Data-driven Review of Blockchain Applications in Supply Chain Management: Key Research Themes and Future Directions

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Abstract

Blockchain (BC) applications in supply chain management (SCM) have recently received extensive attentions. It is important to synthesise the extant literature on the field to identify key research themes and navigate potential future directions. This study thus develops an efficient, scalable data-driven review approach that uses text mining and Latent Dirichlet Allocation (LDA)-based topic modelling for automatic content analysis of full-text documents. Our method overcomes the drawbacks of traditional systematic literature reviews using either manual coding or bibliographic analysis for article classifications, which are highly time-consuming and biased when dealing with large amounts of texts. 108 papers published between 2017 and 2022 were analysed which identified ten key research themes, including revenue management, sustainability, traceability, manufacturing system, scheduling in cloud manufacturing, healthcare SCM, anti-counterfeit system, logistics and transportation, system architecture development, and food & agriculture SC. Five future directions are then suggested, including (1) integration of BC and other emerging technologies for global and scalable SCM, (2) crypto-X applications in SCM, (3) BC-enabled closed-loop SCM, (4) the environmental and social impacts of BC-based SCM, and (5) decentralised autonomous organisations in SCM.

Keywords: Supply Chain, Blockchain, Digital Transformation, Industry 4.0, Text Mining, Data driven Literature Review, Latent Dirichlet Allocation, Topic Modelling

1. Introduction

1.1. Motivation and contribution

The Fourth Industrial Revolution is featured by a wide range of cutting-edge technologies such as Internet of things (IoT), smart sensors, digital twin, big data, etc., which profoundly transform the design and operations of SCM. Among these, BC has recently gained special attentions from both academia and practice due to its capabilities to address various issues in SCM. In principle, BC uses decentralised digital ledgers to securely store, and share untampered or unaltered transactional records within the distributed peer-to-peer network without a need for a trusted authority. Such mechanism offers the unprecedented opportunities and capabilities to enhance visibility, traceability, accountability and transparency across the entire supply chain (SC).

Earlier research focuses on understanding implications of BC in SCM (Treiblmaier 2018), its impact to address key SCM problems such as risk management, sustainability, and efficiency (Kshetri 2018) and its determinants affecting the adoption behaviour (Wong et al. 2020). Recently, research has shifted the focuses to BC implementations in SCM through modelling and system development (Tian et al. 2021).

[Insert Table 1 here]

A growing number of literature review has been conducted to synthesise the latest findings and set research agenda for BC-focused SCM studies, as summarised in Table 1. Compared to the existing ones performing articles classifications by either manual coding (e.g., Saberi et al. 2019; Babich and Hilary 2020; Oguntegbe, di Paola, and Vona 2022) or bibliographic analysis without analysing the full text documents (e.g., Pournader et al. 2020; Astarita et al. 2020), our review uses machine learning-based topic modelling approach to reduce the biased issues and efficiently extract hidden topics from the large-scale textual data. Thus, this paper reveals some new research themes and future directions that are supplementary to the findings of the existing reviews.

The contribution of this research is trifold: methodological, theoretical, and practical. For the methodological contribution, our proposed literature review approach is scalable and adaptable, which means it can be applied for various sample sizes and domain areas. From theoretical perspectives, by automatically analysing the full-text content of each and every document in details, the identified research themes and directions in this study are more evident, focused, and exhaustive to both macro-topics (e.g., BC in cloud manufacturing) and micro-topics (e.g., BC-based service composition optimisation in cloud manufacturing), which turns the BC-SCM literature into a fruitful research area for academia. From practical perspectives, our systematic research agenda can be beneficial and informative to both BC developers who are looking for new application areas to take their technologies into commercialisation, as well as SC practitioners who are struggling to find new solution approach to their existing issues.

1.2. Blockchain fundamentals

A BC system is a set of interconnected mechanisms to function as an infrastructure (Casino, Dasaklis, and Patsakis 2019). The first layer of this infrastructure is *Transactions* signed between peers to denote mutual agreements on tasks. Any entity connected to the BC is called a *Node* which is grouped into a *Block* for transaction validation. The second layer is called *Consensus* which is designed by different mechanisms (e.g., proof-of-work [PoW], proof-of-stake [PoS], Byzantine fault-tolerant [BFT]). The third layer is *Compute Interface* which allows more BC functionalities such users' state and balances calculation. Finally, the *Governance* layer enables BC to connect with the human interactions in the physical world (Casino, Dasaklis, and Patsakis 2019).

