainty. Therefore, we posit the following hypothesis.

H3: Risk performance has a positive impact on firm performance

2.5. BT-based blockchain risk management and firm performance

Each member of a supply chain network exchanges a significant amount of data every day. The goal of BT-SCRM is to reduce vulnerability and ensure continuity (Wieland and Wallenburg, 2012). Firm performance is generally achieved or enhanced with increased complexity because of the available technologies. As such, a blockchain-based risk management system tackles complexity and improves the performance of each organization interlinked in the blockchain system. Researchers suggest that the higher level of interdependence (i.e., higher level of collaboration) in a relationship, the better firm performance (Duffy and Fearne, 2004). Supply chain risk management involves several entities interacting with each other, each with different conflicting requirements (Baryannis et al., 2019). Therefore, constructive collaboration among supply chain partners is crucial to reduce risks. Blockchain technology also contains individual agents (i.e., blockchain nodes such as supplier, buyer, manufacturer). Each agent is a useful system, developing its strategies, management objective, and risk management but interacting within the system to provide unique capability. Therefore, we posit the following hypothesis.

H4: BT-SCRM has a positive impact on firm performance.

3. Methodology

3.1. Sampling and Data collection

We plan to investigate the impact of blockchain adoption within a supply chain context. We will use a measurement scale either taken directly from or scales identified in the existing literature (Bowersox et al., 2000). Data will be collected from a sample of experts (plant and operations managers) following a traditional two-wave mailing procedure. The data will be analyzed to assess the structural modeling using a two-step, covariance-based modeling process in which the measurement model is assessed followed by an assessment of the fit of the theorized structural model (Wisner, 2003). Covariance-based structural modeling is recommended when the purpose of the study is theory confirmation (Hair et al., 2011), as is the case in this study. The survey approach is suitable when investigating a phenomenon that is of interest (in our case, blockchain adoption and its relationship with supply chain risk management and performance). Like most recent studies that used a survey method approach to collect data, this study adds other items from the extant literature. All constructs will be measured by a 7-point Likert scale (ranging from "strongly disagree to 'strongly agree'). The survey will be administered through a leading market research firm from the supply chain professionals. We plan to use firm size as a control variable which may influence the firm performance.

3.2. Data analysis

We plan to use a structural equation modeling (SEM) to test the proposed model. All the analysis will be performed in SPSS + AMOS. Prior to testing the structural model, the measurement model will be tested for construct validities and reliabilities. Confirmatory factor analysis (CFA) will be carried out to examine the proposed factor structure (e.g., chi-squared/degree of freedom, comparative fit index, goodness of fit index, Tucker-Lewis's index, root mean square error of approximation). We also plan to show the value of Cronbach's alpha, average variance extracted (AVE), and standardized factor loadings (SFL) for each construct and its indicators. We will compute Cronbach's alpha and

Joreskog *p* to access reliability and internal consistency of the constructs (Braunscheidel and Suresh, 2009). Convergent validity measures the convergence between items measuring the same construct, indicating that all items in the construct measure the same construct. For establishing convergent validity, the factor loadings of all items exceed the value of 0.6 (Hair et al., 2013) and the value of AVE of all constructs are above 0.5. Regarding unidimensionality, CFI values of all constructs exceed the value of 0.9. Discriminant validity of the constructs indicates the extent to which each construct and its indicators are different from other constructs and their indicators. For establishing discriminant validity, we will test the values of squares inter construct correlation between all pairs of constructs that should be less than the values of AVE of individual constructs.

3.3. Structural model analysis

For testing the structural model, we will carry SEM analysis using AMOS 22 modeling software. Results of SEM should satisfy the following fit namely chi-square/degree of freedom <3, CFI > 0.9, GFI > 0.9, TLI > 0.9, RMSEA < 0.06 (Hu and Bentler, 1999). The following of path coefficients of the structural model should have a significant result with $p < 0.05$: (1) the effects of blockchain adoption on SCRM, (2) SCRM on risk management performance and firm performance, and (3) risk management performance on firm performance. For the robust path analysis, the bootstrapping method will be used with 2,000 iterations of resampling. Bootstrapping is a technique to resample a single dataset to create many simulated samples. Yung and Bentler (1996) considered the bootstrap's potential for obtaining robust statistics in structural equation modeling. This process allows to calculate standard errors, construct confidence intervals, and perform hypothesis testing. We plan to use AMOS program which offers bootstrap-derived robustness check for normal theory hypothesis testing. The bootstrapping method generating 2000 resamples will be used with bias-corrected confidence intervals (95%) to obtain more powerful confidence interval limits. It requires a sample size of 200 or larger for bootstrapping.

