Blockchain and supply chain management integration: a systematic review of the literature

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Abstract

Purpose – This paper aims to identify, analyse and organise the literature about blockchains in supply chain management (SCM) context (blockchain–SCM integration) and proposes an agenda for future research. This study aims to shed light on what the main current blockchain applications in SCM are, what the main disruptions and challenges are in SCM because of blockchain adoption and what the future of blockchains holds in SCM.

Design/methodology/approach – This study followed the systematic review approach to analyse and synthesise the extant literature on blockchain–SCM integration. The review analysed 27 papers between 2008 and 2018 in peer-reviewed journals.

Findings – Blockchain–SCM integration is still in its infancy. Scholars and practitioners are not fully aware of the potential of blockchain technology to disrupt traditional business models. However, the electric power industry seems to have a relatively mature understanding of blockchain–SCM integration, demonstrated by the use of smart contracts. Additionally, the disintermediation provided by blockchain applications has the potential to disrupt traditional industries (e.g. health care, transportation and retail).

Research limitations/implications – The limitations of this study are represented mainly by the scarcity of studies on blockchain–SCM integration in leading journals and databases.

Practical implications – This study highlights examples of blockchain–SCM integration, emphasising the need to rethink business models to incorporate blockchain technology.

Originality/value – This study is the first attempt to synthesise existing publications about the blockchain–SCM integration, shedding light on the disruption caused by, and the necessity of, the SCM reconfigurations.

Keywords New technology, Systematic literature review, SCM practices, Disruption, Supply chain disruptions

Paper type Literature review

1. Introduction

Recent technologies, mainly associated with Industry 4.0, are provoking significant disruptions and forcing the supply chain management (SCM) field to develop new business strategy models. One of the most promising of these technologies is blockchains. Blockchain technology first appeared in the bitcoin context (Nakamoto, 2008). It works in a distributed data structure based on a peer-to-peer network transaction (Christidis and Devetsikiotis, 2016; Marsal-Llacuna, 2018). Blocks are linked by cryptographic hashes (de Leon *et al.*, 2017) and all their nodes have a copy (Al-Saqaf and Seidler, 2017; Scott *et al.*, 2017). Because of these features, the transactions records are considered virtually immutable (Adams *et al.*, 2017a; Cai and Zhu, 2016; Grewal *et al.*, 2018).

Although blockchain technology applications emerged with bitcoins (Nakamoto, 2008), the current applications have the potential to disrupt different, traditional industries (Scott *et al.*, 2017; White, 2017). Based on the decentralisation principle, in which intermediaries can be eliminated, the smart contract is an essential blockchain application that works in an automated manner to transfer assets when a determined condition is satisfied (Al-Saqaf and Seidler, 2017). Thus, smart contracts are reconfiguring several business models, in which producer and consumer can trade without an intermediary. Consequently, blockchain decentralisation and disintermediation features (Scott *et al.*, 2017) can lead to disruption and support SCM innovation and reconfiguration in the digital age.

Despite these significant blockchain applications and their potential to promote changes in all types of supply chains in

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terms of new operation models, the literature about blockchain technology in the SCM field is in its infancy. Literature examining the application of blockchains in SCM, and the impact of subsequent disruptions, is scarce. To shed some light on this hot topic, a systematic literature review (SLR) (Denyer and Tranfield, 2009; Tranfield *et al.*, 2003) was used to answer the following research questions:

RQ1. What are the main current blockchain applications in SCM?

RQ2. What are the main disruptions and challenges in SCM because of blockchain adoption?

RQ3. What is the future of blockchains in SCM?

Thus, this research aims to shed light on blockchain–SCM integration, making a significant contribution to the literature and also having implications for practitioners and decision makers interested in gaining an in-depth understanding of this cutting-edge technology.

Additionally, blockchain technology is a multidisciplinary field, and this study intends to show the current journals that are in the vanguard regarding this hot topic. This study brings relevant insights to scholars and practitioners interested in advancing blockchain–SCM integration. It is a first investigation that analyses the blockchain–SCM integration literature from 2008 to 2018 (February). Also, the SLR revealed important gaps in the literature, highlighting managerial implications and providing a robust research agenda.

The rest of this paper is organised as follows. In Section 2, we introduce the basic concepts of SCM and blockchains. In Section 3, we justify and present the main aspects of the systematic-review methodology based on Tranfield *et al.* (2003) and Denyer and Tranfield (2009). Section 4 provides the main research findings, and Section 5 provides a discussion addressing the three *RQ*s. In Section 6, the managerial implications based on the findings are highlighted. Section 7 details the research implications and proposes an agenda for future research. Section 8 presents the main contributions from the perspectives of methodology, scope, and insights. Finally, in Section 9, final remarks and limitations are presented.

2. Supply chain management and blockchains: basic concepts

2.1 Supply chain management

The Council of Supply Chain Management Professionals (CSCMP), proposed the following definition of SCM:

> [SCM] encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. [Council of Supply Chain Management Professionals (CSCMP), 2018]

Despite this robust definition, there is no consensus, mainly between scholars, on a unified definition of SCM. For instance, Stock and Boyer (2009) analysed 173 SCM definitions and presented an all-encompassing definition for SCM as:

> The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction (Stock and Boyer, 2009, p. 706)

Another well-articulated and widespread SCM definition was provided by Mentzer *et al.* (2001) who defined SCM as:

> The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole. (Mentzer *et al.*, 2001, p. 18)

In this study, we consider that these definitions are convergent and complementary; while the CSCMP highlights the collaboration, integration and coordination needs for the entire supply chain, Stock and Boyer's (2009) definition considers the importance of network relationships, and Mentzer *et al.*'s (2001) definition defines the role of these relationships in long-term performance improvement. This study, therefore, follows the approach provided by these definitions to understand the SCM relationship with, and the potential disruptions caused by, blockchain technology.