There are three main types of BC, namely public, private and consortium BC (Niranjanamurthy, Nithya, and Jagannatha 2019). Public BC offers permissionless and complete decentralisation where the transactions can be checked and verified by every member. Currently, mining and trading cryptocurrencies such as Bitcoin, LiteCoin, and Ethereum are the main uses of public BC. Because of its permissionless nature, organisations might face network administration or scaling problems such as restricting accesses, network slowdown and longer validation time when more nodes accessing the system (Casino, Dasaklis, and Patsakis 2019).

In contrast to public BC, private BC is restricted and centralized since data access is tightly governed and controlled by a single organisation. Therefore, this type of BC provides better security and authorization controls. Exchange networks and other open-source BC applications are two instances of private BC. Since the number of nodes are limited, the data validation time is shorter than in public BC. Nevertheless, private-BC faces difficulties in achieving full trust of its members as the node can be mutable in the centralized model (Sanka et al. 2021).

Consortium BC is a hybrid between public and private BC, in which a BC system is partly decentralised, and information can be either open or private, thus addressing challenges of both public and private BC. As the BC is managed by a collection of enterprises as opposed to a single entity, consortium BC platform, such as Hyperledger, is mostly utilized in business-to-business operations, enabling members to benefit from trust of a decentralization system with a greater level of security. However, due to the complexity of collaborations and the discrepancy in infrastructure and capabilities between members, creating consortium BC can be difficult (Niranjanamurthy, Nithya, and Jagannatha 2019).

1.3. Paper structure

The structure of this paper is as follow. Section 2 describes the review methodology. Section 3 presents the result of topic modelling, followed by the detailed discussion of each key research topic in Section 4. Section 5 outlines future directions. Section 6 concludes the findings and contributions.

2. Methodology

[Insert Figure 1 here]

In this study, we proposed a data-driven literature review methodology as depicted in Figure 1 above. The method consisted of three fundamental steps:

- Step 1: Article search and selection, which entails a structured process of searching and selecting the relevant articles to be reviewed in this study.

- Step 2: Article classification, which uses topic modelling technique to classify the reviewed articles into different research clusters.

- Step 3: Result analysis, which involves the in-depth content analysis of each research cluster, thus revealing literature gaps for future research agenda.

2.1. Article search and selection

Before searching in literature, we identified two groups of keywords that can capture the synthesis of existing literature related to our research topic, i.e., BC in SCM:

- **Group 1: Keywords related to BC**, including "*Blockchain*", "*Bitcoin*", "*Smart contract*", "*Ethereum*", "*Hyperledger*", and "*Distributed ledger*".

- **Group 2: Keywords related to SCM**, including "*Supply chain*", "*Procurement*", "*Purchasing*", "*Sourcing*", "*Manufacturing*", "*Production*", "*Inventory*", "*Storage assignment*", "*Order picking*", "*Logistics*", and "*Transport*".

The keywords - "*Inventory*", "*Storage assignment*", and "*Order picking*" - refer to three key functions of warehouse operations in SCM. The reason to use these specific terms rather than "*Warehouse*" was to avoid the confusion with the "*Data warehouse*" which is a very common technical term in the information system area (Nguyen et al. 2018).

The literature was searched based on all possible pairs between the two groups of keywords over well-established academic databases, including Scopus and Web of Science. The search timeline was chosen from 2008 where the BC technology was first emerged to Q2, 2022. We set to search keywords in pair with the title, abstract, or author–specified keywords option and only include journal articles.

The initial search generated 1,081 journal papers in total. After removing duplication, it reduced to 730 papers. Next, we conducted a screening check on the overall relevance of these papers by removing those that do not contain both BC-related and SCM-related keywords in their titles or abstracts. As a result, the number of papers dropped to 572. Next, we applied the exclusion rule to remove those papers that only mention the application of BC in SCM as a fleeting point of reference or as collateral research topics. Indeed, many BC-related papers only highlight the potential benefits and applications of BC to SCM without investigating how it is implemented to support SCM decision-making processes. They were thus excluded in this review. In the end, the final list of 108 papers were mutually agreed between authors and proceeded to the review.

Figure 2 and Figure 3 depict the distribution of the selected articles by year of publication and by journal, respectively. As can be seen in Figure 2, research interests in BC-SCM had soared dramatically between 2017 and 2019 before a slight slowdown after the Covid-19 pandemic in 2020. This is in line with the timeline of blockchain adoptions, suggesting the accelerations in production and adoption of BC across industries in 2019 after the remarkable success of several prototypes and pilot projects in 2017-2018 (Sanka et al. 2021).

