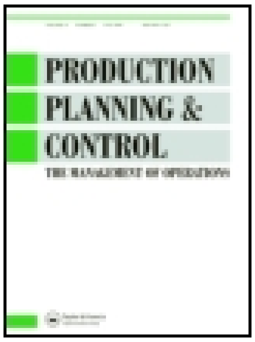

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# Exploring the potential of blockchain-enabled lean automation in supply chain management: a systematic literature review, classification taxonomy, and future research agenda

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# Exploring the potential of blockchain-enabled lean automation in supply chain management: a systematic literature review, classification taxonomy, and future research agenda

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**ABSTRACT**

The purpose of this study is to evaluate how Blockchain Technology (BCT) can support the implementation of Lean Automation. We conducted a systematic literature review to understand how BCT is being implemented in the supply chain management (SCM) domain and to evaluate how this technology can be used to reduce inefficiencies in supply chains. Firstly, we developed a holistic taxonomy of wastes to identify the most common non-value activities. Then, both inductive and deductive content analyses were performed, the latter being coded using the taxonomy. Our findings identified the most common BCT-based application themes in SCM and ways that this technology can be used to support future implementation of Blockchain-enabled Lean Automation (B-eLA). Additionally, we proposed a future research agenda. The study provides important contributions at the intersection between BCT, lean production, and Industry 4.0 within the context of SCM and seeks to exploit BCT's potential to improve businesses' efficiency, effectiveness and productivity.

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Blockchain technology; lean automation; supply chain management

## 1. Introduction

Over recent decades there has been a proliferation of approaches subscribed in SCM to improve supply chain (SC) performance (Arzu Akyuz and Erman Erkan 2010; Tarafdar and Qrunfleh 2017). Amongst these is Lean Production (LP), which has been widely explored and implemented by both scholars and practitioners alike (Chiarini and Brunetti 2019; Ali et al. 2017). LP is a socio-technical management system that focuses on adding value through the continuous identification and minimization of waste in operational processes (Potter 2022; Monden 2011). In general, waste is defined as non-value adding activities in an operational process that causes inefficiencies into the unremitting flow of work processes (Liker and Choi 2004). Non-value adding activities include tangible (solid) waste (e.g. manufacturing) and intangible waste (e.g. information flow) (Ufua, Papadopoulos, and Midgley 2018). Such consistent use of LP is because of the benefits it can entail including the ability to yield production efficiencies (productivity), allow the continuous improvement (kaizen) of operational activities and reduce costs (Lim et al. 2021).

In contemporary supply chains, firms have started adopting Industry 4.0 (I4.0) by deploying smart components and machines that are integrated into a common network based on well-proven internet standards (Tortorella, Narayanamurthy, and Thurer 2021). In this context, firms improve their operational efficiency and effectiveness through the implementation of autonomous technologies to streamline processes (Muller et al. 2019; Dalenogare et al. 2018). Thus, I4.0 has been acknowledged as a technological paradigm shift that can enable firms to achieve superior performance results (Ding, Ferràs Hernández, and Agell Jané 2021; Silvestri et al. 2020). The endorsement of I4.0 technologies entails the establishment of a highly interconnected and integrated organization, allowing modular and changeable production systems to produce highly customized products and services at a mass scale (Tortorella et al. 2021). Therefore, the effective employment of I4.0 technologies facilitates several operational aspects, such as manufacturing management (Fettermann et al. 2018), development of products and services (Dalenogare et al. 2018), and business model innovation (Nascimento et al. 2019).

Although having different approaches, LP and I4.0 are aligned by a shared general objective of reducing inefficiencies in operational processes. On the one hand, LP delivers its impact on supply chains through a systematic and continuous search for waste reduction and improvements (Jasti and Kodali 2014). On the other hand, enabling technologies pertaining to I4.0 introduces automation and interconnectivity to streamline activities (Fatorachian and Kazemi 2021; Bibby and Dehe 2018). It is evident that these two approaches introduce capabilities that can mitigate existing SC inefficiencies and lead firms to improved performance

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standards that are much greater than in the past. Thus, scholars and practitioners have begun exploring the integration of both approaches to realize the benefits of both domains (Chiarini and Kumar 2021). Its successful implementation enables lean automation (LA), which allows firms to achieve higher changeability and shorter information flows to meet future market demands (Kolberg, Knobloch, and Zühlke 2017). The concept of LA was initially conceived during the 1990s, but at that time its application was limited by technological capabilities (Johansson and Osterman 2017). However, with the advent of I4.0, the concept of LA has once again interested both practitioners and scholars due to its ability to improve SC performance.

Despite academic discourse delineating the potential of combining LP and I4.0 to achieve LA, literature discussing how it can be practically implemented is scarce (Tortorella et al. 2021). The main concern for its applicability refers to the development of a common and unified interface that synergies between LP practices and I4.0 technologies. Although some LA initiatives exist, these tend to treat LP and I4.0 as two distinctive dimensions that must materialize at different stages. Moreover, they are applied to specific industrial contexts, thus failing to contextualize how this integration could reduce waste generally across the entire supply chain. This has led to some scholars stating the need for a LA framework that specifically considers the synergies between LP practices and I4.0 technologies. In this sense, exploring innovative yet feasible ways in which LA can be enabled would help make strides towards effective implementation. One technology with the potential to facilitate LA is Blockchain technology (BCT), due to its ability to synchronize digital exchanges between distributed systems in a peer-to-peer manner. In the LA context, BCT can serve as a catalyst for interactions between the widely deployed technologies and systems, whilst also serving as a compatible tool for digitizing traditional LP practices.

Despite these claims, understanding how BCT can facilitate LA remains unclear. This is understandable given the immaturity of BCT application in supply chain management (SCM) and the novelty of the LA concept. Nevertheless, overcoming this knowledge gap is important since digital transformation poses strategic considerations and economic implications (De Giovanni 2020). Furthermore, the lack of studies conducted on the application of BCT in SCM, makes it more difficult to understand if an SC needs to implement the technology (Aslam et al. 2020). Consequently, scholars and practitioners are not fully aware of the potential of BCT to improve supply chains (Vu, Ghadge, and Bourlakis 2021; Lim et al. 2021). We argue that this is a meaningful research gap because it limits our understanding of how BCT can be applied to enhance traditional SCM practices and indicates the need to expand the research scope. However, to expand the research scope, it is important to first synthesize existing boundaries of knowledge. Some scholars like Queiroz et al. (2020), Gurtu and Johny (2019), Cole, Stevenson, and Aitken (2019), and Wang, Han, and Beynon-Davies (2019) have attempted to outline the boundaries of the research on the application of BCT for SCM through systematic literature reviews (SLRs). While these SLRs have contributed to the body of knowledge, they fail to consider how BCT transforms SC operations by reducing wastes. For instance, previous studies have highlighted how BCT enables transparency, trust, and data sharing. Cole, Stevenson, and Aitken (2019) and Fernández-Caramés et al. (2019) among SC partners without evaluating how these factors contributes to improving operational efficiencies and enabling lean practices.

To alleviate these critical research issues, we performed an SLR with the aims of understanding how BCT is being implemented in existing SCM studies and how the technology is being thought of to reduce inefficiencies and SC wastes. In this sense, we evaluate how BCT can enable LA implementation, in other words, B-eLA. Finally, we identified SCM areas that received little attention to help propose a future research agenda. In summary, the following three research questions were formulated:

RQ1—What are the applications of Blockchain for supply chain management, and in what ways does its implementation transform the existing supply chain environment?

RQ2—How has Blockchain technology been considered to minimize waste in supply chains and how can the technology facilitate Lean Automation?

RQ3—What gaps exist in the literature, and what may be done to contribute to future B-eLA research?

The rest of the paper is organized as follows: Section 2 provides a research background relating to I4.0, BCT, LP, and LA. In this section, we also present a taxonomy for the different types of wastes that can arise in supply chains and a discussion on how BCT can facilitate LA. The SLR protocol is described in Section 3 and the study findings appear in Section 4. Section 5 presents a discussion with a future research agenda. Section 6 offers a conclusion with the summary of findings, theoretical and practical implications, and research limitations.

## 2. Background

In this section, we conduct a brief overview of the literature on I4.0, BCT, LP, and LA. Following thus, we introduce our novel approach coined Blockchain-enabled Lean Automation (B-eLA), by introducing how BCT can facilitate LA implementation. We then present a taxonomy of wastes which was developed based on an extensive literature survey.

### *2.1. Industry 4.0*

SCM is experiencing significant changes due to the adoption of new digital technologies (Zhang et al. 2021; Calatayud, Mangan, and Christopher 2019). Advancements in innovations, such as Internet of Things (IoT), artificial intelligence (AI), and robotics are transforming the way SCs operate (Tjahjono et al. 2017). In this context, I4.0 refers to an online economy consisting of complex, interrelated digital technologies that share data for the provision of delivering value to all SC actors (Benitez, Ayala, and Frank 2020). In such an environment, traditional SCs evolve into SC ecosystems

(Ketchen, Crook, and Craighead 2014). This transforms SC relations from one whereby partners interact dyadically to develop solutions, to one where mutually engaged participants communicate and coordinate activities to achieve a common goal (Benitez, Ayala, and Frank 2020). Fundamentally, this reconfigures the dynamics of SC relationships from a transaction-based model towards a value creation approach (Xu, Xu, and Li 2018). To this end, I4.0 advocates a radical yet tangible socio-technical paradigm shift that assumes a fully digitized, complex system that integrates internal and external participants and processes.

