Barriers to the Adoption of Blockchain Technology in Business Supply Chains: A Total Interpretive Structural Modelling (TISM) approach

Deepak Mathivathanan
Centre for Logistics and Supply Chain Management,
Loyola Institute of Business Administration
Loyola College Campus, Chennai, Tamil Nadu 600094, India
Email id: deepak.mathivathanan@liba.edu
ORCID: https://orcid.org/0000-0002-6726-2377

K. Mathiyazhagan*
Department of Mechanical Engineering,
Amity School of Engineering & Technology,
Amity University, Sector 125, Noida-201313, Uttar Pradesh, India
Email id: kmathiyazhagan@amity.edu
ORCID: 0000-0002-2340-7394

Nripendra P. Rana*
School of Management
University of Bradford
Richmond Road, Bradford, BD7 1DP, UK
Email: nrananp@gmail.com
ORCID: https://orcid.org/0000-0003-1105-8729

Sangeeta Khorana
Bournemouth University Business School
Bournemouth University
Bournemouth, BH8 8EB, UK
Email: skhorana@bournemouth.ac.uk

Yogesh K. Dwivedi
School of Management
Swansea University Bay Campus
Fabian Way, Swansea, SA1 8EN, UK
Email: ykdwivedi@gmail.com

*Corresponding author

Abstract

Blockchain is an emerging technology with a wide array of potential applications. This technology, which underpins cryptocurrency, provides an immutable, decentralised, and transparent distributed database of digital assets for use by firms in supply chains. However, not all firms are appropriately suited to adopt blockchain in the existing supply chain primarily due to their lack of knowledge on the benefits of this technology. Using Total Interpretive Structural Modelling (TISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC), this paper identifies the adoption barriers, examines the interrelationships between them to the adoption of blockchain technology, which has the potential to revolutionise supply chains. The TISM technique supports developing a contextual relationship based structural model to identify the influential barriers. MICMAC classifies the barriers in blockchain adoption based on their strength and dependence. The results of this research indicate that the lack of business awareness and familiarity with blockchain technology on what it can deliver for future supply chains, are the most influential barriers that impede blockchain adoption. These barriers hinder and impact businesses decision to establish a blockchain-enabled supply chain and that other barriers act as secondary and linked variables in the adoption process.

Keywords: Blockchain, Supply Chain, Barriers, Total Interpretive Structural Modelling, MICMAC

1. Introduction

Blockchain has been presented by the service providers and manufacturers as the future technology with potential to benefit businesses (Viryasitavat et al., 2018). The World Economic Forum (WEF, 2015) predicts that as an emerging technology blockchain will be among the top computing "mega-trends", which is expected to shape the globe in the coming decade. Gao et al. (2018) suggest that blockchains are likely to revolutionise future supply chain management. So far, the blockchain deployment in supply chain management is in infancy and the technology is primarily known for its success in Bitcoin and finance applications (Kshetri, 2018). In today's digital era, most companies have developed digital infrastructure to use computerised Supply Chain Management (SCM) and Enterprise Resource Planning (ERP), as well as digital scanning of products and shipping information (Wu et al., 2017). Given the growing use of digital infrastructure and deployment of Internet of Things (IoT), Radio Frequency Identification (RFID), Global Positioning System (GPS) tags and Industry 4.0, it is inevitable that blockchain will enable real time tracking of information in supply chains more authentically (Li et al., 2018; Lu and Xu, 2017).

At present, most firms depend on outsourcing and require end-to-end traceability and any traceability breach results in heavy losses. The transfer of reliable supply chain information has become one of the key challenges in business (Shankar et al., 2018). But mastering the information flows has become difficult, which means that trust is integral among internal and external stakeholders (Hou et al., 2018). Blockchains offer a shared and secure record of information flows across the supply chain network for transactions and processes between partners (Kshetri, 2017). This provides data integrity and establishes trust in the data thus making information available for all connected on the blockchain (Kim and Laskowski, 2018; Li et al., 2018). Blockchain builds trust for business logic in supply chain and transportation (Apte and Petrovsky, 2016) this technology can eventually phase out intermediaries, verify

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transactions autonomously and eliminate the complexity in supply chains. From a consumers' perspective, transparency, fair trade, and sustainability are the most influential factors in the decision to do business or not (Tseng et al., 2018; Zhang et al., 2018), and the use of blockchain can ensure this to the consumers effectively.

Researchers have experimented with blockchain for various industrial applications but an examination of its effect on supply chains is missing (O'Leary, 2017; Shermin, 2017). Despite the potential of blockchain to transform supply chain activities, it is unclear if this can be translated into reliable applications (Iansiti and Lakhani, 2017). Recently, Dolgui et al. (2020) developed a blockchain-oriented dynamic modelling of smart contracts design as a flexible flowshop scheduling execution in the supply chain. The technology is still in infancy and there is a lack of full clarity about what blockchain can bring to SCM (Hackius and Petersen, 2017; Lemieux, 2016; Saberi et al., 2019). Schmidt and Wagner (2019) discuss the advantages to supply chains from blockchain integration and identify future research opportunities, one of which, is addressing the barriers and challenges to blockchain adoption. The novelty of blockchain technology and the tremendous potential in supply chain applications motivates this research, which examines barriers in blockchain adoption process. In this regard, this research explores the following research questions:

RQ1: What are the significant barriers to the adoption of blockchain in supply chains?

RQ2: What are the interactions and contextual relationships between the barriers?

Additionally, the current study provides the readers with the basics of what is blockchain technology and highlights a simplified version of blockchain process. The new developments of the growing use of blockchain in international trade are also highlighted.

A few studies analyse the idea of blockchain enabled supply chains and the challenges associated in its successful adoption. Kurpjuweit et al. (2019) conducted a Delphi study to analyse the barriers to blockchain adoption in additive manufacturing and highlight the

potential disruptions to supply chains. Prewett et al. (2020) summarised the risks and barriers to blockchain adoption in traditional business models. Klöckner et al. (2020) analysed how blockchain can innovate the manufacturing business model particularly with respect to 3D printing. Queiroz et al. (2019) empirically investigated and compared the blockchain adoption behaviour in logistics and supply chain fields between India and the USA with the network theory approach and technology acceptance models. Despite several blockchain case studies reported by Angrish et al. (2018), Casado-Vara et al. (2018), Oh and Shong (2017), Pazaitis et al. (2017) and Xu et al. (2019), there is no clarity on the selection of case for research. This paper uses an alternative qualitative method called Total Interpretive Structural Modeling (TISM) to develop a strategic framework which explains supply chain phenomena. TISM supports developing a contextual relationship based performance model for analysing the barriers to the adoption of blockchain technology in supply chains, and to understand the interactions between barriers (Dubey et al., 2017). Sushil (2012) argued the benefits of systems theory based models, such as TISM, support better decision making. Though structural models developed, using the likes of Artificial Neural Networking (ANN) and Structural equation Modeling (SEM), include interaction matrices, graphs and flow diagrams, the interpretation of the embedded relations in the system is missing. TISM offers not only the interpretive logic of relationships within the system, but also explains the causality of each link in the resulting hierarchical model.

The remaining sections of this paper are structured as follows: Section 2 provides an overview on blockchain, highlights its ability to revolutionise supply chain management and reviews barriers to blockchain technology adoption. Section 3 discusses the application of TISM in developing the model for examining barriers in supply chains. Further employs MICMAC analysis to classify the barriers based on their strength and dependence. Section 4 presents the results and discusses the barriers to blockchain adoption. Section 5 highlights the managerial

implications of this research. Section 6 concludes while Section 7 highlights the limitations and elaborates on potential for future research.

2. Literature review

2.1 Blockchain technology and Supply chains

The need for a transparent, decentralised, autonomous, and sustainable and a stable financial system triggered the invention of blockchain technology (Christidis and Devetsikiotis 2016). This was conceptualised in 2008 by Satoshi Nakamoto, which formed the basis for cryptocurrency - bitcoin (Tschorsch and Scheuermann 2016), which is among several cases and applications being tested and implemented (Sikorski et al., 2017). Blockchain is defined as a dispersed public ledger, which can record all the digital transactions in chronological order using cryptography techniques (Li and Wang, 2017). This digital ledger is constantly updated and validated with every new transaction creating a permanent record. Once a transaction is recorded in a blockchain it can only be updated with the consensus of the network participants, which makes the ledger more transparent and auditable (Dorri et al., 2017). This ledger is decentralised as the blockchain network is run by all the members involved in the chain and there exists no central authority or centralised infrastructure (O'Leary, 2017). Hence all the members end up having a local copy of the ledger.

Figure 1 is a modified adoption from Li and Wang (2017) and Kakavand et al., (2017), this represents step-by-step process of how the blockchain transactions work. Here 'X' and 'Y' are parties between whom the transaction occurs. Let 'X' be the one initiating the transaction and 'Y' be the one at the other end. When 'X' initiates the process, a transaction is created between 'X' and 'Y'. The transaction is then transparently broadcast to the entire decentralised network and validated, which creates a new block for approval. Once the network members approve this new block, consensus is added to the existing chain and the execution of the transaction is

completed. Each block in the link is the entry on the ledger, which holds the transaction records as well as a hash that links the previous block in the chain. If there is no consensus the new block is rejected.
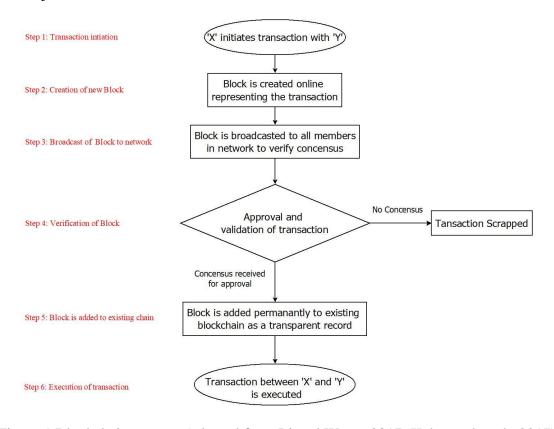

Figure 1 Blockchain process (adapted from Li and Wang, 2017; Kakavand et al., 2017)

There are two major categories of blockchain namely, public-permissionless blockchain and private-permissioned blockchains. The former are open type, which are used by many parties anonymous to each other gain network effects (e.g. bitcoin) but there is the consequent sharing of all the data with every individual connected in the network. The latter finds numerous commercial applications to support a closed set of participants with privacy protection and cryptographic key enabled access controls. Its distributed system helps in providing the exact verified information to all the network members, creating trust between the parties and eliminates intermediaries, like banks and third-party money transfer agencies (Cho et al., 2017; Firica, 2017). This concept has been successfully implemented in bitcoin where parties are transferring digital money since 2009 (Kamble et al., 2019; Kshetri, 2017; Radanović and

Likić, 2018). The decentralised infrastructure has more advantages than the centralised intermediaries, such as banks or third-party websites, because these are prone to hacking (Apte and Petrovsky, 2016; Swan, 2018). Studies highlight the barriers to successful adoption and execution of blockchain technology (Gao et al., 2018; Gausdal et al., 2018). The next section summarises barriers to blockchain adoption in supply chains by conducting a comprehensive literature review.

