Enablers to the adoption of Blockchain Technology in Logistics Supply Chains: Evidence from an Emerging Economy

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Abstract

This study identifies the factors that can enable blockchain technology (BCT) implementation in the logistics sector and reveals the interdependencies, hierarchical structure, and causalities between them. This study uses a three-phased research framework to identify thirteen enablers to BCT adoption in the Logistics Supply Chain (LSC) and analyse the hierarchical and cause-effect relationships using an integrated Interpretive Structural Modelling and Decision-Making Trial and Evaluation Laboratory (ISM-DEMATEL) technique. This study classifies the enablers into three categories: prominent enablers, influencing enablers, and resulting enablers. 'Real-time connectivity and information flow' were identified as the most influencing enabler, whereas traceability was found to be the most prominent and resulting enabler. This study contributes to the literature by identifying the critical BCT enablers and modelling their hierarchical and causal relationships to address the absence of an appropriate decision-making framework that aids managers in understanding why and how BCT can be adopted in LSC, especially in an emerging economy like India. Strategic recommendations on how BCT can help overcome some select challenges faced by LSC organizations are also presented.

Keywords: Blockchain technology; Logistics; ISM-DEMATEL; Logistics Supply Chain; Technology adoption

1. Introduction

In the present era of frequent disruptions, the rapid growth of e-commerce is a globally persistent phenomenon. Recent estimates suggest that global e-commerce sales will grow to as high as 6.5 trillion US dollars by the year 2023 (Statista, 2020). This growth will lead to a natural rise in the number of shipments, resulting in a rapidly increasing demand for logistics services to fulfil the delivery requirements. However, prevailing logistics practices are not economically, environmentally, and socially sustainable (Montreuil, 2011). The global average transportation cost is about 13 percent of GDP, which may go as high as 25 percent for some countries (Hofman, 2017), and the resultant transportation emissions account for 14 percent of global anthropogenic emissions responsible for global warming (IPCC, 2014). Furthermore, the growth of e-commerce will require an increased number of delivery vehicles, resulting in increased energy consumption, vehicular emissions, and deterioration of traffic conditions. Additionally, the role of modern-day consumers makes this problem even more complicated. On the one hand, when acting as online shoppers, the consumers have a growing expectation for speedy, cost-effective, and personalized deliveries, which warrants more delivery vehicles on roads. On the other hand, in the role of inhabitants, consumers expect the logistics practices to be sustainable with reduced carbon footprint and less congested roads. In addition to the aforementioned challenges, the logistics sector is also faced by increasing pressure from policy-makers and social and environmental organizations to switch to more sustainable practices.

The problem further complicates when it concerns emerging economies like India. The logistics sector in India has been a crucial contributor to the country's national development as it provides sustenance to more than 22 million people. However, the Indian logistics sector's transportation costs account for 14% of the GDP, much more than that of developed economies like Germany (8%) and the USA (9.5%). The Government of India's action plan strives to bring it down to at least 10% by 2022 (Sharma, 2018). The Indian logistics sector that handles a freight volume of around 1320 billion ton-kilometer with around 7 million freight vehicles is heavily disintegrated and largely unorganized (Chakraborty et al., 2020). The Indian logistics industry, almost 90% of which is unorganized, is troubled by factors such as lack of trust amongst stakeholders, lack of economies of scale, security and information sharing risks among channel partners, lack of supply chain visibility, poor real-time tracking, unnecessary delays in transaction settlement due to excessive paperwork, to name a few. (Chakraborty et al., 2020; Mitra, 2008).

The past few decades have witnessed the emergence of information technology (IT) that has laid the foundation for various innovations aimed to achieve sustainable growth across businesses. In recent years, several initiatives to explore the potential benefits of IT have been attempted by almost every industry (Matt et al., 2015), and the increased rate of IT adoption in the Indian logistics sector suggests the recognition of the potential benefits associated with the use of emerging disruptive technologies.

Blockchain Technology (BCT), associated initially with cryptocurrencies (Tapscott & Tapscott, 2017), is one of the disruptive technologies that has already found applications in finance (Y. Chen & Bellavitis, 2020; Tapscott & Tapscott, 2017; Singh et al., 2020), agriculture (Y. Chen et al., 2020; R. Sharma et al., 2018), public sectors (Warkentin & Orgeron, 2020; Ølnes, 2016), supply chain management (Tian, 2017; Yadav & Singh, 2020; Jain et al., 2020), and healthcare management (Tanwar et al., 2020; Yue et al., 2016). BCT is anticipated to be a significant contributor to the Logistics Supply Chain (LSC) management and may help address the challenges currently faced by the logistics sector by providing significant improvement in transparency and verifiability by maintaining a default-free information exchange system among all the stakeholders. BCT employs a distributed, shared, decentralized database network that facilitates dynamic sharing of records/assets among stakeholders (Saberi et al., 2018) and reduces the risk of tempering and fraud (Kshetri & Voas, 2018). BCT is prominently recommended for a system that suffers from a lack of trust between the stakeholders (Kosba et al., 2016), as BCT holds promise in bringing transparency and accountability in the operations (Queiroz & Wamba, 2019) and assures cybersecurity (Hasanova et al., 2019; Kshetri, 2017).

Table 1 Select studies exploring BCT implementation in Logistics

Author(s)	**Study Type**	**Objective(s)**	**Key Observation(s)**
Hackius and Petersen (2017)	Survey	To seek logistics professionals' opinions on BCT and its potential in LSCs.	LSC professionals are quite optimistic for BCT; however, several factors must be addressed first to excite the relatively conservative logistics industry
Dobrovnik *et al.* (2018)	Review	To propose a framework that categorizes BCT application potentials and implications	Provided a four-phased transformation framework to identify BCT opportunities in the logistics industry.
Perboli *et al.* (2018)	Use Case design	Integrate the current BCT literature to design a strategy for developing and validating a BCT solution and implement it in fresh food delivery	Designed and implemented a BCT use in fresh food delivery to observe BCT can help reduce logistics and optimize the operations.
Petersen *et al.* (2018)	Conceptual Study	Explore industry expectations concerning the benefits and challenges of BCT.	Categorized the current BCT applications that might prove beneficial for supply chains and logistics in the future.
Tijan *et al.* (2019)	Review	Review the academic literature to understand the possibility of developing sustainable LSCs using BCT	BCT can help minimize/eliminate the problems encountered by the logistics to achieve sustainability
Orji *et al.* (2019)	Multicriteria Decision	Evaluate and rank the factors affecting BCT implementation in	The factors were analyzed using analytic network process to identify 'availability of BCT tools' and 'infrastructural facility' as the most

	Making; Case Study	the Nigerian freight industry under the TOE theoretical lens	affecting factors in the Nigerian freight industry.
Ar *et al.* (2020)	Multicriteria Decision Making; Case Study	Investigate the feasibility of BCT implementation and present solutions and rankings of decision-making strategies under uncertainty	The framework was applied in the Turkish context, and it observed security and visibility as important criteria. Transportation and materials handling are identified as the most feasible logistics operations.
Koh *et al.* (2020)	Position paper	Provide ground for BCT adoption in transport and logistics	Key concepts/methods that represent diverse paradigms in BCT for LSCs are provided aided with future research scenarios and directions.
Kummer *et al.* (2020)	Review	Identify the most relevant BCT theories in the LSC context and formulate research agenda for BCT research	Identified six organizational theories and developed a future research agenda supplemented with relevant research questions.
Pournader *et al.* (2020)	Review	Reviews current literature to understand BCT adoption in the supply chain, transportation and logistics	Four knowledge clusters (trust, technology, traceability, and trade) are identified using co-citation analysis.

Table 1 lists the past studies exploring BCT implementation in LSCs. We observe that majority of these studies are conceptual or review studies, and the empirical literature in LSCs is quite scarce. In table 1, Ar et al. (2020) and Orji et al. (2019) are two works that explore the BCT adoption factors. While Orji et al. (2019) adopt the technology- organization- environment (TOE) theoretical lens to evaluate the factors that affect BCT implementation in the Nigerian freight industry, Ar et al. (2020) study BCT feasibility in a Turkish logistics company. While these studies have enriched the literature in the BCT-LSC domain, we note the growing need to understand BCT adoption's enabling factors and analyse the hierarchical and/or cause-effect relationships (if any) among them. Moreover, since BCT is a relatively new technology, especially in the Indian context, there is an absence of an appropriate decision-making framework that can aid the managers in deciding why and how to adopt BCT in their LSC. Therefore, it is imperative for the practitioners in LSC to understand various enablers of BCT and their interactions with each other. Additionally, we partially address the call by Ar et al. (2020) for future research into the competencies of BCT that can satisfy the requirements of logistics organizations.

This study is conducted to address three research questions (RQs):

RQ1. What are the enablers to implementing BCT in the logistics sector, especially in an unorganized setup like India?

RQ2. What are the interrelationships and the hierarchical levels among these enabling factors?

RQ3. What are the dependencies and causalities between these enabling factors?

To understand BCT adoption in LSCs, it is essential to understand the overall system complexities and reveal the interrelationships and influences of various factors (Sushil, 2012). Interpretive Structural Modelling (ISM) has the ability to draw insights from the indirect and direct interactions among the studied factors and reveal an easy-to-understand hierarchical structure of the complex system (Bhosale and Kant, 2016). However, ISM does not account for the strength of the relationships between the factors which becomes a significant limitation. Therefore, to account for ISM's weakness for not determining the strength of interrelationships among variables, we integrate the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology in our analysis to provide improved insights into the variables and their interrelationships. DEMATEL methodology uses a combination of graphs and matrices to determine the strength of variables' interrelationships (Shieh et al., 2010). Therefore, this paper employs the integrated ISM-DEMATEL method to determine the hierarchical relationships and understand the severity of the interrelationships among the various factors.

The main contributions of the present study are:

1. We identify the critical BCT enablers and model their hierarchical and causal relationships to address the absence of an appropriate decision-making framework that aids managers in understanding why and how BCT can be adopted in LSC.
2. This study is a novel attempt that presents evidence from an emerging economy like India and integrates ISM and DEMATEL methodologies to identify the prominent, influencing, and resulting enablers that affect BCT adoption in LSCs. This classification helps prioritize among the enabling factors based on relative importance and formulate effective implementation strategies.

The remaining paper is organized as follows. The background literature and the identified enablers to BCT implementation are presented in section 2. Section 3 contains the detailed research framework adopted for this study. The integrated ISM-DEMATEL methodology is applied in section 4. The results and discussion are presented in section 5. Finally, section 6 presents the conclusions, contributions, and limitations.