2.2 Blockchain technology

Blockchains emerged as a technology to support transactions in the cryptocurrency field (Nakamoto, 2008). One formal definition of blockchain technology, provided by Risius and Spohrer (2017), is:

> Blockchain technology refers to a fully distributed system for cryptographically capturing and storing a consistent, immutable, linear event log of transactions between networked actors. This is functionally similar to a distributed ledger that is consensually kept, updated, and validated by the parties involved in all the transactions within a network. In such a network, blockchain technology enforces transparency and guarantees eventual, system-wide consensus on the validity of an entire history of transactions. (Risius and Spohrer, 2017, p. 386)

Despite this formal definition, it is clear that there are some other distinctive blockchain characteristics, like data security, tamper-proof transactions and data validation among the network members. A distributed ledger definition is also necessary. Hyperledger (a Linux Foundation initiative for open-source blockchains) defined a distributed ledger as:

> [...] a multi-party database with no central trusted authority. The differentiating nuance is that when transactions are processed in blocks according to the ordering of a blockchain, the result is a distributed ledger. (Hyperledger, 2018)

However, because of the novelty of this subject, blockchains face similar difficulties to SCM in terms of generating a consensual definition. For instance, Al-Saqaf and Seidler (2017, p. 339) provided a brief definition of a blockchain as "a distributed digital ledger or accounting book". Christidis and Devetsiokiotis (2016, p. 2293) defined a blockchain as "a distributed data structure that is replicated and shared among the members of a network". Another recent blockchain definition was provided by de Leon *et al.* (2017) as:

> A digital information recording method capable of recording data using a logbook approach and with the following essential characteristics: 1-Ordered, 2-Incremental, 3-Sound (cryptographically verifiable up to a given block) and 4-Digital. (de Leon *et al.*, 2017, p. 288)

In this context, it is clear that blockchain technology works as "a digital logbook of transactions", in which decentralisation, disintermediation, transaction sharing and tamper-proof can be considered as its main characteristics. Thus, the blockchain concept can be understood as associated with transactions' disintermediation, i.e. without a central authority to validate and offer credibility to transactions. This feature implies some impacts on SCM, involving aspects such as member relationships, collaboration, trust and change in the role-based operations model for cloud agility, among other consequences.

Figure 1 depicts the main elements of blockchain technology in a schematic form. The blocks are linked in a chain (blockchain) in which each block has a hash of the previous blocks and a record of all transactions (Khan and Salah, 2018).

Furthermore, because the block has a copy of all transactions and it cannot be modified, the technology ensures transparency and enhances trust over the network (Khan and Salah, 2018; Yeoh, 2017). Thus, in Figure 1, each block has the hash of the prior block, for instance, block $n + 3$ has the hash of the block $n + 2$ and so on, ensuring traceability. Consequently, this process validates the preceding blocks' information back to the first block that started a process (Hou *et al.*, 2018).

2.3 Blockchains and supply chain relationships

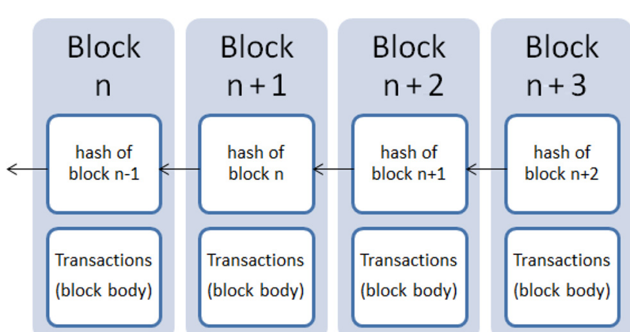
Blockchains, applied in a SCM context, will likely lead to disrupting transformations in all types of industries. Hence, traditional relationship models are already being reconfigured, mainly because of the disintermediation of the transactions. To further understanding of blockchains and supply chain relationships, Figure 2 illustrates a smart-contract operation.

Figure 2 exemplifies the trade between a producer A and a supermarket B. After the fulfilment of the trade conditions for both, a contract is written, coded and "stored" in a blockchain structure. A contract is triggered when it satisfies the conditions of the negotiation. After that, money and goods are transferred according to the contract. This operation does not rely on an intermediary. Therefore, it not only speeds up the transaction but also promotes costs reduction and improves trust, since, within the network, all participants (nodes or actors) have a copy of the ledger (Al-Saqaf and Seidler, 2017; Yeoh, 2017).

3. Methodology

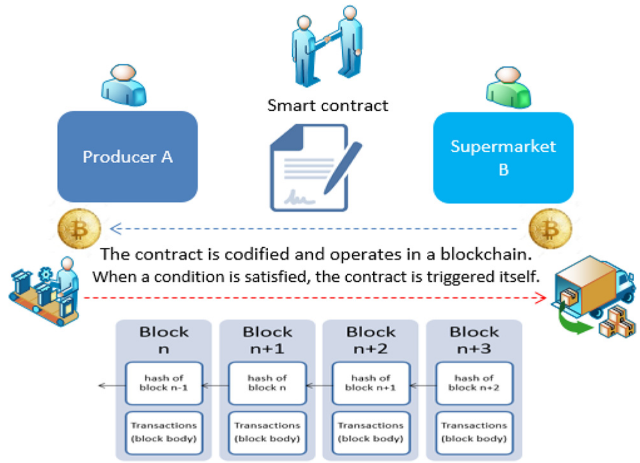
The SLR is a referential method to organise, synthesise and identify emerging paths and opportunities, as well as understanding the relevant issues, contradictions and

Figure 1 Blockchain overview structure



Source: Authors

Figure 2 Smart contract example in the SCM context



Source: authors

limitations, based on previous studies. SLR is a well-established method, mainly in medical research (Cochrane Library, 2018). SLR can be defined as:

> [...] an efficient technique for hypothesis testing, for summarising the results of existing studies, and for assessing consistency among previous studies; these tasks are clearly not unique to medicine. (Petticrew, 2001, pp. 99-100)

SLR has traditionally been applied in established fields (Tranfield *et al.*, 2003). However, the SCM field associated with blockchain technology is relatively young, with an agenda still under development. As Tranfield *et al.* (2003) noted, in emerging topics and rapidly advancing fields, papers published in journals can be scarce. However, recent studies have applied SLR successfully to emerging themes in management. For instance, Pereira *et al.* (2014) applied SLR to understand procurement and supply chain resilience, considering literature published between 2000 and 2013 and selecting 30 papers to analyse. Another recent SLR study with a small sample in an emergent field was conducted by Tachizawa and Wong (2014), who proposed a framework for multi-tier, sustainable supply chains using 39 papers.