[Insert Figure 2 here]

[Insert Figure 3 here]

Figure 3 lists top 15 journals that published most of the research in the selected literature (63 out of the 108 papers). Apart from those in information system domains, top journals in operations research (OR) such as International Journal of Production Research and Transportation Research Part E, have also been actively contributing to the adoption of BC in SCM. This would further stimulate the BC-based SCM to attain its mainstream adoption in near future.

[Insert Figure 4 here]

We also reviewed research approaches employed in the sample, as summarised in Figure 4. Around 87% of the reviewed papers applied simulation analysis method and the remaining using other quantitative and qualitative approaches including case studies, surveys, or interviews. Most reviewed studies focused on the development of BC-based frameworks and architectures, after which they used simulation analysis to test and measure their effect on SCM performance under different scenarios and propositions. Of the simulation method, almost half of them used mathematical models to monitor and test the efficacy of BC-based models, about 40% developed BC-coding applications or prototypes to measure the expected outcomes.

2.2. Article classification

The selected literature of BC applications in SCM was systematically classified into meaningful categories for the full content analysis and research agenda recommendation.

Conventionally, the classification framework and content analysis are mostly performed manually using the coding schemes developed in consultation with field experts who have deep knowledge in the studied subjects. However, the major drawback of this manual content analysis is that it often requires extensive amounts of time to read the papers and create the coding sheets before the analysis, which could potentially dismay the researchers and even lead to a waste of efforts if the results turn out to be invalid (Asmussen and Møller 2019).

With the recent advancement of artificial intelligence, researchers have been increasingly shifting their focus into automated content analysis by using computer-assisted text mining to substitute human coding practices, thereby reducing cost of time and avoiding human errors. Topic modelling, one of the unsupervised machine learning branches for natural language processing, has been widely used for automated content analysis in various use cases such as social media data, newspaper articles, books, and even videos. However, this technique, surprisingly, is much less used for academic papers despite the dire need for a reliable, time-efficient literature review approach with the capability to effectively process and examine the large and fast-growing amounts of research data (Duong et al. 2021). This study adopted LDA for topic modelling to classify the current BC-SCM literature into main research themes.

LDA is widely used to discover the hidden topics in a large collection of text documents or corpus. It includes the generative process which associates three hierarchical layers, namely the document layer ($\boldsymbol{D}$), the word layer ($\boldsymbol{N}$) and the topic layer ($\boldsymbol{K}$). The principle of LDA is to assume that each document d in the corpus D can be represented by a different proportion of K latent topics, where each topic k is defined by a Dirichlet distribution β_k with the parameter η over the V number of words in the vocabulary. For that, each document d has its topic distribution θ_d which is a probability distribution drawn from a Dirichlet prior with parameter α. We denoted W_{dn} as the n^{th} word in document d, and

Z_{dn} as the topic assignment for the n^{th} word in document d. With these notations, the generative process to generate words in LDA involved two stages: (1) randomly choosing the distribution $\theta_d$over topics for each document in the corpus D; and then (2) randomly selecting a topic $Z_{dn}$from the distribution θ_d and randomly choose a word $W_{dn}$from the selected topic. This process could be mathematically represented by the joint distribution of the observed and hidden variables as below:

$$p(\beta_k, \theta_d, Z_d, W_d) = \prod_1^K p(\beta_k) \prod_1^D p(\theta_d) \left\{ \prod_1^N p(Z_{dn}|\theta_d) p(W_{dn}|\beta_k, Z_{dn}) \right\} \quad (1)$$

With Equation (1), the hidden topic structure of each observed document in the corpus could be expressed by the posterior distribution below:

$$p(\beta_k, \theta_d, Z_d|W_d) = \frac{p(\beta_k, \theta_d, Z_d, W_d)}{p(W_d)} \quad (2)$$

As explained in Griffiths and Steyvers (2004), the denominator in Equation (2) contains the intractable element which requires to use an approximate inference method to solve. Prior research had used two main approximation approaches for LDA, namely variational algorithms (Blei, Ng, and Jordan 2003; Teh, Newman, and Welling 2007) and sample-based algorithms (Griffiths and Steyvers 2004). In this paper, we adopted the latter approach using Gibbs sampling as it seems to be more efficient when dealing with the large-scale set of document texts.