The most reported I4.0 enabling technologies are cyber-physical systems (CPS), Radio Frequency Identification (RFID), IoT, AI, Wireless Sensor Network (WSN), Virtual/augmented reality, robots, additive manufacturing (3D printing), Big Data and analytics (BDA), cloud computing and BCT. Their successful employment can bring vertical integration of an enterprises' systems, horizontal integration in collaborative networks, and end-to-end solutions across the value chain (Zhang et al. 2021; Klingenberg, Borges, and Antunes 2019).

While the digital capabilities of I4.0 innovations will help to optimize existing SCM practices, a possible barrier to a fully automated system lies in the lack of synchronization between the different agents who deploy technologies heterogeneously across the SC. Among all these I4.0 technologies is BCT, which is receiving increasing attention due to its potential to transform almost all SCM business models, enhance end-to-end SC business process and thus improve SC performance (Wamba and Queiroz 2020).

### 2.2. Blockchain technology

The potential of BCT has led to an increasing interest in studying the technology for several SCM contexts (Gurtu and Johny 2019). For example, it has been investigated for transportation and logistics (Koh 2020), global trade (Chang et al. 2020), and humanitarian SCs (Dubey et al. 2020). Despite these recent advances, the research in BCT application in SCM is still in its infancy, particularly concerning its capability to streamline processes and create value. Focus has been given to its adoptability (Karamchandani, Srivastava, and Srivastava 2020; Kamble, Gunasekaran, and Arha 2019), and to its traceability features (Behnke and Janssen 2020; Kamble, Gunasekaran, and Sharma 2020).

Developed by the pseudonymNakamoto (2008), the BCT gained popularity as the technology behind the bitcoin protocol. In a blockchain system, exchanged data is aggregated in cryptographic blocks and broadcasted across the network (Wu, Fan, and Cao 2021). This creates an endless chain of data blocks that allows transactions to be traced and verified at any moment (Xu et al. 2021). A successful verification results in an additional block being added to the chain of blocks (Casino et al. 2021). Once transactions have been recorded and certified within one of the data blocks, it becomes immutable and cannot be modified or tampered with (Swan 2015).

Dependent on the type of access mechanism, the BCT can be broadly categorized as permissionless, permissioned, and hybrid. Permissionless BCTs are open for anyone to join and interact with as no permission is required to become part of the network and contribute to its upkeep. Permissioned BCTs requires users to be invited to participate in the network by an authorized gatekeeper. The best way to describe hybrid versions is as a permissionless BCT that is hosted on a permissioned networked. In this kind, the permissionless characteristic is employed to make the ledger available to every single person, with the permissioned aspect functioning it the background to control access to the modifications in the system. It is also worth noting that BCT offers several unique attributes that goes far beyond simply providing an infrastructure that supersedes intermediary activities, such as automation, immutability and encryption, disintermediation, customer centricity, and data access control (Yadav et al. 2020).

According to Swan (2015), the founder of the Institute for Blockchain Studies, the development of BCT has generated three major evolutionary phases commonly referred to as Blockchain 1.0, 2.0, and 3.0. Blockchain 1.0 refers to the evolution of currency and digital payment systems, such as cryptocurrencies like Bitcoin. Blockchain 2.0 saw the implementation of smart contracts to provide transparency and ensure trust between participants in the network. Blockchain 3.0 focuses on the application of BCT in non-financial contexts, such as in government, healthcare, and SCM (Frizzo-Barker et al. 2020).

### 2.3. Lean production and lean automation

Originating in Japan in the 1960s with the Toyota Production System (TPS), and later adopted in the Western world in the 1990s under the term lean manufacturing (LM), the LP paradigm has become the major approach for simultaneously creating highly efficient operational processes and enhancing SC performance.

Following the wide-spread diffusion of LP, many firms have seen positive progress in their financial, operational, and environmental performances (Negrão, Godinho Filho, and Marodin 2016). In contrast, a small number of organizations have struggled with its implementation, and in some cases abandoned the approach completely (Liker and Convis 2011; Mann et al. 2009). A number of reasons for ineffective implementation have been cited in the literature, including but not limited to; poorly planned and executed implementation strategies (Henao, Sarache, and Gómez 2019), insufficient lean-oriented training and knowledge of employees (Adam, Hofbauer, and Stehling 2021) and cultural issues (e.g. willingness to change and organizational culture for change) (Belhadi, Touriki, and El Fezazi 2018). Effective LP implementation is difficult to achieve and typically involves the deployment of multiple tools and practices (Ghobadian et al. 2020).

The view that technology and LP are incompatible has been ubiquitous in both academia and industry for a long time (Pinho and Mendes 2017). This understanding can be traced back to the reflections of Sugimori et al. (1977), who claimed that using computerized systems for material planning increases cost, reduce transparency, and leads to overproduction of goods. In its purest form, LP is technology-independent and is not reliant on its application to perform associated activities. Instead, LP utilizes decentralized control by giving local autonomy to the people interacting with the system (Buer et al. 2021). The fundamental purpose of this is that if an issue arises, it can be managed instantly by the people, preferably by taking care of the root cause of the problem. In contrast, many traditional technologies function in a centralized manner, typically creating 'a single version of truth' (Buer et al. 2021). This could lead to further problems for two main reasons: (i) the adopted technology could create an inaccurate perception concerning the realities of a particular situation, and (ii) due to the complexity and rigidity of traditional technologies it can be extremely difficult to make adjustments to the system to continuously improve, which could subsequently encourage workarounds rather than solving the root cause of the problem.

The adoption of technologies to support automation in LP is aligned with the concept of Jidoka and has been detailed in the above section. With the advancement of I4.0 enabling technologies, a four generation of Jidoka has begun to emerge, characterized by diverse software and hardware components capable of early detection and diagnosis of a problem, and in some cases correcting it before it actually occurs (Romero et al. 2019). Traditionally, firms, such as Toyota, who implement Jidoka are generally denoted by the use of low-cost automation gadgetry, also commonly known as karakuri technologies (Tortorella, Narayanamurthy, and Thurer 2021).

Karakuri technologies are mechanical devices that utilize natural physical phenomena, such as gravity force, wind, and electromagnetic power to assist in accomplishing a given task. These devices assist tasks with limited or no hydraulic, pneumatic, or electric power sources, and are instead usually aided by elemental mechanisms (e.g. human muscle, kinematics, gears, counterweights) to manipulate objects. In this context, these technologies are controlled by the design of the mechanics, rather than by a computer. Nonetheless, it can allow environmental-friendly operations, work-load mitigation, operational simplification, and ease of maintenance (Murata and Katayama 2010). Despite Karakuri technologies proving effective, adopting more advanced, high-technology solutions can improve existing Jidoka solutions and even provide new ones.

### 2.4. Blockchain-enabled lean automation (B-eLA)

The introduction of CPS and other key I4.0 technologies enable distributed computing that is not typically found in traditional centralized systems. This corresponds with traditional lean production, which because of the resource intensity of operationalization, should avoid a centralized hierarchy in favour of a linked, decentralized structure (Zuehlke 2010). Thus, this suggests that both I4.0 and LP are capable of functioning well under decentralized control. Decentralization enables different modules to work independently and autonomously, while simultaneously remaining aligned to the ultimate organizational goal (Gilchrist 2016). Systems profit from decentralization thanks to the simplified planning and coordination of different processes. For example, the synchronization of eKanban with the components of a smart warehouse (e.g. automated guided vehicle or RFID tagged robots) can significantly reduce the complexity of central planning by providing the freedom of decision making (Ghobakhloo 2018). As decentralized structures integrate many processes, such a structure relies on interoperability to facilitate communication, cooperation, and coordination among these processes (Vernadat 2007). Therefore, an infrastructure that facilitates such an environment is a critical success factor for high-performing LA.

BCT is a key enabler for decentralization and its features are proven to enable interoperability between distributed systems. In its broadest sense, the BCT is rooted in the philosophy of using open source, open verified code where data management, transaction, monitoring, and rules of engagement happen in a decentralized manner across multiple nodes (Zutshi, Grilo, and Nodehi 2021). What sets BCT apart from other I4.0 technologies is its ability to provide a digital infrastructure for hitherto disconnected and untrusting agents to communicate in a peer-to-peer manner. The integrity of the network can be secured through a distributed consensus mechanism, which is an advanced cryptographic technique that allows involved participants to reach agreement about the true state of shared data. One of the most used consensus mechanisms is the Proof-of-Work (PoW) protocol adopted in the Bitcoin system. The transparent nature of the technology allows unrestricted traceability of transactions performed within the LA system. As data is ensured through cryptographic proof, untrusted agents can directly interact with each other in real-time, without the need for a trusted third party. Due to the absence of a trusted third party, associated transaction costs can be reduced or even eliminated.