2.2. Barriers for adoption of blockchain in supply chains

Blockchain is an evolving technology and debate on its use is ongoing in the academic domain (Ivanov et al., 2020; Pournader et al., 2019; Wang et al., 2019). The success of blockchain in supply chain, however, depends on the extent of its adoption (Yadav & Singh, 2020). There are various qualitative attributes, which act as barriers to blockchain adoption (Queiroz et al., 2019). The research considered for this review were derived from the database Science Direct, SCOPUS, Web of Science, EBSCO, Emerald and Springer. Articles were searched from the databases and accessed based on keywords, which include "blockchain", "blockchain technology", "supply chain", "benefits", "application" and "barriers". In addition to the above search databases, reputable journal articles, books and reports were accessed to identify the list of barriers. Supply chain related papers and reports were also scanned and analysed to identify the different themes and characteristics of barriers. This process yielded 96 articles, which have been considered for this research. Figure 2 illustrates this process. Based on the findings the key barriers to the adoption of blockchain technology in supply chains were grouped into nine major themes as described in the sub-sections below.
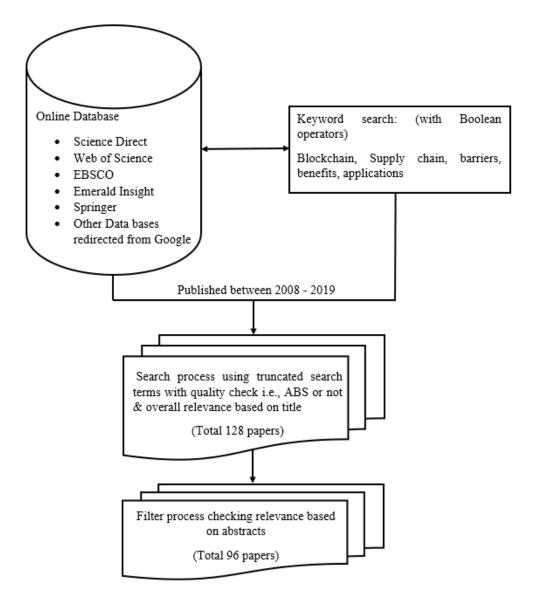
Figure 2. Literature review process

2.2.1. Business owner's unwillingness: Top management support and commitment is one of the major factors for any strategic decision's to succeed (Mathiyazhagan and Haq, 2013). Though business owners are curious on how to use blockchain to gain business success, they should be ready to experiment with the new technology (Saberi et al., 2019). Bringing in a technology like blockchain leads to concepts like digital currencies and contracts, which usher major transformation in existing supply chain activities (Yang, 2019). While the full scope of blockchain is yet to be fully explored, business owners hesitate to risk the major change though start-ups will be more willing to experiment (Ivanov, 2019). Some supply chains may not be

decentralised but are trustworthy so blockchains may not seem vital. Moreover, organisational culture plays an important role in the digital transformation of any business (Kamble et al., 2019). It is a significant decision to completely digitise all the supply chain activities using various data transmission techniques as it involves adopting a number of new technologies into the existing supply chain and in turn is a considerable investment (Longo et al., 2019). This will change the entire mode of working, which aggravates the fear-for-change and is a primary reason why companies hesitate to adopt 'new' technologies (Montecchi et al., 2019). When business owners do not fully commit to blockchain, i.e. undertake the risks involved in its adoption, they cannot act as a critical motivating factor in transforming the entire organisation. This suggests that once the owners believe in change then they can steer their employees towards successful adoption of blockchain technology. Hence, we consider the business owner's unwillingness to experiment newer technologies a major barrier for successful blockchain adoption.

2.2.2. Unfamiliarity with technology: Blockchain is a complicated technical concept that does not lend itself to be built at a basic level (Kshetri and Loukoianova, 2019). Though blockchain was listed as a technology in 2008, it was only the success of bitcoin that put it in the limelight (Kamble et al., 2020). People are still trying to understand the core concepts of blockchain, and researchers are exploring its applications in different fields (Kumar et al., 2019). The blockchain (open ledger) used in bitcoin has been developed with additional functionality and new supporting security features (Shermin, 2017; Tschorsch and Scheuermann 2016). The changes are rapid, and industries are attempting to understand this new technology (Kakavand et al., 2017; Li and Wang, 2017). Moreover, most industries are not familiar with the recent advances and lack awareness of the potential that blockchains have, i.e. to ease business transactions and communication (Lakshmi and Sricharan, 2019).

2.2.3. Data privacy/security concerns: A major attribute that blockchain provides to the supply chain is information transparency (Feng et al., 2019; Lakshmi & Sricharan, 2019). Once information is uploaded in the digital ledger it cannot be removed from the chain (Gromovs and Lammi, 2017), and is available for the entire lifetime of the blockchain. Recent cyber security breaches have resulted in people and firms becoming cautious in sharing personal information online (Engelenburg et al., 2019). Though the blockchains provide us a decentralised network, these are still run by service providers which generates concerns of possible illegal surveillance and possible fear of data misuse (Queiroz et al., 2019). On the one hand, though transparency is desirable in most cases, most companies are still unwilling to share transaction histories with all members of the network (Roeck et al., 2019). However, blockchains are highly secure against hacking and private and permissioned blockchain can maintain a secure network (Engelenburg et al., 2019). On the other hand, efforts are being made by blockchain service providers and governments to educate the public about the technology and eradicate negativity, if so to eradicate this barrier.

2.2.4. Regulatory uncertainty: Blockchain has become the new governance technology competing with the other traditional institutions of capitalism and networks (Shermin, 2017) in that it could disrupt the existing trust and attract criticism from regulatory bodies. Suspected bitcoins associations with money laundering activities have invoked fear among policymakers and regulators (Guo and Liang, 2016). Moreover, regulations vary across countries and some governments opt to regulate the technologies cautiously while others oppose the technological change over (Yeoh, 2017). Therefore, regulatory uncertainty is a major challenge in achieving balance between opportunities provided and the potential for any unintended consequences, which could ensue. The European Union (EU) introduced new regulatory changes and the United States has followed suit (Paech, 2017). However, the financial regulators and

government bodies are still in the phase of developing pragmatic regulations for blockchain, which may manifest as a challenge to its large-scale acceptance and adoption.

2.2.5. Technological infeasibility: Blockchain relies on cryptography and encryption techniques, which provide high level of security and a common platform for consensus in a distributed network (Min, 2019). Therefore, for each transaction, complex algorithms must be run for checking the permission and consensus (Shankar et al., 2018). This is possible only if large computing powers are setup at each node of the network because low powered systems cause huge delays in transactions (Queiroz et al., 2019). However, considering that the supply chain is global, one can never expect all the actors in the supply chain to be at the same level of technical maturity. This raises concerns of its feasibility for large scale adoption (Roeck et al., 2019). Though the world has seen the emergence of technologically advanced concepts like Industry 4.0 and IoTs, many industries are yet to attain the high level of digitisation which would allow them to adapt to blockchains (Mistry et al., 2020). Hence, issues like insufficient internal digital culture are a significant barrier in the adoption of blockchain in supply chains.

2.2.6. Complexity in set up/use: Theoretically, blockchain can offer technological answers but it is not easy to transform the traditional supply chain functions to digital and software platforms (Zheng et al., 2018). Though blockchain requires the same infrastructure and high-speed Internet connection for setting up the network (Reyna et al., 2018), building a blockchain network depends on the existing software platform and developers must decide on which network to use. Further, huge investments are needed across the supply chain to establish common software platforms, which involve initiators' commitment (Queiroz and Wamba, 2019). For any blockchain transaction to occur, a cryptographically powered triple check is required for authenticity and security (Savelyev, 2018). Such complicated rules, standards, and protocol on network operation impacts blockchain adoption.

2.2.7. Uncertain benefits: The use of blockchain for SCM is still in infancy with limited examples of successful large-scale implementation (Yli-Huumo et al., 2016). The knowledge of blockchain functionality, applicability and its usage are unclear in the minds of business owners (Savelyev, 2018). Most industries use enterprise resource planning (ERP) software systems to manage supply chains and are unsure of the need to move to blockchain (Zheng et al., 2018). Moreover, the supply chain benefits must be weighed against the significant barriers to its successful adoption (Mathiyazhagan and Haq, 2013). Hence, uncertain benefits are practical challenges to the adoption of blockchain in supply chains.

2.2.8. Dependence on blockchain operators: Although blockchain is an innovative technology with the potential to revolutionise supply chain activities (Zheng et al., 2018) developing a blockchain network requires considerable theoretical insights and is unlikely to exist in a firm's core competences (Queiroz and Wamba, 2019). Hence, blockchain solutions must be borrowed or setup with the help of existing service providers (Paech, 2017). Other than cost considerations, blockchains are complicated and a global blockchain requires additional resources (Reyna et al., 2019). Since only selected corporate firms have the capability to use blockchain systems, the dependence is higher which leads to cost trade-offs in the initial setup and renders maintenance difficult (Iansiti and Lakhani, 2017). Despite the advantages and hype that surrounds blockchain, many companies fear being dependent on blockchain operators (Kim, 2018).

2.2.9. Lack of cooperation among supply chain partners: Using blockchain solutions require all supply chain partners to have the same level of technological maturity (Queiroz and Wamba, 2019). Given all data scanning, transmission and information infrastructure needs to be identical integrating the existing systems with blockchain and will require cooperation among all partners (Yli-Huumo et al., 2016). To provide a unified platform for blockchains, all stakeholders must adopt an integrated approach. It is necessary that all the stakeholders

involved in the network conduct a consensus assessment review before blockchain adoption (Shermin, 2017). Global supply chains existing today involve numerous stakeholders in different geographies at differing levels of digital readiness. There are times when stakeholders have different conceptions regarding blockchains and there may not be a consensual recognition of the positives of blockchain based supply chain transformations (Deshpande et al., 2017). Adjusting business strategies and cooperating with different stakeholders involves mutual commitment and creating a shared vision is a key challenge to successful adoption of blockchain (Reyna et al., 2018).