By considering previous literature, SLR is a timely and effective approach to the field development, providing a systematised approach to identifying issues not covered, new methodologies for the field, as well as new research avenues. It also guarantees that no relevant research is overlooked and ensures replicability (Pereira *et al.*, 2014). Thus, SLR is a suitable approach to understanding the blockchain–SCM integration. Several SLRs in supply chain contexts have been published in recent years (Abidi *et al.*, 2014; Fischl *et al.*, 2014; Friday *et al.*, 2018; Gligor, 2014; Kamal and Irani, 2014; Pereira *et al.*, 2014). The present study follows the main SLR steps, following Tranfield *et al.* (2003) and Denyer and Tranfield (2009), that have been successfully employed in recent supply chain studies (Abidi *et al.*, 2014; Alexander *et al.*, 2014; Datta, 2017; Friday *et al.*, 2018; Kamal and Irani, 2014; Kembro *et al.*, 2014; Tachizawa and Wong, 2014). SLR's methodological framework provides a rigorous approach for conducting literature reviews (Alexander *et al.*, 2014).

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In Stage 1 (planning the review), the scope of the studies was defined. This is a critical phase because, here, the subject delimitation and the literature range are defined (Tranfield *et al.*, 2003). The investigation, in this sense, determined and depicted what is known and not known about blockchain studies in the SCM field. As recommended by Tranfield *et al.* (2003), this study considered the cross-disciplinary aspect in which blockchain technology has previously been discussed, which led to the three previously-stated *RQ*s. Next, a research protocol was modelled (Table I) to ensure objectivity in the whole procedure (Tranfield *et al.*, 2003).

In Stage 2 (conducting a review), the studies were identified by relevant search strings (Table I). As recommended by Tranfield *et al.* (2003), our study included only the papers that met the full criteria in the research protocol. The detailed inclusion and exclusion criteria are highlighted in Table I. Next, to minimise bias errors, the papers were quality assessed in terms of their internal validity, e.g. peer-review journals and impact factor. According to Tranfield *et al.* (2003), the data extraction phase contributes to bias-error minimisation by applying filters such as title, journal, and others publication details. In data synthesis, a narrative review is produced that integrates the findings of the previous studies. To support and optimise the data synthesis, we used a qualitative data analysis software MAXQDA 2018 version (Schanes *et al.*, 2018).

In Stage 3 (reporting and dissemination), the main findings are presented, and emerging themes and questions are provided (Tranfield *et al.*, 2003). In this study, we provided a research agenda with potential open questions and some suggestions for scholars and practitioners interested in gaining an in-depth understanding of blockchains' potentiality in the SCM field of research. Additionally, managerial and theoretical implications were highlighted in a brief conclusion. Figure 3 presents the main steps, according to recommendations proposed by Tranfield *et al.* (2003), to conducting SLRs.

Figure 4 shows a schematic framework that reflects the procedure adopted in the present study. The number of papers retrieved in each stage is displayed.

4. Findings

A content-analysis approach was used to synthesise the findings (Kache and Seuring, 2014; Pereira *et al.*, 2014; Seuring and Gold, 2012). A coding scheme is fundamental for objectivity, validity and reliability to support data-analysis information (Guthrie *et al.*, 2004; Spens and Kovács, 2006). Table II presents the main categories adopted for content analysis.

4.1 Publication by country and year

Table III reports the number of papers, published by country and year, resulting from the research-protocol application. Despite the prevalence of cutting-edge SCM technologies, especially those related to Industry 4.0, surprisingly, within the 2008-2015 interval, there were no papers related to blockchain–SCM integration. The first such papers were published in 2016, focussing on the US and China. These countries are leaders in investments related to Industry 4.0.

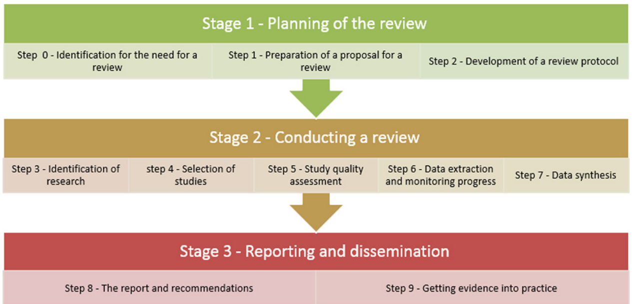
In this regard, the US and China together were responsible for 40 per cent of the total of papers related to blockchains applied in a supply chain context. As pointed out previously, the US and Chinese governments have invested heavily in Industry 4.0 overall. Because of this, scholars and practitioners were able to apply the blockchain concept, beyond bitcoin applications, to strategic areas focussing on improvements in

Table I Research protocol

Research protocol	Details description
Research various databases	Scopus is one of the largest databases of peer-reviewed scientific journals, books, and conference proceedings, with 22,600 titles. Additionally, searches were performed in other leading databases: ScienceDirect (Elsevier); Emeraldinsight (Emerald); Wiley Online Library (Wiley); Taylor & Francis Online (Taylor & Francis); Sagepub (Sage Journals); IEEE Xplore Digital Library (IEEE); and Springer Link (Springer)
Publication type	Only peer-reviewed journals were considered
Language	To generate a wide coverage, only papers published in the English language were considered
Date range	The search was performed for a period of almost 11 years (2008 – February 2018)
Search fields	Titles, abstracts and keywords
Search terms	(TITLE-ABS-KEY(blockchain)ANDTITLE-ABS-KEY(supply ANDchain)ORTITLE-ABS-KEY(logistics)ORTITLE-ABS-KEY(manufacturing)ORTITLE-ABS-KEY(transportation)ORTITLE-ABS-KEY(purchasing)ORTITLE-ABS-KEY(smart ANDcontracts)ORTITLE-ABS-KEY(suppliers)ORTITLE-ABS-KEY(green ANDsupply ANDchain)ORTITLE-ABS-KEY(sustainability)ORTITLE-ABS-KEY(environment)ORTITLE-ABS-KEY(production ANDsystems)ORTITLE-ABS-KEY(industry4.0)ORTITLE-ABS-KEY(iotORinternet ANDof ANDthings)ORTITLE-ABS-KEY(cpsORcyber ANDphysical-systems) ORTITLE-ABS-KEY(bdaORbig ANDdata)) The results were organised in a spreadsheet and duplications removed
Inclusion criteria	Only papers that presented a blockchain application or a relevant discussion in the SCM/logistics field were included
Exclusion criteria	Regarding the relevance to the research topic and strength of the argument, papers focussing only on technical aspects, or bitcoins discussion, financial market focus, banking, fintechs, etc., were excluded
Data extraction and monitoring process	The monitoring process was supported by the qualitative data analysis software MAXQDA version 2018, in which categorisation of the previous studies was performed
Data analysis and synthesis	We used a content-analysis approach to answer the research questions from literature, highlighting the main gaps and suggesting avenues for future research in hot topics within blockchain applications in the SCM field