### 2.5. A holistic taxonomy of waste

Before commencing the analysis of the selected scholarly papers, it is necessary to describe the framework of taxonomy which will be used to analyze the studies and assist future research. Therefore, in this section, the need for a taxonomy of wastes is demonstrated, along with the methodology adopted to construct the proposed model. A taxonomy is a particular classification of the literature that expresses the existing similarities of scientific publications in a comprehensive manner (Rich 1992). The proposed taxonomy aims to provide a clear and comprehensive framework that captures the core wastes that both manufacturing and service industry firms' may commonly encounter within their organizations.

LP is characterized as initiatives that focus on adding value through the identification and reduction of waste in SC processes. Hence, the term waste is frequently used among scholars and practitioners in the lean literature. Although there is a consensus that waste arises as a consequence of non-value adding activities, a closer look at the literature demonstrates inconsistencies concerning the definition of the different types of waste and what related non-value adding activities contribute to its generation (Gopinath and Freiheit 2012). From this brief discussion, it becomes apparent that there is a plethora of interpretations used to understand the different wastes. A coherent understanding of the different wastes is important as if it is conceived differently it will affect comparability and restrict the use of findings for operational practice (Johansson and Osterman 2017). Moreover, it becomes difficult to identify wastes and detect them back to their root cause without a structured schema (Braglia, Gabbrielli, and Marrazzini 2019).

While a few classification schemes have been proposed in the literature to remedy this research problem, they generally focus on one specific type of waste. For example, Ohno (1988) taxonomy of the seven types of wastes in the Toyota Production System deduces waste in line with the interpretation proposed in the manufacturing context. Despite such taxonomies providing a solid foundation for understanding waste, a holistic classification scheme is required to capture a multiplicity of wastes and their associated non-value adding activities. Considering waste transpires at all stages in the life cycle, a more general framework will help researchers understand waste within a variety of processes and support firms to improve their SC performance (Purushothaman, Seadon, and Moore 2020).

The proposed taxonomy (Table 1) was constructed, deployed, and validated through a two-stage procedure: (i) intelligence and (ii) conception (Moreira, Moita, and Panão 2010). The methodological process adopted to design this model is akin to those used by Cherrafi et al. (2019). The intelligence step consisted of performing a comprehensive literature survey to assemble appropriate works which discuss waste in the lean context. The conception stage involved the construction and validation of the proposed classification taxonomy. To facilitate the construction of the taxonomy, a concept map was used to depict the meaningful relationships in the studies amassed from the literature survey, and to identify the respective wastes associated non-value adding activities.

## 3. Systematic literature review protocol

In this section, we discuss the methods adopted in our work. In summary, the protocol employed to conduct the

**Table 1.** Holistic taxonomy of waste.

| Waste | Definition | Examples | References |
|---|---|---|---|
| Operations waste | Operations waste are inefficiencies that arise throughout the entire flow of material. | 7 types of wastes (overproduction, waiting, transportation, over-processing, inventory, movement, and defect); making-do (when a task is started without all necessary inputs) | Ohno 1988; Formoso et al. 2017; Koskela 2004 |
| Information Management waste | Efficient information management can provide steady advantage to generate financial and economic benefits, only if the information flow is accurate, updated, and complete | Flow excess (time and the resources that are necessary to overcome excessive information); flow demand (time and resources spent trying to identify the information elements that need to flow); failure demand (resources and activities that are necessary to overcome a lack of information; flawed flow (resources and activities that are necessary to correct or verify information). | Hicks 2007; Invernizzi, Locatelli, and Brookes 2018; Redeker, Kessler, and Kipper 2019 |
| Environmental waste | Environmental waste is the excessive or unnecessary use of substances or resources released into the water, air, or land that could harm human health or the environment. | Eight green manufacturing wastes (greenhouse gases, eutrophication, excessive resource usage, excessive power usage, pollution, rubbish, excessive water usage, and poor health and safety) | Fercoq, Lamouri, and Carbone 2016; Hines 2009; EPA US and SPNSP Network 2007 |
| Human health | This refers to the safety and well-being of people involved in a firms' SC processes. | Unsafe work environments; human-rights violations; exposure to toxic waste | Purushothaman, Seadon, and Moore 2020; Akbar and Ahsan 2019; Gonzalez-Padron 2016 |
| Governance waste | Governance waste refers to inefficiencies in the economic exchange among firms and their associated organizations | Bureaucracy; poor internal and external communication structures; delays in task completion from external agencies (e.g. consultants) | Burkert, Ivens, and Shan 2012; Yadlapalli, Rahman, and Gunasekaran 2018; Purushothaman, Seadon, and Moore 2020 |
| Technology waste | Technology waste occurs as a result of deficiencies in technological systems. | Hardware faults; software bugs; programming defects; connectivity issues; improper infrastructure; security threats | Bhattacharya and Fiondella 2016; Plenert 2011; Raj et al. 2020; Lee and Lee 2015 |
| Decision-making waste | Decision-making waste refers to any inhibiting factor affecting a decision-makers' rationality. | Uncertainty; heuristics; decision complexity; limited memory | Riedl et al. 2013; Bolis, Morioka, and Sznelwar 2017; Mantel, Tatikonda, and Liao 2006; Eisenhardt and Zbaracki 1992; Carter, Kaufmann, and Michel 2007 |
| Financial waste | Financial waste refers to issues in the efficient finance flow through the SC phases. | Delays in payments; lack of coordination; insufficient funds to complete transaction. | Gelsomino et al. 2016; Abdel-Basset et al. 2020 |

systematic literature review (SLR) consisted of the following eight steps: (1) planning and formulating the problem; (2) searching the literature; (3) data gathering; (4) quality evaluation; (5) data analysis and synthesis; (6) interpretation; (7) presenting the results; and (8) updating the review. This step-by-step approach was devised by Thomé, Scavarda, and Scavarda (2016) and has been adopted in other similar studies in the SCM studies (Cunha, Ceryno, and Leiras 2019; Oliveira, Leiras, and Ceryno 2019). Figure 1 summarizes steps taken for the SLR.

In the planning and formulation phase, we conducted a Rapid Review (RR) to examine the existence of SLR's in this topic to ascertain whether a new review is needed (Thomé, Scavarda, and Scavarda 2016; Tranfield, Denyer, and Smart 2003) and to clearly define the research boundaries (Durach, Kembro, and Wieland 2017). Following the RR process, we developed the three research questions that were presented in Section 1. Specifically, keywords were developed and categorized based on two important groups of keywords underlying the phenomenon in question: (i) Blockchain Technology and (ii) Supply Chain. These two groups of keywords were chosen to focus the search on articles that considered BCT applied in SCM context as both as a standalone technology and in combination with other Industry 4.0 technologies. The keywords were extracted from the rapid review with common acronyms and synonyms used in the academic discourse. Table 2 present the search string inputted in the advanced search option in the following databases: Scopus,