Barrier	Notation	Description	References
Business Owner's unwillingness	B1	Fear of change, investment, organisation culture	Deshpande et al., 2017; Galvez et al., 2018; Ivanov, 2019; Kamble et al., 2019; Montecchi et al., 2019; Longo et al., 2019; Saberi et al., 2019; Yang, 2019
Unfamiliarity with Technology	B2	Lack of awareness, infancy of technology	Kamble et al., 2020; Kakavand et al., 2017; Kshetri and Loukoianova, 2019; Kumar et al., 2019; Lakshmi and Sricharan, 2019; Li and Wang, 2017; Queiroz and Wamba, 2019; Shermin, 2017; Tschorsch and Scheuermann, 2016
Data privacy/security concerns	B3	Cyber security concerns, possible illegal surveillance, and possible fear of data misuse	Engelenburg et al., 2019; Feng et al., 2019; Gromovs and Lammi, 2017; Lakshmi & Sricharan, 2019; Queiroz et al., 2019; Roeck et al., 2019;
Regulatory uncertainty	B4	Regulations vary across countries, and still pragmatic regulations for blockchain are in development stage	Chang et al., 2019; Deshpande et al., 2017; Guo and Liang, 2016; Hackius and Petersen, 2017; Paech, 2017; Shermin, 2017; Yeoh, 2017
Technological infeasibility	B5	Lack of large computing power, level of technical maturity is not the same along the supply chain partners	Deshpande et al., 2017; Galvez et al., 2018; Min, 2019; Mistry et al., 2020; Queiroz et al., 2019; Roeck et al., 2019; Shankar et al., 2018
Complexity in set up/use	B6	Massive financial investment, common software platform required, initiators commitment	Chang et al., 2019; Queiroz and Wamba, 2019; Reyna et al., 2018; Savelyev, 2018; Zheng et al., 2018
Uncertain benefits	B7	Uncertain benefits are key practical challenges	Apte & Petrovsky, 2016; Ferica 2017; Mathiyazhagan and Haq, 2013; Savelyev, 2018; Yli-Huumo et al., 2016; Zheng et al., 2018
Dependence on Blockchain operators	B8	Trade-offs in the initial setup, fear of dependence on blockchain operators	Iansiti and Lakhani, 2017; Kim, 2018; Queiroz and Wamba, 2019; Paech, 2017; Reyna et al., 2019; Zheng et al., 2018
Lack of Cooperation among SC partners	B9	Supply chain partners must have the same level of technological maturity	Deshpande et al., 2017; Queiroz and Wamba, 2019; Reyna et al., 2018; Shermin, 2017; Yli-Huumo et al., 2016

Table 1: List of Barriers, description, and references

2.3 Need for TISM and MICMAC analysis

With the growing popularity of blockchain and the extended benefits it can offer to global supply chains, it might be feasible for firms to apply this within their existing infrastructures. Analysing the relationships between barriers allows managers to take effective decisions towards the successful adoption of blockchains. Though the existing literature has provided an insight on the barriers, and aim at testing particular hypotheses using quantitative methods, there are no studies that build theory and establish the mutual relationships between barriers that impact on the successful adoption of blockchain in supply chains. There are case studies (e.g. Tönnissen and Teuteberg, 2020; Wamba et al., 2020) aimed at analysing the "why" behind particular phenomena but do not provide a clear understanding of relationships between the constructs. In brief, the evidence from existing literature focuses on testing the existing theory or attempting to support past literature but fails to build theory in terms of strategic framework. Hence, this paper aims to bridge this gap by developing a performance model for nine barriers identified to the adoption of blockchain in supply chain by using a contextual relationship based TISM approach and draws on the opinions of the relevant industrial experts. TISM has an edge over the approached such as Diffusion of Innovation (DOI) theory and Technology-Organisation-Environment (TOE) framework. On the one hand, DOI is useful in postulating the firm's adoption of newer technology based on mostly innovation characteristics and organisational characteristics. On the other, TOE identifies factors that influence the firms' ability to leverage technological innovations.

Both TOE and DOI cannot analyse the barriers that affect successful adoption which TISM can, and also TISM helps implementation managers to prioritise the 20% of the cause barriers, which affect 80% of the adoption process similar to the Pareto 80-20 principle to provide better insights in the barrier elimination processes. Technology acceptance model (TAM) is an established model that is used by researchers to investigate new technology adoption for

measuring businesses attitude to technology adoption. Though TAM provides interesting behavioral insights and in-depth information, TISM is focused on analysing the inter-relationships between barriers to adoption that cannot be addressed by TAM. TISM also aims at generating a strategic theoretical framework to overcome the pitfalls of traditional ISM by explaining the transitive links and the reasons behind the linkages between the elements of the interpretive structural modelling (ISM) based model.

TISM is an advancement of traditional ISM (Yadav, 2014) used to develop a contextual relationship-based performance model for the barriers hindering the successful adoption of blockchain in supply chains. This methodology is an interpretive way of modelling specific relationships based on judgments of the group about the relationship between different elements involved (Singh and Sushil, 2013). TISM methodology helps to portray the relationships between elements in a diagraph (Sindhwani and Malhotra, 2017). The hierarchical order and direction of the relationships among the elements are represented by an arrow. The influential barriers can be identified by the levels they are finally placed in the diagraph and the contextual relationships between any two elements are described along the connecting arrow (Shibin et al., 2017). This is one upgrade from the traditional ISM and the other advantage is that the transitive relations can be retraced back with critical reasoning. Unlike ISM, TISM checks the actual reason for the transitivity if any with the help of expert opinion and considers only the effective transitive links in developing the model.

In ISM, transitive relation is said to exist between two constructs, for example, A and C have transitive relationship just if Variable A influences Variable B, which directly influences Variable C using the law of transitivity. But, in case of TISM the transitive links are first obtained from the reachability matrix using the same methodology used in ISM and then checked for their validity and effectiveness through a knowledge-based assessment from the expert opinion. Then the effective transitive links are identified, and the other ineffective

transitive links are eliminated from model building. Hence the final TISM model developed depicts only the effective links and thus provides a more trust-worthy analysis between the constructs.

Furthermore, the barriers are classified with MICMAC (Matriced'Impacts Croises-Multipication Applique' and Classment). The relationships between barriers are always not equal - some may be strong whereas others may be weak. The stronger the relationship the better is the success of the model. Based on the strength of power (dominance) and mutual dependence among each barrier, MICMAC analysis supports categorising barriers and identifying the key elements that drive the structural model. Finally, the TISM model is validated with a different group of industrial experts. The steps involved are discussed in the next section.

3. TISM and MICMAC to analyse barriers of blockchain adoption

This section analyses the barriers for blockchain adoption using TISM approach to build to contextual relationship based structural model followed by MICMAC analysis to classify the barriers based on their driving powers. The following sub-section discusses the steps adopted from Jayalakshmi and Pramod (2015) to develop the TISM model. Then, by using MICMAC analysis the dependent, linkage and autonomous elements in the system are identified. The next section discusses the various steps involved in TISM methodology and the Figure 3 shows the step by step procedure involved.
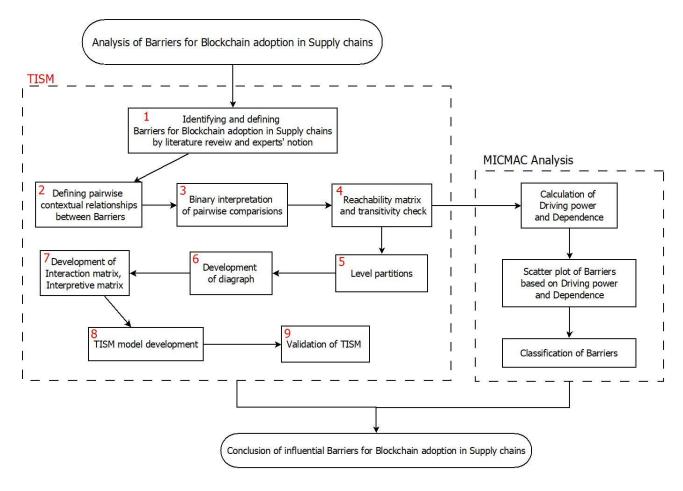
Figure 3. Solution Methodology

3.1. Application of TISM methodology

In this sub-section, TISM is explained by outlining the basic steps involved along with developing the intended contextual relationship-based model to examine barriers to the adoption of blockchain in supply chains. Each progressive step is explained along with data collected in developing and validates the TISM model.

Step I. Identifying and defining the elements: The first step is designing the sample and data collection. Here, we identify various barriers for successful adoption of blockchain in SCM from existing literature and defining them. These are the elements of TISM, for which the relationships are to be modelled. The various potential barriers are identified from the literature; in our case, the nine barriers including business owner's unwillingness (B1), unfamiliarity with technology (B2), data privacy/security concerns (B3), regulatory uncertainty (B4), technology infeasibility (B5), complexity in set up/use (B6), uncertain benefits (B7),

dependence on blockchain operators (B8) and lack of cooperation among supply chain partners (B9) are put in an interpretive knowledge base suitable for capturing expert opinion.

Being a qualitative approach, this study required respondents to provide answers to 72 paired relationship-based questions along with the logic behind each of their responses. This was time consuming for the experts and for our study as a whole. Hence, we decided to target only a few experienced supply chain experts who have significant experience in designing and building supply chains and had faced various technology based various transitional changes in their respective firms over the years. These experts were either at the level of supply chain managers or head of logistics operations and are decision makers in that they define the operation of the supply chain, i.e. adopting and approving changes at functional and operation levels required their authorisation.

In this study, expert from 16 manufacturing firms in the automotive sector and four from academia were identified. The targeted industry experts were employed at a tactical level of supply chains and have at least ten plus years of experience. The academics were from reputed management and engineering institutions with good knowledge of blockchains. But only a total of seven respondents (six industry experts and one academic) provided us with exploitable responses. A general awareness on these barriers was given to the seven experts who had in-depth supply chain knowledge and detailed explanations of each barrier were provided in the personal interviews followed by brainstorming sessions with the group of identified experts. Hence, these experts were appropriate respondents for our TISM model. At this stage, each expert was provided with a detailed description of the nine barriers.

Step II Defining contextual relationships: The next step is to define the contextual relationship between the listed barriers. Here, pair-wise contextual relationships are identified between each of the barriers using expert opinion. i.e. if a Barrier B1 will influence another Barrier B2, and so on, along with the corresponding interpretation. In the context of our study, the clarification

of how the Barrier B1 influences Barrier B2 and so on are recorded in the knowledge base matrix through discussions with the experts in terms of Yes/No answers along with the logical reason behind them; thus, developing the interpretive knowledge base. The contextual relationship between the barriers on a pairwise basis is established based on the experts' opinions. Brainstorming sessions and personal interviews with the experts were used to analyse the pairwise relation between barriers. Here the experts are required to provide pair-wise contextual relationship between all barriers, which further developed the knowledge base in the form of a table with each row representing the compared pair of barriers and their existing contextual relationship, if any.

In our study, since we consider a total of nine barriers, the total number of rows in the knowledge base is 9*8=72. These 72 possible relationships were discussed with the experts and the knowledge base was formed as shown in Table 2. For any comparative measure, a positive response was required by more than 50% otherwise it was scored as a 'No'. All the responses for 'Yes' i.e. the presence of any contextual relationship was examined and the interpretations provided by the experts were used to arrive at combined interpretation statements and tabulated in the explanation column.