2. Literature Review

2.1.Blockchain technology and logistics supply chains

BCT created disruptions in the fintech sector, but it holds immense potential to disrupt other sectors (Wamba & Queiroz, 2020). According to Peck (2017), the majority of the fortune 500 organizations are now researching BCT applications intending to incorporate them into their products. BCT project prototypes are already underway disrupting the management of electronic medical records (Y. Chen et al., 2019), land titling (Thakur et al., 2020), agriculture supply chains (Kamble et al., 2020), banking (H. Wang et al., 2019), and manufacturing (Mandolla et al., 2019). Additionally, studies like Wen et al. (2021) are underway to promote and increase the possibility of social investments in BCT across different fields. The essence of BCT is that it provides a novel way to manage data that is immutable (Attaran & Gunasekaran, 2019), non-repudiable (Mytis-Gkometh et al., 2018), and accountable (Kamble et al., 2020). The BCT is an open ledger peer-to-peer transacting system that is decentralized (Kotobi & Bilen, 2018), distributed (Muzammal et al., 2019), and operates without the need of a trusted intermediary for verifying, settling, and securing the transactions (Nofer et al., 2017). BCT is often seen as a disruption that prepares the technological ecosystem for the Internet of Things (IoT) and functions as a top layer on the internet that coexists with other internet technologies (Fernández-Caramés & Fraga-Lamas, 2018). The primary functional elements of BCT are game theory, which forms its mathematical foundation, cryptographic signatures, the main operational framework, and computer science, which is its realization field (Pilkington, 2016). This paper discusses the potential enablers of BCT in the logistics sector, which, if realized, can lead to reductions in overall transportation costs along with enhancement in freight monitoring and control.

The supply chain is defined as the network of materials and information flow, starting from the initial stage to the stage of final consumption, and at each stage, value is added to the product or service for serving the customer needs (Beamon, 1999; Esmaeilikia et al., 2016; Gao et al., 2017). Supply chain management is a complex process that deals with the creation and distribution of goods. Depending upon the product or service, the supply chain can have several stakeholders, processes, geographic locations, and means of transport (Fiala, 2005; K. C. Tan, 2001; D. T. Wong & Ngai, 2019). Studies in the past have highlighted that due to the complexities in the supply chains such as delay of payments (Protopappa-Sieke & Seifert, 2017), lack of transparency (Saberi et al., 2018), non-responsible sourcing practices (Guo et al., 2016), the procurement of supplies can take several months thereby reducing the overall efficiency of the supply chains (Vogel & Lasch, 2016). Due to the complexities involved in the traditional supply chains, much of the research by practitioners and researchers is concentrated on the introduction of BCT in supply chains as it can be beneficial for enhancing the efficiency of supply chains, thereby making them more transparent and sustainable (Kshetri, 2018; Saberi et al., 2018).

BCT is one of the disruptive technologies (other technologies being cyber-physical systems, IoT, artificial intelligence; see Alladi et al., 2019; Ghobakhloo, 2018; Lee et al., 2019; Olsen and Tomlin, 2020; Xu et al., 2018) which helps in achieving the objectives (process digitalization and enhanced operational efficiency) of industry 4.0 paradigm. It is anticipated that potential blockchain applications in the logistics sector can lead to enhanced operational efficiency and delivery-related lead-times reductions. Furthermore, the implementation of BCT can help realize a real-time LSC as it is critical for LSC organizations to visualize real-time data of their assets and enhance decision-making capabilities (Helo & Shamsuzzoha, 2020). Some of the potential benefits LSC organizations can realize by implementing BCT are real-time dynamic route planning and optimization for transport fleet (Banerjee, 2018); effective resource planning (A. W. K. Tan et al., 2018); maintaining quality management through analysis of customer feedback and delivery related issues on-line; maintaining profit analysis for transport fleet, route efficiency planning, and stock-keeping units; understanding customer order trend and customer behavior over a period of time; real-time risk management simulation based on previous orders and current status of deliveries. Overall, the supply chain transactions' efficiency can be considerably enhanced from the unique characteristics and architecture of BCT. The primary objective of all supply chain management (SCM) organizations is to achieve process visibility across all SCM phases, provenance, and asset tracking capabilities (Queiroz et al., 2019; Treiblmaier, 2018).

Table 2 A list of selective challenges faced by organizations in the logistics sector

Challenge	Impact	References
The poor state of standardization and shareability of operational information	It makes real-time information capturing difficult and reduces effective resource management, worsening already inefficient logistics processes.	(Bealt et al., 2016; Kritchanchai et al., 2018; J. Tan et al., 2019)
Finding independent contractors covering distant geographies	It is often highlighted that finding independent contractors and suppliers covering distant geographies is complicated and cumbersome, requiring expensive integration systems.	(Grant, 2019; Ridwan & Noche, 2018)
Slow data movements related to cargo and extensive documentation	Lack of data transparency and lack of availability of real-time data in the LSC leads to higher operational costs for activities such as documentation, verification, and essential dispatch approvals.	(Fu & Zhu, 2019; Pournader et al., 2020; Tian, 2016)
Higher administrative costs	Studies in the past have highlighted that higher administrative costs increase the financial constraints on the organizations.	(Frontoni et al., 2020; Solakivi et al., 2018)
Delays in payments (warehouse, transporter)	Delays in payments from either supplier or LSC organization lead to reduced flexibility, increasing the delivery lead-time, thus drastically affecting performance.	(Aljazzar et al., 2018; Tijan et al., 2019)
Lack of transparency and trust	Many studies have reported that stakeholders' cargo thefts and dishonest behaviour lead to a lack of transparency and trust in LSC organizations.	(Baharmand & Comes, 2019; Khan et al., 2019; Pournader et al., 2020)
Lack of freight monitoring and quality control	It has been reported that improper freight monitoring and quality control activities lead to inadequate shipment control and product damage, resulting in revenue loss for LSC organizations.	(Fossheim & Andersen, 2017; Nuzzolo et al., 2016; Orji et al., 2019)

Table 2 highlights the problems current logistics organizations face owing to obsolete processes and technologies. Therefore, it can be inferred that there are problems aplenty in the traditional logistics processes, which the application of BCT can reduce.

2.2. Enablers to the BCT adoption

Based on the review of the literature (see methodological details in section 3), table 3 highlights and provides a brief description of the BCT enablers that drive logistics organizations to adopt BCT in their LSCs.

Table 3 List of Enablers to Blockchain technology

Code	BCT Enabler	Description	References
E1	Decentralized Database System	BCT makes use of an open database that allows a decentralized database and ensures that the data is not stored on a centralized point.	(Arslanian & Fischer, 2019; K. Biswas & Muthukkumarasamy, 2016; Davidson et al., 2016; Glaser et al., 2018; Kouhizadeh & Sarkis, 2018)
E2	Distributed Database System	BCT makes use of an open database that facilitates a shared ecosystem, and access to data is provided to the appropriate stakeholders.	(Crosby et al., 2016; Dorri et al., 2017; Fanning & Centers, 2016; Muzammal et al., 2019; Tian, 2017)
E3	Cybersecurity	The use of a cryptographic private key helps maintain the data privacy of the network participants.	(Dai et al., 2017; Kshetri, 2017; Mylrea & Gourisetti, 2017)
E4	Immutability	Once data is written in the blockchain block, none of the stakeholders can change or tamper with the data.	(Ateniese et al., 2017; Lin et al., 2017; Zheng et al., 2017)
E5	Transparency	Real-time data visibility to the concerned stakeholders and consensus-based transaction mechanism of BCT helps promote transparency, building trust and reputation.	(Chod et al., 2020; Kshetri, 2017; Montecchi et al., 2019; Venkatesh et al., 2020)
E6	Verifiability of transactions	A distributed and decentralized database system ensures that the blockchain is error-free and helps verify all the transactions in the blockchain network. BCT provides a trail of transactions and is non-repudiable.	(Galal & Youssef, 2018; Zhang et al., 2018)

E7	Enhanced Risk Mitigation	Deploying BCT ensures improved traceability of the underlying assets and thereby enhances the risk mitigation capabilities.	(Boussard et al., 2019; Fu & Zhu, 2019)
E8	Smart Contracts	Electronic contracts between the stakeholders based on the mutually agreed terms and conditions.	(Kosba et al., 2016; Watanabe et al., 2015; X. Xu et al., 2016)
E9	Lower Transaction Settlement Time	Deploying blockchains in the business processes can use data characteristics ingrained in the transactions, making the flow of transactions to be time conditional, thereby reducing the transaction time.	(Kamble et al., 2020; Min, 2019)
E10	Lower transactional costs	BCT reduces the transaction cost, compared to the traditional LSCs, by eliminating some intermediaries and excessive paperwork.	(Giungato et al., 2017; Niranjanamurthy et al., 2019)
E11	Provenance	As digital tokens accompany the blockchains, implementing blockchain in a supply chain will help trace the origins of an asset throughout the supply chain.	(Kim & Laskowski, 2018; Liang et al., 2017)
E12	Real-time connectivity and information flow	BCT assures seamless connectivity among the stakeholders in the blockchain network.	(Bahga & Madisetti, 2016; Banerjee, 2018; Mudliar et al., 2018; Shrestha & Nam, 2019; Munir et al., 2019; Sun et al., 2016; Unal et al., 2019; Weernink et al., 2017)
E13	Traceability	BCT has the capability to provide asset traceability.	(Behnke & Janssen, 2020; Kamble et al., 2020; Tian, 2016)

2.3. *Barriers and drivers to BCT adoption*

Drawing upon the TOE theoretical lens (Bai & Sarkis, 2020; Lai et al., 2018; Tornatzky et al., 1990; L.-W. Wong et al., 2019) for identification of various barriers and drivers for BCT adoption in the logistics context, the BCT barriers and opportunities are categorized into technological (T), organizational (O), and environmental (E) barriers/opportunities. The former two barriers, i.e. T and O, are endogenous to the technology (BCT) and the organizations, while the latter barrier E is exogenous. The technological barriers related to BCT implementation include immaturity of the technology, technology scalability, and security-based risks. Organizational barriers comprise top management commitment, organizational policies and culture. Environmental barriers include government policies, laws, and regulations. Apart from the barriers, BCT adoption has numerous opportunities if viewed from the TOE theoretical lens. For example, BCT offers data security, integrity, data privacy, and cost savings in the technological context. Under the organizational context, factors such as value-chain benefits, organizational benefits, and business model benefit support BCT adoption. Finally, in the environmental context, opportunities to improve relationships with supply chain partners support BCT adoption. Further, Table 4 briefly highlights the TOE barriers and opportunities to the adoption of BCT.