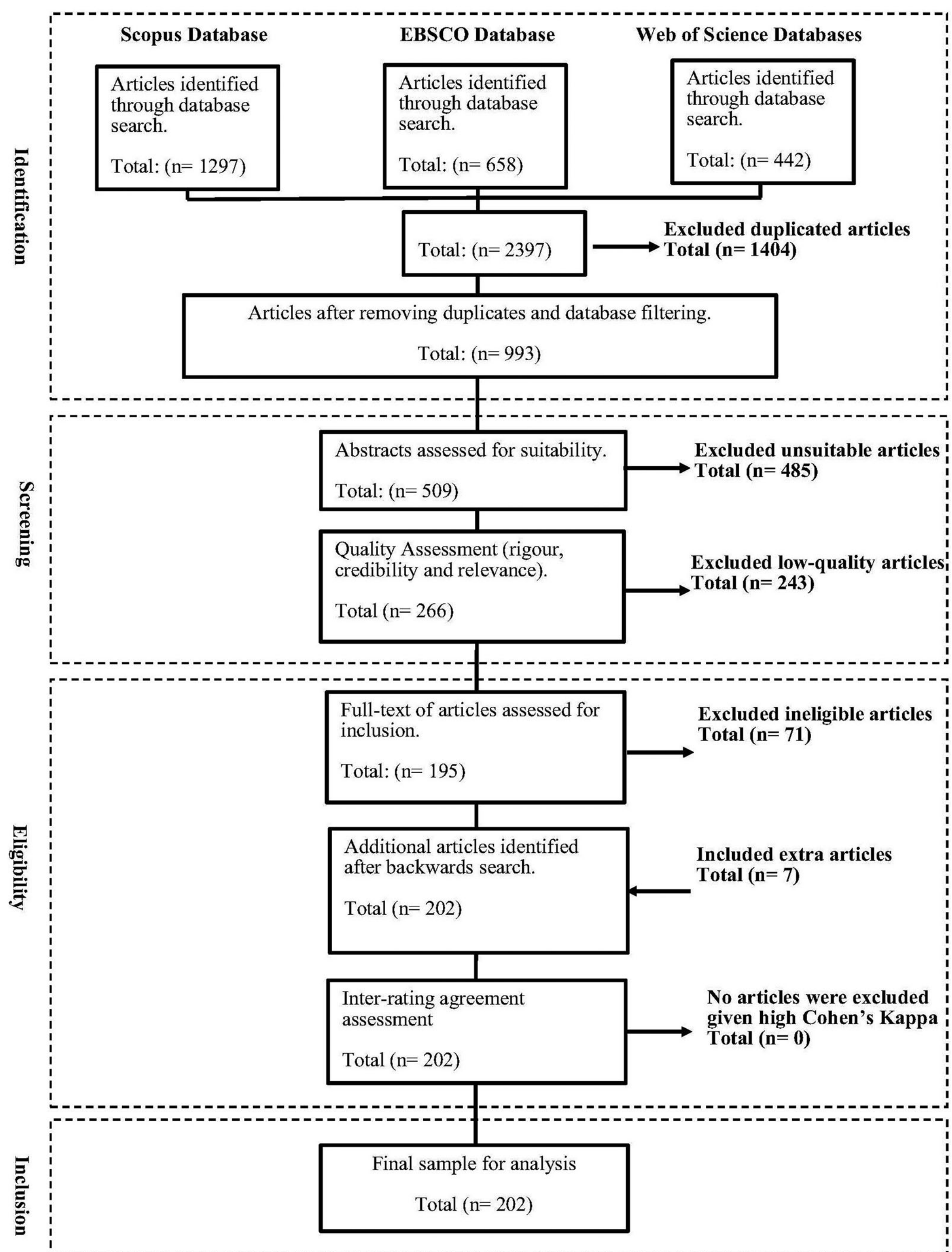


Figure 1. Literature search protocol.

EBSCO, and Web of Science, due to their large repository of literature and open access to the academic community (Derwik and Hellström 2017). Figure 1 demonstrates this process.

A total of 2397 articles were located from this search, with Scopus producing 1297 papers, EBSCO with 658 publications, and Web of Science providing 442 articles. The initial database results were consolidated by removing duplicates, delimiting studies to the English language, and including only peer-reviewed journals or conferences. Conference papers were intentionally included as journals tend to lag when considering the adoption of new technologies (Wang, Han, and Beynon-Davies 2019).

After eliminating duplicates and limiting to journal articles or conferences, the abstracts of the remaining 993 papers were assessed based on their suitability to the research. Articles that were deemed unsuitable were excluded, for instance when one of the two groups of keywords were simply cited but were not the focus of the work. In this way, 483 articles were removed. The full-text of the remaining 509 studies were assessed against the list of quality assessment questions for the inclusion/exclusion of articles. These questions were informed by Dybå and Dingsøyr (2008) to substantiate the rigour, credibility, and relevance of the studies for the full-text review (Table 3). This procedure left a total of 266 studies for full-text review.

Next, two researchers independently assessed the full-text of the 266 articles to determine their inclusion based on the eligibility criteria presented in Table 4. Articles that answered 'no' to each of these questions were included for further analysis. After numerous meetings between the research team to solve any discrepancies, this procedure yielded 195 articles. In line with Webster and Watson (2002), a backwards search was performed by handsearching the citations of the final consolidated articles selected after the full-text review process. The objective was to identify articles that could have been missed from the search string search. This process concluded in 7 additional studies. Thus, a final sample consisting of 202 papers were considered for further inquiry.

Following this eligibility criteria procedure, two researchers thoroughly analysed the full-text of the 202 papers. The purpose of this was three fold; (i) to measure the degree of inter-rater agreement between the authors; (ii) to determine which papers should be included for analysis; and (iii) reducing potential bias in the paper selection process (Thomé, Scavarda, and Scavarda 2016). To measure the degree of agreement, we applied the Cohen's Kappa coefficient (as suggested by Durach, Kembro, and Wieland 2017). The statistics for Cohen's Kappa vary from 0 to 1. If the evaluation is 1, it suggests the researchers are in complete agreement and that agreement was not achieved by chance. If the evaluation is 0, there is no agreement amongst the researchers. The Cohen's Kappa value undertaken for the quality evaluation procedure was 0.9, which indicates an almost perfect agreement (Pérez et al. 2020). So, we decided to maintain all 202 papers for analysis.

Finally, we used inductive-deductive content analysis approach to review the existing applications of BCT in SCM to understand how the technology is being considered to reduce the different types of waste. After carefully reading through the full-texts several times to obtain the sense of the whole and to identify meaning units, we performed two rounds of coding. The first round was an inductive coding, which consisted of creating codes and creating a hierarchy of codes with central codes denoting the central categories and the auxiliary codes signifying the many dimensions of the central categories. In performing this task, previously coded transcriptions were reassessed when new codes emerged to verify the occurrence of new codes (Crabtree 1999). The second round of coding was deductive to collapse the sub-themes developed in the inductive coding into main overarching themes and to ensure the content analysis was not too broad. The waste classification taxonomy presented in Table 1 was used as a reference throughout this coding phase. Referring continuously to the classification taxonomy

**Table 2.** String inputted in the advanced search option of the databases.

| |
|---|
| '*Blockchain*' OR '*distributed ledger*' AND '*procurement*' OR '*supplier*' OR '*supply chain*' OR '*agriculture**' OR '*warehouse*' OR '*storage*' OR '*production*' OR '*value chain*' OR '*consumer*' OR '*logistics*' OR '*transportation*' OR '*distribution*' OR '*supply network*' OR '*processor*' OR '*retailer*' OR '*manufacturer*'. |

**Table 3.** Quality assessment questions (Source: Adapted from Dybå and Dingsøyr 2008).

| Purpose of quality assessment question | Quality assessment question |
|---|---|
| To appraise the rigour of the study. | Has a thorough and appropriate approach been applied to the key research methods in the study? |
| To appraise the credibility of the study. | Are the findings well-presented and meaningful? |
| To appraise the relevance of the study. | How useful are the findings to the supply chain industry and research community? |

**Table 4.** Eligibility criteria after assessing full-text.

| Purpose of eligibility criteria | Eligibility question |
|---|---|
| To consider papers focussed on the application of BCT rather than the computational performance or design issues of the technology. | Is this a technical paper that is focussed on the computational performance and/or design issue of BCT systems? |
| To locate papers where data was collected first-hand. | Is this an informative or review paper? If so, has secondary research been conducted? |
| To ensure BCT was not being considered as a solution for a phenomenon which was already being investigated. | Does the paper propose the use of BCT as a solution at the end of the article? |
| To ensure papers that solely focussed on BCT were considered. | Does the paper focus its discussion on BCT's integration with other I4.0 technologies? |

ensured a clear structure was followed throughout the content analysis and boundaries were set concerning the different types of waste in the literature, as suggested by Downe-Wamboldt (1992). Appendix A presents the coding scheme for this round.

## 4. Results of the systematic literature review

This section presents the findings from the SLR protocol performed in the aforementioned section. Firstly, a bibliometric analysis was used in Section 4.1 to provide a general overview of the sample papers. Next, we discuss the findings from the inductive content analysis in Section 4.2. Lastly, we detail the findings from the deductive content analysis in Section 4.3. A heatmap can also be found in Section 4.3, which shows the relationship between how BCT is being adopted in SCs and how it is being considered to reduce waste.

### *4.1. Bibliometric analysis*

Figure 2 summarizes the bibliometric analysis for the selected articles. Figure 2(a) illustrates the distribution of publications by year and was performed to assess the trends in the number of studies on the topic. In summary, there were no studies on the subject before 2016, which is understandable given the term BCT was first coined in 2008 and its initial application was considered within the financial sector. Since the first two papers were retrieved in 2016, there has been a continuous increase in research publications per annum until 2020. Note that we selected ten articles from 2021 (last search was done at the end of January) indicating the topic has continued to gain momentum amongst scholars and is on an upward trend. The main reason for such an increase could be attributed to the increased number of special issues in the field (e.g. International Journal of Production Research's Blockchain in Transport and Logistics). Moreover, 2019 introduced several BCT related events that received significant media interest, thus raising public interest in the research community. Just to name a few, the scrutiny of Facebook's Libra by regulators across the world, the drastic surge in Bitcoin's price which more than doubled, and the announcement of Walmart working together with IBM on a food safety BCT solution are some of the leading examples that received wide-spread publicity in the news media.