Table 2. The interpretive logic knowledge base

SN	Notations of Barriers under comparison	Paired comparison	Any relationship exists?	Brief explanation of relationship if any
1	B1-B2	Business Owner's Unwillingness will influence Unfamiliarity with Technology	No	-
2	B2-B1	Unfamiliarity with Technology will influence Business Owner's Unwillingness	No	-
.	.	.	.	.
.	.	.	.	.
72	B9-B8	Lack of Cooperation among Supply Chain Partners will influence Dependence on Blockchain Operators	Yes	Non-cooperation hinders going for blockchain operators

Step III Binary interpretation of pair-wise comparisons: The logical interpretation of the Yes/No relationship between the compared barriers are entered in terms of a 'n x n' matrix where, n is the number of barriers considered in the study. For each $(i,j)^{th}$ cell, the value of either '1' or '0' is entered based on the influence of barrier B_i over the barrier B_j where '1' depicts the presence of influential relationship of B_i over B_j and '0' denoting the absence of a relationship (Jayalakshmi and Pramod, 2015). In our case, we developed a 9 x 9 matrix, and the total number of pair-wise comparisons is 9*8=72. Based on the knowledge base, the initial reachability matrix is prepared. The comparisons are represented in the form of a matrix with each element except the diagonal elements carrying binary values '1' or '0'. The value '1' is given in the cells if the logic knowledge base shows any existing relationship between the compared barriers, otherwise value '0' is entered (Dubey et al., 2015). The initial reachability matrix thus developed is shown in the following Table 3. Here the cells carrying a value '1' and are highlighted in blue and these are the direct relationships only. The diagonal values highlighted in pink are always assumed as '1' (Sushil, 2012).

Table 3. Initial reachability matrix

Barrier		B1	B2	B3	B4	B5	B6	B7	B8	B9
Business owner's unwillingness	B1	1	0	0	0	0	0	0	1	1
Unfamiliarity with technology	B2	0	1	1	0	0	0	1	0	0
Data privacy/security concerns	B3	1	0	1	1	0	0	0	0	1
Regulatory uncertainty	B4	1	0	1	1	0	0	0	0	0
Technological infeasibility	B5	1	0	0	0	1	1	0	0	1
Complexity in set up/use	B6	1	0	0	0	0	1	0	0	0
Uncertain benefits	B7	1	0	0	0	0	0	1	0	1
Dependence on blockchain operators	B8	0	0	1	0	0	0	0	1	0
Lack of cooperation among supply chain partners	B9	0	0	1	0	1	1	0	1	1

Step IV Reachability matrix and a check of transitivity: The initial reachability matrix obtained from the logical interpretation of the Yes/No relationship is checked for any possible transitivity based on the transitivity rule if B_x influences B_y and B_y influences B_z, then B_x influences B_z (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). For each possible transitive link, the knowledge base is renamed as 'transitive link', and the interpretation column is filled with one or more elements for the transitive relationship. One such example of transitive

relation is that which exist between the barriers B3 (Data privacy and security concerns) and B8 (Dependence on Blockchain operators). Here the initial reachability matrix did not confer any relation between them but the TISM model suggests that the privacy and security concerns of firms prevent them from trusting the blockchain operators, thus indirectly impacting the adoption process. Only the transitive relationships having a significant interpretation are considered, and the rest are ignored for further analysis (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). The binary interpretation offers the base for the initial reachability matrix based on direct relationships.

Several indirect relations may exist. These relations are identified by transitivity check. The transitive relations are identified, and the final reachability matrix obtained is represented in Table 4 (Reachability matrix and transitivity check). Here the transitive relations obtained by using the transitivity rule are marked in green and the corresponding elements, which provide transitivity, are also noted. Then the transitive relations are analysed with the same experts and based on their opinion the explanation for the transitive links are derived and the logic base is updated. Not all the transitive links are effective and hence based on the experts' opinions the ineffective transitive links are eliminated (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). This is one of the major upgrades that a TISM model provides.

In regular ISM the transitive relations are formed based just on the transitivity rule but in case of TISM the logic behind the transitivity is examined and the effective links alone are considered for further study. In Table 4 in the first matrix, the direct links are highlighted in blue as earlier and the transitive links are highlighted in green. The adjacent matrix represents the corresponding barrier(s), which is/are responsible for the transitive link. For example, the transitive relationship B1-B5 is obtained due to Barrier B9. Hence, Barrier B9 is represented as '9' in the corresponding relationship cell in the adjacent matrix. If we examine the transitive link B1-B3, there are two barriers B8 and B9, which contribute to the transitive link, based on

the law of transitivity. Thus, the barriers responsible for each transitive links are identified and noted down in the adjacent matrix.

The next step is to examine the transitive links with help of experts' opinion. The experts are contacted, and the derived transitive links are discussed one by one and the possibility of existence of transitivity is inferred and the knowledge base is once again updated. Out of the 22 transitive links identified only 13 were found to be effective. The ineffective transitive links are highlighted in dotted green in the final reachability matrix, which is represented in Table 4a and Table 4b, respectively.

Table 4a. Final reachability matrix

	B1	B2	B3	B4	B5	B6	B7	B8	B9
B1	1	0	1	0	1	1	0	1	1
B2	0	1	1	1	0	0	1	0	1
B3	1	0	1	1	1	1	0	1	1
B4	1	0	1	1	0	0	0	1	1
B5	1	0	1	0	1	1	0	1	1
B6	1	0	0	0	0	1	0	1	0
B7	1	0	1	0	1	1	1	1	1
B8	1	0	1	1	0	0	0	1	1
B9	1	0	1	1	1	1	0	1	1

Table 4b. Elements providing transitivity

	B1	B2	B3	B4	B5	B6	B7	B8	B9
B1			8,9		9	9			
B2				3					3
B3					9	9		9	
B4								1	1,3
B5			9					1,9	
B6								1	
B7			9		9	9		9	
B8	3			3					3
B9	3			3					

Step V Level partitions: Like ISM, the partitioning of levels is done to identify the level-wise placement of barriers. The reachability set, antecedent set and intersection set are determined based on the driving and the dependence power of each barrier and arranged in a table. The barriers in top hierarchical level do not reach the barriers above their own level (Mathiyazhagan et al., 2013). A similar iterative process followed in ISM is employed to determine the levels of each of the barriers. These levels make the basis for diagraph and TISM model. The previous step provides us with the final reachability matrix, which is made up of entries on pair-wise assessments due to direct relationships together with some of the entries derived from inferred transitive relationships i.e., the effective transitive relationships. From the final reachability matrix, the reachability, antecedent and the intersection sets for each barrier are developed (Mathiyazhagan et al., 2013). The barrier for which the intersection set is the same as the

reachability set is designated the topmost level (Level I) and the Level I barriers are removed from the entire set for the next iteration table. This process is continued until each barrier is assigned their corresponding levels. Finally, after 4 iterations all the elements are assigned their levels and this iterative process is represented in Table 5.

Table 5. Levels partition of barriers for blockchain adoption in supply chains

Barrier	Reachability set	Antecedent set	Intersection set	Level
B1	1,3,5,6,8,9	1,3,4,5,6,7,8,9	1,3,5,6,8,9	I
B2	2,3,4,7,9	2	2	IV
B3	1,3,4,5,6,8,9	1,2,3,4,5,7,8,9	1,3,4,5,8,9	III
B4	1,3,4,8,9	2,3,4,8,9	3,4,8,9	II
B5	1,3,5,6,8,9	1,3,5,7,9	1,3,5,9	III
B6	1,6,8	1,3,5,6,7,9	1,6	II
B7	1,3,5,6,7,8,9	2,7	7	IV
B8	1,3,4,8,9	1,3,4,5,6,7,8,9	1,3,4,8,9	I
B9	1,3,4,5,6,8,9	1,2,3,4,5,7,8,9	1,3,4,5,8,9	III

Step VI Development of digraph: The barriers are arranged graphically based on their levels and the links between the barriers are represented in terms of arrows based on the relationships in the final reachability matrix (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). First a simple version of the diagraph is developed which represent direct links through continuous arcs, and after examining the transitive links only those links which are identified to be effective transitive links and have a significant relationship, are represented in the diagraph using dashed arcs (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). This represents the final TISM model obtained. Developing a diagraph in our case involves arranging all nine barriers graphically based on their levels obtained during the level partitions. The links between the barriers are represented in terms of arrows based on the relationships in the final reachability matrix. Figure 4 is the diagraph developed representing the generated hierarchical model with the direct links in continuous arcs and effective transitive links in dashed arcs.
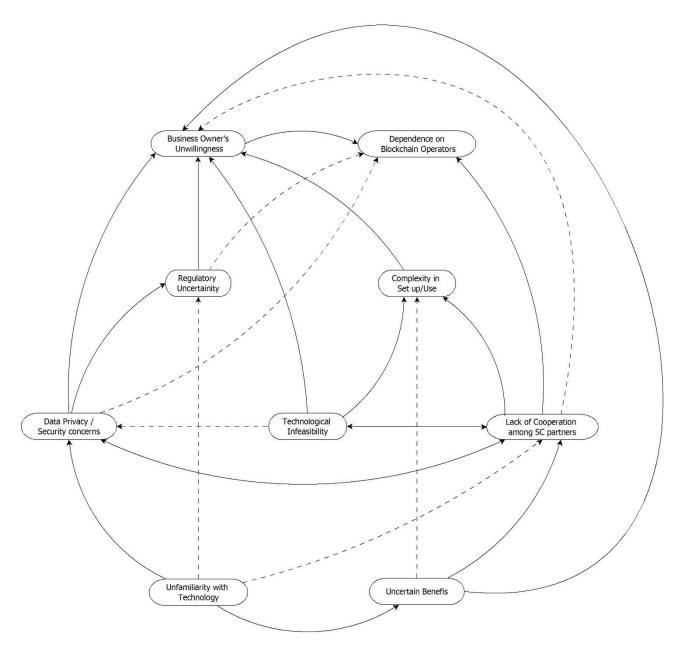
Figure 4. Digraph showing both direct and transitive links (TISM model)

Step VII Interaction matrix and Interpretive matrix: Based on the derived diagraph a binary interaction matrix is obtained by translating all represented interactions as '1' and the rest of the cells are void of entry (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). The effective transitive links are represented as 1*. The cells with entries are construed with the help of the knowledge base in the form of a matrix (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). In our case, we develop a 9 x 9 interpretive matrix with entries from the logic knowledge base

for the cells with value '1'. The Table 6 and Table 7 present the interaction matrix and interpretive matrix, respectively.

