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Understanding blockchain technology for future supply chains: a systematic literature review and research agenda

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Understanding blockchain technology for future supply chains: a systematic literature review and research agenda

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Abstract

Purpose – This paper aims to investigate the way in which blockchain technology is likely to influence future supply chain practices and policies.

Design/methodology/approach – A systematic review of both academic and practitioner literature was conducted. Multiple accounts of blockchain adoption within industry were also consulted to gain further insight.

Findings – While blockchain technologies remain in their infancy, they are gaining momentum within supply chains, trust being the predominant factor driving their adoption. The value of such technologies for supply chain management lies in four areas: extended visibility and traceability, supply chain digitalisation and disintermediation, improved data security and smart contracts. Several challenges and gaps in understanding and opportunities for further research are identified by this research. How a blockchain-enabled supply chain should be configured has also been explored from a design perspective.

Research limitations/implications – This systematic review focuses on the diffusion of blockchain technology within supply chains, and great care was taken in selecting search terms. However, the authors acknowledge that their choice of terms may have excluded certain blockchain articles from this review.

Practical implications – This paper offers valuable insight for supply chain practitioners into how blockchain technology has the potential to disrupt existing supply chain provisions as well as a number of challenges to its successful diffusion.

Social implications – The paper debates the poential social and economic impact brought by blockchain.

Originality/value – This paper is one of the first studies to examine the current state of blockchain diffusion within supply chains. It lays a firm foundation for future research.

Keywords Design, Supply-chain management, Impact, Systematic literature review, New technology, Information transparency

Paper type Literature review

1. Introduction

Considered as one of the most disruptive technologies, the blockchain (a peer-to-peer distributed data infrastructure) enables the creation of decentralised currencies (e.g. Bitcoin), self-executing digital contracts (smart contracts) and intelligent assets that can be controlled over the internet (smart property) (Kosba *et al.*, 2016; Wright and De Filippi, 2015). Originally created by Nakamoto (2008), recent research on the blockchain has focussed primarily on financial transactions and distributed ledger systems (Pilkington, 2016). Blockchain technology uses a shared data infrastructure that updates itself in real-time and can process and settle transactions in minutes using computer algorithms, with no need for third-party verification. Within the financial sector, the blockchain is proposed as a means for the management of financial transactions without the need for trusted intermediaries such as banks.

However, the blockchain as a technology has potential to disrupt many other domains of organisation, including the supply-chain. As a blockchain allows secure exchange of data in a distributed manner, it starts to impact upon the way organisations are governed, supply chain relationships are structured and transactions are conducted. Integrated with other technologies, like the Internet-of-Things (IoT), the blockchain could be used to create a permanent, shareable, actionable record of every moment of a product's trip through its supply chain, creating efficiencies throughout the global economy. Improved visibility facilitated through such technology may also afford product traceability, authenticity and legitimacy.

Although many speculate about the impact of blockchain technology upon supply chains, current understanding of its potential remains limited. As the development and diffusion of this technology is still in its infancy, a systematic review of current thinking is likely to assist both academics and managers' sensemaking, where they become aware of this technological innovation, sense its potential disruptive effect, make an initial exploration of its efficacy and decide whether to

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either embrace or ignore it. A systematic review will provide a solid foundation by cultivating a deep understanding of blockchain technology when its tangible benefits are unclear, disruptive effect unpredictable and its diffusion path ambiguous. A systematic review will separate the hype from reality by identifying evidence where the blockchain has potential to disrupt supply chains (both positively and negatively), identify challenges to its future diffusion and offer agendas for future research.

Our systematic literature review aims to answer the following question:

RQ1. How will the blockchain influence future supply chain practices and policies?

We further set the following research objectives (ROs) in relation to this research question:

RO1. To identify drivers to blockchain deployment within supply chains

RO2. To identify areas where the blockchain provides the most value for supply chain management

RO3. To investigate the challenges/barriers to further diffusion of the blockchain within the supply chain

RO4. To develop elements of a future research agenda for the blockchain within the supply chain.

This paper begins with a high-level description of the architecture of blockchain technology, followed by a discussion of the methodology used within our investigation. From our research database, we identified four major ways in which the blockchain is approached within the extant academic supply chain literature. We further provide a summary of the latest developments in practice. This is followed by a discussion of the insights the literature provides in terms of our research objectives. We conclude by highlighting our contribution to the literature, as well as considering certain limitations of the research.

2. Blockchain technology

Technically, the blockchain refers either to a distributed data infrastructure or a method for recording data using a crypto-analytic hash function. Blockchains consist of nodes situated upon some communication network which use some common communication protocol – each node on the network stores a copy of the blockchain and a consensus function is implemented to verify transactions to preserve the immutability of the chain (transactions cannot be changed) (Bashir, 2017). The blockchain can be perceived as another application layer that runs on top of internet protocols and that enables economic transactions between relevant parties. It can also be used as a registry and inventory system for recording, tracing, monitoring and transacting assets (tangible, intangible or digital). Some think of the blockchain as a giant spreadsheet appropriate for registering all types of assets and an accounting system for transacting such assets on a global scale (Swan, 2015).

A blockchain is an encoded digital ledger that is stored on multiple computers in a public or private network. Blockchains comprise data records or blocks. As each transaction occurs, it is put into a block. Each block is connected to the one before and after it. Each block is added to the next in an irreversible chain and transactions are blocked together – hence the term "blockchain". Once these blocks are collected in a chain, they cannot be changed or deleted by a single actor. Instead, they are verified and managed using governance protocols (Cheng *et al.*, 2017) (Figure 1).

In a blockchain, no single party controls the data. The entire data infrastructure is visible to all parties. Every party can verify the records of its transaction partners directly, without an intermediary or distributed consensus mechanism. The verification process, along with modern encryption methods, can effectively secure data on blockchain ledgers against unauthorised access or manipulation. As existing blocks in the chain cannot be overwritten, users always have access to a comprehensive audit trail of activity (Miles, 2017). As such, the bigger the blockchain network, the more tamper-resistant the blockchain will be. The decentralised storage of data reduces the risk of single point of access failure associated with centralised databases.

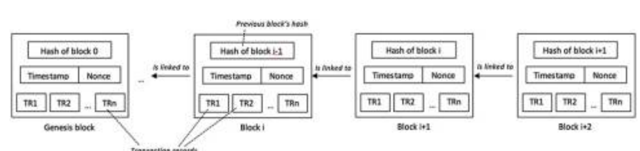
Two main types of blockchain are distinguished in terms of access control – who can read a blockchain, submit transactions to it and participate within the consensus process. Within public blockchains, every transaction is public ("permissionless"), and users can remain anonymous. The network typically has an incentivizing mechanism to encourage participants to join the network. Bitcoin and Ethereum are examples of public blockchains. Within permissioned blockchains, participants need to obtain an invitation or permission to join. Access is controlled by a consortium of members (consortium blockchain) or by a single organisation (private blockchain).

New applications of the blockchain technology, beyond financial transactions, are being experimented with and exploited in sectors such as financial services, insurance, food, health care and government. Within the supply chain, some compelling cases of blockchain adoption have been identified. For example, the blockchain can be deployed as a means of enabling a record of complete provenance details for each component part of an aircraft. These details can be accessed by each manufacturer within the production process (Gupta, 2017).

3. Methodological approach to literature review

To help build transdisciplinary understanding of blockchain developments for supply chain transformation, we have conducted an integrated and systematic review of both

Figure 1 A standard blockchain string



Source: Yli-Huumo *et al.* (2016)

academic and practice literature. A systematic review of academic literature is a well-established method that provides a replicable, transparent and auditable trail of the reviewers' decisions, procedures and conclusions (Bryman, 2012; Tranfield *et al.*, 2003). The systematic review approach can explore the literature in fields that aim to elucidate interventions with specific benefits such as cause and effect analysis (Saunders *et al.*, 2012; Tranfield *et al.*, 2003). The method allows for systematic analyses and syntheses of relevant research by breaking down each study into its constituent parts (Bryman, 2012). This enables a conceptual analysis of the research objects (Tranfield *et al.*, 2003). We follow the structured approach outlined by Tranfield *et al.* (2003) and detailed further by Denyer and Tranfield (2009) and Rousseau *et al.* (2008). It is worth noting that our systematic literature review does not include published books, mainly because some these publications do not usually go through rigorous academic peer reviews. However, we have used certain popular books on the blockchain such as Antonopoulos (2014), Mougayar (2016), Tapscott and Tapscott (2016), Bashir (2017) and Hofmann *et al* (2017) to help us understand the ways in which the blockchain is framed in popular literature.

As with many areas of technological innovation, academic studies tend to lag in their application of technologies in practice. Solely relying on journal publications would provide a rather narrow view of the literature. Reviewing the current state of practice is therefore essential to provide a solid ground for understanding how blockchain technology is being used in practice. A wide range of sources was consulted to identify the trend of current industrial exploitation and development of the blockchain.

For instance, public and industrial databases, such as Lloyd's List insights (maritime intelligence), European Commission foresight studies and OECD reports, provide a good indication of current blockchain development efforts at the European and international levels. Industrial forums and trade associations, such as the Chartered Institute for IT, the Chartered Institute of Logistics and Transport, the Global Shippers' Forum and the EU Blockchain Observatory and Forum, were surveyed on blockchains because these stakeholders tend to be at the forefront of discussions and actions on emerging technological trends. The publications of leading IT service providers and consulting companies, such as IBM, Gartner and McKinsey, were also closely examined, as these represent the latest thinking on blockchain developments. Popular blockchain platforms, such as Hyperledger, R3 Corda, MultiChain and Ethereum, were visited frequently to gather information on the latest developments. Further insights were gained by attending industrial workshops, in which industry leaders discussed their latest efforts in blockchain developments. All these activities led us to identify a list of promising supply chain-related blockchain initiatives, which we discussed in Section 5. Information obtained in this way from practice helped in our interpretation and analysis of the academic literature and particularly informed our identification of future research opportunities.