Table 4 Barriers and Drivers to BCT adoption (TOE perspective)

Category	Opportunities / Drivers	References	Barriers	References
Technological	Data security; data integrity; data privacy; cost savings	(G. Chen et al., 2018; Iansiti & Lakhani, 2017)	Immaturity of technology; scalability issues; slow throughput; interoperability issues; usability; technology uncertainty; latency; energy consumption	(B. Biswas & Gupta, 2019; Kamble et al., 2020; Swan, 2015)
Organizational	Value-chain benefits; organizational benefits; business model benefits; innovativeness;	(Iansiti & Lakhani, 2017; Swan, 2015)	Lack of technical competence and technology awareness; lack of top management commitment; high implementation costs	(Kamble et al., 2020; Lemieux, 2016; Mangla et al., 2017; Saberi et al., 2018)
Environmental	Improved relationships with supply chain partners; business case examples and prototypes	(Morabito, 2017; Seebacher & Schüritz, 2017)	Government policies, legal, and regulatory framework	(Lacity, 2018; Li et al., 2019; Yeoh, 2017)

2.4. Managerial challenges for BCT adoption

With continuous advancements in BCT, various use cases will emerge, and organizations across all sectors will face complex challenges and dependencies, especially with the lack of awareness about BCT and its applications. Drawing from the technology acceptance model (TAM), Rogers (2010) describes three attributes of innovation that play a crucial role in technology resistance, viz. complexity, compatibility, and trialability. Despite the disruptive potential of BCT, little is known about BCT's diffusion in various sectors, its impact on people and processes, and the reasons that motivate its adoption. Nonetheless, before BCT can be integrated with the existing IT frameworks, there has to be a process that ensures the interoperability, data protection protocols, and regulatory adherence of the BCT system with the existing systems. Also, before BCT systems are widely adopted, other issues such as technology scalability, information integration, data standardization, and regulation of BCT systems must be introspected and resolved carefully (Iansiti & Lakhani, 2017; Kot, 2019)

Past studies have reported a lack of readiness and technology immaturity for BCT due to the lack of experience and knowledge of BCT systems from their existing systems (see Dobrovnik et al., 2018; Verhoeven et al., 2018). It is anticipated that BCT will revolutionize the traditional logistics processes, as customers will trust the BCT system to verify electronic transactions and secure their data. However, for their widespread adoption in LSCs, BCT based systems need to prove their resilience with less (or negligible) downtime (for ensuring reduced transaction settlement times, ensuring real-time traceability). Technology scalability in BCT is also a significant hurdle that needs to be overcome as the number of transactions increases (Crosby et al., 2016). Further, research (see Walsh et al., 2021) has highlighted that as the nodes in a BCT network increase, the network becomes more centralized and prone to cyber threats. The continuous dynamism of BCT has made smart contracts more relevant than ever because of their immutable nature but, they are also one of the inhibitors for BCT adoption. Smart contracts become inflexible for certain organizations as they cannot adapt to uncertain business environments (Gonzalez Rivas et al., 2018).

Prior literature (Kamble et al., 2020; Strong et al., 2019; Winkelhaus & Grosse, 2020) has also reported that the implementation cost of any new technology is often high and requires host of other activities (such as infrastructure capabilities and other supporting activities) to be up and ready before the actual technology is implemented. The experts believe that new technology shall be implemented if it can outweigh the lacunae of existing technology, which would thereby help in further enhancing the organization's operational efficiency (Kamble et al., 2020). New technologies can bring benefits only if the various risks and shortcomings are overcome.

3. Research methods

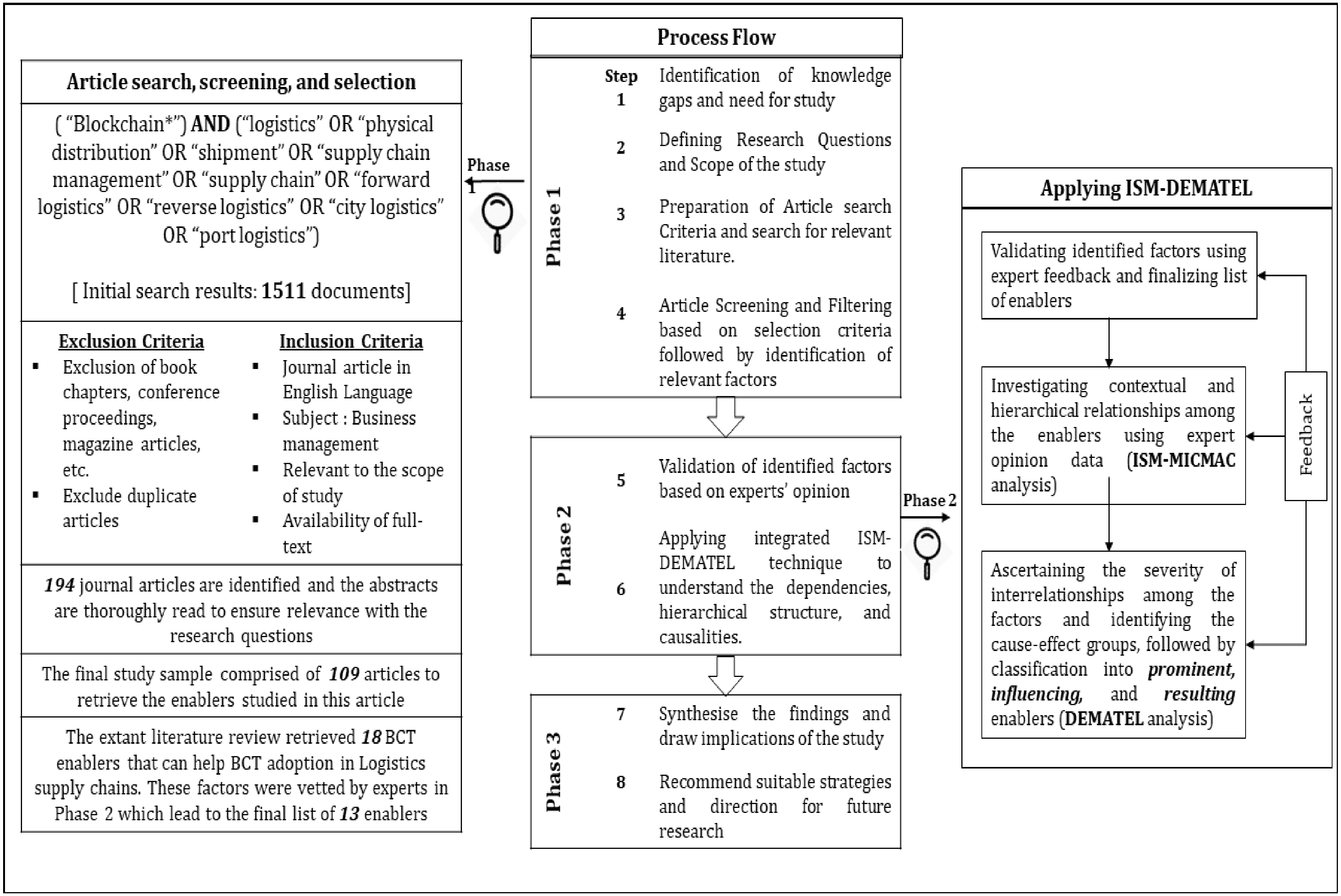
3.1. Methodological Framework

Figure 1 presents the summarizing snapshot of the research framework employed in this paper. This study adopts a three-phased methodology. In phase 1, we first identify the relevant knowledge gaps and ascertain the need for the study. The next step is to set the study's scope and draw up specific research questions. Once the scope and objectives are established, article search criteria are developed to identify relevant literature for review. A literature review helps provide critical insights for investigating research in emerging fields and aids in charting directions for future research (Govindan et al., 2015; Junior & Godinho Filho, 2010).

We consulted previous studies to include relevant keywords in our search. The finalized query was as follows: ("Blockchain*") AND ("forward logistics" OR "logistics" OR "physical distribution" OR "shipment" OR "supply chain management" OR "supply chain" OR "reverse logistics" OR "city logistics" OR "port logistics"). We searched for the articles in the Scopus database as it is more exhaustive than the Web-of-Science database (Yong-Hak, 2013) and covers peer-reviewed journals from assorted fields (Fahimnia et al., 2015). The query was searched in the "title, abstract, keywords", and it initially yielded 1511 results.

We applied several inclusion and exclusion criteria to finalize the sample of articles that fit the scope of our study. Only the peer-reviewed journal articles are considered for this study as they are 'certified knowledge' (Ramos-Rodríguez & Ruíz-Navarro, 2004). Additionally, we only include articles that are published in the English language and are part of the ‘business management’ subject. Finally, the abstracts of all the articles were analyzed to create a final portfolio containing 109 articles.

Figure 1 Snapshot of the research framework



To identify the relevant technological enablers to BCT implementation in LSC, we reviewed the portfolio of selected studies and compiled eighteen enablers. However, the studied literature represents various contextual, institutional, and economic settings dissimilar to the Indian context. Therefore, it is imperative that a group of relevant industry experts must appraise the factors found in the literature and help reveal the hierarchical structures and cause-effect relationships (if any) among them.

In phase 2, considering the importance of choosing the right respondents, a group comprising twelve experts from relevant backgrounds was identified. Appendix A presents the details of the expert group composition. The selected expert group adheres to the group size requirements recommended by Robbins & Coulter (2012) and Murry & Hammons (1995). The experts were initially subjected to semi-structured interviews to discuss the identified factors. These discussions eliminated few factors and also merged some factors to form broader factors. As a result, thirteen factors were selected based on this validation exercise for this study (see table 3). We then apply the integrated ISM-DEMATEL technique to analyze the hierarchical structures and cause-effect relationships among the studied factors based on data retrieved from expert opinion. An indicative questionnaire employed in the study is presented in Appendix B. In the third phase, we finally synthesize the findings and draw implications from the obtained results to recommend suitable strategies for implementation and aid future research.