Another issue of LDA is that it requires users to predefine the number of latent topics K before clustering. A common way to select the optimal value of K in LDA is using the perplexity score of the holdout set to evaluate the clustering performance of the trained LDA model (Blei, Ng, and Jordan 2003). The perplexity score can be measured using Equation (3). Generally, the lower perplexity score indicates better model performance.

$$perplexity(D_{test}) = exp\left\{-\frac{\sum_1^D logp(W_d)}{\sum_1^D N_d}\right\} \quad (3)$$

Prior to explore the topics/themes using LDA, it is important to convert the corpus of document texts into a mathematical object called document term matrix (DTM), so that quantitative techniques such as clustering can be applied. Typically, DTM describes the occurrence of all terms (i.e., words) in each document. Since texts can be highly unstructured and noisy, we apply some text processing techniques to remove terms that do not contain semantic information before creating the DTM. These techniques include tokenizing sentences into terms, lower case transformation, non-letter removal, English stop word removal, and truncating terms to their base form using stemming (i.e., the process to reduce the inflected words into their root form). After this text processing procedure, the DTM only contains keywords with semantic information to be fed into the LDA mechanism described earlier.

3. Result of LDA-based topic modelling

In this study, we used R language to perform the LDA-based topic modelling approach. As aforementioned, we needed to perform some text pre-processing techniques to create a DTM that describes the occurrence of all words in the corpus. Figure 4 lists the occurrence of top 15 words in the DTM derived after processing the full text of the 10 selected publications. It was noteworthy that these words are presented in its stemmed form (e.g., reducing "*logistics"* into "*logist"*) to avoid miscalculate the term distribution. As can be seen in the figure, manufacturing and logistics seems to be the most prominent topic in BC-SC literature.

[Insert Figure 5 here]

Next, the DTM was fed into the LDA model to identify the topic structure of each document in our 108-paper corpus, thereby revealing the key research themes in the BC-SC literature. We adopted the LDA model with Gibbs sampling method to infer the topic distribution within the corpus (Grün and Hornik 2011).

Another important issue is that LDA requires to specify the number of topics K in advance. We used the perplexity score of the holdout (i.e., unseen) dataset to evaluate the model performance in terms of clustering the document texts into meaningful topics (Figure 5). To avoid the resampling bias, we used the five-fold cross validation technique as commonly used in machine learning-based studies (Witten, Frank, and Hall 2011; Nguyen et al. 2019). Generally, the lower perplexity score implies the better model performance; however, it also leads to higher computing resources as number of clustered topic increases. Therefore, the optimal value of K is the one that can balance out both the model performance and the computing resource. From Figure 5, the selected number of topics (K) is 10 where the perplexity score drops the most significantly (i.e., indicating the highest improvement in model performance). When there are more than 10 topics, the model performance only improves incrementally but requires much more computing resources.

[Insert Figure 6 here]

As a result, LDA produces the weighted list of keywords in each topic, which visualised by the word clouds in Figure 6 below. After critically reviewing document members and top keywords identified in each topic, we chose the label that represents its research theme, as summarised in Table A2 in Appendix. Since topic 4 and 5 seen to have several overlapping keywords, we joined them together.

[Insert Figure 7 here]

4. In-depth review of research themes

4.1 Theme 1: Revenue management in BC-enabled SC

A recent emerging research stream emphasised on the revenue management of BC-enabled SCM. Hayrutdinov, Saeed, and Rajapov (2020) examined the revenue-sharing contractual mechanism, considering the cost factor of BC-enabled product lifecycle (PLC) information sharing efforts and the influence of product price sensitivity. Zheng et al. (2019) simulated a three-level spacecraft SC model to explore how the buyer's risk coefficient changes the contract term and the supplier's application degree of BC technology. Liu, Li, and Qi (2019) developed a mean-Conditional Value at Risk (CVaR) to understand the decision making of each SC member under different risk aversion and BC application degree contexts, thus designing a revenue-sharing contract for SC coordination. Li, Wang, and Yang (2019) addressed SC coordination issues under the combined effect of BC-based revenue sharing contract and random customer demand.

Another research stream is to investigate the costs and benefits of adopting BC applications in the anti-counterfeit online selling platform. For example, Niu et al. (2021) analysed the incentives for multinational firms (MNF) to sell on BC-based e-commerce platform and found that BC increases the MNF's wholesale profits but reduces its retail profit and tax planning benefits. Studying the operations of BC-supported diamond authentication and certification (BDAC) platform, Choi (2019) suggested that all parties across the luxury SC can be beneficial if BDAC cost (e.g., creating a digital thumb print and the corresponding digital certification) can be reduced. Yang et al. (2022) optimised BC applications in financial institution-based SC finance system while considering tradeoffs among operational security, cost and efficiency. Dong et al. (2021) examined the effect of BC-driven agricultural cross-channel information strategy on retailing price strategy and consumer behaviour. Lately, the impact of BC adoptions in the platform economy has also gained increased research interests. Wu and Yu (2022) posited that BC is a powerful tool for suppliers to adjust prices and control markets on platform SC by eliminating information asymmetry and transaction cost. Tao et al. (2022) also postulated that BC can benefits both suppliers and consumers by allowing the SC platform to provide products with high quality and low price. However, it stressed that there are cases where suppliers will have incentives to decrease product quality with BC, which eventually hurt consumers' interests. In short, although several advantages of BC applications in online revenue management have been studied, the uptake of BC in platform SC is still relatively low since customers' perceptions and economic incentives for BC adoption remain as the main barriers (Niu et al. 2021).