3.1 Pilot review

A pilot systematic literature review was used to decide upon the appropriate breadth for the final literature review. Given that the term *blockchain* was introduced in 2008 (Nakamoto, 2008), our review spans the period 2008 to 2017. Multiple articles discuss the general features of blockchains (e.g. ABI inform global generates 5,667 articles) within this period. To ensure academic rigour and quality, only peer-reviewed scholarly articles were captured (Saunders *et al.*, 2012; Tranfield *et al.*, 2003). This method generated a reasonable number of articles to explore, increasing the credibility of selected articles. Other terms such as a *digital ledger*, *distributed ledger* and *shared ledger* were used as synonyms for the blockchain. To be as comprehensive as possible, the keyword string used to collect articles related to blockchain technology was "blockchain" or "digital ledger" or "distributed ledger" or "shared ledger".

As blockchain is an emerging topic in supply chain management, it is necessary that we review research from other fields such as engineering, innovation, IT and finance where the topic is more established. This approach afforded us further insights about the implications of blockchain for supply chain. As pointed out by Holmström *et al.* (2009), navigating multiple domains of inquiry is of great value for making theoretical abstractions and abductive reasoning. Abduction of tested results from other field to supply chain management will serve as the basis for explorative design science research. We identified that, due to the rapid development of blockchain technology, a large majority of articles were published in the first half of 2017. However, to ensure the maximum inclusion of relevant publications within our review, an additional search was conducted in December 2017 to January 2018, prior to the submission of this paper. Finally, relevant literature discussed in these papers identified, but not captured by our keyword search, was reviewed for a more comprehensive analysis.

3.2 Initial selection of articles

Nine integrated databases that cover heterogeneous disciplines were used to collect the articles: ABI Inform Global, Emerald, IEEE Explore, Jstor, Science Direct, Scopus, Springer, Taylor and Francis and Web of Science. To narrow down the research scope to that of supply chains, only articles including the terms "logistics", "supply chain", "demand chain" and "value chain" were selected. After this initial review, our search acquired 227 articles.

3.3 Contents screening and complementary search

We used a wide definition of supply chain management to include articles related to freight operations, warehousing, integrated logistics, retail/global/cross-border supply chain operations, humanitarian logistics, global trading including shippers and intermediaries. Titles, keywords and abstracts of articles were read to determine their suitability for inclusion. If required, the main texts of the articles were also closely investigated. Articles that clearly specified aspects of the blockchain that support supply chain philosophy or practices received further scrutiny (Bryman, 2012). Moreover, for the identification of supply chain activities or processes supported by the blockchain, articles clearly addressing the purposes of blockchain use were selected (Bryman, 2012). Articles that did not use blockchain technology as their primary focus, such as articles using the blockchain to explain Bitcoins not in the context of supply chain management were excluded. This process retained 24 articles out of 227 articles. Our initial literature review took place between June and December 2017.

An additional search using the same method (i.e. initial article selection and contents screening) was conducted between December 2017 and January 2018, which identified five more articles. The total list of 29 selected articles are summarised in Table I.

4. Current perspectives and research efforts on blockchains

4.1 State of art developments in academia

Although the blockchain is still in its infancy, supply chain researchers have started to recognise its potential for supply chains. Its expected value was discussed in the literature, and actions/implementation strategies required to materialise its value were also proposed. However, the overall state of such research remains generally at the sense-making and exploratory stage.

Blockchain deployments in practices are mostly in the pilot stage, with no evidence of large-scale adoption within the supply chain. Consequently, there is limited empirical evidence as to how the blockchain has benefited or disrupted existing supply chains. We found four major ways in which the blockchain was approached within extant supply chain literature. A small part of this literature describes pilots that applied the blockchain in agriculture and pharmaceuticals. Some articles addressed the potential of blockchains for the supply chain while others predicted how blockchains will impact supply chains. Finally, certain articles diagnose specific problems with contemporary supply chains and propose the blockchain as a solution to address these issues.

We categorised the studies into four types – descriptive, conceptual, predictive and prescriptive.

- *Descriptive* (3 articles, 10%): Descriptive papers answer the question: "*How has the blockchain been deployed in the supply chain*?" Piloting schemes in the agri-food and pharmaceutical industries demonstrated the usefulness of blockchain applications in product provenance and traceability.
- *Conceptual* (4 articles, 14%): This stream of literature seeks to answer the question: "W*hat does the blockchain mean for the supply chain?"* To provide a better understanding of blockchain technology, conceptual papers interpret its underlying values, disruptive characteristics and consider implications of the blockchain for supply chain management. They also debate whether the blockchain will provide a new paradigm for supply chain management.
- *Predictive* (11 articles, 38%): This stream of literature deals with the question: "*Where will the blockchain penetrate supply chains*?" It does so by considering possible application areas for the blockchain within the supply chain. The proposed application areas include: cross-border digital integration of multiple stakeholders, product traceability, financial settlement, process automation and contract management.
- *Prescriptive* (11 articles, 38%): This stream of literature tackles the question: "*How should the blockchain be deployed within supply chains*?" Prescriptive papers tend to diagnose current problems within supply chain practices and provide technical and business solutions. They concentrate on the lack of trust in product/information legitimacy caused by information asymmetries within supply chain practices. Various data architectures or conceptual models are proposed to resolve such asymmetries. A limited number of papers report system performance results after trial runs, providing valuable insights into the practicality and cost implications of blockchain deployment.

Although all streams of research contribute to our knowledge of the emerging technology of blockchain, the development of prescriptive knowledge tends to be field problem driven and solution oriented, describing and analysing alternative courses of action in dealing with certain blockchain-related problems. This design-oriented approach enhances the relevance of academic research to practice. If these solutions are "well-tested, well-understood and well-documented general solutions", they can then be used as the basis for the design of a "specific variant of it for a specific case" in practice (van Aken, 2005, p. 23). However, we are not yet at the stage of architecting general blockchain solutions, as almost all initiatives in practice are still being tested in the piloting stage, which we shall discuss in the following section.

4.2 State-of-the-art developments in practice

Many proof-of-concept (POC) or piloting schemes have been developed in recent years, particularly in 2017, using blockchain technology. IBM alone is working with hundreds of enterprises on blockchain implementations (IBM, 2018). Application-specific implementations, such as Everledger for diamond tracking and Filament for IoTs, have emerged. However, concrete, real-life, end-to-end implementations are unavailable as of this writing, providing very limited evidence for us to assess the true impact of blockchain technology on supply chains. Because of the high level of uncertainty associated with current blockchain development, identifying precisely those areas where blockchain technology may hold promise compared with those areas where uptake is unlikely is therefore not possible.

Nevertheless, a review of emerging practices within the supply chain discipline offers us some useful indications on the latest developments. This complements insights gained from our review of the academic literature. Table II presents a summary of 17 popular piloting cases we have identified, with the focuses ranging from product provenance and traceability, international shipping and cross-border supply chain to trade finance, secure data exchange and record, smart contracts and social impact. Whilst the main themes evident within this material are largely in line with the academic literature, we do observe a broader range of applications in practice. For instance, blockchain pilots on social impact and trade finance have received less attention in the academic literature but are actively explored in practice.

We summarise some common themes observed from the cases in this section, and then we embed our further discussion of piloting schemes or use cases in Section 5.2, where we explore areas in which the blockchain may provide the most value for supply chain management. In Section 5.4, we showcase some less-known but promising blockchain applications.

Table I List of articles identified through systematic literature review

Research types	Paper	Focus	Applied areas	Key findings
Descriptive Papers (3 papers)	Bocek *et al.* (2017)	Traceability and integration of IoTs of blockchain	Pharmaceutical industry	Blockchain allows pharmaceutical supply chains to monitor temperature and humidity over the transport of medical products
	Mackey and Nayyar (2017)	Anti-fraud	Pharmaceutical industry	A few blockchain use cases and initiatives were identified and briefly discussed for security and anticounterfeiting purposes
	Lu and Xu (2017)	Product traceability	Agri-food industry	Using the originChain case demonstrates the value of blockchain in tracing the origin of products across complex supply chains. This blockchain system requires a transparent, tamper-proof metadata infrastructure that is also adaptable to changing environments and regulations
Conceptual Papers (4 papers)	Hull *et al.* (2017)	Challenges of smart contract implementation in supply chains	Global supply chains	Single trusted source of data from blockchain will contribute to streamlined data sharing and dispute resolution. Smart contracts will prevail in supporting supply chain collaboration but several challenges need to be addressed: diversity and variation in country policies, product types, transport and tax rates; programming language, solution architectures, interoperability and verification process
	Mansfield (2017)	Blockchain concept and its future implications	Pharmaceutical, gemstones, airline industries	Blockchain's impact will reach far beyond financial sectors providing 'assurance as a service' in the commercial world
	Patel *et al.* (2017)	Blockchain concept, technical fundamentals, application cases of blockchain	Multiple sectors	Blockchain technology will revolutionise several financial and non-financial sectors. However, it will also face security, legal, regulatory and technological challenges
	Shireesh and Petrovsky (2016)	Value and limitation of blockchain in verifying material ingredients	Pharmaceutical industry	Blockchain will enable advances in authentication and validation of supply chain information auditing process
Predictive Papers (11 papers)	Casey and Wong (2017)	Product traceability	Global supply chains	End-to-end traceability and the encrypted inclusion of human beings to the supply chain audit is a significant value of blockchain
	Collomb and Sok (2016)	Disintermediation effect of blockchain	Global supply chain	Disintermediation in international trade finance and settlement will increase efficiency in cross-border operations
	Glover and Hermans (2017)	Product traceability	Pharmaceutical industry	Blockchain technology has the potential to improve the traceability of a clinical trial supply chain and track patient responses
	Guo and Liang (2016)	Disintermediation effect of blockchain	Global supply chains	Disintermediation and digitisation of supply chain finance enabled by blockchain will enhance the efficiency in cross border trade settlement
	Korpela *et al.* (2017)	Digital supply chain integration	Manufacturing/physical distribution	Blockchain will enable hyper-levels of supply chain integration with end-to-end integration of product and process data
	Kshetri (2017a)	Integration of blockchain with IoTs	Manufacturing/physical distribution	Blockchain can play a key role in tracking the sources of insecurity in supply chains and in handling crisis situations like product recalls that occur after safety and security vulnerabilities are found
	Kshetri (2017b)	Potential value of blockchain to reduce corruption and fraud	Global supply chains (in relation to the third world economy)	Blockchain will enable the promotion of transparency in international trade finance in the third world
	Lee and Pilkington (2017)	Transparency and supply chain visibility	Electronics industry	Transparency and process integration in consumer electronics supply chain management will be enhanced by blockchain. Areas where blockchains can affect supply chains include a tamper-proof history of product manufacturing, handling and maintenance, digital identity for ownership and packaging, tendering across the supply chain through smart contracts and engagement with consumers