Table 5 Select studies on the application of ISM-DEMATEL methodology

S.No.	ISM-DEMATEL application area	Reference
1	Barriers for IoT implementation in the manufacturing industry	Singh and Bhanot (2019)
2	End of life vehicle recycling management	Zhou et al. (2019)
3	Sustainable Agri supply chain selection	Chauhan et al. (2019)
5	Analyzing the challenges in sustainable Agri supply chains	Gardas et al. (2019)
6	Implementation of knowledge management practices	Mousavizade and Shakibazad (2019)
7	Analysis of barriers for sustainable online consumption	Song et al. (2020)
8	Integrated solid waste management practices	Tsai et al. (2020)

To address the study's RQ2 and RQ3, we used the integrated of ISM-DEMATEL decision-making technique (Kamble et al., 2020) as it is superior to other interpretive and decision modelling techniques (Mangla et al., 2018). Table 5 lists some recent studies that employed the ISM-DEMATEL technique. Apart from study's objectives, the standalone limitations of ISM and DEMATEL methodologies also motivate to employ this integrated technique. For example, although ISM helps identify a well-defined hierarchical structure from a complex problem by identifying relationships among factors based on their driving and dependence power, it does not account for the strength of these relationships. In comparison, the DEMATEL methodology reveals the severity of these interrelationships by using a combination of graphs and matrices. Therefore, this integrated method assists in revealing the importance of identified factors through numerical rankings and well-explained diagrams (ISM-based hierarchical digraph and causal digraph in DEMATEL).

The subsequent sections describe the stepwise procedure of applying ISM and its integration with the DEMATEL technique.

3.2. ISM technique

ISM methodology (Warfield, 1974) is an interactive learning process with its roots in relational mathematics and can transform poorly and unclearly expressed mental models of complicated systems into well-described, visible models valuable for several purposes (Sushil, 2012). ISM's fundamental objective is to prepare a hierarchical structural model comprising multiple levels by decomposing the complicated system into smaller subsystems based on the experts' subject knowledge (Rana et al., 2019). The ISM structural model helps in analyzing the dependencies and inter-relationships among the various factors.

While ISM has been successfully applied to model structural variables across various domains, the technique primarily depends on the subjective judgment of the concerned experts and carries an inherent potential for experts' personal biases affecting the results (Mangla et al., 2018). According to R. Sharma et al., (2021), the steps of implementing ISM are as follows (the detailed application of ISM is presented in section 4):

Step 1: Review the literature and consult domain experts to identify the factors directly or indirectly influencing the system.

Step 2: Seek expert opinion for establishing contextual relationships among the validated variables leads to developing a structural self-interaction matrix (SSIM), consisting of symbols allocated for the interrelationships.

Step 3: Transform the SSIM into the initial reachability matrix (IRM) by assigning binary elements (0 and 1) for each relationship as per the conversion rules.

Step 4: The IRM is evaluated for the rule of transitivity. If the transitivity rule is violated, the SSIM is inspected and adjusted, which leads to a final reachability matrix (FRM).

Step 5: The FRM is processed for extracting the associated structural levels and drawing a digraph. The transitive relationships are removed from the digraph, and the contextual relationships from the IRM are established again. Finally, the variable nodes are interchanged with the statements to transform the digraph into a finalized model.

3.3. Integration of DEMATEL methodology with ISM

In ISM, while the contextual relationships among the variables are represented using binary numbers (1, if a relationship exists and 0 for no relationship), it does not account for the strength of the interrelationships among these variables. According to Bhosale and Kant (2016), the strength of interrelationships can vary between low, moderate, and strong. Considering the limitation of ISM and to provide improved insights about variables' interrelationships, we have integrated the DEMATEL methodology into our analysis. DEMATEL methodology reveals the relationship strength using a combination of graphs and matrices (Shieh et al., 2010).

DEMATEL (Gabus and Fontela, 1972) identifies the interrelationships among the variables and resolves cause-effect relationships to analyze complex problems (Kumar and Dixit, 2018). DEMATEL's resultant output is a graphical representation of factors' interrelationships, also known as an influence relations map. Similar to Sharma *et al.* (2021), the DEMATEL methodology is applied on the IRM obtained from ISM using the following procedure:

3.3.1. Calculating the initial average direct influence matrix

First, the experts score the existing relationships in the IRM (which was developed using ISM). The IRM's diagonal elements are reset to zero, and the experts are requested to evaluate the relationships denoted by 1 in the IRM. All existing relationships are evaluated by allotting 0, 1, 2, or 3 (where, 0 = "no influence", 1 = "low influence", 2 = "moderate influence", and 3 = "high influence”). In the case of n number of experts, we get n initial relation matrices. The average direct influence matrix A is developed by aggregating responses from all *n* experts as follows:

$$A = 1 / n \sum_{k=1}^{n} [x_{ij}^{k}] \text{ ; Where } [x_{ij}^{k}] \text{ is matrix computed for each expert } k. \quad (1)$$

3.3.2. Normalizing average direct relation matrix

Matrix A is then normalized to prepare the normalized direct-relation matrix (X) as follows:

$$X = A \times Z; where\ Z = \frac{1}{max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (2)$$

3.3.3. Computing the total relation matrix

Next, we compute the total relation matrix (T) as follows:

$$T = X\,(I - X)^{-1} \quad \text{where } I \text{ is identity matrix} \quad (3)$$

3.3.4. Preparing the digraph and causal influence

3.3.4.1. Computing the sum of rows (r_i) and columns (d_j)

For every row (i) and column (j) in matrix T, the sum is calculated as:

$$r_i = \sum_{j=1}^{n} T_{ij} \ \forall\, i \quad (4)$$

$$d_j = \sum_{i=1}^{n} T_{ij} \ \forall\, j \quad (5)$$

3.3.4.2. Computing the prominence (P_i) and the net effect (E_i)

The prominence *(P_i)* and the net effect *(E_i)* is computed by*:*

$$P_i = r_i + d_j \ \forall\, i = j \quad (6)$$

$$E_i = r_i - d_j \ \forall\, i = j \quad (7)$$

The P_i values signify the prominence (i.e., influence, visibility, and importance) of the variable in the studied system. For factors having $E_i > 0$, they are called the influencing or the net cause factors, which are considered to be the foundation for other factors. The factors with $E_i < 0$ are called the resulting or net effect factors (Bai and Sarkis, 2013). The P_i and E_i values of each factor are then plotted on a two-dimensional axis (Tzeng et al., 2007).

3.3.4.3. The digraph

The final step is to prepare the digraph. A threshold value *(α)* is established to filter the negligible effects (Liou *et al.*, 2007). If $T_{ij} \geq \alpha$, then factor *i* is said to be a causal factor for factor *j*, and a directed arrow is included in the digraph.

4. Application of integrated ISM-DEMATEL to analyze BCT enablers in Logistics

4.1. Applying ISM

4.1.1. Establishing contextual relationships

As discussed in previous sections, thirteen enablers were finalized from literature review and expert validation. We used a "helps to achieve" type of relationship structure, which means that one enabler helps to achieve" another enabler.

4.1.2. SSIM development

The experts used to validate the BCT enablers were consulted to develop the contextual relationships among the BCT enablers (see data collection matrix in Appendix B). These experts were asked to define contextual relationships among the enablers by assigning one of the symbols (→,←, X, O) as follows:

> *If E_i helps to achieve E_j, assign →; if E_j helps to achieve E_i, assign ←; if E_i and E_j are interrelated and help to achieve each other, assign X; and assign O, if there is no relationship among E_i and E_j.*

Table 6 presents the SSIM.

Table 6 Structural self-interaction matrix (SSIM)

Enablers	E13	E12	E11	E10	E9	E8	E7	E6	E5	E4	E3	E2	E1
E1	→	X	→	→	→	→	→	→	→	→	→	X	
E2	→	X	→	→	→	→	→	→	→	→	→		
E3	→	←	→	X	X	←	→	→	→	→			
E4	→	←	X	←	←	←	←	X	←				
E5	→	←	→	←	←	←	→	→					
E6	→	←	X	←	←	←	←						
E7	→	←	→	←	←	←							
E8	→	←	→	→	→								
E9	→	←	→	X									
E10	→	←	→										
E11	→	←											
E12	→												
E13													

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

4.1.3. IRM development

The symbols assigned in the SSIM developed in the previous step are now converted into binary elements (1 and 0) to prepare the IRM presented in table 7, as per the following transformation rules:

- *If cell (i, j) in SSIM is assigned "→", the cell (i, j) in the IRM will have a value of '1' and cell (j, i) will have '0'.*
- *If cell (i, j) in SSIM is assigned "←", the cell (i, j) in the IRM will have a value of '0' and cell (j, i) will have '1'.*

- *If cell (i, j) in SSIM is assigned "X", the cell (i, j) in the IRM will have a value of '1' and cell (j, i) will have '1'.*
- *If cell (i, j) in SSIM is assigned "O", the cells (i, j) and (j, i) in the IRM will have '0'.*

Table 7 Initial Reachability Matrix (IRM)

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	1	1	1	1	1	1	1	1	1	1	1	1	1
E2	1	1	1	1	1	1	1	1	1	1	1	1	1
E3	0	0	1	1	1	1	1	0	1	1	1	0	1
E4	0	0	0	1	0	1	0	0	0	0	1	0	1
E5	0	0	0	1	1	1	1	0	0	0	1	0	1
E6	0	0	0	1	0	1	0	0	0	0	1	0	1
E7	0	0	0	1	0	1	1	0	0	0	1	0	1
E8	0	0	1	1	1	1	1	1	1	1	1	0	1
E9	0	0	1	1	1	1	1	0	1	1	1	0	1
E10	0	0	1	1	1	1	1	0	1	1	1	0	1
E11	0	0	0	1	0	1	0	0	0	0	1	0	1
E12	1	1	1	1	1	1	1	1	1	1	1	1	1
E13	0	0	0	0	0	0	0	0	0	0	0	0	1

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

4.1.4. FRM development

The IRM is then inspected for transitivity to establish the partition levels, i.e., for variables K, L, and M, if K impacts L and L impacts M; then K also impacts M. Table 8 and Table 9 present the FRM and the involved iterations in establishing partition levels. The detailed iterations on partition levels can be found in Appendix C. The ISM hierarchical structure presented in figure 2 is drawn based on these partition levels.