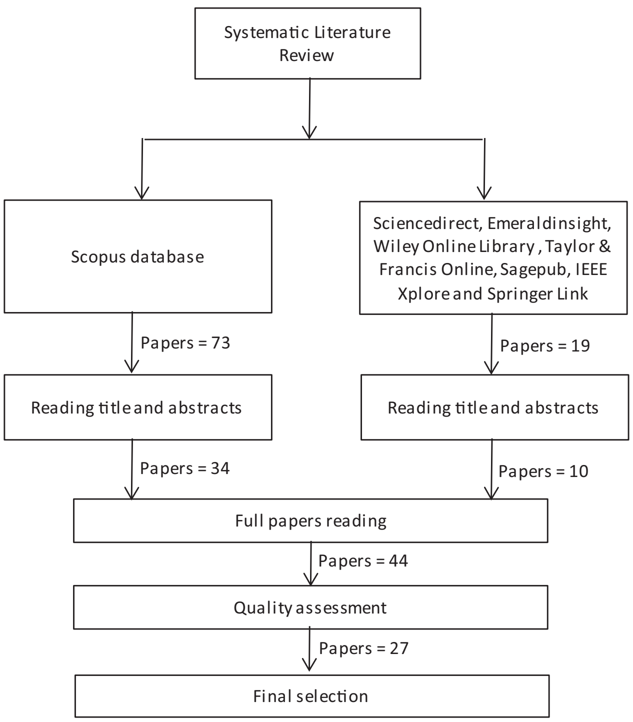
Source: Based on Alexander *et al.* (2014) and Pereira *et al.* (2014)

Figure 3 Main steps to conduct systematic literature reviews



Source: Tranfield *et al.* (2003)

Figure 4 Schematic representation of the systematic review process



Note: Adapted from Pereira *et al.* (2014)

Table II Categories for content analysis

Category	Explanation/example
Total number of papers published between 2008 and February 2018	Number of publications by year
Journal	Papers published by the journal
Blockchain application area	Supply chain, electric-power industry, transportation, etc.
Blockchain application context	Main context of the blockchain approach
Main technologies	Blockchain, IoT, CPS, etc.
Main theoretical approach	Conceptual, review, frameworks development, etc.

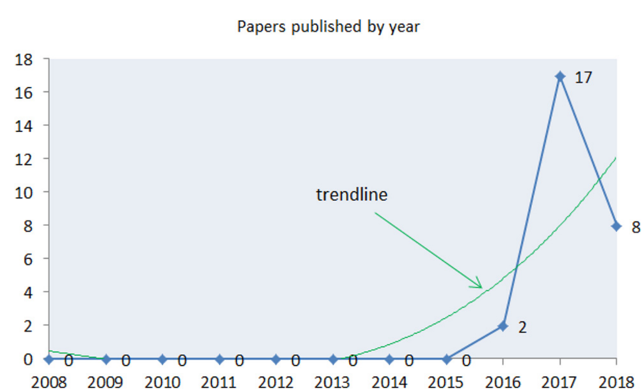
Table III Participation by country in blockchain–SCM publications between 2008 and February 2018

Country	2008-2015	2016	2017	2018 (to February)	(%)
US	–	1	7	2	23.81
China	–	1	4	2	16.67
United Kingdom	–	–	2	1	7.14
Germany	–	–	1	2	7.14
Singapore	–	–	1	1	4.76
Australia	–	–	3	–	7.14
Pakistan	–	–	–	1	2.38
United Arab Emirates	–	–	–	1	2.38
Finland	–	–	1	–	2.38
Hong Kong	–	–	–	1	2.38
Greece	–	–	1	–	2.38
Italy	–	–	–	1	2.38
Romania	–	–	–	1	2.38
Austria	–	–	1	–	2.38
South Korea	–	–	1	–	2.38
Latvia	–	–	1	–	2.38
Canada	–	–	1	–	2.38
Netherlands	–	–	1	–	2.38
Norway	–	–	1	–	2.38
Japan	–	–	1	–	2.38

Notes: In the 2008-2018 (February) interval, several papers addressing blockchain technology were published within diverse contexts, especially in bitcoins. We accounted for all the countries according to authors' affiliation (e.g. a paper with an author from China and a co-author from the US was considered twofold)

productivity and, consequently, increased competitiveness. Germany, however, another pioneer of Industry 4.0, was responsible for only 7.14 per cent of the papers retrieved. When we consider the analysis based on continent, European and Asian researchers both participated in 33.33 per cent of the papers, North American authors 26.19 per cent (the US with 23.81 per cent), and finally, Oceanian authors 7.14 per cent. Unfortunately, no papers from either Latin America or African institutions were found. Figure 5 presents the papers by year of

Figure 5 Summary of papers published by year



Note: The systematic literature review covered 2008-2018 up to February publication. As previously stated, the present study considered only papers concerning blockchains applied in an SCM context. It is possible to recognise a growing trend of publications in coming years.

4.2 Papers published by journal

Table IV organises the papers according to the journal and their respective impact factor (*Journal Citation Reports – JCR*). The *Applied Energy* journal was responsible for 11.54 per cent of the publications, followed by *IEEE Access*, with 7.69 per cent.

Applied Energy and *IEEE Access* were, together, responsible for approximately 20 per cent of the papers retrieved. It is also important to highlight the high impact factor of these journals (7.182 and 3.244, respectively). Of the 24 journals identified in this SLR, only six journals did not have an impact factor. The content from the 24 journals was distributed in different areas, including multidisciplinary, energy, information systems, computer systems, telecommunications, medical sciences, industrial management and others. Information technology and energy journals dominated the list, followed by medical sciences. Surprisingly, the SLR did not identify papers from top SCM/logistics journals, nor from top business-management journals. This fact suggests that this subject is still in the early stages of study.