(***continued***)

Table I

Research types	Paper	Focus	Applied areas	Key findings
	Shanley (2017)	Supply chain security, traceability and technical obstacles	Pharmaceutical industry	Blockchain's serializations of products and tracking of origin will be significant value of pharmaceutical supply chains
	Wang *et al.* (2017)	Transparency and traceability, contract and asset management and challenges of implementation	Construction industry	Three types of blockchain-enabled applications are proposed to improve the current processes of contract management (notarization), supply chain management (transparency and traceability), and equipment leasing (asset management) for construction engineering management
	Saberi *et al.* (2018)	Information authenticity and product stewardship	Reverse logistics and product recycling	Blockchain-enabled product life cycle assessment and end-of-life management will benefit reverse logistics industry
Prescriptive Papers (11 papers)	Engelenburg *et al.* (2017)	Smart contract	Global supply chains	Followed a design science approach to develop a software architecture for business-to-government information sharing for cross-border activities enabled by blockchain technology
	Chen *et al.* (2017)	Smart contract and smart inspection	Personal computer industry	A blockchain-based supply chain quality management (SCQM) framework is proposed which consists of IoT sensor, blockchain data, contract and business layers
	Li *et al.* (2017)	Supply chain visibility and real-time tracking	Manufacturing/physical distribution	A framework that supports supply chain visibility by using a hybrid (semi-open) P2P architecture is introduced, providing the cost-effective real-time tracking information of shipments to all stakeholders
	Nakasumi (2017)	Information symmetry and capacity risk mitigation	Global supply chains	A blockchain-based solution is proposed to address the problems of double marginalisation and information asymmetry in supply chain
	Polim *et al.* (2017)	Information integration capability of blockchain	Advanced transport systems development	A blockchain data structure is designed to promote fair competition among 3PLs in a retailer-centred network and the system removes the intermediary 4PL
	Tian (2016)	Product traceability	Agri-food industry	A conceptual framework for an agri-food supply chain traceability system is proposed, integrating RFID and blockchain technology
	Tian (2017)	Product traceability	Agri-food industry	To address the scale-up issue of blockchain application, a decentralised traceability conceptual system based on IOTs and blockchain technology was proposed. A scenario demonstrated how it works in a food supply chain with Hazard Analysis and Critical Control Points (HACCP)
	Toyoda *et al.* (2017)	Anti-fraud and product authenticity	High value product supply chains	A blockchain-based product ownership management system is proposed for anti-counterfeit in the post supply chain. A POC experimental system has been implemented on the Ethereum platform and results demonstrate the cost for managing products with the proposed system is less than US$1 when the number of owner transfers is less than or equal to six
	Weber *et al.* (2016)	Inter-organisational business process monitoring and execution (smart contract)	Manufacturing/physical distribution	Specific techniques are proposed to integrate blockchain into the choreography of processes in such a way that no central authority is needed, but trust maintained in a collaborative process execution
	Xu *et al.* (2017)	Secure information integration and sharing	Manufacturing and physical distribution	A supply chain on blockchain management system is proposed that uses a hybrid model and two-steps method to maintain a decentralized ledger based on blockchain. It introduces a protection mechanism to prevent supply information stored on the ledger from being accessed by unauthorised participants
	Yuan and Wang (2016)	intelligent transportation systems (ITS) and real-time ride-sharing	Advanced transport systems development	A blockchain-based ITS (B^2ITS) conceptual framework is proposed, highlighting its potential in supporting sharing economy in transport

Table II A List of popular blockchain initiatives in practice

Case no.	Industrial focus	Led by	Case description (source of information)	Supply chain objectives	Blockchain platforms	Source
1	Product provenance and traceability	Walmart and other large food businesses	Since October 2016, Walmart has been working with IBM in a pilot study to trace food products in the blockchain. In April 2018, Walmart started to get suppliers involved in the blockchain. Following this, Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, Unilever, Walmart and others started to collaborate with IBM to further champion the blockchain	To improve food safety, achieve product provenance and reduce fraud	Hyperledger Fabric	Russon (2018) and IBM (2017c)
2		Provenance	Provenance, a UK social enterprise organisation, is one of the early pioneers providing blockchain-enabled solutions for product tracking and tracing. This tech start-up has successfully piloted two projects: a) tracking tuna through southeast Asian supply chains in 2016 and b) working with a large consumer cooperative to track fresh produce from its origin to the supermarket in 2017	To increase the integrity of certifications, as well as ensure food provenance and fair payment	Ethereum	Provenance (2017)
3		Everledger	In 2015, London-based start-up Everledger first started to securely track and trace the authenticated provenance of diamonds by using the best of emerging technology on a global digital ledger. Working with a range of stakeholders across the diamond supply chain, Everledger has since encrypted the provenance of over 2 million diamonds in a short span of three years	To create and track the entire lifetime journey of a diamond in a manner that is accessible to all	Hyperledger Fabric	Everledger (2018)
4		Airbus and others	Airbus, the French aircraft maker, is looking to use blockchains to monitor the many complex parts that come together to make a jet plane. A number of airlines have already expressed a keen interest in developing blockchain solutions, with the likes of Lufthansa, Air New Zealand and British Airways already working with blockchain start-ups on ambitious projects. (https://cryptonews.com/news/airbus-rolls-royce-seeking-blockchain-air-parts-traceability-1700.htm)	To create and maintain trust in supply chains and to automate records for complex products that currently require significant manual efforts	Hyperledger Fabric	Alper (2018)
5	International shipping, cross-border supply chain	Maersk	Working with IBM, Maersk did a POC in September 2016, tracking a container of flowers from Kenya to Rotterdam. Following this, a few pilots, including the international shipment of electronics from Rotterdam to Newark, as well as that of Mandarin oranges from California and pineapples from Colombia to Rotterdam, were completed in 2017	To digitalise global trade (paperless trade) and provide end-to-end supply chain visibility	Hyperledger Fabric	Groenfeldt (2017)
6		Hyundai Merchant Marine (HMM) (South Korea)	HMM announced in September 2017 that it successfully completed its first blockchain integrated pilot voyage from South Korea's Busan port to China's Qingdao port with reefer containers from August 24 to September 4, 2017. Blockchain was applied not only to shipment booking but also to cargo delivery. HMM also tested and reviewed the combination of DLT with IoT through real-time reefer-container monitoring and management on the vessel	To allow secure information sharing between multiple stakeholders, reduce paper work and ensure real-time monitoring of containers	Ethereum	HMM (2017)

(*continued*)

Table II

Case no.	Industrial focus	Led by	Case description (source of information)	Supply chain objectives	Blockchain platforms	Source
7		Pacific International Lines (PIL) and the Port Authority of Singapore (PSA) (Singapore)	Following the signing of the MOU in August 2017, PIL, PSA and IBM worked on a POC exercise to track and trace cargo movement from Chongqing to Singapore via the Southern Transport Corridor. The pilot was considered successful in December 2017. The partners believed that sufficient evidence now exists to show that the concept can be taken to the next stage	To enhance the security, transparency and efficiency of the supply chain network in southeast Asia	Hyperledger Fabric	PIL (2018)
8	Trade finance	Daimler and Landesbank Baden-Württemberg (LBBW)	Daimler AG and LBBW jointly used blockchain technology to execute a financial transaction. Through LBBW, Daimler launched a €100 million one-year corporate Schuldschein, in which savings banks (Kreissparkasse) Esslingen-Nürtingen, Ludwigsburg and Ostalb, as well as LBBW, acted as lenders. The entire transaction was digitally carried out via blockchain technology, in cooperation with the IT subsidiaries TSS (Daimler) and Targens (LBBW)	To make financial processes simpler and more efficient and to enable new business models	Hyperledger Fabric	Daimler (2017)
9		Foxconn and Dianrong	The financial services arm of iPhone manufacturer Foxconn (Taiwan) partnered with the Chinese online P2P lender Dianrong to launch Chained Finance, which claims to be the first-ever blockchain platform for supply chain finance. The two companies recently completed a successful pilot and POC by securing funding for small and medium enterprises (SMEs) in China that were otherwise unable to secure their needed capital. (www.scmp.com/tech/leaders-founders/article/2102840/blockchain-sharpens-dianrongs-edge-p2p-lending-small)	To provide supply chains with easier access to funding at competitive rates	unknown	Soo (2017)
10		Skuchain	CGI, a trade finance platform used by banks in 90+ countries worldwide, and its banking partners successfully completed a POC in 2017, which integrates CGI's trade finance platform (CGI Trade360) and its blockchain-based platform (Skuchain Brackets) to demonstrate how banks can provide trade finance services digitally to their customers conducting business on blockchain B2B platforms	To establish seamless interoperability between a trade platform and a supply chain execution platform	Hyperledger	Market Insider (2017)
11		OriginalTrail	OriginalTrail is a Slovenian IT company specialising in traceability and quality control systems, and it created the cryptocurrency Trace Token. The purpose of this currency is to serve as compensation for the multiple nodes within a network that keep copies of transactional data generated by supply chains. This may address the issue of high transaction costs associated with the blockchain and would speed up cash flow exchanges	To assist in the financial settlement between supply chain partners	Ethereum	OriginTrail (2018)
12	Data security and dispute resolution	NHS	Google's DeepMind is working with Britain's National Health Service (NHS) to deploy a private blockchain for creating robust audit trails that track exactly what happens to personal data	To ensure the security of patient data	Unknown	Suleyman and Laurie (2017)