Table 6. Interaction matrix

Barrier		B1	B2	B3	B4	B5	B6	B7	B8	B9
Business owner's unwillingness	B1	-	0	0	0	0	0	0	1	0
Unfamiliarity with technology	B2	0	-	1	*1**	0	0	0	0	*1**
Data privacy/security concerns	B3	1	0	-	1	0	0	0	*1**	1
Regulatory uncertainty	B4	1	0	0	-	0	0	0	*1**	0
Technological infeasibility	B5	1	0	*1**	0	-	1	0	0	1
Complexity in set up/use	B6	1	0	0	0	0	-	0	0	0
Uncertain benefits	B7	1	0	0	0	0	*1**	-	0	1
Dependence on blockchain operators	B8	0	0	1	0	0	0	0	-	0
Lack of cooperation among supply chain partners	B9	*1**	0	1	0	1	1	0	1	-

Table 7 Interpretive matrix

		B1	B2	B3	B4	B5	B6	B7	B8	B9
Business Owner's unwillingness	B1	-	0	0	0	0	0	0	Security risks limit full dependency	0
Unfamiliarity with technology	B2	0	-	Technological immaturity increases privacy / security concerns	*Evolving technology increases regulatory uncertainty*	0	0	0	0	*Technological immaturity reduces interests*
Data privacy/security concerns	B3	Growing concerns hinders willingness to adopt blockchains	0	-	Growing concerns increases uncertainty	0	0	0	*Privacy concerns hinder dependency*	Security concerns decreases level of cooperation
Regulatory uncertainty	B4	Uncertainty creates negative impact	0	0	-	0	0	0	*Uncertainty hinders dependency*	0
Technological infeasibility	B5	Infeasibility hinders interest in blockchains	0	*Infeasibility increases security concerns*	0	-	Technological immaturity hinders ease of set up	0	0	Difference in maturity level affects cooperation
Complexity in set up/use	B6	Complexity increases unwillingness	0	0	0	0	-	0	0	0
Uncertain benefits	B7	Unclear benefits reduce business owner's interest in blockchains	0	0	0	0	Unclear benefits hinder ease of set up	-	0	Unclear benefits lessens cooperation
Dependence on blockchain operators	B8	0	0	0	0	0	0	0	-	0
Lack of cooperation among SC partners	B9	*Lack of cooperation hinders technology changes*	0	Lack of cooperation increases security concerns	0	Lack for cooperation hinders technological advancements	Non-cooperation affects Complexity in set up	0	Non-cooperation hinders choosing blockchain operators	-

Step VIII TISM model: The final step is the development of TISM model. The information in the interpretive matrix is portrayed over the respective links in the obtained diagraph (Dubey et al., 2015; Jayalakshmi and Pramod, 2015). Thus, the fully reasoned model is obtained and shown in the Figure 5.
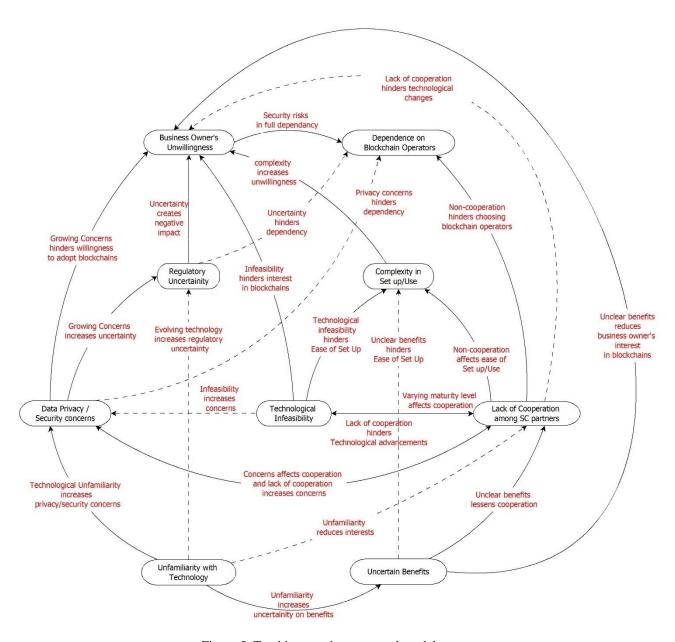

Figure 5. Total interpretive structural model

Step IX Validation of TISM: The developed TISM model was developed with an inherent limitation of low number of responses. This is mainly because the experts had to give more time for pairwise comparisons and provide the interpretive logic behind each pair of comparison. In our case the experts were required to provide inputs on 9x8=72 comparisons.

Providing contextual relationships and the associated logic behind the relationships for 72 pairs was highly time consuming. It was also very difficult to get volunteers for this demanding process. Thus, we had only seven respondents who volunteered and helped in developing the model. Once the TISM model is developed we had a drastic reduction in the number of links. The developed model has only 24 meaningful links. This drastic reduction in the number of meaningful relationships makes it much easier in terms of time consumptions for any expert to validate the links. Hence as proposed by Jayalakshmi and Pramod (2015), the same group of experts was contacted and this time a larger group of experts (12 experts) assessed the developed TISM model.

Each expert was asked to rate the links on a Likert scale of '1' to '5' with '1' being 'strongly disagree' and '5' being 'strongly agree'. Each link in the model is accepted if the link gained an average score of three and the entire model is accepted if the average score of all the links is above three. The assessment of the TISM model is presented in the Table 8 below. From this table, it is found that all the links except one link B4–B8 i.e., namely regulatory uncertainty influencing the dependence on blockchain operators is found to be ineffective since its average score is below three. The overall score of the model is above three and hence we can accept the model. The final validated TISM model is presented in Figure 6.

Table 8. Assessment of TISM model

SN	Derived relationship	Responses from experts (E)												Average response	Accept / Reject link
		E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E10	E11	E12		
1	Data privacy/security concerns will influence Business Owner's unwillingness	4	4	5	5	4	5	4	4	5	4	5	4	4.42	Accept
2	Regulatory uncertainty will influence Business Owner's unwillingness	3	4	3	4	3	3	3	3	4	3	3	3	3.25	Accept
3	Technological infeasibility will influence Business Owner's unwillingness	4	4	4	3	3	4	3	4	4	3	4	4	3.67	Accept
4	Complexity in set up/use will influence Business Owner's unwillingness	3	3	3	4	3	4	4	4	4	3	4	3	3.50	Accept
5	Uncertain benefits will influence Business Owner's unwillingness	4	4	4	4	3	4	4	4	5	4	4	4	4.00	Accept
6	Business owner's unwillingness will influence their dependence on blockchain operators	5	4	3	5	3	4	3	4	4	4	4	3	3.83	Accept
7	Lack of cooperation among supply chain partners will influence business owner's unwillingness	3	4	3	5	3	4	3	3	4	3	4	4	3.58	Accept
8	Unfamiliarity with technology will influence Data privacy/security concerns	3	4	3	4	3	4	3	4	5	3	4	4	3.67	Accept
9	Unfamiliarity with Technology will influence Regulatory uncertainty	2	4	3	4	3	4	3	4	4	3	4	4	3.50	Accept
10	Unfamiliarity with Technology will influence Lack of Cooperation among supply chain partners	4	3	4	4	4	4	3	3	4	3	5	4	3.75	Accept
11	Data privacy/security concerns will influence Regulatory uncertainty	4	4	4	4	4	3	4	4	4	3	3	4	3.75	Accept
12	Technological infeasibility will influence Data privacy/security concerns	3	3	3	2	4	3	3	4	3	2	4	4	3.17	Accept
13	Data privacy/security concerns will influence the dependence on blockchain operators	3	3	4	3	4	3	3	3	2	3	4	3	3.17	Accept
14	Dependence on Blockchain operators will influence Data privacy/security concerns	3	4	4	4	3	4	3	4	3	3	3	3	3.42	Accept
15	Data privacy/security concerns will influence Lack of Cooperation among supply chain partners	3	4	4	5	3	3	3	4	2	3	3	3	3.33	Accept
16	Lack of cooperation among supply chain partners will influence data privacy/security concerns	3	3	4	5	3	3	3	4	3	3	4	3	3.42	Accept
17	*Regulatory uncertainty will influence dependence on blockchain operators*	*3*	*2*	*2*	*3*	*3*	*3*	*2*	*3*	*1*	*3*	*2*	*3*	*2.50*	*Reject*

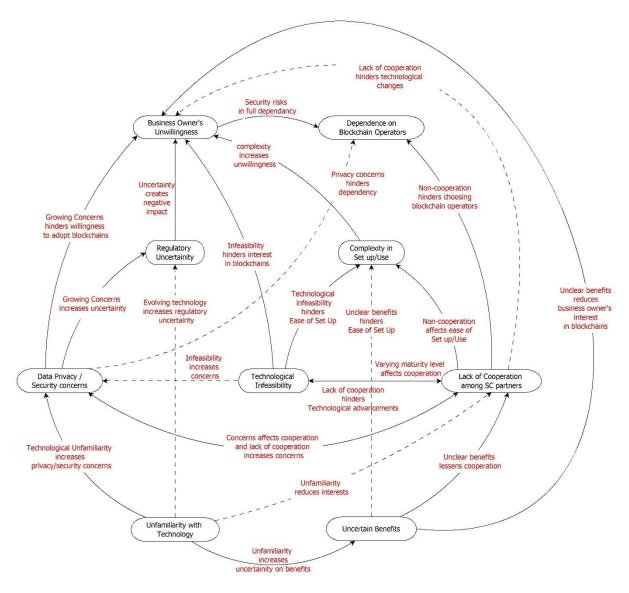|																
18	Technological infeasibility will influence the complexity in set up/use	3	3	3	4	3	4	3	4	3	4	2	3	3.25	Accept
19	Technological infeasibility will influence the lack of Cooperation among supply chain partners	4	4	3	4	4	3	3	4	3	3	3	3	3.42	Accept
20	Lack of cooperation among supply chain partners will influence T=technological infeasibility	4	3	4	4	2	4	3	4	4	3	4	3	3.50	Accept
21	Uncertain benefits will influence Complexity in set up/use	3	3	2	3	3	4	3	4	2	4	3	3	3.08	Accept
22	Lack of cooperation among supply chain partners will influence the complexity in set up/use	4	4	3	5	3	3	5	4	3	4	4	3	3.75	Accept
23	Uncertain benefits will influence lack of cooperation among supply chain partners	3	4	5	4	4	3	3	5	4	3	3	3	3.67	Accept
24	Lack of cooperation among supply chain partners will influence dependence on blockchain operators	5	4	5	4	4	4	4	5	4	4	5	5	4.42	Accept
	Average score for the Model													**3.54**	**Accept**

Figure 6. Validated TISM model

3.2. MICMAC analysis

The MICMAC is an established methodology to analyse the impact of variables/elements measured by relationships (Dubey and Ali, 2014; Jain and Raj, 2015; Diabat et al., 2013; 2014). We apply MICMAC to identify the key barriers that hinder the adoption of blockchain. MICMAC delivers a graphical representation of the barriers in four quadrants namely autonomous, dependent, linkage and driving based on the driving and dependence power of each barrier, which is calculated as the row sum and column sum from the final reachability matrix presented in Table 9. For example, if we consider barrier B2 the row wise summation of 1 corresponding B2 i.e., row 2 will be equal to what is considered its driving power and the

column-wise sum corresponding to B2 i.e., Column 2 will be equal to 1 is its dependence. The barriers are then plotted on a graph of driving power against dependence and are classified under the above mentioned four quadrants as shown in Figure 6. The first quadrant represents the autonomous elements, which are the barriers having low driving and dependence powers. The second quadrant consists of barriers, which are weak drivers but are strongly dependent in nature. The third quadrant consists of barriers, which have high driving and dependence power. These barriers which fall in this quadrant are called the linkage elements which are unstable, and their actions affect the entire system. The fourth quadrant represents the driving elements which have strong driving powers but weak dependence power.