Table 8 Final reachability matrix (FRM)

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	Driving power
E1	1	1	1	1	1	1	1	1	1	1	1	1	1	13
E2	1	1	1	1	1	1	1	1	1	1	1	1	1	13
E3	0	0	1	1	1	1	1	0	1	1	1	0	1	9
E4	0	0	0	1	0	1	0	0	0	0	1	0	1	4
E5	0	0	0	1	1	1	1	0	0	0	1	0	1	6
E6	0	0	0	1	0	1	0	0	0	0	1	0	1	4
E7	0	0	0	1	0	1	1	0	0	0	1	0	1	5
E8	0	0	1	1	1	1	1	1	1	1	1	0	1	10
E9	0	0	1	1	1	1	1	0	1	1	1	0	1	9
E10	0	0	1	1	1	1	1	0	1	1	1	0	1	9
E11	0	0	0	1	0	1	0	0	0	0	1	0	1	4
E12	1	1	1	1	1	1	1	1	1	1	1	1	1	13
E13	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence Power	3	3	7	12	8	12	9	4	7	7	12	3	13	

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

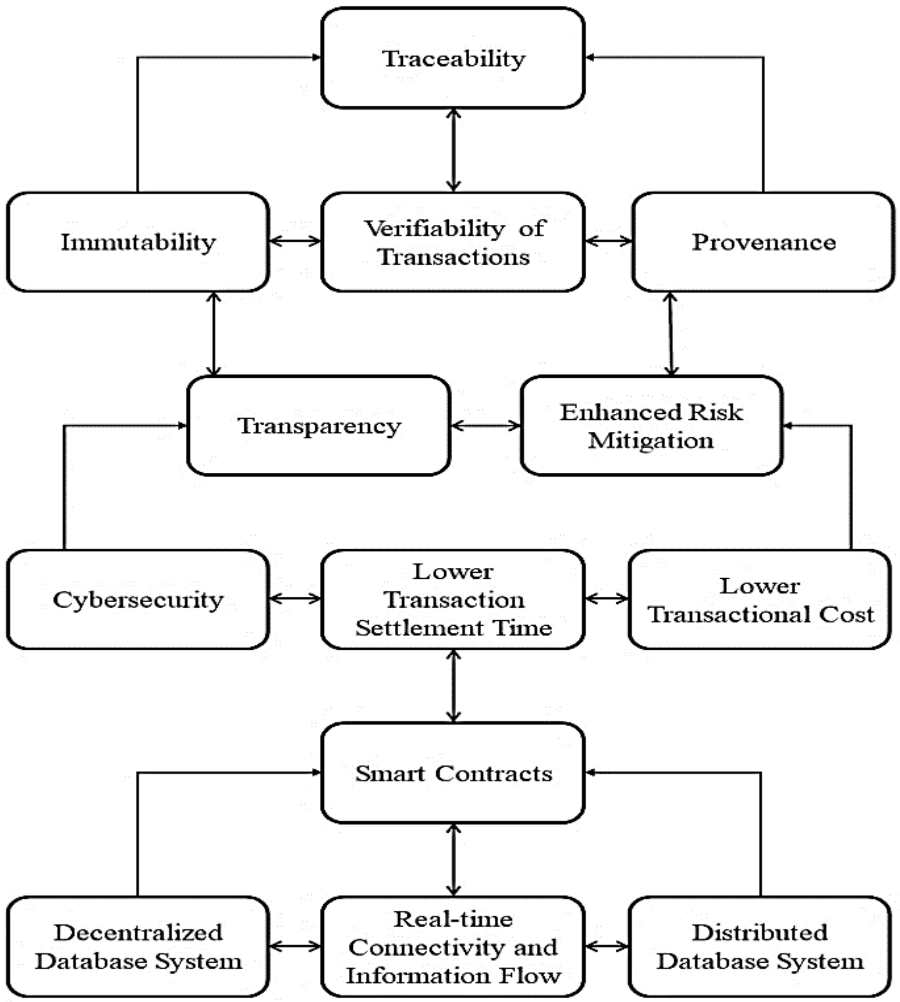
Table 9 Level partition iterations

Iteration	Enabler	Reachability Set	Antecedent Set	Intersection Set	Level
1	E13	13	1,2,3,4,5,6,7,8,9,10,11,12,13	13	I
2	E4	4,6,11	1,2,3,4,5,6,7,8,9,10,11,12	4.6.11	II
3	E5	5,7	1,2,3,5,8,9,10,12	5,7	III
3	E7	7	1,2,3,5,7,8,9,10,12	7	III
4	E3	3,9,10	1,2,3,8,9,10,12	3,9,10	IV
4	E9	3,9,10	1,2,3,8,9,10,12	3,9,10	IV
4	E10	3,9,10	1,2,3,8,9,10,12	3,9,10	IV

5	E8	8	1,2,8,12	8	V
6	E1	1,2,12	1,2,12	1,2,12	VI
6	E2	1,2,12	1,2,12	1,2,12	VI
6	E12	1,2,12	1,2,12	1,2,12	VI

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability

Figure 2 ISM Digraph

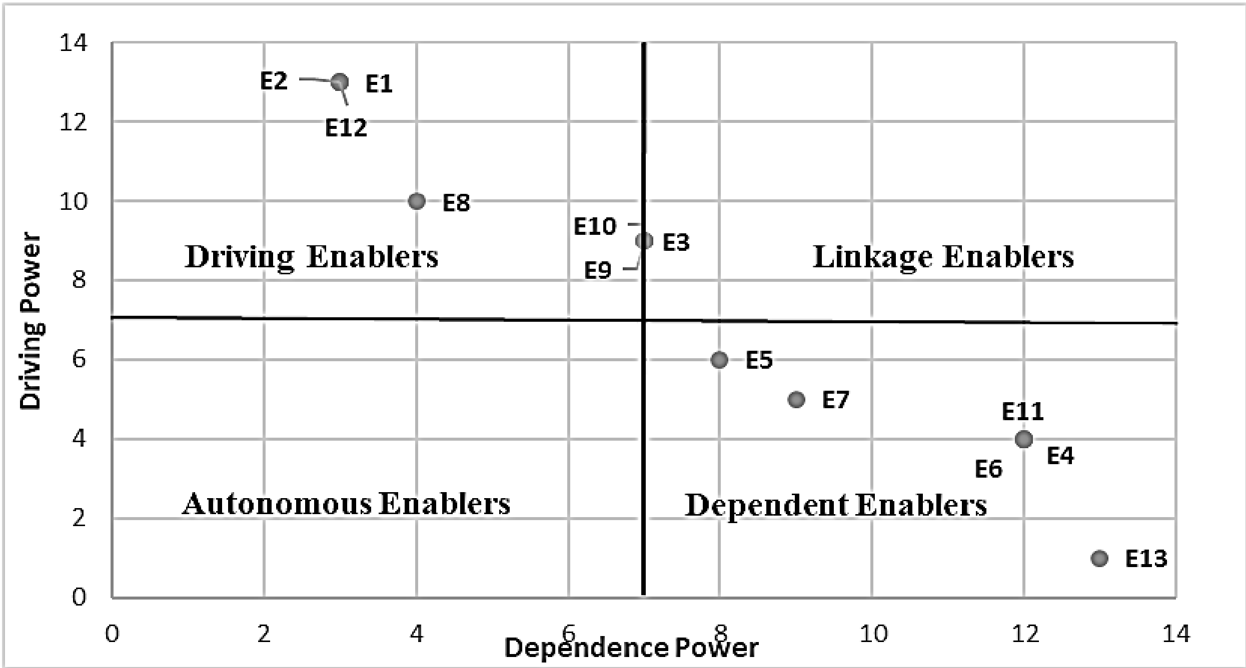


4.1.5. ISM-MICMAC analysis

The dependence and driving powers of each enabler are computed in table 8. The enablers are classified into four quadrants based on their driving and dependence powers (see figure 3).

- *Autonomous enablers:* These BCT enablers have weak dependence and driving power and are considered relatively less significant to the studied system. Our results do not find any autonomous enablers, and all the enablers were found to be significant for BCT adoption in the LSC.
- *Dependent enablers:* These BCT enablers, shown in the upper half of the ISM model, have weak driving power but strong dependence power and are considered to have minimal influence on other factors. Six enablers, namely traceability (E13), immutability (E4), verifiability of transactions (E6), provenance (E11), enhanced risk mitigation (E7), and transparency (E5), are classified in this category.
- *Linkage enablers:* These factors are said to be unstable factors due to their strong driving and dependence power, and change in these factors is considered to have a high effect on the overall system. We do not have any factors in linkage enablers category.
- *Driving enablers:* These factor, shown in bottom of the ISM model, have weak dependence power but strong driving power. This study has seven enablers, namely cybersecurity (E3), lower transactional cost (E10), lower transaction settlement time (E9), smart contracts (E8), real-time connectivity and information flow (E12), decentralized database system (E1), and distributed database system (E2), classified in this category.

Figure 3 MICMAC analysis



Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time;

4.2. Applying DEMATEL

4.2.1. Average direct influence matrix

As discussed in section 3.3.1, we used DEMATEL technique to have improved understanding about interrelationships among the BCT enablers. We seek inputs from the expert group to evaluate the interrelationships among the factors by providing integer values ranging between 0 and 3, where 0 signifies “no influence”, and 1, 2, and 3 signify “low influence”, “moderate influence”, and “high influence”, respectively. Table 10 shows the average direct influence matrix (A) calculated using equation (1).

Table 10 Average Direct Influence Matrix (A)

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0.000	1.333	2.000	2.667	2.500	2.667	1.833	1.500	1.667	1.667	2.500	1.333	2.833
E2	1.333	0.000	1.500	2.667	2.500	2.667	2.667	1.333	1.333	1.833	2.333	1.333	2.833
E3	0.000	0.000	0.000	2.833	1.500	2.500	2.000	0.000	1.333	1.333	1.833	0.000	2.667
E4	0.000	0.000	0.000	0.000	0.000	1.500	0.000	0.000	0.000	0.000	1.667	0.000	2.833
E5	0.000	0.000	0.000	1.667	0.000	1.500	1.833	0.000	0.000	0.000	1.500	0.000	2.500
E6	0.000	0.000	0.000	2.833	0.000	0.000	0.000	0.000	0.000	0.000	1.333	0.000	2.667
E7	0.000	0.000	0.000	1.667	0.000	1.833	0.000	0.000	0.000	0.000	1.833	0.000	2.500
E8	0.000	0.000	1.333	1.500	1.833	1.667	2.833	0.000	1.333	1.333	1.500	0.000	2.667
E9	0.000	0.000	1.667	2.667	1.833	1.833	2.667	0.000	0.000	1.333	2.333	0.000	2.833
E10	0.000	0.000	1.500	1.667	1.333	1.667	1.667	0.000	1.333	0.000	1.833	0.000	2.833
E11	0.000	0.000	0.000	1.333	0.000	1.333	0.000	0.000	0.000	0.000	0.000	0.000	2.000
E12	1.500	1.500	1.833	2.667	2.667	2.667	2.667	1.500	1.833	1.667	2.500	0.000	2.667
E13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

4.2.2. Normalized average direct-relation matrix

Table 11 presents the normalized initial direct-relation matrix (X) obtained using equation (2).