(continued)

Table II

Case no.	Industrial focus	Led by	Case description (source of information)	Supply chain objectives	Blockchain platforms	Source
13		FedEx	FedEx, a multi-national shipping company, launched a pilot programme using blockchain to store data for dispute resolution. The company comes into the blockchain sphere in the wake of a high-profile cyber-attack on its TNT express branch in Europe in the past year	To streamline all data exchanges in a secure way	Ethereum and Hyperledger	Rajamanickam (2018)
14	Smart contract	Slock.it	Slock.it, a German start-up, has partnered with energy giant RWE to transform the way electric cars are charged. Cars with digital wallets will be able to 'talk' to autonomous electric charging stations which use smart contracts to allow users to rent the station, put up a deposit, charge their car and then get their deposit back	To speed up, simplify and automate the electric car charging process and payment settlement	Ethereum	Allison (2016)
15		Barclays	Barclays Corporate Bank recently partnered with a start-up, Wave, a platform that stores bill-of-lading documents in the blockchain and uses smart contracts to log change of ownership and automatically transfer payments to ports upon arrival	To streamline cross-border trade finance	Waves	Ream *et al.* (2016)
16	Social impact	Moyee Coffee	Moyee Coffee (www.moyeecoffee.ie) launched a pilot project in Ethiopia in November 2017 with blockchain pioneers Bext360 and the FairChain Foundation to give all stakeholders access to data across the entirety of the supply chain. At the point of collection, the Bext360 platform instantly creates cryptotokens. As the commodity flows through the entire supply chain, new tokens are automatically created. These tokens increase in value as the beans move through the supply chain	To create a fairer and honest supply chain	Stellar (a payment network)	Moyee Coffee (2018)
17		WFP	The Building Blocks pilot project by the World Food Programme (WFP) initiated a POC in 2017 using an Ethereum-based blockchain technology to help refugees of the Syrian Civil War in the Azraq refugee camp in Jordan. As of January 2018, more than 100,000 people have received food from entitlements recorded on a blockchain-based computing platform. Refugees purchase food from local supermarkets in the camp by using an eye scan instead of cash, vouchers or e-cards	To reduce payment costs associated with cash transfers, better protect beneficiary data, control financial risks, and set up assistance operations more rapidly in the wake of emergencies	Ethereum	WFP (2017)

An important observation of blockchain initiatives in practice is that most of them deploy permissioned blockchain solutions. Given the sensitivity of supply chain information, this is not surprising, as revealing proprietary details, such as demand, capacities, orders and prices, at all points of the supply chain to unknown participants is unwise. Permissioned blockchains are also more effective at controlling the consistency and integrity of the data that are appended to the blockchain, which is critical for decision-making.

Many pilots feature some degree of centralised control. Funding members often form a consortium, which then determines the social structure of the network and how decisions are made. There tends to be a network orchestrator, who is likely one of the funding members, facilitating coordination and cooperation among the different stakeholders in a blockchain-based supply chain network. This orchestrator plays a critical role in future-oriented value creation, appropriation and distribution among network members. In addition to pursuing socio-economic gains, some consortia have broader aims. For instance, Blockchain in Trucking Alliance is a forum founded in August 2017 for the development of blockchain technology standards and education for the freight industry.

By design, the blockchain enables multiple supply chain stakeholders to transact with one another without requiring an intermediary. Therefore, it seems to be best applied when a problem across multiple parties exists, and these parties can each benefit from addressing the problem. This shared value encourages participation and incentivises collaborative behaviours among participating members. Blockchain technologies also allow competing organisations to become involved in the same network. For instance, IBM Food Trust has multiple retailers on board (see Case 1).

Technically, most blockchain projects in supply chains are developed on either Ethereum or Hyperledger Fabric. The former is an open, generic platform (but has recently started to offer private blockchain solutions) that is well-known for its ability to execute smart contracts and allow monetary transactions. By contrast, the latter is a private modular platform led by Linux Foundation; it is backed by leading technology service providers, such as IBM, Cisco and SAP, and it aims to advance cross-industry blockchain developments. A major difference between the two is their consensus mechanism. Ethereum relies on mining-based "proof of work" to validate transactions, meaning that all participants need to reach consensus on the order of all transactions that have taken place. It uses a built-in cryptocurrency ("ether") to reward miners and pay transaction fees. Hyperledger, in contrast, provides a more fine-grained access control, and only those parties participating in a transaction need to reach consensus.

5. Findings and discussion

5.1 RO1: identify drivers to blockchain deployment in supply chains

Trust is the most influential factor driving interest in the blockchain (26 out of 29 articles, 90 per cent) within supply chain management. Trust refers to the reliability of information provided by trade partners, or the safety and security of the data managed by a central authority. Trust is normally discussed as that which perfectly mirrors every dimension of truth regarding events and transactions. Such truth has been described as a "shared source of truth" (Michelman, 2017, p. 18), "one data" (Nakasumi, 2017, p. 144) or "one trusted source of data" (Hull *et al.*, 2017, p. 2). Trust arising from data security was also discussed (Collomb and Sok, 2016; Patel *et al.*, 2017).

Some researchers argue that geographically dispersed facilities and trade partners often lead to disconnections and complexity among supply chain actors. Therefore, acquiring and maintaining reliable data is critical. In this context, the blockchain's role is to provide seamless networks (Bonino and Vergori, 2017; Wang *et al.*, 2017; Xu *et al.*, 2017), entire visibility (Li *et al.*, 2017) and symmetric information to all (Nakasumi, 2017). Such seamless connectivity and reliability are also required for business ethics and social responsibility. Due to the increasing concerns of food safety (e.g. horsemeat scandal in the UK, toxic milk powder in China) (Tian, 2016, 2017) and sustainability related issues (e.g. child labour, fair-trade, organic products) (Abeyratne and Monfared, 2016), consumers pay much more attention to the authenticity and legitimacy of the products they purchase. They increasingly demand to know how, when and where products are sourced and processed.

Another motivational driver to blockchain deployment is public safety and security. To prevent antisocial behaviours, like terrorist attacks on ships and maritime containers, Engelenburg *et al.* (2017) proposed the implementation of blockchain-based customs systems. Mackey and Nayyar (2017) argued that the grey market that commercialised fake products calls for blockchain technology implementation. Corruption and fraud is a serious problem in some developing economies. Guo and Liang (2016) and Kshetri (2017b) posited that the blockchain is required to resolve such legal issues by providing much needed transparency. Table III summarises the key drivers for blockchain adoption in supply chains.

5.2 RO2: identify areas where blockchain provides the most value for supply chain management

5.2.1 Extended visibility and product traceability

As evident in Table I blockchains are expected to add the most value to supply chains through their extended visibility and product traceability. As such, product traceability will likely be the point at which the blockchain sees large-scale deployment. Centralized IT platforms/systems often inefficiently gather and authorise every piece of data along a supply chain. Blockchain-enabled transactions (a series of transactions required to get a product from place to place) offer transparency to participating companies. A block could be created for each transaction following the product's digital footprint, from manufacturing to distribution and sale (Patel *et al.*, 2017). This level of transparency and visibility is essential for improving the traceability of products and ensuring product authenticity and legitimacy (Casey and Wong, 2017; Lu and Xu, 2017; Mansfield, 2017). Real-time tracking is made possible when the blockchain is integrated with field sensor agents (Li *et al.*, 2017).

Moreover, the use of time-stamping enhances information completeness. Time-stamping is the process of providing a temporal order among sets of events (Abeyratne and Monfared, 2016). When an event is recorded in the chain chronologically,

Table III Drivers of blockchain deployment

Drivers	Reference
Trust: reliability and security of information	Collomb and Sok (2016), Hull *et al.* (2017), Michelman (2017), Nakasumi (2017), Patel *et al.* (2017)
Supply chain disconnections and complexities	Li *et al.* (2017), Nakasumi (2017), Bonino and Vergori (2017), Wang *et al.* (2017)
Product safety, authenticity and legitimacy	Tian (2016, 2017), Toyoda *et al.* (2017), Mackey and Nayyar (2017)
Public safety and anti-corruption	Engelenburg *et al.* (2017), Kshetri (2017b), Guo and Liang (2016)

Source: Authors

each node (a header in a block) contains a field with a time-stamp recording of the event (Engelenburg *et al.*, 2017). Hence, it can prove the existence of certain data at a point of time. With this logic, time-stamping supports the management of time-sensitive issues by providing a record of historical events (Yuan and Wang, 2016; Lee and Pilkington, 2017). Information completeness is also enhanced by the wide range of data that a blockchain system accommodates. Data in a blockchain can include ownership (chronological list of owners), location data (places the material has been and where is it now), product specific data (attributes and performance of the products) and environmental impact data (energy consumption, CO_2 emission, etc.) (Abeyratne and Monfared, 2016). Data could also contain price, quality, date and state of the product (Lee and Pilkington, 2017).

By design, every transaction along a blockchain supply chain is fully auditable. The extended traceability afforded by the blockchain benefits industries that are sensitive to products and material provenance. Some advocate the use of the blockchain to trace the origin and production process of food ingredients (Foerstl *et al.*, 2017; Tian, 2016) and the ownership of luxury textile products (Toyoda *et al.*, 2017). Advocates also propose the blockchain as a solution to manage counterfeit medicine. For example, Mackey and Nayyar (2017) ascertained that a blockchain will enable the tracking of pharmaceutical raw materials and finished goods, making it easier to detect fakes by allowing blockchain participants to verify the authenticity of data. Hence, the blockchain might serve as an open standards technology to integrate various databases and different actors within the pharmaceutical supply chain.