Table 9. Driving power and dependence of barriers

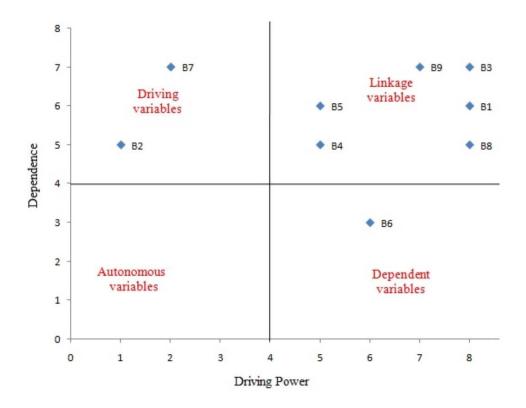| Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9
Driving power	6	5	7	5	6	3	7	5	7
Dependence power	8	1	8	5	5	6	2	8	8

Figure 7. Driving and dependence power diagram

4. Discussion

A four-level TISM model (see Figure 6) was obtained with barrier B1 i.e. Business owners' unwillingness to adopt blockchain and Barrier B8, i.e., dependence on blockchain operators at Level 1 are the least influential barriers and hence they are found at the top-most layer of the diagraph. This infers that these barriers are not the pivotal barriers to the adoption of blockchain in supply chain management, but may be influenced by other factors, which are more critical. Apart from the cost of adoption, business owners lack the awareness about the technology and its future benefits. Since the architecture of blockchain is complex, the firms must depend on blockchain service providers, but this brings the security risk of letting a third party handle the firm's entire transactional data (Iansiti and Lakhani, 2017).

Level 2 consists of two barriers B4 (Regulatory uncertainty) and B6 (Complexity in setup/use). Also, the changing regulations in different parts of the globe complicates the terms of negotiations between global partners and, hence, hinders blockchain adoption. Further, the difficulty involved in setting up a sophisticated technology like blockchain involves high level knowledge acquisition and transfer at both managerial and operational level. Barriers, such as B3 (Data privacy and security concerns), B5 (Technological infeasibility) and B9 (Lack of cooperation among supply chain partners) form Level 3 of the TISM model.

These are the most critical barriers and provide valuable interlinks to the whole system as these connect the other levels. Finally, in Level 4 the bottom most layer of the model consists of two barriers - B2 (Unfamiliarity with technology) and B7 (Unclear benefits) are the most influential barriers. When business owners are not familiar with the technology and have a vague sight of how these could benefit them in future it upsets the adoption of blockchain (Iansiti and Lakhani, 2017). Blockchain is still evolving and no globally established successful case examples are available yet, but these are the most influential barriers of all. The research provides insights that once these barriers are addressed, companies could adopt blockchain in SCM.

Further, the MICMAC analysis provides the driving and dependence power diagram that shows the relative importance and the relationship between barriers. The first quadrant comprises the autonomous barriers i.e., they are the least influential and least influenced practices, which have the least links to the system due to their low driving and dependence powers (Mathiyazhagan and Haq, 2013). They do not practically affect the system positively or negatively. In our case we do not have any autonomous variables. If autonomous variables are present, they have to be considered as driving variables and treated with high importance. The second quadrant consists of barriers, which are highly dependent on the other barriers in system but have low driving power to individually disrupt the system (Mathiyazhagan and Haq, 2013). Complexity in setup/use (B6) falls into this category indicating that this is not the core reason against blockchain adoption, but this indirectly affects successful adoption and also the magnitude of the effect is dependent on a number of other variables. In line with literature (Wang et al., 2019) our results confirm that with proper understanding of the technology, developing technological capabilities within the firm, accompanied with flexible and enthusiastic collaboration with supply chain partners, paves the way for successful blockchain adoption. As explained in Mathiyazhagan and Haq (2013), the third quadrant consists of the linking variables, which provide stability to the entire system and any changes to these will disturb the entire system. Regulatory uncertainty (B4), data privacy/security concerns (B3), technological infeasibility (B5), lack of cooperation among the supply chain partners (B9) and business owner's unwillingness to adopt blockchain (B1) fall in the linking variable category. These are an integral part of the entire system because these variables have the strength and show high dependence which helps to drive the entire system but, at the same time, have the ability to disrupt the entire system if they are not addressed given their high dependence on the other variables, as pointed out by Mathiyazhagan and Haq (2013). The fourth quadrant includes barriers, B2 (Unfamiliarity with the technology) and B7 (uncertain benefits), which possess

strong driving power but less dependence power. Hence, these are the most influential barriers, which can act as the root cause for the other barriers and should be treated with top-most priority and eliminated at first while adopting blockchains.

4.1. Theoretical contributions

This research provides multi-fold theoretical contributions to the existing knowledge in the area of blockchain adoption in general and barriers to the adoption in business supply chains in particular. First, this is the first research of its kind to explore and explain the significant barriers to the adoption of the business supply chains. Secondly, this research establishes contextual linkages between identified barriers of business supply chain using TISM-MICMAC based approach. None of the existing research studies have yet examined the interrelationships between barriers of supply chain using novel techniques such as TISM and MICMAC. The use of MICMAC approach also allows the researchers to classify the identified barriers into different categories including autonomous barriers, independent barriers, dependent barriers and linkage barriers to understand their nature.

Based on the review of literature and data collected from various experts, we also computed the driving and dependence power for each barrier in the study and they fell into one of the four categories represented by MICMAC diagram based on their driving and dependence power. Finally, through partitioning of levels for barriers in the proposed TISM model and their interconnections across different hierarchies would help researchers to understand the levels and interrelationships between these barriers. As a result, this research is not only able to provide a strong methodological contribution by including the novel techniques of TISM and MICMAC but also give researchers a sense of interrelationships between barriers and across different levels. We hope that future researchers will be able to empirically test relationships between some of the key variables derived from the TISM model.

4.2. Managerial implications

This study offers implications for managers, in terms of offering insights on what blockchain technology could offer in revolutionising the supply chains and the barriers that managers should pay attention to successfully adopt blockchain in the existing supply chains. This study in particular shows that lack of technical knowledge about blockchains and the uncertainty about the benefits the technology could bring to the firms hinders the adoption to the most. Therefore, managers should consider eradicating these major barriers by conducting knowledge transfer sessions with supply chain partners and also look upon employee training programs to develop the knowledge base within the firm which enable them to understand the new technology in light of how it works and what benefits it could bring to the firm.

By doing so, managers can ensure cooperation among supply chain partners to further ease the adoption process. Technical infeasibility is another important barrier to be looked upon. The managers should educate and train the employees towards the technological advances and develop the skill sets to convince the business owners and coordinate with blockchain operators in successful adoption. The proposed framework provides the managers with the hierarchy and categories of barriers. Paying attention to these barrier means managers should assess the current situation by analysing each barrier individually in their firm's perspective and acquire or develop capabilities and establish practices to eradicate them tactically on the road to successful adoption of blockchain technology.

4.3. Limitations and future research directions

In this paper, though the model developed using TISM identifies the barriers to blockchain adoption, the impact is only subjectively analysed and lacks mathematical quantification. ISM has no weights for variables to indicate their relative importance and techniques, hence structural equation modelling (SEM) and analytic network process can be used to validate the developed model. Grey and Fuzzy theories can be used by the future researchers to overcome

the drawback of the limited number of responses and also to consider the fuzziness of the respondents. Grey weights-based MICMAC analysis can be incorporated to include the priority and experience of the respondents. In addition, Decision Making Trial and Evaluation Laboratory (DEMATEL) can be used to identify the dominant barriers and a hybrid technique like D-ANP (DEMATEL based Analytic Network Process) can be used to develop a causal effect-based model for barriers and to quantify the mutual dominance of each. Further, in this research a structured questionnaire was not used to test the developed model. Confirmatory factor analysis is one option to look into in the future to test this developed framework.

5. Conclusion

This paper analyses the barriers to successful adoption of blockchain technology in supply chains. A contextual relationship between barriers that impact the offtake of blockchain technology has been developed. The TISM explores the dynamic interactions and transitive linkages between the barriers and provides a hierarchical model depicting appropriate behaviours of each barrier to blockchain adoption in the supply chain. Further, this paper identifies influential barriers that need to be addressed and eliminated for effective adoption of blockchain in supply chains. A structural model was developed using TISM, which revealed that the lack of familiarity with blockchain technology and a lack of critical awareness on what it can deliver for future supply chain are the most influential barriers. These barriers impact the decision to establish a blockchain enabled supply chain and other barriers act as linkage variable in the process, as confirmed by the MICMAC analysis.

By analysing the interactions within barriers using TISM and identifying the influential barriers using MICMAC analysis, this research minimises the lack of clarity around the adoption of blockchain. This paper has contributed to the supply chain literature addressing blockchain applications and innovations. It adds to the existing literature (see Kurpjuweit et al. (2019), Prewett et al. (2020), Queiroz et al., (2019), Angrish et al. (2018), Casado-Vara et al. (2018),

Oh and Shong (2017), Pazaitis et al., (2017) and Xu et al., (2019)) by offering an innovative and alternative TISM based strategic framework development through both literature analysis and experts' opinion. This paper examines the capability of TISM to explore the reasons for transitive links, which enables a deeper understanding of the system and validates the developed TISM model for the nine barriers to implement blockchain in supply chains. This is a step forward in the applicability of TISM proposed by Sushil (2012).

This study contributes to the current literature on blockchain technology in supply chain management. Though the various adoption and maturity models like TAM, DOI and TOE etc., provide insights on adoption behaviour and maturity levels of adoption, these do not address the barriers to implementation. The adoption of new technology by focusing on enablers of adoption is important and the adoption managers can tackle the task of eliminating the barriers for successful implementation of blockchains across the supply chain. Once the barriers are eliminated the success of the adoption process becomes inevitable. Also, the Pareto 80-20 principle suggests that 80% of the effects are due to 20% of the causes.

Thus, we argue that the novelty of the research lies in supporting managers in identifying top barriers that must be eliminated for blockchain adoption in supply chains. The TISM method coupled with MICMAC analysis provides the information on influential barriers with a higher driving force which must be eliminated first so that the other dependent barriers in the system can also be eliminated. In this regard, our results reveal that barriers, lack of technical knowledge about blockchains and the uncertainty around the benefits of this technology are the driving barriers, which trigger dependent barriers. Hence, the adoption managers should focus on knowledge development on blockchain functionalities with the employees and inform the top management about the benefits blockchain adoption could bring to the firm, will improve the adoption process.

This study suggests that, for successful adoption of blockchain, companies should begin by mapping the potential applicability of blockchain within their own business and invest in developing knowledge of the technology. With assistance of an expert, a team creating blockchain strategy and designing a demonstrable case on a smaller scale before wholesale adoption is recommended. Finally, through iterative process rapid progression on the prioritised cases, the industry can move towards creating a successful business case on a commercial scale. Though barriers exist to blockchain based transformation in the supply chain, these barriers are not insurmountable. Despite its relative infancy, this technology has attracted many business owners irrespective of industrial sector to which they belong. Talking about supply chains, blockchains offer a wide range of applications dealing with issues like transparency, traceability, anti-counterfeiting, provenance, shared resource management, contract management, demand/forecast management, and robust cyber security, etc. Blockchain adoption, however, demands more resources in terms of capital, time and processes to eliminate the barriers in the way of its adoption and to realise its full potential.