Table 11 Normalized initial direct relation matrix (X)

Enablers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1	0.000	0.052	0.078	0.104	0.097	0.104	0.071	0.058	0.065	0.065	0.097	0.052	0.110
E2	0.052	0.000	0.058	0.104	0.097	0.104	0.104	0.052	0.052	0.071	0.091	0.052	0.110
E3	0.000	0.000	0.000	0.110	0.058	0.097	0.078	0.000	0.052	0.052	0.071	0.000	0.104
E4	0.000	0.000	0.000	0.000	0.000	0.058	0.000	0.000	0.000	0.000	0.065	0.000	0.110
E5	0.000	0.000	0.000	0.065	0.000	0.058	0.071	0.000	0.000	0.000	0.058	0.000	0.097
E6	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.000	0.104
E7	0.000	0.000	0.000	0.065	0.000	0.071	0.000	0.000	0.000	0.000	0.071	0.000	0.097
E8	0.000	0.000	0.052	0.058	0.071	0.065	0.110	0.000	0.052	0.052	0.058	0.000	0.104
E9	0.000	0.000	0.065	0.104	0.071	0.071	0.104	0.000	0.000	0.052	0.091	0.000	0.110
E10	0.000	0.000	0.058	0.065	0.052	0.065	0.065	0.000	0.052	0.000	0.071	0.000	0.110
E11	0.000	0.000	0.000	0.052	0.000	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.078
E12	0.058	0.058	0.071	0.104	0.104	0.104	0.104	0.058	0.071	0.065	0.097	0.000	0.104
E13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability

4.2.3. Computing the Total relation matrix

Table 12 shows the total relation matrix (T) obtained using equation (3).

Table 12 Total relation matrix (T)

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	r_i
E1	0.0061	0.0555	0.0995	0.1901	0.1301	0.1779	0.1220	0.0649	0.0852	0.0858	0.1711	0.0551	0.2362	1.4796
E2	0.0555	0.0061	0.0800	0.1875	0.1278	0.1762	0.1494	0.0587	0.0717	0.0900	0.1638	0.0551	0.2340	1.4558
E3	0.0000	0.0000	0.0068	0.1507	0.0656	0.1304	0.0925	0.0000	0.0552	0.0552	0.1079	0.0000	0.1708	0.8351
E4	0.0000	0.0000	0.0000	0.0105	0.0000	0.0626	0.0000	0.0000	0.0000	0.0000	0.0689	0.0000	0.1234	0.2654
E5	0.0000	0.0000	0.0000	0.0813	0.0000	0.0721	0.0714	0.0000	0.0000	0.0000	0.0726	0.0000	0.1265	0.4238
E6	0.0000	0.0000	0.0000	0.1146	0.0000	0.0098	0.0000	0.0000	0.0000	0.0000	0.0599	0.0000	0.1222	0.3065
E7	0.0000	0.0000	0.0000	0.0780	0.0000	0.0802	0.0000	0.0000	0.0000	0.0000	0.0807	0.0000	0.1206	0.3594
E8	0.0000	0.0000	0.0591	0.1052	0.0820	0.1040	0.1307	0.0000	0.0580	0.0580	0.0984	0.0000	0.1737	0.8691
E9	0.0000	0.0000	0.0686	0.1475	0.0788	0.1106	0.1192	0.0000	0.0065	0.0558	0.1288	0.0000	0.1815	0.8974
E10	0.0000	0.0000	0.0624	0.1030	0.0599	0.0959	0.0802	0.0000	0.0555	0.0061	0.1023	0.0000	0.1666	0.7320
E11	0.0000	0.0000	0.0000	0.0584	0.0000	0.0557	0.0000	0.0000	0.0000	0.0000	0.0067	0.0000	0.0907	0.2115
E12	0.0620	0.0620	0.0948	0.1953	0.1380	0.1829	0.1551	0.0657	0.0920	0.0869	0.1762	0.0064	0.2375	1.5550
E13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d_j	0.1236	0.1236	0.4713	1.4222	0.6823	1.2584	0.9204	0.1893	0.4240	0.4379	1.2372	0.1167	1.9837	

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

4.2.4. Digraph and causal influence

4.2.4.1. Calculating the sum of rows (r_i) and columns (d_j)

As explained in section 3.3.4., table 13 shows the values of sum for all rows *(r_i)* and columns *(d_j)* computed by equations 4 and 5, respectively. The *(r_i)* values signify the total indirect and direct effect of factor *i* on other factors. Whereas *(d_j)* values signify the total indirect and direct effect on factor *j* from other factors.

4.2.4.2. Computing overall prominence (Pi) and the net effect (Ei)

Table 13 also presents the prominence *(P_i)* and net effect *(E_i)* values of each BCT enablers computed by equations (6) and (7), and classifies the factors into cause and effect groups based on their *(E_i)* values (If E_i is negative: effect; If E_i is positive: cause).

4.2.4.3. Causal digraph

Figure 4 presents the causal digraph obtained from the DEMATEL method that shows effects surpassing the threshold value. Following Shieh et al. (2010), the mean of the matrix T was used to determine the threshold value (α = 0.0556) and filter negligible relationships. In Figure 4, the arrows are drawn from the cause enablers to the effect enablers.

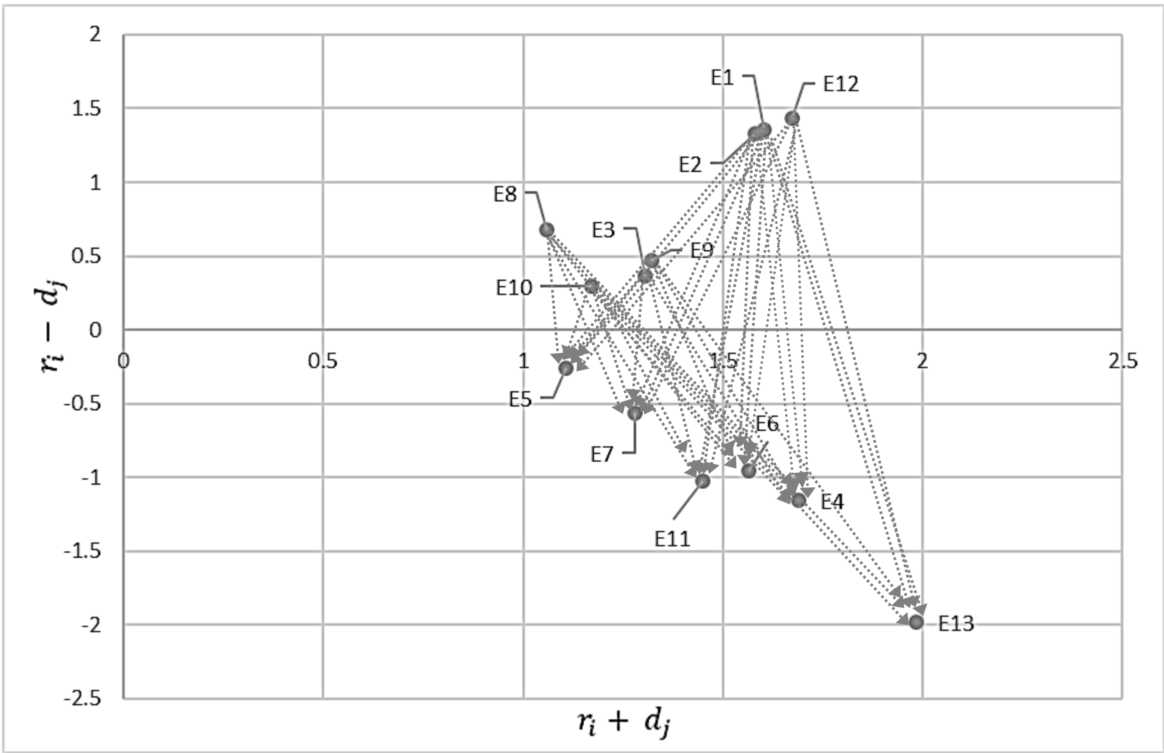
Table 13 Prominence and Net cause-effect

	r_i	d_j	*Prominence* $r_i + d_j$	*Net effect* $r_i - d_j$	*Net cause/effect*
E1	1.479603	0.123635	1.603237	1.355968	C
E2	1.455828	0.123635	1.579463	1.332193	C
E3	0.835062	0.471275	1.306336	0.363787	C
E4	0.265415	1.422211	1.687626	-1.1568	E
E5	0.423834	0.682261	1.106095	-0.25843	E
E6	0.306521	1.258393	1.564914	-0.95187	E
E7	0.359433	0.92044	1.279873	-0.56101	E
E8	0.869129	0.189302	1.05843	0.679827	C
E9	0.897399	0.42401	1.321409	0.473388	C
E10	0.731987	0.437925	1.169912	0.294062	C
E11	0.211529	1.237221	1.44875	-1.02569	E
E12	1.555027	0.116741	1.671768	1.438286	C

E13	0	1.983718	1.983718	-1.98372	E

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

Figure 4. Prominence causal diagram



5. Results and discussion

This study is conducted using a three-phased research framework. First, enablers to BCT adoption in the Indian logistics sector are retrieved from academic literature and validated by experts from industry and academia. Then, using the ISM digraph and MICMAC analyses, we identified the hierarchical structure and the individual nature of the identified factors. MICMAC analysis suggests seven driving enablers and six dependent enablers. Further, the DEMATEL technique was applied to understand the interrelationships among the factors. Overall, three components are analyzed to understand the findings of this research: prominent enablers, influencing enablers, and resulting enablers. The classification and ranking of these enablers are presented in table 14.

Table 14 Classification and ranking of enablers

Classification	Ranking
Prominent enablers	E13 > E4 > E12 > E1 > E2 > E6
Influencing enablers	E12 > E1 > E2 > E8 > E9 > E3 > E10
Resulting enablers	E13 > E4 > E11 > E6 > E7 > E5

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability.