For testing multiple mediations and calculating estimated values of specific indirect effects, we will use AMOS Bayes estimation and resampling method (Gaskin et al., 2016). We will test multiple mediator effects simultaneously. A simultaneous testing provides the advantage of learning whether the effect of one mediator and other mediator is independent or not. We plan to follow the procedures proposed by Gregory et al. (2009) to test mediating effects of environmental risk management, operational risk management, information risk management, and financial risk management. We will compare three alternative models (direct, indirect, saturated) in terms of fit indices and path coefficients. If the chi-square difference between the direct and saturated models is significant, it indicates that all four risk management factors can mediate the influences of blockchain adoption on risk management performance.

Table 1. Survey item

Risk management performance (1= 'strongly disagree', 7= 'strongly agree')	
1	The company's ability to confront opportunities and threats in the environment compared to three years ago.
2	The company's risk management ability compared to three years ago.
3	The company's resource input into risk management compared to three years ago.
4	The company's level of agility compared to three years ago.
5	The company's level of integration between upstream and downstream supply chains compared to three years ago.
Firm performance (1= 'strongly disagree', 7= 'strongly agree')	
1	The company's level of customer loyalty compared to its major competitors.
2	The company's level of customer satisfaction compared to its major competitors.
3	The company's corporate identity compared to its major competitors.
4	The company's overall service level compared to its major competitors.
5	The company's operational performance compared to its major competitors.
6	The company's sales volume compared to its major competitors.
7	The company's market share compared to its major competitors.
8	The company's net profit before tax compared to its major competitors.

Blockchain adoption (1= 'strongly disagree', 7= 'strongly agree')	
1	My company invests resources in blockchain-enabled supply chain applications.
2	Business activities in our company require the use of blockchain technologies.
3	Functional areas in my company require the use of blockchain technologies.
Blockchain based supply risk management (1= 'strongly disagree', 7= 'strongly agree')	
1	Reducing hidden, invisible risks that cannot be easily detected by a limited number of participants (e.g., seller, buyer, financial institutions) in supply chain activities.
2	Reducing the risk of contract life cycle due to Smart Contract which automates self-verifying/self-executing agreement.
3	Detecting and preventing contractual fraud when Blockchain based Smart Contract incorporates the Internet of Things (IoT).
4	Tracing the origin of an asset which prevents the transaction of fake or counterfeit assets.
5	Reducing the risk of loss and damage during transit due to the shipment (e.g., asset) tracking capability of Blockchain.
6	Making difficult for anyone to tamper with shipping labels and misplace shipments during transit due to Blockchain's resilience on cryptographic signatures.
7	Reducing the risk of fulfillment error due to visibility of the order fulfillment process.
8	Mitigating the risk of cybercrime and hacking due to the immutable nature of Blockchain.
9	Improving process efficiency (ex: poorly designed operations create unnecessarily slow processes which threaten the company's ability to achieve business objectives).
10	Meeting our required delivery lead times consistently from our suppliers.
11	Meeting our inventory/volume requirements consistently from our suppliers.
12	Suppliers deliver our orders as promised (e.g., service level).
13	Consistently meeting our overall requirements from our suppliers.
14	In blockchain supply chain, orders from our customers are consistent with their nominated delivery lead time.
15	In blockchain supply chain, customers commit to demand forecasts.
16	In blockchain supply chain, customers' actual demands are consistent with our forecast.
17	Identifying counterfeit products.
18	Mitigating Supply chain information asymmetry/incompleteness.
19	Tracking information which eliminates fraud and manipulation.
20	Protecting information stored on the servers against identity theft.
21	Preventing installation of malware code on a server for malicious activities.
22	Identifying IP spoofing (false source IP address) and forgery.
23	Avoiding data leakage among unauthorized members in the supply chain.
24	Making useful for payment audits (e.g., freight payment audits, international payment audits) due to the secure nature of Blockchain.
25	Reducing transaction costs in supply chain.
26	Reducing the cost of processing cross border payments (fast and simplified).
27	Verifying financing information used in order process.
28	Minimizing the risk of duplicate payment in supply chain transaction.
29	Minimizing the risk of incorrect amount of financing caused by forged documents.
30	Minimizing the risk of non-existing collateral from the bank caused by incorrect documents.
31	Managing currency exchange rate risk in the supply chain.

4. Theoretical and Managerial Implication

4.1. Theoretical implication and managerial implication

From a theoretical perspective, this study contributes to emerging technology shedding more light on risk management and performance in logistics/SCM area. Second, this study is a foundational research stream about blockchain adoption and its impacts on performance with a robust theoretical model. The results will be validated the model in two countries, India and US. Our research will show that blockchain is an effective technology to support supply chain risks and performance. Moreover, managers will gain an in-depth understanding of the blockchain adoption complexities. To support blockchain implementation, managers should put an effort into observing the relationship between blockchain constructs. Our results will show that supply chain risks and performance have a strong relationship. We expect that blockchain plays a more fundamental role in supporting an organization's operations.

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