4.3 Blockchain studies' categorisation

To gain an in-depth understanding of blockchains applied to different supply chain approaches, Table V shows the blockchain categorisation by application area, application context, main technologies and main theoretical approach. Papers from the electric power industry represented 25.93 per cent of the publications, suggesting that the learning curve of this area is optimised. The next-highest represented area was blockchain applications to improve security (e.g. the Internet of things [IoT] and cyber-physical systems [CPS] communications), representing 18.52 per cent of the papers. Traditional applications in the SCM field (e.g. supply chain distribution) accounted for 18.52 per cent of the articles. Transportation, a traditional area of SCM and logistics, represented 11.11 per cent of the publications, but these papers were focussed mainly on intelligent transportation-systems applications.

From the main technology perspective, the most popular combination of blockchains with other technologies was with IoT and CPS, suggesting that there are important integration and adherence with Industry 4.0. Furthermore, blockchains can be considered an Industry 4.0 component. While most scholars believe in the potential of blockchain–IoT integration (Khan and Salah, 2018; Kshetri, 2017a) and its impact on various business models' transformation, e.g. by improving supply chain security, Marsal-Llacuna (2018) reported that models based on blockchain–IoT integration were unfeasible, mainly because of the computational efforts and costs involved in performing real-time processing.

Surprisingly, the SLR did not find strong integration between blockchains and big data analytics (BDA). It is also important to note that, in a theoretical approach, to the best of our knowledge, there are no empirical studies reporting blockchain–BDA integration in the supply chain field. Additionally, the majority of approaches were related to proposing frameworks and conceptual studies.

Table IV Journals and number of papers published

Journal	Papers	Impact factor (2016)
Applied Energy	3	7.182
IEEE Access	2	3.244
Strategic Change	1	–
Journal of Intelligent Information Systems	1	1.294
IT Professional	1	1.661
Future Generation Computer Systems	1	3.997
Peer-to-Peer Networking and Applications	1	1.262
Telecommunications Policy	1	1.526
Expert Opinion on Drug Safety	1	3.439
Computer Science – Research and Development	1	–
International Journal of Information Management	1	3.872
IEEE Communications Magazine	1	10.435
Journal of Information Processing Systems	1	–
IEEE Internet of Things Journal	1	7.596
Journal of Medical Systems	1	2.456
IEEE Transactions on Industrial Informatics	1	6.764
Sensors	1	2.677
Industrial Management & Data Systems	1	2.205
Symmetry	1	1.457
Information	1	–
Transport Problems	1	–
Intelligent Systems in Accounting, Finance and Management	1	–
International Journal of Energy Research	1	2.598
IEEE Software	1	2.879

5. Discussion

Drawing on our main findings, the following sub-sections address the three *RQ*s.

5.1 *RQ1*. What are the main current blockchain applications in SCM?

Based on the research results, only 27 papers that addressed blockchain–SCM integration were identified over almost 11 years. Thus, it can be seen that research dealing with blockchain–SCM integration is still at the incipient stage. Among the limited number of peer-reviewed publications, however, different and significant applications were discovered. For instance, we identified various specific segments such as transportation, the electric power industry, security improvement, traditional SCM (distribution), education, smart-contract transactions, governance, emissions trading, healthcare systems and business information.

The electric power industry is a sector with relative expertise in blockchain applications (Hou *et al.*, 2018; Kang *et al.*, 2017; Mengelkamp *et al.*, 2018a, 2018b; Pop *et al.*, 2018; Sikorski *et al.*, 2017; Zhang and Wen, 2017). Based on a traditional bitcoin model, smart grids offer a decentralised market in which prosumers (energy producers and consumers at the same time) can negotiate with other consumers without any intermediary stakeholder (Mengelkamp *et al.*, 2018b; Pop *et al.*, 2018).

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Table V Findings organised according to blockchain categorisation

Authors	Blockchain application area	Blockchain application context	Main technologies	Main theoretical approach
Wu *et al.* (2017)	Supply-chain distribution	Supply-chain visibility supported by blockchains, using a shipment tracking framework in physical distribution	Blockchain	Framework
Mackey and Nayyar (2017)	Pharmaceutical supply chain	To combat the global trade in fake medicines with blockchain applications	Blockchain, Mobile, RFID	Review
Dorri *et al.* (2017)	Automotive security and privacy	Vehicular ecosystem security enhancement with a blockchain architecture to protect the privacy of the users	Blockchain, Wireless remote software	Framework
Gromovs and Lammi (2017)	Education	To generate innovation with blockchains and IoT in the field of logistics education	Blockchain, IoT	Conceptual
Pop *et al.* (2018)	Smart energy grids	Using blockchain tools in the energy sector, responding to the demand for distributed energy prosumers, generating transparent, secure, reliable, and timely energy flexibility for all the stakeholders	Blockchain, IoT	Framework
Sikorski *et al.* (2017)	Electricity market and chemical industry	Blockchain and M2M application in the electricity market in the chemical industry,	Blockchain, M2M, IoT	Conceptual
Lei *et al.* (2017)	Intelligent transportation systems	Blockchain-framework development to generate secure key management in a heterogeneous network of intelligent transportation systems	Blockchain, CPS	Framework
Christidis and Devetsikiotis (2016)	Smart contracts	To provide an example of how smart contracts work in several areas, including SCM and blockchain–IoT combinations	Blockchain, IoT	Conceptual
Kshetri (2017a)	Blockchain security in supply chains	The importance of blockchains in tracking supply-chains sources of insecurity in IoT devices	Blockchain, IoT	Conceptual
Sharma *et al.* (2017)	Vehicle network and smart cities	Considering the smart city, the authors proposed a vehicle network architecture based on blockchains	Blockchain, IoT	Framework
Kshetri (2017b)	Security in the supply chain	Supply-chain networks' security enhancement with the integration of blockchains and IoT	Blockchain, IoT	Conceptual
O'Leary (2017)	Blockchain architectures for transactions	Different blockchain architectures for processing transactions in different settings	Blockchain, ERP, Data warehouse	Conceptual
Mengelkamp *et al.* (2018a)	Microgrid energy markets	Designing microgrid energy markets with blockchain applications	Blockchain	Framework, Case study
Shermin (2017)	Governance disruption	Demonstration of the governance disruption with blockchains and smart contracts	Blockchain	Use cases
Kang *et al.* (2017)	Electricity-trading model	Trading-model development for buying and selling electricity in hybrid electric vehicles in smart grids	Blockchain	Conceptual
Khaqqi *et al.* (2018)	Emissions-trading-scheme management	Blockchain application to solve emissions-trading-scheme management and fraud issues	Blockchain	Multi-criteria analysis, Case study, "Model proposition"
Khan and Salah (2018)	IoT security problems	Blockchains applied to solve IoT security issues	Blockchain, IoT	Review
Yin *et al.* (2017)	CPS security problems	Blockchains applied in M2M communication security enhancement in a CPS environment	Blockchain, M2M, CPS	Conceptual, Case study