5.1. Prominent enablers

The prominent enablers are those that score high on the prominence score (P_i), which indicates that these enablers have a high correlation with other enablers. Our findings suggest that traceability is the most crucial enabler for BCT in the LSC, with $P_i = 1.983$. Since the Indian logistics sector is largely unorganized and is troubled by poor supply chain visibility and poor real-time tracking (Chakraborty et al., 2020; Mitra, 2008), the traceability enabler is the most attractive feature of BCT that will be considered when adopting BCT in the LSC. The adoption of BCT in the LSC will enhance the visibility and traceability of operations, which is considered challenging to achieve in a disintegrated traditional LSC. With the customers' increased expectations on real-time tracking of their products along with speedy delivery, the pressure on the LSCs to enhance supply chain traceability has increased manifold. Earlier studies suggest that BCT can integrate supply chains seamlessly, thus providing increased visibility, traceability, and transparency (Nakasumi, 2017; J. Wang & Yue, 2017; L. Xu et al., 2017).

5.2. Influencing enablers

Based on the highest net effect (E_i) values, the three most crucial influencing enablers that have critical effects on other enablers are identified as 'real-time connectivity and information flow' (E12), 'decentralized database system' (E1), and 'distributed database system' (E2), respectively. These enablers can be understood as the enablers, which shall help in the achievement of other enablers.

The BCT feature 'real-time connectivity and information flow' (E12) is the most influential enabler of BCT adoption in LSC. The achievement of other enablers such as transparency (E5), traceability (E13), verifiability of transactions (E6), lower transaction settlement lead time (E9), among others, is significantly dependent upon the real-time connectivity amongst the involved stakeholders, which results in seamless information flow and enhances LSC visibility.

Decentralized and distributed database system (E1 and E2) are also identified as crucial influencing enablers of BCT adoption in LSC. While decentralization of the database ensures that the information is not stored in a single centralized position, the distribution of information ledgers amongst the participants ensures that all the participants have a copy of relevant transactions from the shared system. Thus, decentralization and distribution of database ensure the protection of transactions against centralized attacks and accidents, and the trust among the stakeholders is enhanced.

5.3. Resulting enablers

The resulting enablers are those enablers that are highly influenced by other enablers. These enablers are primarily dependent on the achievement of other enablers, i.e., the organizations should focus on the influencing enablers first, and then the resulting enablers can also be mainly achieved as a by-product of achievement of the influencing barriers. These factors have a net effect (E_i) value of less than zero. Based on the E_i values, the top five resulting enablers are 'traceability' (E13), 'immutability' (E4), 'provenance' (E11), 'verifiability of transactions' (E6), and 'enhanced risk mitigation' (E7). While traceability, immutability, verifiability are essential enablers of BCT adoption, it is essential to recognize that these factors are primarily dependent on influencing variables such as distributed and decentralized database system, real-time connectivity and flow of information, cybersecurity, among others.

5.4. Appraisal of findings and BCT-based remedial strategies for LSC challenges

This study observes that traceability (E13) is the most sought-after enabler in the LSC's context; however, it is the top resulting (dependent) factor among the studied factors. The results of our study are in line with the findings of Kamble et al. (2020), who revealed traceability as the key driving factor for BCT adoption. Our findings also resonate with the observations of Ar et al. (2020), who identify visibility and security as the most essential criteria in a Turkish LSC context. Finally, these findings find support from Hastig & Sodhi (2020), who advocate traceability governance as an essential factor of BCT adoption.

Table 15 Summary of BCT based remedies for Select LSC challenges

LSC Challenge	BCT enabled remedy
The poor state of standardization and shareability of real-time information worsens the Operational efficiency	BCT enables real-time information sharing, which improves supply chain visibility and operational efficiency
Finding independent contractors covering distant geographies is cumbersome and expensive	A decentralized and distributed database makes information sharing and integration possible across geographies
Slow data movements related to cargo and extensive documentation affects operational effectiveness	Real-time information exchange effectively reduces delivery delays, loss of documentation, and other similar errors, thereby enhancing operational effectiveness
Higher administrative costs due to obsolete technologies	BCT is interoperable with other existing technologies, thereby minimizing administrative costs.
Undue delays in payments lead to flexibility reduction and increased delivery lead times.	Smart contracts reduce transaction settlement time and costs and help speed up the payment cycle, thereby reducing delivery lead times.
Lack of transparency and trust among stakeholders	Real-time traceability and transparency helps in improving trust and cooperation among the stakeholders
Inadequate freight monitoring and quality control lead to issues such as product damage or thefts	Real-time asset traceability and information exchange improve freight monitoring and quality control.

In this appraisal, we also revisit the LSC challenges that we highlighted earlier in Table 2 and attempt to formulate BCT enabled remedies for the identified challenges (a summary is presented in Table 15). We observe that BCT is expected to improve the data capture and standardization throughout the LSC operations. Data generated from production to the consumption stage can be documented and recorded via a timestamp (equivalent to a transaction), and thereby, a permanent digital identity of the product is created. BCT effectively supports tracking and tracing of every asset along the nodes in the LSCs, and hence the payment invoices, orders, certificates, copyrights, warranty claims, and receipts can be effectively tracked. Information sharing on a real-time basis about various distribution processes can be effectively achieved between the stakeholders. Further, BCT implementation can effectively reduce documentation loss, delivery delays, and other similar errors. Moreover, BCT implementation will lead to supply chain visibility throughout the LSC processes and improve inventory management practices. The real-time information sharing feature also helps in effective vehicle routing by optimizing the traffic data and thereby improve sustainability in LSC operations by reducing the carbon footprint. BCT also facilitates information integration and collaboration among the stakeholders in the LSCs, thereby increasing trust and cooperation. Real-time information flow also improves freight monitoring and enhances quality control.

The smart contracts feature of BCTs help in facilitating payments to the suppliers and contractors in the LSCs. These are like contractual agreements, and the legal provisions are formalized in programmable codes. The contracts are executed without needing a third party. Smart contracts reduce the transaction settlement times, reduce costs, and speed up payment cycles. The smart contracts act as innovative solutions in payment systems and improve the existing lacunae in the payments and settlements in LSCs and improve the business process efficiency.

BCT applications ensure data security and transparency. BCT utilizes decentralized architecture based on distributed computing and avoids centralized architecture, which is considered a bottleneck. Another exciting feature of BCT is that it guarantees data reliability without information being tampered with because of distributed consensus mechanism. It also features privacy protection (to protect stakeholder privacy) and openness (transparency in transactions for audits).

5.5. Implications for research and practice

This study presents several implications for managers, researchers, and policymakers. Studies investigating BCT adoption in LSCs are relatively scarce, and past research (see, e.g., Tob-Ogu et al., 2018) suggests that the LSC sector continues to be plagued by technology adoption challenges and lack of awareness of BCT adoption factors. Therefore, knowing the adoption enablers and their interrelationships informed in this study can help managers achieve higher success in adopting BCT in their LSCs. On the one hand, identifying the driving and dependent enablers using the ISM methodology will help the managers cope with the challenges of implementing BCT in LSC. On the other hand, the DEMATEL technique, by classifying the enablers into prominent, influencing, and resulting enablers, has helped identify the severity of cause and effect relationships among these enablers. This classification of enabling factors will help the managers focus on the influencing (cause) enablers to ensure quicker implementation of BCT in LSCs. The results of this study recommend that the managers are needed to give more attention to the identified influencing (cause) enablers (E12, E1, E2, E8, E9, E3, and E10) before the resulting (effect) enablers (E13, E4, E11, E6, E7, and E5). The P_i and E_i values indicate that the real-time connectivity and information flow (E12) and a decentralized, distributed, and cryptographically secured database system (E1, E2, and E3) are the crucial enablers to BCT adoption in LSC. These influencing enablers can help LSCs in achieving lower transactional costs (E10) and the reduction in associated transaction settlement lead times (E9) aided by the smart contracts (E8), which will ultimately lead to the development of a blockchain environment which possesses immutability (E4), facilitates verifiability of transactions and provenance (E6 and E11), enhances risk mitigation (E7), provides transparency and traceability (E5 and E13).

The results of this study indicate the promising potential of BCT adoption in the Indian logistics sector as it may help in resolving (or minimizing) several issues faced by the currently unorganized sector. For example, BCT can simplify the operational processes by facilitating real-time track and trace of the assets, thereby helping bottleneck identification and reduction. Furthermore, Indian LSCs can efficiently utilize the smart contracts that will help automate the contract fulfilment based on criteria set by the stakeholders (Meyer et al., 2019) and help minimize payment delays resulting in improved operational efficiency.

The study findings highlight that the domain experts put primary focus on ensuring transparency and traceability in the LSC operations. The strong inclination towards developing a transparent system is reasonably expected as transparency is considered to be one of the most important (but challenging to achieve) characteristics of LSCs (or supply chains, in general) (Tijan et al., 2019). Furthermore, since BCT facilitates secured tracking of all types of transactions (including money, data, information, among others), it can minimize delay times, human errors, and overall operational costs in the LSC (Tijan et al., 2019).

For the BCT community, the study opens up new avenues of BCT applications in LSC organizations. Despite using the current technologies, most operations-related information remains restricted within the respective departments, which act as silos, but with the adoption and implementation of BCT, there will be real-time visibility throughout the processes. The interoperability of BCT with other existing technological platforms will enhance auditability and traceability that further improves operational efficiency in LSC organizations. BCT holds numerous potentials for Operations Management (OM) discipline. Combining BCT with the existing disruptive technologies in OM will give rise to new business models such as disintermediation and pave the way for secured data sharing via a decentralized platform. Implementation of BCT will lead to improved collaboration in networks through enhanced trust among stakeholders. The transparency and traceability feature of BCT will improve the real-time data processing capabilities as well.

6. Conclusion

6.1. Summary

At present, the BCT is in the infancy stage and is currently faced with numerous technological, organizational, and environmental challenges that BCT needs to address to ensure widespread adoption and acceptance. Additionally, in an economy like India that is in the process of developing critical technological infrastructure development required for the implementation of technologies like BCT, the BCT's need for colossal computing prowess and high bandwidth internet connection becomes another significant challenge for its widespread adoption. However, BCT has exceptional possibilities of addressing the operational challenges faced by the logistics sector if its enablers are reinforced with supportive futuristic strategies and policies.

We formulated three RQs to be addressed in this study. We address our first RQ by identifying and validating a list of 13 enablers that affect the BCT adoption in LSCs in an emerging economy context. We address our RQ2 and RQ3 by applying the integrated ISM-DEMATEL technique. Specifically, ISM modelling was implemented to identify the underlying contextual interrelationships and to develop a hierarchical structure. Finally, the cause-effect relationships among the identified factors were analysed using the DEMATEL technique.