In practice, crucial supply chains, such as food, diamond and pharmaceutical products, have become the hotspots for blockchain initiatives (see Cases 1 to 4 in Table II). These supply chains carry a sense of urgency for reliable traceability and product provenance. Knowing the origin and the footprints of how products have travelled throughout the supply chain delivers not only commercial benefits, such as improving consumer confidence towards the brand (Cases 2 and 3), but also serious safety consequences, such as in the case of aircraft manufacturing (Case 4) or food traceability (Case 1). Walmart's recent trial has demonstrated that blockchain-enabled tracking takes only 2.2 s to trace a package of sliced mangoes from its US stores back to its source Mexico farms, while previously, it used to take about seven days using conventional tracking methods (McKenzie, 2018). This blockchain-based tracking allows food retailers and manufacturers to respond quickly to recalls and other food safety issues, thus reducing the spread of foodborne illnesses.

5.2.2 Supply chain digitalisation and disintermediation

Disintermediation implies that the integrity of data in a blockchain is guaranteed by a whole network, not by an intermediary (Michelman, 2017). For financial transactions, it means that peer-to-peer (P2P) asset transfers and interfirm trading/payments occur without the authentication of a third party (Yuan and Wang, 2016). Michelman (2017) claims that the blockchain reduces verification and transaction costs by removing intermediaries. Wang *et al.* (2017) argue that the P2P network is particularly useful for temporary business relationships, as it reduces the cost of building trust. Polim *et al.* (2017) propose a blockchain system that allows retailers to directly tender their shipments to third-party logistics (3PLs), removing fourth-party logistics services (4PLs) from the network.

The attributes of the blockchain are ideally suited to large networks of disparate parties and are seen as a viable solution to ease the complexity of global supply chains (Abeyratne and Monfared, 2016; Nakasumi, 2017). International trade is considered the most complicated supply chain practice as it involves large numbers of supply chain stakeholders. Most processes are also paper-based, causing delays, and hindering the efficient flow of goods. Centralized platforms are the main transaction paradigm (Harris *et al.*, 2015), but there are certain limitations when dealing with a large volume of fast-paced transactions (Casey and Wong, 2017). A blockchain-based platform could help digitise paper-based documentation, and establish an immutable, shared record of all transactions among network participants in real-time. Table IV offers a comparison of current practices and blockchain-enabled international trade and supply chains.

Guo and Liang (2016) report that by replacing trade finance (where banks act as financial mediators) with a blockchain platform, the processing time can be reduced from 7 to 10 days to 1 to 4 h. Engelenburg *et al.* (2017) argue that a blockchain would provide real-time visibility of shipments directly to customs authorities, significantly improving the information available for risk analysis, safety and security control (Kshetri, 2017b).

International trade tends to involve a variety of stakeholders and supply chain actors. Its complexity often results in the lack of information visibility – which can be unethically or illegally exploited (Abeyratne and Monfared, 2016; Nakasumi, 2017). Collomb and Sok (2016) argue that the blockchain could address the third world's corruption problem in international trade due to its transparency.

In practice, maritime shipping lines and ports (see Cases 5 to 7 in Table II) have been actively exploring blockchain-enabled solutions that address the inefficiencies caused by a low level of

Table IV Paradigm shift of international trade by blockchain technology

Business paradigm	Current international trade and supply chain	Blockchain-based international trade and supply chain
System architecture	Trusted third-party/central coordinator based platform	Decentralized/peer-to-peer transaction basednetwork
Database	Single copy in data repository	Peer verifiedmultiple copies
Security	Controlled access/firewalls	Cryptography
Transaction execution	Intermediation	Smart contract based onconsensus/proof of work

Source: Collomb and Sok (2016)

digitisation within complex cross-border activities. For instance, a simple shipment by Maersk of refrigerated goods from East Africa to Europe in 2014 was found to have gone through nearly 30 people and organisations, including more than 200 different interactions and communications among them (IBM, 2017a). In cross-border trade, the costs associated with trade documentation processing and administration could be up to one-fifth of the actual physical transportation costs (Maersk Press Release, 2018).

In 2016, a blockchain pilot was initiated jointly by IBM and Maersk to improve the workflow and visibility of each shipment. Multiple stakeholders were involved, including trading partners, government authorities and logistics companies. Each participant in this blockchain network can view the progress of cargo through the supply chain and determine where a container in transit is. Each participant can also see the status of customs documents or view bills of lading and other data. The detailed visibility of a container's progress through the supply chain is enhanced with the real-time access to original supply chain events and documents. No one party can modify, delete or even append any record without the consensus of others on the network (IBM, 2017a). Following the successful pilot, IBM and Maersk have announced a joint venture to commercialise the initiative (White, 2018). This endeavour signals the dawn of a wider diffusion of blockchain technology in supply chains, going beyond the POC and pilot stage.

5.2.3 Improved data security for information sharing

Thirteen articles (45 per cent) within our review stated that decentralisation is a unique data security mechanism of the blockchain. Collomb and Sok (2016) and Tian (2016) point out that a centralised database has three potential deficiencies in that information can be corrupted, falsified and generated asymmetrically, sometimes causing data to be lost or hard to retrieve.

The data in the blockchain is immutable because the sequence of transactions is saved in chronological blocks of nodes broadcast to all other nodes (Tian, 2016). The stored data are tamper-proof as the updating and deletion of transactions is prohibited according to the consensus mechanism (Patel *et al.*, 2017; Weber *et al.*, 2016). This is an important advancement as any falsification of the information has to be done in real-time, making it much harder than simply substituting new data (Shireesh and Petrovsky, 2016). Patel *et al.* (2017) argue that the merit of this mechanism is fault-tolerant because multiple sources of original information are available. Ultimately, increased data security would lead to increased confidence and trust of transactions between supply chain partners and end-consumers.

Security in data sharing is important to supply chain actors as business transactions often contain highly-sensitive commercial information. A permissioned blockchain may be of particular value to the supply chain as it offers enhanced privacy, auditability and increased operational efficiency (Gupta, 2017; Weber *et al.*, 2016). With a blockchain supply chain, actors can encrypt the description of goods and sensitive information and use business rules to control access by customs and required bodies (Engelenburg *et al.*, 2017; Kshetri, 2017b).

Blockchain-enabled data integrity and security also protects against fraud and cybercrime. Cybercrime leads to data breaches, financial crimes, market manipulations, theft of IP and poses public safety and security risks. The vulnerability of the supply chain and logistics system was clearly illustrated by the recent case of the NotPetY, a cyberattack to the world's largest container shipping line, Moller-Maersk. The attack affected all its business units' operations, resulting in $300m of lost revenue (Milne, 2017). Although there might be various factors contributing to this vulnerability, deploying a decentralised system could mitigate the threat. A key weakness of a centralised system is that if a system is hacked or there is some technical malfunction, the whole system may be brought to a halt. The blockchain offers an alternative way to manage data and is more resilient to such hacks.

Blockchain technology offers highly secure and immutable access to supply chain data. Although this indelibility applies to all blockchain use scenarios, it is of particular value to cases such as those in 12 and 13 in Table II. In Case 12, Google is working with NHS to develop a private blockchain for storing patient data and affording a coordinated approach to the management of health records. In Case 13, FedEx piloted a blockchain initiative for data storage after having experienced a high-level cyber-attack. The blockchain has no single point of failure, so it is more resistant to attack. The same information will be available to all participants, so potential conflicts among participants regarding a particular transaction are reduced. Smart contract logic can be written into a blockchain to further reinforce contractual agreements and mitigate potential disputes.

5.2.4 Smart contracts

The notion of a smart contract may be the most transformative blockchain application for supply chains. A smart contract is a computerised transaction protocol that automatically executes the terms of a contract upon a blockchain. The general objectives are to satisfy common contractual conditions, while reducing the costs and delays associated with traditional contracts (Gupta, 2017).

Smart contacts are considered of utmost value to supply chain automation and self-execution by 52 per cent of the literature (15 articles). A smart contract can be made partially, fully self-executing, self-enforcing and can be monitored by the network (Weber *et al.*, 2016). For example, a smart contract might send a payment to a supplier as soon as a shipment is received by the buyer. A GPS-tracked product return could log its location in real-time and trigger a signal within the blockchain for immediate refunds. A smart contract, thus, eliminates payment withheld issues and improves efficiency by eliminating contract registration, monitoring and updating efforts and time (Collomb and Sok, 2016; Wang *et al.*, 2017). Bocek *et al.* (2017) claim that smart contracting reduces the number of intermediaries and requires less manual interventions, resulting in reduced operational cost.

Smart contracts could be deployed by sectors where supply chains are temporary and fragmented with multiple tiers of suppliers and subcontractors. Due to the large number of supply chain stakeholders involved in a construction project, it is difficult to track the progress status of agreed tasks and settle financial payment accordingly. Smart contracts can automate processes like delivering the agreed contracts to specified parties for digital execution, updating programmes based on agreed variations or compensation events and releasing copyright documents to relevant parties (Kinnaird and Geipel, 2017; Wang *et al.*, 2017).

Smart contracts are mostly being piloted within financial transactions and settlements (see Cases 14 and 15) in practice. In the automotive sector, a German start-up, Slock.it (Case 14), has piloted the digital wallet blockchain initiative, which automates the payment process when a passenger car is charged at a charging station. Although the pilot is for passenger cars only, when it is extended to commercial vehicles, frictionless machine-to-machine charging will have a significant impact on logistics operations. In pilot Case 15, a smart contract is used by Barclays to trigger automatic payment at the point where cargo ownership changes.

A smart contract feature is not available to all blockchains but is becoming desired functionality due to its flexibility and power to include business logic under certain conditions. However, this is also where disruptions are the most severe. Smart contracts imply significant technological (e.g. security), legal (enforcement mechanism when disputes arise) and societal (e.g. removal of intermediaries and potential job losses) implications. The adoption of smart contracts fundamentally changes both organisational and supply chain structures and governance, and hence it may take decades for it to become the norm within supply chain management (Hull *et al.*, 2017; Wang *et al.*, 2017).