Figure 2(b) illustrates the categorization of the literature sample based on the following three research types: (i) prescriptive, (ii) predictive, and (iii) conceptual. The author adapted the criteria proposed by Wang, Han, and Beynon-Davies (2019) to facilitate this process. Although included by Wang, Han, and Beynon-Davies (2019), the descriptive

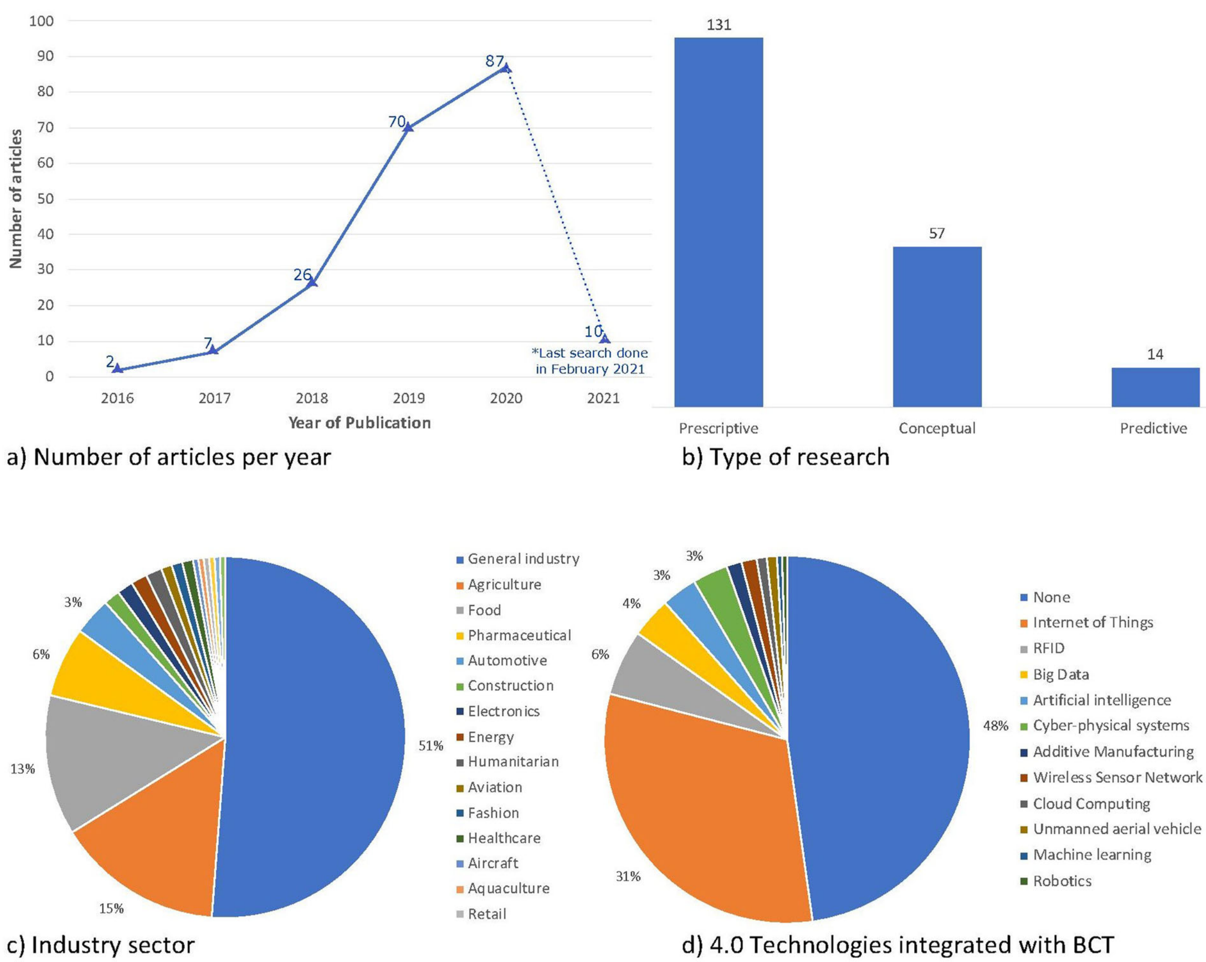


Figure 2. Bibliometric analysis of selected articles.

categorization was not considered as they were these papers were removed as part of the selection criteria (Section 3). Thus, the papers were classified based on the following guidelines:

i. **Prescriptive** papers diagnose current problems within supply chain practices and provide technical business solutions. This stream of literature tackles the question; 'How should the BCT be deployed within supply chains?'.
ii. **Predictive** papers consider potential application areas for BCT with the supply chain. It poses the question; 'Where will the BCT penetrate supply chains?'.
iii. **Conceptual** papers seek to answer the question 'What does the BCT mean for the supply chain?'. This stream of literature aims to provide a better understanding of BCT technologies by providing conceptual papers to interpret its underlying values, highlight its disruptive characteristics and consider implications for SCM.

Based on our findings the large majority (131) of publications are prescriptive, indicating a clear trend towards the acceptance of BCT being a viable solution to existing SC issues. Moreover, given the advanced developments in key BCT features, such as smart contracts, consensus mechanisms, and immutability it can be expected that prescriptive papers will become more common in the domain as researchers seek to adopt the BCTs features to streamline complex SC processes. In the same vein, conceptual papers still contribute towards a good number of studies on the phenomena. As highlighted in Figure 2(a) the application of BCT in the SC context is young, therefore it is plausible to theorize that the strong number of conceptual papers is a consequence of the technology's low maturity, lack of application experience, and recently emerged academic interest. Predictive papers contributed a low number of publications in this study with thirteen in total. This is understandable because as the application of BCT in SCs becomes more widespread and diverse, there is a need for high standardization and agreement concerning feasible use cases. This view aligns with many scholars who loosely imply common tenets on the application of BCT is important to understand whether it is just pure hype or a credible solution to real-world industrial problems (Lohmer, Bugert, and Lasch 2020; van Hoek 2019).

Referring to the retrieval results found in Figure 2(c), half of the articles consider BCT application in generic industrial context and half of them evaluated the technology usage in specific industries. This can be expected because as BCT become more popular and improves over-time, uses cases will inevitably emerge for how its adoption can benefit organizations. Fourteen different industry sectors are explored, and the most common ones are agriculture, food, pharmaceutical and automotive. Figure 2(d) displays the I4.0 enabling technologies integrated with the BCT. The findings revealed that 48% of studies did not integrate I4.0 technologies with BCT, instead considering BCT as a standalone technology. This is understandable as BCT is in its infancy, thus researchers are still attempting to make sense of the technology to exploit its full potential. The remaining 52% of papers integrated a host of I4.0 enabling technologies, suggesting there is a consensus amongst the research community that the seamless implementation of both domains can offer novel benefits to the SC. These findings are foreseen given the compatibility between the two and because of the complimentary features offered by BCT. This view is consistent with Lee, Azamfar, and Singh (2019) who state BCT possess the capabilities to sustainably support the I4.0 initiative and eliminate problems related to it. IoT is by far the most common I4.0 enabling technology integrated with BCT, followed by Cloud computing, BDA, AI, and CPS.

Table 5 presents the most productive journals, the number of articles included, and their respective impact factor. International Journal of Production Research, Journal of Cleaner Production, and International Journal of Information accounted for nearly 27% of all publications. The majority of journal publications were done in operations, production, and SC and information management, with the exception to Robotics and Computer Integrated Manufacturing, Sustainability, and Computers & Industrial Engineering. Note that majority of papers in technology, computer, and engineering fields were published in peer reviewed conferences that do not appear in Table 5.

### 4.2. Applications of blockchain technology in SCM

Table 6 contains the summary of findings derived from the first round of coding, which was performed inductively, helping to answer RQ1. Generally speaking, we can observe various implementation areas concerning the application of BCT in SCM. This suggests that scholars do not question the adoption of BCT per se, but rather their opinions diverge when it comes to its industrial context. Despite this parallel, different SCM practices serve different purposes, therefore it is important to understand how the technology is being applied to serve each purpose. To this end, the following section expands on our findings to discuss the role the BCT's relational characteristics play in influencing the application context.