(*continued*)

Table V

Authors	Blockchain application area	Blockchain application context	Main technologies	Main theoretical approach
Zhang and Wen (2017)	IoT electricity-business model	IoT electricity-business model supported by blockchains with smart contracts	Blockchain, IoT	Conceptual, Case study
Li *et al.* (2018)	Framework for a secured network	Proposed a framework with blockchains and edge computing to support an open, decentralised, and secured network	Blockchain, Edge computing	Proposed Framework, Case study
Yue *et al.* (2016)	Healthcare systems	App development based on blockchains for patient control and sharing of their data easily, as well as enhancing the healthcare systems' security	Blockchain	Conceptual
Engelenburg *et al.* (2017)	Business information	Blockchain software architecture for information sharing between government and organisations	Blockchain	Design science, Case study
Kshetri (2018)	SCM	Blockchain investigation from the SCM perspective, considering cost, quality, speed, dependability, risk reduction, sustainability, and flexibility	Blockchain, IoT	Case study, Theory-building
Hou *et al.* (2018)	Photovoltaic energy	Applying blockchain technology to promote the development of distributed photovoltaic energy in China	Blockchain	Conceptual
Toyoda *et al.* (2017)	Anti-counterfeiting	Proposes a blockchain-management system in the anti-counterfeiting context	Blockchain	Conceptual/algorithmic
Mengelkamp *et al.* (2018b)	Energy trading	Blockchains used in the smart grid to provide energy prosumers and consumers with a decentralised market platform	Blockchain	Conceptual/simulation
Lu and Xu (2017)	Product traceability	A case study reporting a blockchain product-traceability system's characteristics	Blockchain	Case study

From this perspective, the electric power industry can be considered an essential example blockchain–SCM integration and the results from the present study suggest that it should be a benchmark for scholars and practitioners interested in gaining an in-depth understanding of the main blockchain mechanisms and the disintermediation provided by the smart-contracts approach. Moreover, in the electric power industry, and in other sectors that are using blockchain applications, smart contracts constitute a significant blockchain application for cost reduction, tracking, visibility and security enhancement (Christidis and Devetsikiotis, 2016; Shermin, 2017; Zhang and Wen, 2017).

Therefore, blockchain technologies have the capacity and flexibility to be applied to different SCM contexts. For instance, tracking and providing visibility through the entire supply chain optimises the information flow and generates cost reduction (Wu *et al.*, 2017). In this context, Wu *et al.* (2017) proposed an interesting framework based on blockchains to support peer-to-peer shipment-tracking information for suppliers and customers to improve the supply chain physical-distribution visibility.

Another important example of blockchain–SCM integration was found in the pharmaceutical supply chain. Mackey and Nayyar (2017) concluded that blockchains could improve the supply chain information sharing, making SCM more trustworthy and secure. Consequently, it could strengthen procedures for detecting fake medicines in global trade.

Blockchains offer a way to face the challenge of protecting and improving security in intelligent transportation systems (Dorri *et al.*, 2017). Blockchain technology can strengthen IoT and CPS security, both leading Industry-4.0 technologies, resulting in improvements in smart objects and machines security (Khan and Salah, 2018; Kshetri, 2017a, 2017b; Yin *et al.*, 2017), consequently improving security in the entire supply chain. Hence, we can assert that the areas both of intelligent transportation systems and IoT/CPS in the Industry-4.0 context have adopted blockchain applications to improve the SCM security.

5.2 *RQ2*. What are the main disruptions and challenges in SCM because of blockchain adoption?

This study revealed that traditional SCM had been reconfigured. As pointed out previously, blockchain–SCM integration can be considered a disruptive technology that will impact the entire network from a global perspective. For example, based on our findings, disintermediation resulting from smart-contract adoption will increase in the coming years (Christidis and Devetsikiotis, 2016). Consequently, smart contracts will contribute to several SCM improvements such as improved responsiveness, lead-time reduction, transaction-costs reduction, increased visibility and more trust, security and transparency in the network.

Furthermore, innovative changes in goods traceability (Wu *et al.*, 2017) will improve network transparency, dramatically reducing the costs of monitoring processes. Therefore, the impacts will be perceived in various SCM spheres, for instance, insurance costs will be significantly mitigated. Following these traceability disruptions, the ability to combat counterfeiting (Toyoda *et al.*, 2017) and fake drugs (Mackey and Nayyar, 2017) will be significantly improved in the coming years.

As an example of this trend, blockchain–SCM integration is bringing the new business models to the electric power industry, where the distribution models are becoming disrupted because of market decentralisation (Mengelkamp *et al.*, 2018b) that relies on smart contracts. Additionally, we believe that the "consumer/prosumer" trade model will be increasingly adopted in other industry sectors (e.g. agriculture, furniture, fishing, education and others).

5.3 *RQ3*. What is the future of blockchains in SCM?

Based on the findings illustrated so far, it is possible to affirm that blockchain–SCM integration will be disseminated both in academic and practical contexts. This study's findings suggest that there are industries with significant expertise in this integration (e.g. the electric power industry, intelligent transportation systems, healthcare systems, and CPS and IoT applications). The blockchain–SCM applications in these industries can be considered benchmarks for other industries.