5.3 RO3: investigate the challenges/barriers to its further diffusion within the supply chain

Although the literature agrees that the blockchain will disrupt the status quo and transform supply chain practices generally for the better, this technology clearly presents many challenges.

5.3.1 Organisational and user-related challenges

Current economic winners may resist change out of the fear of losing revenue models (Michelman, 2017). For example, banks may be reluctant to coordinate blockchain-enabled business transactions (Zhao *et al.*, 2016). It is reasonable to assume that other intermediaries may have the same fear of being removed from supply chains and resist its deployment.

Other supply chain actors may not want the total transparency provided by a blockchain. Unwillingness to share valued information has long been recognised as a barrier to effective supply chain performance (Fawcett *et al.*, 2007; Kembro *et al.*, 2014). The technical complexity of the blockchain makes it a challenge for individual users to understand, accept and have confidence in participation. Some negative perceptions are associated with blockchains due to the use of Bitcoin for nefarious or criminal purposes (Hoy, 2017; Kshetri, 2017b).

The blockchain affords pseudonymity, meaning that all transactions are transparent, yet are not explicitly connected to real-world individuals or organisations. However, this anonymity could be broken, connecting individual transactions to parties. This may not be of concern for upstream suppliers. For instance, for individual farmers in the food sector, this transparency brings marketing and branding benefits. However, for downstream consumers, their privacy may be compromised and sensitive detailed personal information revealed (Boucher *et al.*, 2017). There are also environmental concerns regarding blockchains, as it requires a high level of energy consumption to maintain the network (Hoy, 2017; Kshetri, 2017b).

5.3.2 Technological challenges

Although the blockchain is perceived as a highly secure decentralised data infrastructure, hacking is still possible. It can happen when a group of miners temporarily control over 50 per cent of the network's mining hash-rate (the measurement unit of processing power of a network of nodes that power a blockchain) (Yuan and Wang, 2016; Zhao *et al.*, 2016) While hacking into a public (permissionless) blockchains requires significant financial and computational power, a permissioned blockchain may be more prone to cyber-attack (Patel *et al.*, 2017).

Latency is another barrier, as time passes for each verified block of transactions to be added to the ledger (Wang *et al.*, 2017). For Ethereum, one of the most popular blockchains for smart contracts, this occurs "approximately every 17 seconds – a far cry from the milliseconds to which we are accustomed while using non-blockchain databases (Ream *et al.*, 2016)". Effective incentive mechanisms for miners are needed to improve system performance (Nakasumi, 2017). For fast-paced scenarios, private customised blockchains work best (Weber *et al.*, 2016).

The blockchain protects the system from any type of manipulation by interested parties, but at the same time this may also create problems. When mistakes happen, these cannot be reversed (Patel *et al.*, 2017). Equal and opposite transactions could set records straight. Finally, interoperability between blockchains and integration with existing IT systems need to be addressed to ensure smooth data transfer (Collomb and Sok, 2016; Korpela *et al.*, 2017; Patel *et al.*, 2017; Wang *et al.*, 2017).

5.3.3 Operational challenges

For a blockchain to work in the supply chain, all related supply chain actors should be on board (Kshetri, 2018). Blockchain-enabled global supply chains operate in a complex environment that requires various parties to comply with diverse laws, regulations and institutions. Implementing a blockchain in such an environment is an extremely complex task (Casey and Wong, 2017). The blockchain, while tamper-proofing the digital attributes of transactions, could not always accurately mirror the physical movement of materials in the supply chain

(Shireesh and Petrovsky, 2016). In reality, accidental errors, conflicts of interests, corruptions and malicious attacks could still happen (Boucher *et al.*, 2017; Kshetri, 2018).

Chen *et al.* (2017) raised questions as to what data should be stored in blockchains, how such data will be collected and fed into the system and who should be responsible for data input and provision. The cost of implementing or participating in a blockchain system may also be an issue, due to the technical and specialised expertise required for participation (Patel *et al.*, 2017; Wang *et al.*, 2017). It may be even more challenging for small-to-medium-sized supply chain companies to participate, due to their lack of skills and financial constraints.

Finally, as blockchains place trust and authority in a decentralised network, it represents a total shift away from the traditional ways of organising and managing a supply chain. The loss of control may be unsettling for many supply chain actors. Therefore, cultural resistance and existing business processes will be major barriers to change (Patel *et al.*, 2017; Wang *et al.*, 2017).

5.4 RO4: develop a future research agenda

There is a clear lack of theory and methodological pluralism in much of the literature we reviewed. None of the papers under review deployed an explicit theoretical lens. An alarming majority of papers were either conceptual or technical in nature. Theory is an indispensable part of the research of technological innovations and adoption in supply chains. There is an urgent need for systematic inquiry to study blockchains from a multi- or inter-disciplinary perspective. Rigorously developed conceptual and empirical contributions will improve our understanding of this emerging technological phenomenon and its impact on supply chains, industries and the wider society.

Given the embryonic state of blockchain technology, there are many exciting research opportunities for the future.

5.4.1 Cryptocurrency and supply chain finance

Studies need to explore how digital currency, or cryptocurrency, may affect supply chain finance. Supply chain finance is a generic term for a variety of financing instruments that finance various parties within a supply chain and support the movement of capital behind a physical supply chain (Pfohl and Gomm, 2009). Given that most established applications of blockchains are cryptocurrency, supply chain partners may start to trade and settle their payments using cryptocurrency. A particularly promising area where we may see cryptocurrency is as a data marketplace for IoTs. With the increasing number of IoT devices in supply chains, they generate tremendous volumes of data, and this data could provide business intelligence about supply chains. Big data is so valuable that it has become a new asset class for supply chain management. Early efforts in practice use distributed ledger technology (not necessarily the blockchain) to allow businesses to securely store, sell and access data streams generated by IoTs (see IOTA.org).

Another example is OriginTrail (Cases 11 in Table II), a Slovenian IT company specialising in traceability and quality-control systems, which created the cryptocurrency, Trace Token. The purpose of this currency is to serve as compensation for multiple nodes within a network that keep copies of transactional data generated by supply chains (Bowman, 2018). This may address the issue of high transaction costs associated with the blockchain and would speed up cash-flow exchanges.

Smart contract-enabled transactions may allow instant payment from customers to suppliers. This shortens the cash payment cycle but does not solve the issue of the upfront need for funds to keep the production/service running by suppliers or buyers. To address this issue, blockchain-based financial service platforms have been piloted in practice. For example, the financial services arm of iPhone manufacturer, Foxconn of Taiwan, partnered with the Chinese online lender, Dianrong, have launched Chained Finance, which claims to be the first-ever blockchain platform for supply chain finance (Case 9 in Table II). The two companies recently completed a successful pilot and proof of concept by securing funding for small and medium enterprises (SMEs) in China that were otherwise unable to secure needed capital. During the pilot, Chained Finance originated US$6.5m (RMB45m) in loans for these SME supply chain operators (Sawers, 2017). In April 2017, IBM and the Chinese firm, Sichuan Hejia Co., Ltd., announced the launch of a blockchain-based, supply chain financial services platform for pharmaceutical procurement to help improve the efficiency, transparency and operation of supply chain finance (IBM, 2017b). Again, this platform is beneficial to SME companies which often find it difficult to raise funds due to underdeveloped credit systems and a lack of established credit evaluation and risk control. The platform is designed to help establish the authenticity of the transactions among supply chain participants, allowing banks to be more informed and grant access to funding for SME pharmaceutical retailers. The blockchain's ability to track ownership in a distributed and immutable way could also potentially lead to new crowdfunding and peer-to-peer lending initiatives (Collomb and Sok, 2016). Similar cases (Cases 8 and 10) are also observed where financial transactions are carried out using blockchain technology.

Research in supply chain finance is very limited (Caniato *et al.*, 2016; Carter *et al.*, 2015). Research that bridges blockchain and supply chain finance is nearly non-existent. As such, blockchain diffusion into the supply chain provides fertile ground for future research. Examining this emerging phenomenon would offer valuable insights about how blockchain supports financial collaboration across supply chain echelons, not just bilateral financial settlement. More importantly, it will allow us to interrogate the economic value of the blockchain and see whether it affects the bottom line of the business.

5.4.2 Disintermediation and reintermediation

The elimination of intermediaries in the market system, as claimed by blockchain communicators (Tapscott and Tapscott, 2016), will address the asymmetrical issues among economic participants and allow peer-to-peer asset trading. Disintermediation often occurs when a novel technology application could take the cost or time out of the supply chain or add more value to customers (Shunk *et al.*, 2007). For supply chains, the blockchain may cause the extinction of certain types of intermediaries. However, it is hard to fully predict its impact on the structure of markets and supply chains. Some compare the current level of development to the internet and World Wide Web in the early 1990s. Just as TCP/IP dramatically lowered the cost of connections, the blockchain could dramatically reduce the cost of transactions (Iansiti and Lakhani, 2017).

When the internet was first commercialised, it reshuffled many industries by removing some traditional intermediaries, while leading to a plethora of new types of intermediaries. For example, in the book sector, when electronic marketplaces were introduced, the business of the traditional wholesaler/distributor was severely disrupted. However, new intermediaries like Amazon and eBay emerged, generating value by providing value-added services to participants (O'Reilly and Finnegan, 2010).

Future research should explore whether supply chains will still need banks to settle financial transactions, whether transport service providers will be eventually phased out from supply chains and whether the echelons such as distributors/wholesales/service agents will still add value in blockchain-enabled supply chains. Disintermediation will take place if the cost of existing supply chain intermediaries exceeds the value they add. Meanwhile, a new breed of intermediaries may emerge, which will seize the missing opportunities in the supply chain and promote greater economic, environmental and social benefits. Research into these new intermediaries and the effect of reintermediation will provide further insight about the change of supply chain structures generated by blockchains.