References

Angrish, A., Craver, B., Hasan, M. and Starly, B., 2018. "A case study for blockchain in manufacturing FabRec: A prototype for peer-to-peer network of manufacturing nodes." *Procedia Manufacturing*, 26: 1180-1192.

Apte, S. & Petrovsky, N. 2016. "Will blockchain technology revolutionize excipient supply chain management?" *Journal of Excipients and Food Chemicals*, 7(3): 76-78.

Casado-Vara, R., Prieto, J., De la Prieta, F. and Corchado, J.M., 2018. "How blockchain improves the supply chain: case study alimentary supply chain." *Procedia Computer Science*, 134: 393-398.

Chang, Y., Iakovou, E. & Shi, W. 2019. "Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities." *International Journal of Production Research*, DoI: 10.1080/00207543.2019.1651946.

Cho, S.H., Park, S.Y. & Lee, S.R. 2017. "Blockchain consensus rule based dynamic blind voting for non-dependency transaction." *International Journal of Grid and Distributed Computing*, 10(12): 93-106.

Christidis, K. and Devetsikiotis, M., 2016. "Blockchains and smart contracts for the Internet of things." *IEEE Access*, 4: 2292-2303.

Deshpande, A., Stewart, K., Lepetit, L. and Gunashekar, S., 2017. "Distributed Ledger Technologies/Blockchain: Challenges, opportunities and the prospects for standards." *Overview Report of The British Standards Institution*, 1-34.

Diabat, A., Kannan, D. and Mathiyazhagan, K., 2014. "Analysis of enablers for implementation of sustainable supply chain management–A textile case." *Journal of Cleaner Production*, 83: 391-403.

Diabat, A., Khreishah, A., Kannan, G., Panikar, V. and Gunasekaran, A. 2013. "Benchmarking the interactions among barriers in third-party logistics implementation: An ISM approach", *Benchmarking: An International Journal*, 20(6): 805-824.

Dolgui, A., Ivanov, D., Potryasaev, S., Sokolov, B., Ivanova, M. and Werner, F. 2020. "Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain", *International Journal of Production Research*, 58(7): 2184-2199.

Dorri, A., Steger, M., Kanhere, S.S. and Jurdak, R., 2017. Blockchain: A distributed solution to automotive security and privacy. *IEEE Communications Magazine*, 55(12): 119-125.

Dubey, R. and Ali, S.S., 2014. "Identification of flexible manufacturing system dimensions and their interrelationship using total interpretive structural modelling and fuzzy MICMAC analysis." *Global Journal of Flexible Systems Management*, 15(2): 131-143.

Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S.J., Shibin, K.T. and Wamba, S.F. 2017. "Sustainable supply chain management: Framework and further research directions", *Journal of Cleaner Production*, 142: 1119-1130.

Dubey, R., Gunasekaran, A., Wamba, S.F. and Bag, S., 2015. "Building theory of green supply chain management using total interpretive structural modeling (TISM)." *IFAC-PapersOnLine*, 48(3): 1688-1694.

Engelenburg, S., Janssen, M. & Klievink, B. 2019. "Design of a software architecture supporting business-to-government information sharing to improve public safety and security: Combining business rules, Events and blockchain technology." *Journal of Intelligent Information Systems*, 52(3): 595-618.

Feng, Q., He, D., Zeadally, S., Khan, M.K. & Kumar, N. 2019. "A survey on privacy protection in blockchain system." *Journal of Network and Computer Applications*, *126*: 45-58.

Firica, O. 2017. "Blockchain technology: Promises and realities of the year 2017." *Quality - Access to Success*, 18: 51-58.

Galvez, J.F., Mejuto, J.C. and Simal-Gandara, J., 2018. Future challenges on the use of blockchain for food traceability analysis. *TrAC Trends in Analytical Chemistry*, 107: 222-232.

Gao, Z., Xu, L., Chen, L., Zhao, X., Lu, Y. & Shi, W. 2018. "CoC: A Unified Distributed Ledger Based Supply Chain Management System." *Journal of Computer Science and Technology*, 33(2): 237-248.

Gausdal, A.H., Czachorowski, K.V. & Solesvik, M.Z. 2018. "Applying Blockchain technology: Evidence from Norwegian companies." *Sustainability*, 10(6): 1-16.

Goldsby, T.J. & Zinn, W. 2017. "Research and Researchers: The Enduring Value of Conferences to Logistics and Supply Chain Scholars." *Journal of Business Logistics*, 38(3): 148-150.

Gromovs, G. & Lammi, M. 2017. "Blockchain and internet of things require innovative approach to logistics education." *Transport Problems*, 12: 23-34.

Guo, Y. and Liang, C., 2016. "Blockchain application and outlook in the banking industry", *Financial Innovation*, 2(1): 24.

Hackius, N. and Petersen, M., 2017. "Blockchain in logistics and supply chain: trick or treat? In Digitalization in Supply Chain Management and Logistics: Smart and Digital Solutions for an Industry 4.0 Environment", *Proceedings of the Hamburg International Conference of Logistics (HICL)*, 23 (pp. 3-18). Berlin: epubli GmbH.

Hasan, H., AlHadhrami, E., AlDhaheri, A., Salah, K. & Jayaraman, R. 2019. "Smart contract-based approach for efficient shipment management." *Computers and Industrial Engineering*, 136: 149-159.

Haughwout, J. 2018. "Tracking medicine by transparent blockchain." *Pharmaceutical Processing*, 33(1): 24-26.

Hawlitschek, F., Notheisen, B. & Teubner, T. 2018. "The limits of trust-free systems: A literature review on blockchain technology and trust in the sharing economy." *Electronic Commerce Research and Applications*, *29*: 50-63.

Hou, Y., Wang, X., Wu, Y.J. and He, P., 2018. "How does the trust affect the topology of supply chain network and its resilience? An agent-based approach." *Transportation Research Part E: Logistics and Transportation Review*, *116*: 229-241.

Hughes, A., Park, A., Kietzmann, J. and Archer-Brown, C. 2019. "Beyond Bitcoin: What blockchain and distributed ledger technologies mean for firms." *Business Horizons*, *62*(3): 273-281.

Hughes, T.M. 2018. "The global financial services industry and the blockchain." *Journal of Structured Finance*, *23*(4): 36-40.

Iansiti, M. and Lakhani, K.R., 2017. "The truth about blockchain." *Harvard Business Review*, *95*(1): 118-127.

Ivanov, D., Dolgui, A. & Sokolov, B. 2019. "The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics." *International Journal of Production Research*, *57*(3): 829-846.

Ivanov, D., Tang, C.S., Dolgui, A., Battini, D. and Das, A., 2020. "Researchers' perspectives on Industry 4.0: Multi-disciplinary analysis and opportunities for operations management", *International Journal of Production Research*, 1-24.

Jain, V. and Raj, T., 2015. "Modeling and analysis of FMS flexibility factors by TISM and fuzzy MICMAC." *International Journal of System Assurance Engineering and Management*, *6*(3): 350-371.

Jayalakshmi, B. and Pramod, V.R. 2015. "Total interpretive structural modeling (TISM) of the enablers of a flexible control system for industry." *Global Journal of Flexible Systems Management*, *16*(1): 63-85.

Jennath, H.S., Adarsh, S. and Anoop, V.S. 2019. "Distributed IoT and Applications: A Survey. In Integrated Intelligent Computing, Communication and Security." Springer, Singapore, 333-341.

Kakavand, H., Kost De Sevres, N. and Chilton, B. 2017. "The blockchain revolution: An analysis of regulation and technology related to distributed ledger technologies." SSRN, 1-27.

Kamble, S., Gunasekaran, A. and Arha, H. 2019. "Understanding the Blockchain technology adoption in supply chains-Indian context." *International Journal of Production Research*, *57*(7): 2009-2033.

Kamble, S.S., Gunasekaran, A. and Gawankar, S.A. 2020. "Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications." *International Journal of Production Economics*, *219*: 179-194.

KamelBoulos, M.N., Wilson, J.T. and Clauson, K.A. 2018. "Geospatial blockchain: Promises, challenges, and scenarios in health and healthcare." *International Journal of Health Geographics*, *17*(25); 1-10.

Kim, H.M. and Laskowski, M. 2018. "Toward an ontology-driven blockchain design for supply-chain provenance." *Intelligent Systems in Accounting, Finance and Management*, *25*(1): 18-27.

Kim, S. and Kim, D. 2018, "Design of an innovative blood cold chain management system using blockchain technologies." *ICIC Express Letters, Part B: Applications*, 9(10): 1067-1073.

Kim, S. 2018. *Blockchain for a trust network among intelligent vehicles*. In Advances in Computers, 111: 43-68.

Klöckner, M., Kurpjuweit, S., Velu, C. and Wagner, S.M., 2020, "Does Blockchain for 3D Printing Offer Opportunities for Business Model Innovation?", *Research-Technology Management*, 63(4): 18-27.

Kshetri, N. and Loukoianova, E. 2019. "Blockchain Adoption in Supply Chain Networks in Asia." *IT Professional*, *21*(1): 11-15.

Kshetri, N. 2017. "Can Blockchain Strengthen the Internet of Things?" *IT Professional*, *19*(4): 68-72.

Kshetri, N. 2018. 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of Information Management*, *39*: 80-89.

Kumar, A., Liu, R. and Shan, Z. 2019. "Is Blockchain a Silver Bullet for Supply Chain Management? Technical Challenges and Research Opportunities." *Decision Sciences*, DoI: 10.1111/deci.12396.

Kurpjuweit, S., Schmidt, C.G., Klöckner, M. and Wagner, S.M. 2019. "Blockchain in Additive Manufacturing and its Impact on Supply Chains." *Journal of Business Logistics*, 1-25.

Lakshmi, M.V.N.N. and Sricharan, Y.V.N.S. 2019. "Blockchain: Single source of truth in shared services? an empirical paper on the relevance of blockchain for shared services." *International Journal of Recent Technology and Engineering*, 7(6): 1783-1788.

Lemieux, V.L. 2016. "Trusting records: is Blockchain technology the answer?", *Records Management Journal*, 26(2): 110-139.

Leng, K., Bi, Y., Jing, L., Fu, H. and Van Nieuwenhuyse, I. 2018. "Research on agricultural supply chain system with double chain architecture based on blockchain technology." *Future Generation Computer Systems*, *86*: 641-649.

Li, X. and Wang, C.A., 2017. "The technology and economic determinants of cryptocurrency exchange rates: The case of Bitcoin." *Decision Support Systems*, 95: 49-60.