However, our results showed that there is an essential gap in the literature regarding blockchain–SCM integration in emerging economies. For instance, there were no studies from Latin American and African institutions. The fact that blockchain–SCM applications are in initial stages in these countries' industries could be one of the reasons for limited awareness about the relevance, development, implementation, and benefits associated with this trend. This condition suggests another issue: workers' skills will be critical in enabling blockchain–SCM integration.

Finally, future blockchain–SCM integration will transform relationships not only in business-to-business contexts, but also in business-to-customer and customer-to-customer contexts. Blockchain–SCM integration is, therefore, a cutting-edge technology that is still in its early stages. However, the disruptive effects on the supply chain are being seen already. Consequently, our current business models could soon be outdated.

6. Managerial implications

This study has important implications for managers, practitioners, consultants and decision makers interested in a deeper understanding of blockchain applications in the SCM field. In this context, blockchains are already generating several paradigm-disruption effects on supply chains around the world. For instance, blockchains are remodelling the follow-up concepts with tracking enhancement in supply chains. Consequently, real-time visibility (Wu *et al.*, 2017) can be considered an important benefit to SCM.

Another blockchain-related disruption is the contribution to decentralised operations, as observed in the electric power industry, in which there is no intermediary to regulate prosumer–consumer transactions, as they are carried out via smart contracts. This condition represents a crucial disruption in this traditional sector that has the potential to be implemented in others. Moreover, blockchains can improve IoT and CPS operations, improving devices and machines' security. Also, smart contracts will benefit the factories and their networks by reducing transaction costs (Christidis and Devetsikiotis, 2016). Thus, smart contracts have the potential to disrupt traditional governances models (Shermin, 2017), providing cost optimisation, security and visibility.

Therefore, based on the main findings, SCM professionals will be challenged to rethink their strategies to incorporate blockchains in their businesses. We believe that the electric power industry, intelligent transportation systems, and healthcare systems represent potential benchmarks. Additionally, in the Appendix, we provide practical examples of, and references to, practitioners gaining an in-depth understanding of blockchain applications in the SCM/logistics field.

7. Research implications and future research

From the academic perspective, this study offers essentials insights to scholars interested in advancing these hot topics. Blockchain applications can be used in any supply chain context. Thus, as highlighted in Figure 5, we expect a growing trend in publications on this subject in the short term. Consequently, this represents an interesting agenda for future research. As an important contribution, we propose an articulated and consistent agenda for future research. Table VI presents the proposed research agenda on blockchain–SCM integration.

Our study revealed that there is a scarcity of empirical studies reporting on the implementation lessons and the main challenges. Also, as reported in Table III, emerging economies are underrepresented compared to developed countries in terms of publications. To overcome this, we suggest research directed to understanding the current level of maturity blockchain–SCM integration and the mapping of the main difficulties. Additionally, empirical studies reporting different perspectives of blockchain applications in different supply chain contexts is a potential topic. Table VI highlights the necessity of understanding: the main blockchain capabilities required by organisations for implementation; and the effects on supply chain performance if only a few members implement blockchain application (e.g. smart contracts).

8. Main contributions

This study makes several significant contributions, including theoretical advances related to blockchain–SCM integration. In the following subsections, the main contributions, in three areas, are emphasised.

8.1 Methodology

From a methodological perspective, because of the novelty, the most common approaches found in the literature were conceptual, framework proposals and case studies. Consequently, methods reporting analytical modelling and operations research (mathematical optimisation, simulation, decision analysis, queueing theory, multiple-criteria decision analysis, among others) represent relevant fields and opportunities for future studies on blockchain–SCM integration. Another significant gap from the methodological perspective relates to the paucity of studies employing a quantitative empirical approach. Relevant advances in understanding can be developed by using surveys as a

Table VI Agenda for future research

Research gaps	Future study opportunities
Empirical studies reporting implementation benchmarks in organisations	To investigate the main best practices associated with blockchain implementation in different types of organisations
Empirical studies reporting challenges to implementation	To investigate the main challenges that are associated with implementation and to identify the main strategies used by organisations overcome the difficulties
Framework development	To propose frameworks for blockchain implementation in SCM
Blockchain capabilities	To investigate the capabilities required by organisations to implement and utilise blockchains in supply-chain operations
Smart contracts	To investigate new possibilities afforded by the use of smart contracts in SCM
Transaction costs	To investigate costs savings in organisations that implemented smart contracts
Governance disruption	To identify common disruptions in the supply chain. Did all companies that implemented smart contracts achieve a significant level of governance disruption?
Buyer and seller relationships	In a smart-contract environment, what are the roles of the buyer and sellers? Is there already an emerging reconfiguration?
Blockchain security	To identify the level of security provided by blockchains in supply chains. What are the main benefits?
Blockchain integration with BDA	To investigate the benefits and challenges of blockchain integration with BDA
Blockchains and green supply chain/ sustainable supply chain	To investigate the possible blockchain utilisation in the green supply chain/sustainable supply chain field. How can blockchains enhance the tracking and visibility of green suppliers?
Blockchain and anti-counterfeiting efforts	How can blockchains aid anti-counterfeiting efforts from a global trade perspective?
Blockchains in emerging economies	What is the level of maturity of blockchains in emerging economies? What are the main difficulties?
Blockchain integration with smart production systems	What is blockchain's contribution to smart production systems? What are the main elements of this integration? What are the benefits?
Blockchain–IoT integration	To investigate the enablers and feasibility of blockchain–IoT integration
Blockchain–CPS integration	To investigate the enablers and feasibility of blockchain–CPS integration
Blockchains and competitiveness	To identify gains in competitiveness of networks utilising blockchains

methodological route to understanding blockchain–SCM enablers, organisations' adoption behaviour, barriers and implementations benchmarks. Finally, from a qualitative perspective, it is necessary to promote studies with in-depth cases to understand particularities, mainly associated with implementation, post-implementation best practices and difficulties.

8.2 Supply chain management scope

From the scope perspective, the study identified the blockchain–SCM relationship within well-established SCM areas, e.g. SCM distribution, product traceability, intelligent transportation systems, and anti-counterfeiting efforts. Nevertheless, the literature reporting blockchain–SCM integration in other classic SCM topics is scarce, e.g. inventory and warehouse management, network modelling, vehicle routing problems, production/lot sizing, customer relationship management, procurement, quality, etc. One of the central roles of the SLR relates to supporting new-topic development, mainly through knowledge-gap mapping (Denyer and Tranfield, 2009). In this context, this study provided important contributions reporting the extant blockchain–SCM literature and the aforementioned SCM classic topics pertaining to blockchains.