5.4.3 Digital trust and supply chain relationship management

Blockchains are often recognised as the missing trust layer of the internet and as such may challenge the conventional ways of understanding and researching "trust" in supply chains. Trust is a key catalyst to building close supply chain relationships and has a positive impact on innovation and supply chain performance (Kwon and Suh, 2005; Panayides and Lun, 2009). Trust also influences the risks associated with collaborative projects. High levels of trust enhance joint decision-making and problem solving which mitigate many execution problems and increase the probability of success (Fawcett *et al.*, 2012). Research also suggests that interdependence fosters trust between supply chain partners (Capaldo and Giannoccaro, 2015). Nyaga *et al.* (2010) posited that supply chain collaborative activities lead to trust and commitment, which lead to improved satisfaction and performance.

The research on trust in buyer–supplier relationships has emphasised the need for long-term relationships and mutual investment between supply chain actors to build trust (Fawcett *et al.*, 2012; Handfield and Bechtel, 2002; Kwon and Suh, 2004). With ongoing globalisation and the growing complexity and volume of global transactions, this approach is becoming more time-consuming, costly and inefficient. With the blockchain, "trusting" supply chain partners may be irrelevant. Given that the trust has been "programmed" into a blockchain through cryptography, relational investment is not as essential as in traditional supply chains. In a blockchain, people, businesses or things come together spontaneously to interact in a well-defined context. The "trust" only extends to the requested action at that point in time, and that may change rapidly as conditions change. A blockchain-enabled supply chain may be established via the orchestration of a variety of services to fulfil a certain demand or order. Once the order is fulfilled, the formation of this supply chain may dissolve or evolve into a new structure for future demands. This "trust by design" has led to the digital trust concept, as proposed by Gartner (Gaehtgens and Allan, 2017).

> It is often said that trust takes years to build, seconds to break and forever to repair. Digital trust, on the other hand, takes instants to build, an instant to break and is continuously adaptive.

Digital trust may help prevent supply chain actors from behaving unethically or opportunistically (Hill *et al.*, 2009; Wang *et al.*, 2014). As every transaction in a blockchain builds on every other transaction, any corruption or unethical behaviour will be readily visible to all network participants. This is valuable to humanitarian supply chains where (inter) national aid is often perceived as not reaching target beneficiaries (Hyndman and McConville, 2017). The built-in trust would help brands build consumer-confidence when they know their products are from legitimate suppliers. As Gupta (2017) pointed out, this self-policing mechanism can mitigate the need to depend on current levels of legal or government safeguards and sanctions to monitor and control the flow of business transactions.

However, as there is no central authority to police or enforce honesty in a blockchain-enabled supply chain, predicting future honest behaviour is impossible. Will collaborative relationship and relational capital become less critical in a blockchain-enabled supply chain? How will companies build their reputation within a blockchain network? What happens if unethical behaviours take place? How does distributed governance work in practice? To what extent will the blockchain reduce or eliminate corruption in the supply chain, particularly in developing countries and humanitarian supply chains where this problem prevails?

5.4.4 Blockchain, inequality and supply chain sustainability

When blockchain technology matures, some believe it could address social inequality and poverty (Kshetri, 2017b; Tapscott and Tapscott, 2017). One scenario mentioned is international remittance. This is the application area where a blockchain app is developed for people who work in a developed country so that they can send money to their relatives who live in a developing country. Traditional money transfers are processed through a network of central clearing bodies or correspondent banks. There is limited visibility to value flow for both senders and recipients. The whole process normally takes days and the transaction charges are high due to the number of intermediaries involved. Also, those in receipt of monies frequently do not have a bank account. Blockchain initiatives that target this problem could reduce the timing of international monetary transactions of this nature to less than an hour (Abra.com, 2018).

Similarly, the blockchain has been deployed in the food and beverage industry to tackle poverty and ensure fairer and faster payments to small scale farmers. In the coffee sector, although 25 million smallholder farmers produce 80 per cent of the world's coffee (Fairtrade.org, 2018), many fail to earn a reliable living from coffee. Moyee Coffee (Case 16) launched a pilot project in Ethiopia with the blockchain pioneers Bext360 and the FairChain Foundation to give all stakeholders – farmers, roasters and consumers – access to data (including prices) across the entirety of the supply chain. Not only did this bring radical change to traditional coffee supply chains, its potential social value could be significant: offering opportunities for small businesses, addressing power imbalance between small producers and large wholesalers/roasters, allowing a fairer distribution of value along the supply-chain, and thus playing a significant role in poverty reduction.

Another blockchain application that delivers social value is the Building Blocks pilot project (Case 17) by the World Food Programme (WFP). The project uses an Ethereum-based blockchain technology to help refugees of the Syrian Civil War. In the Azraq refugee camp in Jordan, 10,000 people receive food from entitlements recorded on a blockchain-based computing platform. Refugees purchase food from local supermarkets in the camp by using an eye scan instead of cash, vouchers or e-cards (WFP.org, 2017). This pilot has offered valuable insights for future humanitarian supply chains and may enhance humanitarian agility and responsiveness – a key success factor in volatile situations (Oloruntoba and Gray, 2006).

The sustainability of blockchain deployment in the long-term remains uncertain. Its predecessor M-PEASA resembles many of the desired social attributes pursued by blockchain initiatives. The M-PEASA system was launched by Vodafone's Safaricom mobile operator in 2007 in Kenya to allow those without a bank account to transfer funds quickly and easily. As of 2017, there were 30 million users in ten developing countries and services included international transfers, loans and health provisions. M-PEASA was lauded for its social value impact, since 2 per cent of Kenyan households were lifted out of extreme poverty through access to mobile money services (Monks, 2017). As it took M-PEASA ten years to reach to a large-scale deployment in East Africa, we can reasonably assume that the same level of impact by blockchain will not happen overnight. This transition period will provide a fruitful time for theory-driven or theory-developing research to make systematic inquiries as to how blockchains may transform the lives of individuals and the relationships among individuals, organisations and society.

Supply chain researchers have paid increasing attention to the social dimension of supply chain management and its sustainability performance (Dillard *et al.*, 2008; Marshall *et al.*, 2015; Pullman *et al.*, 2009). Often linked with the concept of corporate social responsibility (Eriksson and Svensson, 2015) (Andersen and Skjoett-Larsen, 2009), the literature emphasises the impact of business through engaging the poor as suppliers or customers (Ma¨rquez *et al.*, 2010). Research about the bottom/base of pyramid (BoP) (Karnani, 2007; Khalid *et al.*, 2015) suggests that for technology to serve its purpose of developing all stakeholders, including the BoP, the technology should be "participatory" (Berger and Nakata, 2013; Hall *et al.*, 2014). Blockchain-enabled social innovations will provide interesting avenues for this stream of research.

Future research should seek to explain how value is created, captured and distributed in blockchain-enabled social supply chains. Efforts can also examine issues regarding conditions that will ensure the survivability and prosperity of such initiatives. Theories and concepts from various disciplines could be integrated to evaluate the effectiveness of these social innovations. Insights will help broaden our understanding of the wider impact of blockchains on multiple supply chain actors, including those who are vulnerable, exploited and poor.

5.4.5 The dark side of blockchain

We adopt the broad term, "dark side" (Tarafdar *et al.*, 2013), to depict potential negative phenomena associated with blockchain use, with the potential to infringe on the well-being of individuals, organisations and societies. Dark side phenomena include issues like governance, ethics, law, crime, security, privacy, intellectual piracy, automation-induced unemployment and technical vulnerability issues.

The dark side of blockchain technology is already evident in cryptocurrency. Several cyber hacks have targeted popular cryptocurrencies. The criminal use of cryptocurrency is equally alarming when the automatic and autonomous properties of a blockchain are exploited: money laundering, illicit marketplaces and ransomware. Increasing cybercrimes lead to data breaches, financial crimes, market manipulation, IP theft and public safety and security risks. This makes cybersecurity a top priority for blockchain-enabled supply chains. The biggest challenge is that, unlike the internet, blockchains have no sophisticated governance system in place.

Technical vulnerability seems a far reaching issue for supply chain researchers, since we may not be able to propose technical countermeasures. However, understanding how these vulnerabilities are open to misuse and their subsequent impact on supply chain management is of paramount importance. For instance, Juels *et al.* (2016) pointed out a number of ways in which things could go wrong in smart contracts. To build a secure blockchain supply chain, technology solutions are only part of the integrative measures, as appropriate (inter)organisational policies and procedures, laws and industry standards are needed. Supply chain researchers could play a part in the latter.

Blockchain development presents significant regulatory challenges. The absence of an intermediary in most or all steps of the supply chain could create uncertainty for the parties involved, especially regarding automated forms of execution and transaction supervision of transactions. Criteria are needed to ensure the legal validity and enforceability of smart contracts under the law (Boucher *et al.*, 2017). Privacy is another challenge. As data are visible to all who participate in a blockchain (whether public or permissioned), this level of openness may not be welcomed by all supply chain actors, particularly end consumers.

Through their distributed consensual nature, blockchains also threaten the role of intermediaries. If those intermediaries could be eliminated, this would reshuffle the whole freight sector and create fundamental changes. It may also result in job losses in the short-term, although new intermediaries offering blockchain-related digital services might emerge, creating new employment opportunities. However, this means job reskilling is of critical importance for supply chains.

While the dark side use of technology has been actively discussed in the IT/IS discipline, this issue has not received equal attention from supply chain researchers, although IT/IS has been recognised as a key enabler to effective supply chain management. Tarafdar *et al.* (2013) proposed a guiding framework as a basis for research on dark side phenomena.

They suggested that research should look at the context of their occurrence, negative outcomes and mitigation mechanisms. They further proposed that these aspects can be investigated at different level of analysis: individual, organisational and societal. Taking multiple theoretical lenses to examine these phenomena would benefit the overall understanding of the relationship between blockchains and their potential negative outcomes on a range of supply chain actors.