BCT has emerged as a possible solution to support a factory of the future by providing an infrastructure to fuse the physical and virtual world into CPS. For example, Mandolla et al. (2019) analyzed the potential use of BCT to create a digital twin for additive manufacturing (AM) in the aircraft industry. While Lee, Azamfar, and Singh (2019) proposed a BCT enabled CPS architecture to better interconnectivity between I4.0 manufacturing systems. Concerning tracking and tracing, the decentralized and immutability components of the BCT enable the distribution of the same information across the entire network as no single entity can control transactions. In this context, Huang, Wu, and Long (2018) proposed a BCT-based drug system for pharmaceutical companies to know exactly where a product has been and where it has gone along the SC. The BCT's consensus mechanism was recognized as key for information and knowledge sharing activities as participants can collectively agree on the

Table 5. Top five journals and number of papers included.

| Rank | Source name | Specialised domain(s) | Number of papers | Impact factor (2019) |
|---|---|---|---|---|
| 1 | International Journal of Production Research | Manufacturing and production engineering, logistics, production strategy. | 19 | 4.577 |
| 2 | Journal of Cleaner Production | Cleaner production, environmental, and sustainability. | 8 | 7.246 |
| 3 | International Journal of Information Management | Information, knowledge, and content management | 7 | 8.210 |
| 4 | Robotics and Computer Integrated Manufacturing | Robotics, manufacturing technologies, and innovative manufacturing strategies | 5 | 5.057 |
| 4 | Sustainability | Environmental, cultural, economic, and social sustainability of human beings. | 5 | 2.966 |
| 5 | Supply Chain Management | Operations, logistics, and supply chain management | 4 | 4.725 |
| 5 | Transportation Research Part E: Logistics and Transportation review | Logistics and transportation infrastructure and management | 4 | 4.69 |
| 5 | Production Planning and Control | Operations and supply chain management and business improvement | 4 | 3.605 |
| 5 | International Journal of Production Economics | Engineering and business, production economics, and manufacturing. | 4 | 5.134 |
| 5 | Computers & Industrial Engineering | Computers and electronic communication and industry engineering | 4 | 4.135 |
| 5 | Journal of Business Logistics | Logistics and supply chain management and business improvement | 4 | 4.697 |

Table 6. Findings from the inductive content analysis.

| BCT-based application themes | Characterization | Illustrative examples of papers |
|---|---|---|
| Factory of the future | The use of BCT to advance production processes. | Kurpjuweit et al. 2021; Lee, Azamfar, and Singh 2019; Mandolla et al. 2019; Mushtaq and Haq 2019; Li, Barenji, and Huang 2018 |
| Tracking and tracing | The application of the BCT to identify past and present location details of a product. | Caro et al. 2018; Fernández-Caramés et al. 2019; Figorilli et al. 2018; Hastig and Sodhi 2020; Huang, Wu, and Long 2018; Miehle et al. 2019 |
| Information and knowledge sharing | The use of BCT to allow information and/or knowledge sharing within and/or across SCs in a collaborative manner. | Epiphaniou et al. 2020; Li, Barenji, and Huang 2018; Liu and Cai 2018 |
| Re-inventing trust | The use of BCT as a trust mechanism rather than placing trust in the hands of a traditional intermediary. | Leng et al. 2019; Hang, Ullah, and Kim 2020; Malik et al. 2019; Zhang et al. 2019 |
| Quality control | The use of the BCT to ensure that product quality is maintained or improved. | Kuhn et al. 2018; Maiti et al. 2019; Mondal et al. 2019 |
| Fraud and counterfeit prevention | The adoption of the BCT to authenticate transactions and/or products. | Toyoda et al. 2017; Kumar et al. 2019; Rahmadika et al. 2019 |
| Disintermediation | The application of the BCT to replace the role of intermediaries who were previously responsible for coordinating and verifying transactions. | Angrish et al. 2018; Wen et al. 2019 |
| Automatic decision-making | The adoption of the BCT to make independent choices without the need for human intelligence. | Liu and Cai 2018 |
| Transparency | The use of BCT to better visibility in the SC. | Venkatesh et al. 2020; Wu, Fan, and Cao 2021; Reimers, Leber, and Lechner 2019 |
| Security | The application of the BCT to ensure confidentiality, integrity, and availability. | Miraz, Mahbubulhye, et al. 2020; Su, Wang, and Kim 2018 |
| Data recording and storage | The use of BCT as a robust and comprehensive infrastructure that allows for a network that can record and store pertinent information. | Xie, Sun, and Luo 2017; Naidu et al. 2018; Sidorov et al. 2019 |
| Resilience | The adoption of BCT to enhance the SC's ability to be prepared for unexpected events and respond and recover quickly to these events. | Dubey et al. 2020 |

actual information and knowledge being shared, with participants being held accountable if the information and knowledge shared are unauthenticated. Bearing this in mind, Epiphaniou et al. (2020) presented Cydon, a BCT platform that used a novel search and retrieve algorithm to electronically regulate data sharing within and across organizational entities in the SC.

If we analyze the essence of trust, which is encumbered with many meanings in itself, it becomes clear that BCT and its associated features does not actually create or eliminate trust, but merely shifts trust from one form to another. In other words, re-inventing trust occurs as SC parties subject themselves to the authority of a technological system that they trust will act in a trustworthy manner, rather than in people and institutions who are regarded as untrustworthy. If we look at the study conducted by Hang, Ullah, and Kim (2020), trust was ensured by using smart contracts to automatically perform actions and reduce the risk of error or manipulation. For quality control, BCT's transparency components were utilized to ensure product requirements and specifications were maintained throughout the SC. This can be found in the work of Kuhn et al. (2018), who exploited the openness of BCT to develop a holistic system that can be harnessed for quality improvement, failure prevention, and reliability predictions. Akin to this is the implementation of BCT for fraud and counterfeit prevention, which also used the openness of the BCT to achieve greater transparency and improve the traceability of products. For example, Kumar et al. (2019), used BCT to solve the challenges associated with counterfeit drugs.

BCT enables disintermediation by using cryptography to manage peer-to-peer exchanges between the networked SC partners. Lee, Azamfar, and Singh (2019) used a cryptographic algorithm for their BCT system, to ensure customers and manufacturers can interact securely, without the need for trusted third parties to intervene. When it comes to automatic decision-making, smart contracts were incorporated with a set of programmed conditions to allow the BCT to intelligently make decisions rather than depending on humans. This can be seen in Liu and Cai (2018) paper, where the authors used BCT and its smart contract feature to design an automatic decision-making value system within the pharmaceutical manufacturing industry. Regarding transparency, BCT's distributed ledger and immutable components allow for a full, unalterable audit trail of transactional data throughout the entire SC lifecycle. Venkatesh et al. (2020) exploited these features to design a BCT-based SC that allows sellers to monitor their social sustainability. Moreover, these features were leveraged by Wu et al. (2017) to facilitate the validation of shipment information in pseudo real-time.

When referring to security, the BCT's distributed and shared nature ensures that there is no single point of failure. The high Byzantine fault tolerance was also recognized as a key attribute for preventing malicious mining efforts. Wan et al. (2019) referred to these properties to propose a BCT-based solution to improve security and privacy in a smart factory environment. Whereas Miraz, Mahbubulhye, et al. (2020) utilized these features to securely transfer money and enable swift authentication in the retail industry. Regarding data recording and storage, the decentralized infrastructure of the BCT offers an alternative model compared to traditional centralized systems. An example can be noted by Xie, Sun, and Luo (2017) who adopted BCT to propose a double-chain storage scheme for tracking agricultural products.

Finally, the resilience of SCs may be improved as the peer-to-peer architecture of the BCT keeps records of transactional information in lieu of centralized databases, meaning the different SC actors can be more responsive when adverse challenges arise. As articulated by Dubey et al. (2020) within the humanitarian SC context, BTC offers a permanent, searchable, irrevocable public records repository, thus helping to build trust and improve collaboration amongst involved humanitarian actors. Dubey et al. (2020)'s work is the only article found to identify BCT-based opportunities to enhance SC resilience. They found that by removing inefficiencies in the flows of disaster-relief materials, critical information, and emergency funds, humanitarian SCs can respond faster to crisis. In summary, their work raises the questions of whether BCT can enable both leanness (through efficiency) and resilience. Now that we have a broad understanding of how BCT in being applied in SCM, the next section addresses how the technology is being considered to minimize waste.

### 4.3. B-eLA: blockchain technology as means to minimize waste in supply chains

Figure 3 illustrates a heatmap to depict the relationship between how BCT is being applied in SCs and how the technology is being considered to minimize waste. Given the growing complexity of SCs, it becomes difficult for firms to achieve a high-level of visibility. This lack of visibility

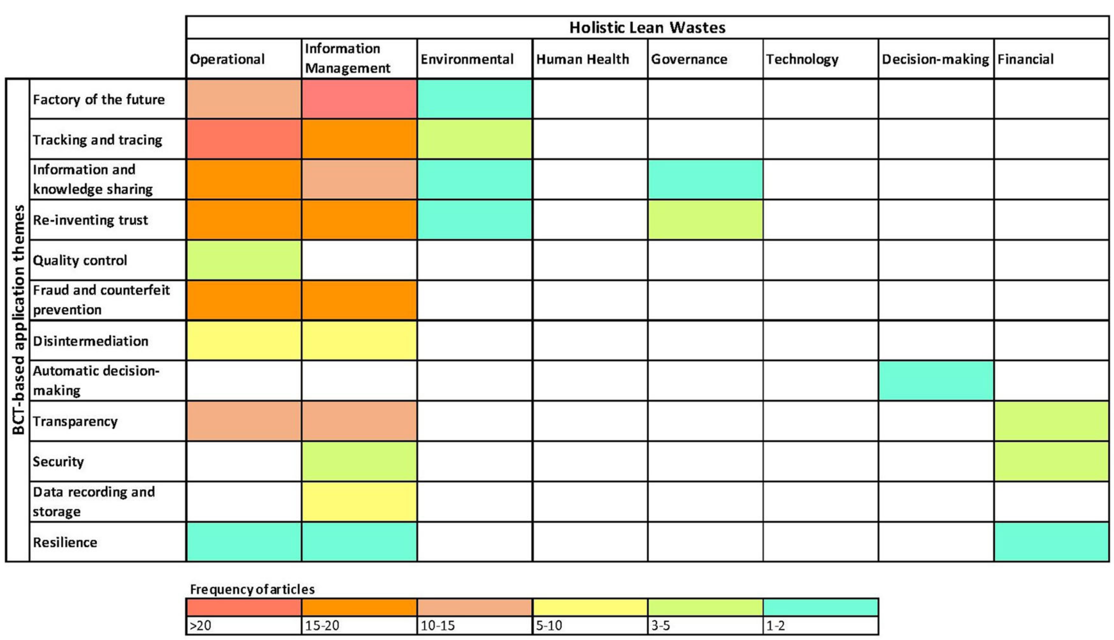


Figure 3. Heatmap of blockchain application and waste reduction.