6.2. Contributions of the study

The critical contributions of the present study are as follows.

- This study identifies the critical BCT factors that enable BCT implementation in the context of the Indian logistics sector and addresses the absence of an appropriate decision-making framework that aids managers in understanding why and how BCT can be adopted in LSC.
- This study is a novel attempt that presents evidence from an emerging economy like India and integrates ISM and DEMATEL methodologies to model and analyse the underlying hierarchical structure and interrelationships among the BCT enablers.
- The study's derived framework and the classification of the enablers into the prominent, influencing, and resulting enablers are expected to aid the practitioners in prioritizing the enabling factors based on relative importance and formulate effective implementation strategies.

6.3. Limitations and the directions for future research

The present study identifies 13 enabling factors for the implementation of BCT in LSC. The enablers are obtained by reviewing the existing literature, followed by validation from the industry and academia experts related to logistics and technology. However, the study is in the context of the Indian logistics sector, and the experts chosen for this study are from India, where BCT is in its incubation stage. Therefore, the possibility of missing some enablers that may have been relevant in the context of other economies cannot be ignored entirely. Therefore, we recommend future studies to carry out similar studies in other economies, preferably the countries structurally different from India, to validate and refine the present study's findings and to search and include new enablers, which could influence the BCT adoption.

Lastly, since the integrated ISM-DEMATEL methodology used for this research is based on subjective judgment and individual evaluations of the subject matter experts, the findings of this study, despite taking significant care, cannot be assured of being completely free from personal biases. Therefore, we recommend further validating the relationships established in this study by using other MCDM techniques and comparing the findings with our study's findings. An empirical research design based on survey methodology could also be another way to validate the present study's findings.

Appendices

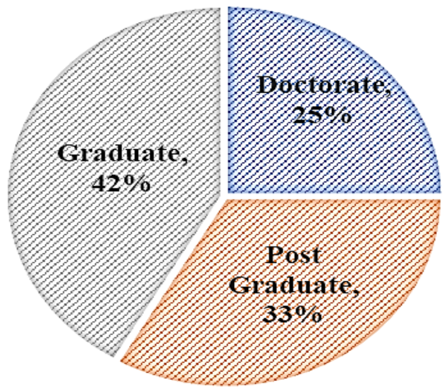
Appendix A: Details of respondents' profiles

This section contains the relevant details of the respondents who participated as experts in the present study. The information about their area of expertise, work experience, and educational qualifications are as follows:

A1.1. Educational Qualification of the Respondents

The educational qualification of the respondents was a crucial aspect of the accomplishment of the objectives of this study. The respondents' profile breakup is shown in figure A1.

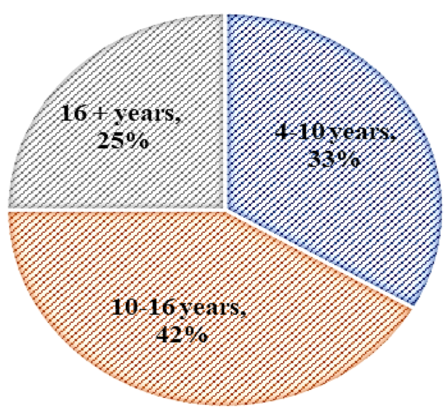
Figure A1. The breakup of respondents based on their educational qualification



A1.2. Work Experience

The work experience of the experts can be an indication of their level of expertise on the subject. Figure A2 presents information about the work experience of the panel of experts chosen for this study. It can be inferred from Figure A2 that nearly 67% of the respondents have 10+ years of rich experience in the supply chain domain.

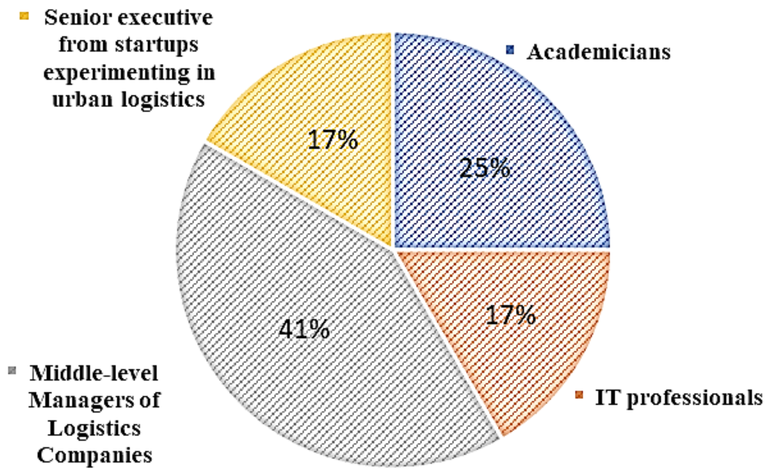
Figure A2. Work experience of the respondents chosen for the study



A1.3. Background of Respondents

The background of the respondents is essential for accessing the correct information on supply chain performance. Figure A3, which presents the distribution of respondents based on their backgrounds, indicates that the expert panel comprises respondents from relevant and diverse backgrounds that shall result in the comprehensiveness of the analysis.

Figure A3. Background of the experts chosen for this study



Appendix B. Questionnaire for data collection

The experts were initially subjected to discussions guided by the following indicative checklist.

1. What is your take on the impact of modern ICTs in LSCs?
2. Do you perceive that BCT can play a significant role in the transformation of LSCs towards sustainability? If yes, how?
3. Potential issues and challenges that may impede the uptake of ICTs in the LSCs?

➔ Along with qualitative opinions on the potential of BCT adoption in LSC, the initial list of enablers identified from academic literature was vetted by experts to retrieve the list of finalized factors modelled in this study.

After that, following the methodological steps presented in section 3, expert opinions were sought on individual matrices for applying the integrated ISM-DEMATEL technique.

E	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
E1													
E2													
E3													
E4													
E5													

E6													
E7													
E8													
E9													
E10													
E11													
E12													
E13													

Appendix C Detailed iterations of ISM partition levels

Iteration	**Enabler**	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	E1	1,2,3,4,5,6,7,8,9,10,11,12, 13	1,2,12	1,2,12	
	E2	1,2,3,4,5,6,7,8,9,10,11,12, 13	1,2,12	1,2,12	
	E3	3,4,5,6,7,9,10,11,13	1,2,3,8,9,10,12	3,9,10	
	E4	4,6,11,13	1,2,3,4,5,6,7,8,9,10,11,12	4.6.11	
	E5	4,5,6,7,11,13	1,2,3,5,8,9,10,12	5	
	E6	4,6,11,13	1,2,3,4,5,6,7,8,9,10,11,12	4,6,11	
	E7	4,6,7,11,13	1,2,3,5,7,8,9,10,12	7	
	E8	3,4,5,6,7,8,9,10,11,13	1,2,8,12	8	
	E9	3,4,5,6,7,9,10,11,13	1,2,3,8,9,10,12	3,9,10	
	E10	3,4,5,6,7,9,10,11,13	1,2,3,8,9,10,12	3,9,10	
	E11	4,6,11,13	1,2,3,4,5,6,7,8,9,10,11,12	4,6,11	
	E12	1,2,3,4,5,6,7,8,9,10,11,12, 13	1,2,12	1,2,12	
	E13	13	1,2,3,4,5,6,7,8,9,10,11,12, 13	13	I
2	E1	1,2,3,4,5,6,7,8,9,10,11,12	1,2,12	1,2,12	
	E2	1,2,3,4,5,6,7,8,9,10,11,12	1,2,12	1,2,12	
	E3	3,4,5,6,7,9,10,11	1,2,3,8,9,10,12	3,9,10	
	E4	4,6,11	1,2,3,4,5,6,7,8,9,10,11,12	4.6.11	II
	E5	4,5,6,7,11	1,2,3,5,8,9,10,12	5	
	E6	4,6,11	1,2,3,4,5,6,7,8,9,10,11,12	4,6,11	II
	E7	4,6,7,11	1,2,3,5,7,8,9,10,12	7	
	E8	3,4,5,6,7,8,9,10,11	1,2,8,12	8	
	E9	3,4,5,6,7,9,10,11	1,2,3,8,9,10,12	3,9,10	
	E10	3,4,5,6,7,9,10,11	1,2,3,8,9,10,12	3,9,10	
	E11	4,6,11	1,2,3,4,5,6,7,8,9,10,11,12	4,6,11	II
	E12	1,2,3,4,5,6,7,8,9,10,11,12	1,2,12	1,2,12	

3	E1	1,2,3,5,7,8,9,10,12	1,2,12	1,2,12	
	E2	1,2,3,5,7,8,9,10,12	1,2,12	1,2,12	
	E3	3,5,7,9,10	1,2,3,8,9,10,12	3,9,10	
	E5	5,7	1,2,3,5,8,9,10,12	5,7	III
	E7	7	1,2,3,5,7,8,9,10,12	7	III
	E8	3,5,7,8,9,10,	1,2,8,12	8	
	E9	3,5,7,9,10	1,2,3,8,9,10,12	3,9,10	
	E10	3,5,7,9,10	1,2,3,8,9,10,12	3,9,10	
	E12	1,2,3,5,7,8,9,10,12	1,2,12	1,2,12	
4	E1	1,2,3,8,9,10,12	1,2,12	1,2,12	
	E2	1,2,3,8,9,10,12	1,2,12	1,2,12	
	E3	3,9,10	1,2,3,8,9,10,12	3,9,10	IV
	E8	3,8,9,10,	1,2,8,12	8	
	E9	3,9,10	1,2,3,8,9,10,12	3,9,10	IV
	E10	3,9,10	1,2,3,8,9,10,12	3,9,10	IV
	E12	1,2,3,8,9,10,12	1,2,12	1,2,12	
5	E1	1,2,8,12	1,2,12	1,2,12	
	E2	1,2,8,12	1,2,12	1,2,12	
	E8	8	1,2,8,12	8	V
	E12	1,2,8,12	1,2,12	1,2,12	
6	E1	1,2,12	1,2,12	1,2,12	VI
	E2	1,2,12	1,2,12	1,2,12	VI
	E12	1,2,12	1,2,12	1,2,12	VI

Note- E1: Decentralized Database System; E2: Distributed Database System; E3: Cybersecurity; E4: Immutability; E5: Transparency; E6: Verifiability of transactions; E7: Enhanced Risk Mitigation; E8: Smart Contracts; E9: Lower Transaction Settlement Time; E10: Lower Transactional Costs; E11: Provenance; E12: Real-time connectivity and information flow; E13: Traceability. (Source: Prepared by authors)

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