8.3 Insights

From the insight perspective, blockchains represent a cutting-edge technology that promises to transform established business models. In this context, considering the contribution to the real world, blockchain technology is remodelling product safety, thanks to traceability improvements. Consequently, product provenance will impact positively on the quality of life and also reducing the healthcare system's costs. Environmental and social sustainability, and even social change, are areas already affected by blockchain applications. On this topic, for example, there is criticism related to the environmental costs of blockchain transactions related to the waste energy employed in the network. From a social-change perspective, blockchains are already remodelling the relationships between customers and organisations, as well as business-to-business relationships without an intermediary to validate the transaction (e.g. bitcoins and smart contracts). Finally, associated with the Industry-4.0 evolution, for the next few years, blockchains will continue significantly impacting traditional areas like manufacturing (e.g. blockchains and their integration with IoT, CPS, 3D printing, machine-to-machine interaction, etc.).

9. Final remarks and limitations

This study investigated the current state of blockchain applications in the SCM field. The literature review has used a systematic and interdisciplinary approach to discovering blockchain applications in the SCM context. The findings revealed, that although blockchain–SCM applications are still in their early stages, there are some areas with relevant accumulated knowledge in blockchain–SCM integration, e.g. the electric power industry (Mengelkamp *et al.*, 2018a, 2018b; Pop *et al.*, 2018), Industry 4.0 with IoT (Khan and Salah, 2018) and CPS security-problem improvement (Yin *et al.*, 2017).

Notably, our review revealed that developed countries dominate the blockchain–SCM literature (e.g. the US participated in 23.81 per cent of the papers, while UK and Germany participated in 7.14 per cent). However, the review retrieved no papers from Latin America or Africa. This has important implications for scholars and decision makers. First, there is a research opportunity to understand through empirical studies the maturity level and capabilities in these countries. Second, for decision makers, it represents an opportunity to gain an in-depth understanding of blockchain–SCM integration and to start projects in their organisations.

To scholars interested in blockchain–SCM integration, our selected journals list (Table IV) is important as an initial research source. However, this list does not contain blockchain–SCM papers in any supply chain/logistics-devoted top journal. This reveals an important gap and an opportunity for these journals in forthcoming editions. The trendline in Figure 5 shows that blockchain–SCM integration is a hot topic. Additionally, our SLR showed that the main theoretical approaches used in the papers were conceptual and frameworks propositions. This reveals avenues for scholars to use other methods and the necessity to develop empirical studies. From this perspective, we believe that this study makes essential contributions to blockchain–SCM integration literature. The first is a state-of-the-art representation of blockchain–SCM integration literature. The second draws attention to the need to develop more studies in emerging countries. The third is fact that blockchain–SCM integration is a hot topic, requiring the engagement of the top SCM/logistics journals. Finally, we provided a well-articulated agenda for scholars and practitioners interested in advancing this topic.

This study has some limitations, mainly related to the scarcity of blockchain–SCM integration literature in research journals and databases, most likely because of the subject novelty. Although this study used a broad list of keywords in leading research databases, we risk some important work not having been recovered owing to the dispersion in function of the employed keywords in this field. Another limitation is related to the fact this study did not consider "grey literature", i.e. the general non-academic literature (e.g. technical reports, newspapers, blogs and magazines) (Adams *et al.*, 2017b). Thus, the proposed agenda for future research represents an important attempt to overcome these limitations and advance the literature (Table AI).

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Appendix

Table AI Practical examples of the blockchain applications in supply chains

#	Case	Blockchain application	Reference
1	Maersk and IBM	Blockchain solution for shipping industry digitisation, in which millions of containers can be tracked easily, with more transparency provided by information sharing	www-03.ibm.com/press/us/en/pressrelease/51712.wss
2	Provenance	Blockchains applied to generate transparency in SCM, with traceability of certifications and proving the authenticity of the products in all stages of SCM	www.provenance.org/whitepaper
3	Carrefour	Blockchains used for the traceability of foods. The solution is using the free-range Carrefour Quality Line Auvergne chicken's traceability	www.carrefour.com/current-news/carrefour-launches-europes-first-food-blockchain
4	DHL	Blockchain solution for tampering and errors in the pharmaceutical supply chain	https://newsroom.accenture.com/news/dhl-and-accenture-unlock-the-power-of-blockchain-in-logistics.htm
5	Walmart and IBM	Blockchains for food safety, enhancing the traceability, transparency, data redundancy, and minimising the number of counterfeits	www-01.ibm.com/events/wwe/grp/grp308.nsf/vLookupPDFs/6%20Using%20Blockchain%20for%20Food%20Safe%202/$file/6%20Using%20Blockchain%20for%20Food%20Safe%202.pdf
6	JD.com	Blockchain Food Safety Alliance in China involving Walmart, JD.com, IBM and Tsinghua University	http://corporate.jd.com/whatIsNewDetail?contentCode=9u7uGE4FRrZlsy0SHVdQwg%3D%3D&pagePath=resources
7	Alibaba	Blockchains applied to track goods on the platform, in which more transparency can be generated for consumers	www.securingindustry.com/alibaba-launches-blockchain-initiative-for-t-mall-/s112/a7051/#.Wqwa0ujwaUk
8	Petroteq	Blockchain project with IoT integration for operations monitoring, information sharing and workforce optimisation	https://globenewswire.com/news-release/2018/03/13/1421548/0/en/Petroteq-s-PetroBLOQ-Announces-Capabilities-of-Blockchain-Based-Oil-Gas-Supply-Chain-Management-Platform.html
9	BITA – Blockchain in Transport Alliance	Forum with transportation experts to develop blockchain insights and solutions for the freight industry	www.penskelogistics.com/newsroom/2018_1_12_pl_gains_membership_in_bita.html
10	Port of Rotterdam	Blockchain Lab for the development of solutions for energy and logistics using blockchain technology	www.portofrotterdam.com/en/news-and-press-releases/port-authority-and-municipality-of-rotterdam-launch-blockchain-technology

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