inevitability led to a range of operational inefficiencies. Therefore, concerning operational waste, the capabilities of BCT to track and trace, re-invent trust, and prevent fraud and counterfeit products were used to improve SC performance by reducing process inefficiencies and product tampering. For example, Angrish et al. (2018) exploited the smart contract feature of the BCT to reduce 'trust tax' and all other costs associated with ensuring trust among all parties in an SC, such as audits and inspections. Arena et al. (2019) developed a BCT-based application for the traceability and the certification of extra virgin olive oils from farming, harvesting to production, packaging, and distribution. While Toyoda et al. (2017) proposed a novel BCT-based product ownership management system for anti-counterfeits in the post-SC (after product leaves main retailer).

Regarding information management waste, studies referred to BCT's inherent peer-to-peer infrastructure and functional components (i.e. smart contract, distributed ledger, and immutability) to reduce the inefficiencies associated with centralized data storage and processing. For example, Epiphaniou et al. (2020) adopted BCT to distribute encrypted data across an SC network to provide partners with fast access to data and prevent single points of failure. Furthermore, Wang, Han, and Beynon-Davies (2019) introduced the BCT to reshape the traditional Industrial Internet of Things (IIOT) architecture and ensure security and privacy in production process which are performed in a partially decentralized smart factory environment. Moreover, previously discussed themes, such as tracking and tracing and re-invent trust were associated with less need to correct or verify information.

For environmental waste, BCT was introduced as a promising enabler for the facilitation of a circular economy. In this context, the provenance aspect of the technology was perceived as a feasible tool to record, store, and share pertinent information not only on a material's source but also on its current state. Thus, making strategic planning for material reusability practical. A key example can be found in the work of Rane and Thakker (2019), who analyzed the integration of BCT and IoT as an interface for making procurement activities more sustainable. Zhang et al. (2019) applied BCT to incentivize the efficient use of rural wastes through the adoption of a cryptocurrency that can be traded between farmers and entrepreneurs. Moreover, Hammi, Bellot, and Serhrouchni (2018) proposed a robust, transparent, and energy-efficient BCT-based authentication mechanism which was designed especially for devices with computational, storage, and energy consumption constraints. Despite the opportunities of BCT in facilitating sustainability, very few articles directly linked the BCT features of traceability, advanced manufacturing, information sharing, and trust to the improved resource (re)usability and efficiency.

When speaking about governance waste, BCT transpired as a tool to enforce agreements and achieve greater cooperation and coordination in a way that bypasses traditional principal-agent dilemmas of organizations. To reduce these inefficiencies, Liu et al. (2019) applied BCT to facilitate exchanges between various stakeholders involved in the different product life cycle stages. Also, Muller et al. (2019) explored the application of BCT to develop an inter-organizational distributed tracking system that not only increases transparency but also enables logistics firms to rely on shared information when it comes to conflicts with respect to inter-organizational deliveries. Additionally, Liu et al. (2019) investigated the integration of BCT and edge computing to propose a cross-enterprises knowledge and services exchange framework to achieve a higher level of sharing of knowledge and services in manufacturing ecosystems.

The BCT's automation characteristic provides a new model for decision-making that is independent from a firm's governance structure. Thereby, decision-making waste can be minimized as the need for intermediaries to assess the integrity of data before taking action is eliminated and instead conducted securely within the system. Hence, Liu and Cai (2018) considered BCT to develop an automatic decision-making value system to optimize the enterprise value chain and assess the true value of the enterprise from four aspects: integration, optimization, control, and value-added satisfaction. Whereas Kshetri (2018) considered how BCT can help firms make decisions on key SCM activities, such as cost, risk reduction, and flexibility. Regarding how BCT is being considered to minimize financial waste in SCs, the ability of the technology to create an immutable audit trail for all transactions, which in turn makes for a more cost-efficient way for verifying transactions amongst SC partners, rather than firms having to pay trusted third parties for this service. To this end, Miraz, Kamal, et al. (2020) used BCT to improve the management of monetary transactions in the retail sector, and Durach, Kembro, and Wieland (2017) explored possible BCT-based business opportunities for SC transactions.

In summary, we addressed RQ2 by using our proposed waste taxonomy to cluster articles based on how they are considering BCT to minimize waste. Our findings revealed that BCT is primarily considered to minimize operational and information management wastes. With regard to operational waste, BCT was focussed on addressing defects throughout production and improving inventory management using smart contracts, decentralized data storage, and peer-to-peer communication. Concerning information waste, BCT applications can improve transparency, efficiency, and security, which in turn provides solutions in processes like information exchange, information availability and accessibility, and information storage. We also identified the potential for the implementation of BCT to address environmental, governance, decision-making, and financial wastes, although these applications can be further explored. By the BCT working as the interface between LP and I4.0 technologies, LA could be achieved. The transparent nature of the technology allows unrestricted traceability of transactions and processes performed within the LA system. As data integrity is ensured through cryptographic proof, untrusted parties can directly interact with each other in real-time, without the need for a trusted third party. As a result of answering RQ2, we gained deepened understanding of the current works on the phenomenon and shed light on areas that were not explicitly studied in the scholarship.

## 5. Future research agenda

The inductive-deductive qualitative content analysis and findings from the heatmap in Figure 3 evidenced opportunities for knowledge development in the studied research context. We found that a few themes were not given consideration. For instance, (i) BCT as means of achieving sustainability by reducing environmental waste, (ii) BCT as means of achieving both leanness (efficiency) and resilience, and (iii) and BCT as means to boost lean application in the service sector, given the predominance of BCT being applied in the manufacturing context (factory of the future) and for mainly tracking and tracing of physical goods.

In short, there is much scope for furthering our understanding of the capabilities of BCT integration in SCM for achieving LA. In answer to our RQ3, a future research agenda has been proposed based on the above key topics which were seldom addressed by the existing literature.

### 5.1. What role can the application of blockchain technology play in promoting lean sustainable supply chain management?

Increasing pressure on resources and concerns about environmental impacts and climate change is forcing SCs to search for innovative strategies that deliver sustainable development. In the SCM context, this challenge is of particular interest because industrial activities are a major cause of the global problems of environmental degradation and resource depletion/scarcity. Despite these concerns, our findings revealed the academic literature focussing on the application of BCT to improve sustainable SCM performance is limited. The central tenant of studies that do address this issue typically focussed on improving the performance of focal firms rather than the SC network as a whole. However, developing effective relationships is critical in sustainable SCM as value resources and capabilities rarely exist within one firm. Effective relationships can assist focal firms in the successful implementation of sustainability practices in their SC systems. From this perspective, this suggests a firm's sustainable SCM practices are dependent on the strategies of other firms. Put simply, trying to solve existing sustainability issues is a task for all SC participants. Therefore, more comprehensive environmental issues need to be investigated to better understand the embeddedness of SC actors to understand the role BCT can play in promoting sustainability across the entire network structure. BCT is very suitable for solving these challenges faced by the SC since it has several core features that allow firms to move beyond optimizing individual performance.

The decentralized nature of BCT means it can act as an infrastructure for cooperative and collaborative between distributed systems, without the need for intermediaries to manage exchanges. This peer-to-peer infrastructure is essential to a circular economy as shared and transparent information are the foundation for building different resource and material flows (Derigent and Thomas 2016). In this manner, BCT could enable circular sourcing of renewable inputs and support resource efficiency. Additionally, BCT could reduce resource consumption by providing transparency and traceability, which efficiently facilitates the provenance of products. Trust is gained through BCT-enabled data integrity and security. Although the application of BCT to improve SCM sustainability is receiving little attention in academia, examples of current efforts for improving the sustainability of SCM can be found in practice. For instance, MonoChain exploits some key features of BCT to encourage fashion retailers to adopt a circular economy. Additionally, IBM and an agricultural company called Farmer Connect launched a BCT system where users can track and trace coffee beans across the entire SC. This BCT system reassures consumers that they are buying coffee that was produced ethically and to offer those same consumers the opportunity to donate to site-specific campaigns like environmental protection or to the actual farm where the coffee was manufactured.