Li, Z., Barenji, A.V. and Huang, G.Q. 2018. "Toward a blockchain cloud manufacturing system as a peer to peer distributed network platform." *Robotics and Computer-Integrated Manufacturing*, *54*: 133-144.

Longo, F., Nicoletti, L., Padovano, A., d'Atri, G. and Forte, M. 2019. "Blockchain-enabled supply chain: An experimental study." *Computers and Industrial Engineering*, *136*: 57-69.

Lu, Q. and Xu, X. 2017, "Adaptable Blockchain-Based Systems: A Case Study for Product Traceability", *IEEE Software*, *34*(6): 21-27.

Mackey, T.K. and Nayyar, G. 2017, "A review of existing and emerging digital technologies to combat the global trade in fake medicines." *Expert Opinion on Drug Safety*, *16*(5): 587-602.

Makhdoom, I., Zhou, I., Abolhasan, M., Lipman, J. and Ni, W. 2020, "PrivySharing: A blockchain-based framework for privacy-preserving and secure data sharing in smart cities", *Computers and Security*, *88*: 101653.

Mandolla, C., Petruzzelli, A.M., Percoco, G. and Urbinati, A. 2019, "Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry", *Computers in Industry*, *109*: 134-152.

Mao, D., Wang, F., Hao, Z. and Li, H. 2018, "Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain." *International Journal of Environmental Research and Public Health*, *15*(8): 16-27.

Mathiyazhagan, K. and Haq, A.N., 2013. "Analysis of the influential pressures for green supply chain management adoption—an Indian perspective using interpretive structural modeling." *The International Journal of Advanced Manufacturing Technology*, *68*(1-4): 817-833.

Mathiyazhagan, K., Govindan, K., Noorul Haq, A. and Geng, Y. 2013. "An ISM approach for the barrier analysis in implementing green supply chain management." *Journal of Cleaner Production*, *47*: 283-297.

Meng, W., Tischhauser, E.W., Wang, Q., Wang, Y. and Han, J. 2018, "When intrusion detection meets blockchain technology: A review." *IEEE Access*, *6*: 10179-10188.

Mense, A. and Athanasiadis, L. 2018, "Concept for Sharing Distributed Personal Health Records with Blockchains." *Studies in Health Technology and Informatics*, *251*: 7-10.

Min, H. 2019. "Blockchain technology for enhancing supply chain resilience." *Business Horizons*, *62*(1): 35-45.

Mistry, I., Tanwar, S., Tyagi, S. and Kumar, N. 2020. "Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges." *Mechanical Systems and Signal Processing*, *135*: 106382.

Montecchi, M., Plangger, K. and Etter, M. 2019. "It's real, trust me! Establishing supply chain provenance using blockchain", *Business Horizons*, *62*(3): 283-293.

Notheisen, B., Cholewa, J.B. and Shanmugam, A.P. 2017, "Trading Real-World Assets on Blockchain: An Application of Trust-Free Transaction Systems in the Market for Lemons", *Business and Information Systems Engineering*, *59*(6): 425-440.

Oh, J. and Shong, I., 2017. "A case study on business model innovations using Blockchain: focusing on financial institutions", *Asia Pacific Journal of Innovation and Entrepreneurship*, *11*(3): 335-344.

O'Leary, D.E., 2017. "Configuring blockchain architectures for transaction information in blockchain consortiums: The case of accounting and supply chain systems", *Intelligent Systems in Accounting, Finance and Management*, *24*(4): 138-147.

O'Leary, D.E., 2018. "Open Information Enterprise Transactions: Business Intelligence and Wash and Spoof Transactions in Blockchain and Social Commerce." *Intelligent Systems in Accounting, Finance and Management*, *25*(3): 148-158.

Paech, P., 2017. "The governance of blockchain financial networks", The Modern Law Review, *80*(6): 1073-1110.

Pazaitis, A., De Filippi, P. and Kostakis, V., 2017. "Blockchain and value systems in the sharing economy: The illustrative case of Backfeed", *Technological Forecasting and Social Change*, 125: 105-115.

Peck, M.E. 2017. "Blockchain world - Do you need a blockchain? This chart will tell you if the technology can solve your problem", IEEE Spectrum, 54(10): 38-60.

Peters, G., Panayi, E. and Chapelle, A., 2015. "Trends in cryptocurrencies and blockchain technologies: a monetary theory and regulation perspective." *Journal of Financial Perspectives*, 3(3): 1-46.

Pilkington, M. 2016. "Blockchain technology: Principles and applications" in Research Handbooks on Digital Transformations, 225-253.

Pournader, M., Shi, Y., Seuring, S. & Koh, S.C.L. 2019. "Blockchain applications in supply chains, transport and logistics: A systematic review of the literature." *International Journal of Production Research*, DoI: 10.1080/00207543.2019.1650976.

Prewett, K.W., Prescott, G.L. and Phillips, K., 2020. "Blockchain adoption is inevitable—Barriers and risks remain." *Journal of Corporate Accounting & Finance*, 31(2): 21-28.

Queiroz, M.M. and Wamba, S.F., 2019. "Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA." *International Journal of Information Management*, 46: 70-82.

Queiroz, M.M., Telles, R. and Bonilla, S.H. 2019, "Blockchain and supply chain management integration: a systematic review of the literature." *Supply Chain Management*, DoI: 10.1108/SCM-03-2018-0143.

Radanović, I. and Likić, R., 2018. "Opportunities for use of blockchain technology in medicine." Applied Health Economics and Health Policy, 16(5): 583-590.

Reyna, A., Martín, C., Chen, J., Soler, E. and Díaz, M., 2018. "On blockchain and its integration with IoT. Challenges and opportunities." *Future Generation Computer Systems*, *88*: 173-190.

Roeck, D., Sternberg, H. and Hofmann, E. 2019. "Distributed ledger technology in supply chains: a transaction cost perspective." *International Journal of Production Research*, DoI: 10.1080/00207543.2019.1657247.

Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L., 2019. "Blockchain technology and its relationships to sustainable supply chain management." *International Journal of Production Research*, 57(7): 2117-2135.

Sander, F., Semeijn, J. and Mahr, D., 2018. "The acceptance of blockchain technology in meat traceability and transparency." *British Food Journal*, 120(9): 2066-2079.

Savelyev, A. 2018. "Copyright in the blockchain era: Promises and challenges." *Computer Law & Security Review*, 34(3): 550-561.

Schmidt, C.G. and Wagner, S.M., 2019. "Blockchain and supply chain relations: A transaction cost theory perspective." *Journal of Purchasing and Supply Management*, 25(4): 100552.

Shankar, R., Gupta, R. and Pathak, D.K. 2018. "Modeling critical success factors of traceability for food logistics system." *Transportation Research Part E: Logistics and Transportation Review*, 119: 205-222.

Shermin, V. 2017. "Disrupting governance with blockchains and smart contracts." *Strategic Change*, 26(5): 499-509.

Shibin, K.T., Gunasekaran, A. and Dubey, R. 2017. "Explaining sustainable supply chain performance using a total interpretive structural modeling approach." *Sustainable Production and Consumption*, 12: 104-118.

Sikorski, J.J., Haughton, J. and Kraft, M. 2017. "Blockchain technology in the chemical industry: Machine-to-machine electricity market." *Applied Energy*, 195: 234-246.

Sindhwani, R. and Malhotra, V., 2017. "A framework to enhance agile manufacturing system: a total interpretive structural modelling (TISM) approach." *Benchmarking: An International Journal*, 24(2): 467-487.

Singh, A.K. and Sushil, 2013. Modeling enablers of TQM to improve airline performance. *International Journal of Productivity and Performance Management*, 62(3): 250-275.

Sushil, S. 2012. Interpreting the interpretive structural model. *Global Journal of Flexible Systems Management*, 13(2): 87-106.

Swan, M. 2018. "Blockchain for Business: Next-Generation Enterprise Artificial Intelligence Systems." *Advances in Computers*, 111: 121-162.

Tönnissen, S., and Teuteberg, F. 2020. "Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies." *International Journal of Information Management*, 52, 101953.

Toyoda, K., Takis M.P., Sasase, I. and Ohtsuki, T. 2017. "A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti-Counterfeits in the Post Supply Chain." *IEEE Access*, 5: 17465-17477.

Tschorsch, F. and Scheuermann, B., 2016. Bitcoin and beyond: A technical survey on decentralized digital currencies. *IEEE Communications Surveys & Tutorials*, 18(3): 2084-2123.

Tseng, J.-., Liao, Y.-., Chong, B. and Liao, S. 2018. "Governance on the drug supply chain via gcoin blockchain." *International Journal of Environmental Research and Public Health*, 15(6): 1055.

Viryasitavat, W., Da Xu, L., Bi, Z. and Sapsomboon, A. 2018. Blockchain-based business process management (BPM) framework for service composition in industry 4.0. *Journal of Intelligent Manufacturing*, 1-12.

Wamba, S.F., Kamdjoug, J.R.K., Bawack, R.E., and Keogh, J.G. 2020. "Bitcoin, blockchain and fintech: a systematic review and case studies in the supply chain." *Production Planning & Control*, 31(2-3): 115-142.

Wang, Y., Han, J.H. and Beynon-Davies, P. 2019. "Understanding blockchain technology for future supply chains: A systematic literature review and research agenda." *Supply Chain Management*, 24(1): 62-84.

WEF 2015. Deep shift technology tipping points and societal impact survey report. Retrieved from https://bit.ly/2ILqUfD on 20th November 2020.

Wu, H., Li, Z., King, B., Miled, Z.B., Wassick, J. and Tazelaar, J. 2017. "A distributed ledger for supply chain physical distribution visibility." Information (Switzerland), 8(137): 2-18.

Xu, X., Lu, Q., Liu, Y., Zhu, L., Yao, H. and Vasilakos, A.V. 2019. Designing blockchain-based applications a case study for imported product traceability. *Future Generation Computer Systems*, 92: 399-406.

Yadav, N. 2014. "Total interpretive structural modelling (TISM) of strategic performance management for Indian telecom service providers." *International Journal of Productivity and Performance Management*, 63(4): 421-445.

Yadav, S. and Singh, S.P. 2020. "Blockchain critical success factors for sustainable supply chain." *Resources, Conservation and Recycling*, 152: 104505.

Yang, C. 2019. "Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use." *Transportation Research Part E: Logistics and Transportation Review*, 131: 108-117.

Yeoh, P. 2017. "Regulatory issues in blockchain technology." *Journal of Financial Regulation and Compliance*, 25(2): 196-208.

Yli-Huumo, J., Ko, D., Choi, S., Park, S. and Smolander, K., 2016. "Where is current research on blockchain technology? —A systematic review." *PloS One*, 11(10): e0163477.

Zhang, Y., Deng, R.H., Liu, X. and Zheng, D. 2018. "Blockchain based efficient and robust fair payment for outsourcing services in cloud computing." *Information Sciences*, 462: 262-277.

Zheng, Z., Xie, S., Dai, H.N., Chen, X. and Wang, H. 2018. "Blockchain challenges and opportunities: A survey." *International Journal of Web and Grid Services*, 14(4): 352-375.