5.4.6 A design perspective on a blockchain-enabled supply chain

This study has explored the aforementioned strategic issues that we think are worthy of further investigation. Future work should also seek to develop valid knowledge that can directly inform and support practice. Interest in design thinking and design science has increased in both the operations management (van Aken *et al.*, 2016) and information technology/information systems (IT/IS) disciplines (Baskerville *et al.*, 2018). In practice, large IT companies, such as SAP and IBM, have been actively using design thinking methods to articulate problems or opportunities with their clients and multiple stakeholders and to identify solutions that will deliver value to their target beneficiaries.

While the design of blockchain-enabled supply chains is highly context dependent and no one optimal design exists for all supply chains, researchers could aim to deploy a design science approach that focuses on developing generic actions, processes and systems to address field problems or to exploit promising opportunities afforded by the emerging technology of blockchain. The generic design can then be operationalised in various contexts.

From our review of practices, current efforts have been rather exploitative instead of explorative and consist largely of a collection of incremental advances. Over time and as both societies and industries grow in their use of blockchain networks, we anticipate structural changes to business models across industries, which may then lead to significant socio-technological and economic changes worldwide. One way of generalising knowledge from emerging practices is to examine a number of case-specific designs of the intended domain and derive generic and transferable essentials (mechanisms) which produce desirable outcomes (van Aken *et al.*, 2016). We offer a few preliminary observations from our understanding of the literature to inspire further research, and these are as follows:

5.4.6.1 Selecting a blockchain's entry point to the supply chain. The starting point in designing a blockchain-enabled supply chain would be to identify areas where there are pertinent problems in an existing supply chain that blockchain technology would help address. This aspect is where a design thinking exercise could be introduced to elucidate and articulate areas where the blockchain may bring ultimate value to the supply chain. Typically, a problem or several problematic areas can be identified via brainstorming sessions with multiple stakeholders. Potential ideas/goals, as well as barriers/problems, will be explored. A clustering exercise could be conducted to group-related issues into themes which can then be prioritised based on factors, such as value for organisations, time and ease of implementation. Once a use case is finalised, a POC can then be established and tested to determine how effective the performance is.

As discussed in Section 4.2, the sample problem needs to be one that is experienced by multiple players in a supply chain network. The core value of a blockchain system is in its shared, append-only, distributed ledger across a network of organisations. If the problem is organisational rather than interorganisational, the blockchain may not be the right technological solution. Another prerequisite is to consider whether sharing data securely across a supply chain is needed while protecting privacy. A private blockchain network would support a shared repository and ensure that confidential or commercially sensitive information is only broadcasted to relevant parties.

For the blockchain to provide value to supply chains, assets need to be transferred between supply chain players. A major difference between a blockchain and a traditional distributed database is that the blockchain can be used to record transactions of assets between organisations. Assets could be physical products or electronic files/intangible items, such as a letter of credit. Supply chain organisations that need to track how often and through how many parties an asset changes hands can benefit from the blockchain's provenance capability. The blockchain can also be deployed when greater trust and transparency are needed in a supply chain network, for example, to comply with legal regulations, reduce risks or avoid fraud.

5.4.6.2 Building a blockchain ecosystem. Once a business case is identified, the next question to consider is who should participate in the blockchain-enabled supply chain. At the pilot stage, a small group of consortia with three to five participants has been suggested as a viable number needed to understand the core concerns and test assumptions across the solution space (IBM, 2016). This founding network can then expand to include more actors at a later stage. This consortium would usually include a lead organisation as a supply chain orchestrator (for instance, in Case 1, it is Walmart, and for Case 5, it is Maersk) that will play a significant role in shaping the direction of blockchain development and deployment and in coordinating the tasks of participating organisations to ensure that objectives are aligned and collective actions are agreed upon. Depending on the specific case involved, other participating organisations could include a technology service provider, a supplier and public authorities, such as customs, banks or logistics service providers. The common incentives that encourage participation in a pilot could be both tangible (e.g. cost and time reduction, new revenue or risk reduction) and intangible benefits (e.g. industry leadership, standards development or first-mover advantages).

5.4.6.3 Articulating the platform value. A blockchain-enabled supply chain can be viewed as a value platform, a concept proposed by Perks *et al.* (2017), upon which network members co-create value through a set of specific practices via the dynamic configuration of tangible and intangible resources. At the strategic level, its key ingredients include value proposition, value creation and value distribution within the blockchain network.

The value proposition dictates the network revenue/cost model and its core activities/processes. The consortium needs to decide, for instance, whether a membership fee should be charged, how participants should pay and how transactions will be charged. Considerations should also be sought about whether smart contracts should be coded into the blockchain and whether a digital token should be used to facilitate transactions. The perception of a fair value distribution by all participating members is critically important to maintain and nurture the resilience of the blockchain value platform.

5.4.6.4 Establishing the governance model. Blockchain-enabled supply chain governance can be particularly challenging because of its decentralised nature – each participant will have a stake in how the blockchain supply chain is configured and operated. A set of rules on how the participating members interact with one another needs to be determined. In terms of participants, one needs to clearly define:

- the ways by which the participants access or exit a blockchain network;
- the types of roles each member will play; and
- the ways to resolve potential disputes among members.

In terms of data, considerations should be given to concerns, such as the kinds of data that should be appended in the blockchain and the people responsible for inputting the needed data. Once the data are in the blockchain, who has ownership of them and how IP ownership should be dealt with need to be set, as well.

In terms of transactions, those in charge of validating them and the number of nodes needed should be established. In the case of a smart contract, clear roles and responsibilities on which party should review and approve it and how the code captures the right business logic should be laid out. As smart contracts have significant legal consequences, they further complicate the governance of the blockchain network.

The governance of a supply chain network has been well examined in the literature, and a number of frameworks have been proposed (Milward *et al.*, 2014; Provan *et al.*, 2007). However, as discussed above, a blockchain-enabled supply chain makes determining the nuances of governance mechanisms more complicated.

5.4.6.5 Exploring legal implications. A number of unique legal matters emerge from a blockchain's distributed nature, as blockchains are decentralised and, in many cases, global. They cannot be shut down by any one legal system, and they exist outside the boundaries of conventional laws defined by jurisdiction. Local and international laws, industry-specific regulations, data sharing regulations, intellectual property, liability and general commercial agreements, such as the service level and performance assurances, should all be carefully examined (IBM, 2018). Organisations should work with law professionals to define rules and a detailed set of contingencies for anticipating potential legal issues.

5.4.6.6 Scaling up a blockchain-enabled supply chain network. The IT/IS discipline has long explored the factors that influence the diffusion of interorganisational technological innovations (Robey *et al.*, 2008). How these factors can be applied to the emergence of blockchain technology has yet to be examined. In practice, the pioneers of blockchain technology (as shown in Table II) have asserted that if the future vision of a blockchain network emphasises the sharing of value among all participants, it will likely attract more participants. Other factors, such as interoperability with core enterprise IT systems, ease of use (e.g. multiple ways of accessing the platform) and security of the system, will also help encourage further network adoption.

6. Conclusion

This study explored how blockchain technology can potentially influence future supply chain practices and policies. Basing on a systematic review of both the academic and practitioner supply chain literature, we identified the main drivers of blockchain deployment within supply chains, as well as within areas in which this emerging technology may provide the most value for supply chain management. We have engaged with certain blockchain initiatives evident in contemporary practice to demonstrate not only some of the technology's latest applications but also a range of technological, organisational and operational challenges that are likely to affect its further diffusion.

The supply chain literature is particularly interested in blockchain technology as a way of allowing organisations and individuals to make and verify transactions without needing a controlling central authority. This feature is of great interest because it may facilitate digitalisation and disintermediation in the supply chain, as well as resolve issues associated with inter-organisational trust. However, the use of blockchain technology as a means of implementing distributed ledgers and smart contracts raises as many issues as it resolves. From our analysis of the literature, we have raised a number of issues associated with the potential socio-economic impact of blockchains and proposed a range of future research avenues worth investigating.

To our knowledge, this study is the first to examine the current state of blockchain diffusion within supply chains. Our work is timely in that it provides a solid foundation for evaluating a technology whose benefits are not yet entirely clear, whose negative effects are unforeseeable and whose diffusion path remains uncertain. Our contribution has been to identify and organise the otherwise disjointed studies published on blockchains in such a way that their relevance to the supply chain management discipline becomes apparent. Academic scholars will hopefully gain some leverage from this analysis, as it provides an understanding of the trends in the emerging landscape of blockchain technology. Scholars new to it will find in this study both a comprehensive review of blockchain fundamentals and a systematic analysis of blockchain research relevant to supply chain management.

From a managerial standpoint, the findings of this study can assist practitioners in making a strategic sense of the disruptive effect and potential opportunities afforded by blockchain technology to supply chains. This study not only pinpoints areas where blockchain technology may disrupt existing supply chain provisions but also highlights certain challenges and barriers to the technology's deployment. As such, our study should help guide managers' decisions about formulating and implementing blockchain-enabled supply chain initiatives. From a design perspective, this study offers both practitioners and scholars valuable insights into identifying a use case that addresses a supply chain problem, operationalising the desired blockchain supply chain model and focussing on legal and governance issues for long-term sustainability. Our findings serve to alert managers, particularly the network orchestrator, of the need to nurture network relationships among participating members and to develop a shared value among all members.

Finally, although much care was taken in the selection of the search terms used in our study, we acknowledge that our choice may have excluded certain blockchain articles from this review. As blockchain development is still in its embryotic phase, our discussions of future research opportunities are mainly conceptual. While conceptualisation is an important process in making sense of related blockchain observations, future research should keep a close track of blockchain developments and add more empirical evidence to the various strands of research opportunities we have identified. Revisiting this area and conducting another round of literature review once blockchain technology has had time to mature as a supply chain technology would be worthwhile.

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