### 5.2. How can blockchain technology implementation help balancing leanness and resilience in SCM?

Any event that negatively affects the information and material flow between original supplier and end user should be considered as a risk for SCs (Spiegler et al. 2012). The vulnerability of SCs to disruptions has grown over the last decades due to the more complex SC networks and stronger focus on SC efficiency and leanness, thus the effects of disruptions no longer only affect individual members but tend to spread across the entire network, a phenomenon known as the ripple effect (Ivanov 2020). Amid such difficulties, this triggered interest in finding a competitive balance between lean and resilience (Purvis et al. 2016). Amongst the approaches suggested for improving resilience and developing a recovery plan are collaborating with suppliers and accelerating technology implementation (van Hoek 2019). Thus, one interesting research avenue is how BCT can be effectively implemented to reduce the negative impacts of disruptions on SCM processes and performance whilst maintaining cost efficiency and effectiveness.

The attributes of BCT could enable SCs to endure and ricochet from severe SC disruptions and support disaster-relief operations (Dubey et al. 2020). BCT-enabled SCs bring partners together into a common network. In this sense, firms can access key information (e.g. production capacity, asset tracking, suppliers stock levels), can be used by firms to assess risks and take preventative action in real-time. Moreover, BCT can help detect invisible risks, such as cyber-attacks, computer hacking, counterfeiting, miscommunication, credit failures, and contract frauds (Min 2019).

### 5.3. How can blockchain technology be applied to better support lean production practices in the service sector?

Due to the extraordinary growth in the service sector many service organizations now pay attention to the efficiency and effectiveness of their operations (Cavaness and Manoochehri 1993). Despite this, the productivity of the service sector has been far lower than that of manufacturing (Suárez-Barraza, Smith, and Dahlgaard-Park 2012). In this sense, organizations in the service sector now look to the manufacturing sector to learn and implement techniques and methods to become more 'lean' and thus focus their service activities from a lean perspective (Kinnie and Arthurs 1996). Despite this growing pressure, our investigation found that studies still tend to focus on applying BCT to minimize waste in the classical manufacturing and primary sector context. Thus, how LP practices operate in relation to service enterprises remains an underexplored research area. Future research should be devoted to appreciating the contextual differences of the service environment with the aim of understanding how LP implementation can be better supported to improve SC performance. With BCT, service enterprises looking to adopt LP practices can benefit from its wide-ranging features.

If we take a closer look at the design of the BCT we can observe there are many different functionalities within the system that can benefit LP processes in the service industry context:

- BCT can enable *poka yoke* by helping to identify human error with its real-time data acquisition capability.
- The transparency of the BCT supports 'pull systems' by making just-in-time deliveries and work scheduling more feasible.
- BCT can facilitate continuous improvement (kaizen) by integrating customer feedback and business improvements into the system.
- The decentralized infrastructure of the BCT means variability can be reduced by redirecting work to the desired SC actor.
- The consensus mechanism makes use of visual management by providing a shared reality of the current situation.

Despite the academic discourse paying less attention to BCT facilitating LP practices in the service industry, there are growing initiatives in practice that are dedicated to making this practical. For example, the World Food Programme (WFP) used a private Blockchain called 'Building Blocks', to ensure refuges can use their biometric information to purchase food instead of using cash. According to media reports, The WFP's reason for using BCT was to cut payment costs, control financial risks and respond more rapidly in wake of emergencies. Another example is TUI, a leading global tourism company, that used BCT to help maintain records of hotel bed inventories in real-time.

## 6. Conclusion

In this paper we performed a SLR to understand how BCT is being implemented in SCM field and evaluated how this technology can be used to reduce inefficiencies in SCs. When answering RQ1 in Section 4.2, we identified the most common BCT-based application themes in SCM. Later in Section 4.3, we made links between these themes and the holistic taxonomy of waste, by evaluating how the technology can be considered to minimize waste and therefore supporting future implementation of B-eLA (answering RQ2). Lastly, in answering RQ3 in Section 5.0, we were able to provide a future research agenda which scholars can adhere to when investigating the phenomenon.

In terms of our contributions, one of the key roles of the SLR is to support new theory development, mainly through knowledge-gap mapping (Denyer and Tranfield 2009). In this context, our study provided important contributions on the intersection between the BCT, LP, and I4.0 within well-established SC areas. The proposition of a LA approach that specifically considers the working together between LP practices and I4.0 technologies is a contribution to the literature. This LA approach builds upon the work of Kolberg, Knobloch, and Zühlke (2017) who calls for the development of a common, unified communication interface for LA. Furthermore, to the best of our knowledge, the investigation of how BCT can facilitate the implementation of LA is the first of its kind, presenting a heat map of current research developments in this area. Under this rationale, this study ascertains a conceptual foundation on which future studies can build upon.

Another theoretical contribution refers to the proposed taxonomy of waste modelled in this research. In the lean literature, there is agreement that non-value adding activities contribute to waste generation. In this study, a taxonomy of wastes, along with examples of key associated non-value adding activity was constructed based on concepts from various sources of literature. The proposed taxonomy allows scholars to refer to a single source for the different types of wastes rather than exploring the literature to find a coherent meaning. Typically, classifications are biased towards manufacturing, but the broad nature of this taxonomy means it can be applied across a range of contexts, particularly within service industries. This is in line with authors, such as Hines and Rich (1997) and Bicheno and Holweg (2008) who endorsed the adaption of waste concepts to different contexts, such as service systems.

In practical terms, our study is a 'first-step' towards supporting effective B-eLA efforts. This paper supports companies to become leaner by contextualizing how their inefficiency problems can be solved through the adoption of BCT. Specifically, our taxonomy of waste can be used by firms to identify the types of waste that exist in their supply chains so that they can draw upon these to develop highly efficient improvement programs. The themes on how BCT transforms supply chains provides understanding of how waste can be minimized in this kind of environment. On this matter, our work is guiding organizations to explore the broader benefits of the Blockchain. The fact that BCT has been conceptually linked as an interface for LA helps to motivate supply chain managers to think deeper about the workings of the technology to consider how it can enable LA implementation.

Like most studies, this research contains some limitations. Firstly, Scopus, EBSCO, and Web of Science were used as the database for the SLR. Although these databases were carefully selected due to their specialisms, it is likely that a few studies that were not included within these databases were missed. Secondly, the sampled literature collected for further analysis was restricted to peer-reviewed academic journals and conference papers. While the assumption is that peer-reviewed papers are more esteemed because they have gone through several rigorous processes, it does not take away from the fact that non-peer-reviewed papers could still provide valuable insights that can be used to facilitate theory development. The third limitation is that only papers written in English were included. Again, this may have led to the exclusion of valuable data. The fourth limitation is common with other qualitative and conceptual studies, whereby the interpretation of the literature and coding processes is influenced by the researchers involved. While various approaches were used to prevent this, there still may be a certain degree of bias involved due to researcher experience and prior knowledge. Finally, the B-eLA concept that we proposed was not empirically validated by scholars or practitioners. Although the purpose of this paper was to conceptually link the idea, it still needs to be assessed on its feasibility and to clarify the contexts in which it might be impractical. In future research, we plan on validating B-eLA as a concept by conducting case studies with the collaboration of sector actors to develop a framework that provides a formal description of B-eLA and the structural design of the concept. We then aim to explore how B-eLA can impact supply chain efficiency.

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## Notes on contributors

***Aaron Jackson*** is currently a PhD candidate in Management Science at the Kent Business School, University of Kent. His research has an empirical focus on the potential applications of blockchain technology to explore how the technology can be used to enhance existing operational processes. His co-authored paper on these topics was presented at the Logistics Research Network annual conference in 2021. He is motivated to investigate real-world use cases for blockchain technology that provide practical and theoretical insights to the literature of supply chain management and operations management. Outside of academia, Aaron works with industry to develop tailored blockchain technology and Web3 solutions for organisations.

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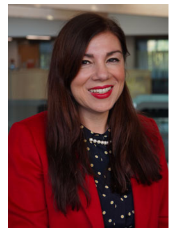

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## Appendix A

**Table A1.** Coding sheet for the deductive content analysis.

| Overarching theme | What the coder must ask themselves | What should the coder refer to when making a decision? | Coding rules |
|---|---|---|---|
| Operational | Does the content seek to reduce any of the eight types of waste proposed in the operational waste section? (i.e. overproduction; waiting; transportation; over processing; inventory; movement; defect and making-do). | Operational section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Information management | Does the content seek to reduce any of the four types of waste proposed by Hicks (2007)? (i.e. flow excess, flow demand, failure demand, and flawed flowed). | Information management section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Human health | Does the content aim to improve safety and well-being of stakeholders in supply chain processes? | Human health section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Environmental | Does the content aim to minimize excessive or unnecessary use of substances or resources released into the water, air, or land that could harm human health or the environment? | Environmental section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Governance | Does the content aim to reduce processes in an exchange among firms and their associated organizations? | Governance section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Technology | Does the content seek to minimize waste in technology? (i.e. hardware, software, or both) | Technology section of taxonomy in Section 2.4. | 0—No<br>1—Yes |
| Decision-making | Does the content seek to minimize judgement or 'goal-directed behaviour' in the presence of options? | Decision-making section of taxonomy in Section 2.4. | 0—No<br>1—Yes |