4.2 Theme 2: BC-enabled SC sustainability

Recent studies consistently highlight the BC's traceability and transparency ability as a key enabler to the development of sustainable SC operations. For example, the importance of BC technology in tracking and managing carbon emissions has been highlighted in the textile industry (Fu, Shu, and Liu 2018), agriculture (Kamble, Gunasekaran, and Sharma 2020; Rane and Thakker 2019), and mineral SC (Yousefi & Mohamadpour Tosarkani, 2022). Wu, Fan, and Cao (2021) found that BC enables the traceability for e-tailers to reduce wastes in fresh product SC. Rane and Thakker (2019) analysed the shared architecture of BC and Internet of Thing (IoT) for green procurement activities. Zhang et al. (2020) proposed an architecture of a BC-based life cycle assessment system with four layers to enhance the input material and output wastes managing performance. In the context of Covid-19 pandemic, Wang et al. (2022) designed a BC system that ensure the compliance of sustainability standards across the multi-tier SC of personal protective equipment.

Several studies aim to explore the potentials of BC in reducing environmental impact from logistics and transportation activities. Tian et al. (2021) developed a BC-based evaluation approach for customer delivery satisfaction in sustainable urban logistics, of which a long-short-term-memory (LSTM) model is used to predict customer satisfaction and a smart contract is used for compensating dissatisfied customers. Philipp, Prause, and Gerlitz (2019) explored how BC smart contract can support collaborative logistics structures and integrate SMEs into the sustainable maritime SC. Dealing with the high demand volatility risks, Yoon et al. (2020) revealed that BC adoptions can shorten lead time and reduce ocean transport cost, thus reduce carbon emissions by reducing air transport shipments. Manupati et al. (2020) proposed BC-based production allocation models under a carbon taxation policy. Aiming to maximise the SC utility for lower carbon emissions, Zeng et al. (2022) developed a sustainable SC scheduling model for the production and transportation system under the BC environment. To ensure the success of BC implementations, Orji et al. (2020) identified critical success factors for BC-based freight logistics industry, while Bai and Sarkis (2020) introduced a hybrid group decision method based on fuzzy theory and SC transparency and sustainability appraisal model. In addition, major causes that help achieve sustainable SC after integrating BC technology are unveiled in Yadav and Singh (2020). Apart from transporting, Ar et al. (2020) found that warehousing, order processing, materials handling, and fleet management are among the most feasible BC implementations in logistics operations.

4.3 Theme 3: BC-enabled SC traceability

To solve the fraud problems, there is a research stream focusing on exploring how the BC and IoT integrated platform can optimise the traceability and transparency in different areas of SCM, for example, the BC-IoT shelf-life management system for perishable food (Tsang et al. 2019), the IoT-based smart shipping containers with an Ethereum BC-based smart contract for efficient shipment management and governance (Hasan et al. 2019), and the Lock-flock platform based on the BC-IoT-Cyber Physical System (CPS) integration for digital assets management in SC finances (Rachana Harish et al. 2021). Khan and Ahmad (2022) is one of few studies employing the BC-IoT technologies to e-waste track and traces in smart cities.

In addition to IoT, BC integrations with other emergent technologies are also studied for advanced SC traceability. For example, Meyer, Kuhn, and Hartmann (2019) extended the BC integration ability towards the Physical Internet's distributed network structures to develop the decentralised structure within the logistics networks. Li, Shen, and Huang (2019) developed the BC and cloud-based workflow operating platform for logistics resource sharing in real estate e-commerce. Other studies highlighted the traceability feature by employing BC-based crypto services, for instances, cryptographic hashes for data management in product development process and additive manufacturing system (Papakostas, Newell, and Hargaden 2019), or Ethereum-based digital token for tracing manufacturing process (Westerkamp, Victor, and Küpper 2019).

A research stream, which is important to leverage BC traceability but still elusive in current literature, is analysing how key aspects of the BC-SCM integration can be operationalised. As BC is a distributed database, it is important to have a common interpretation of data across different SC organisations. Therefore, Kim and Laskowski (2018) proposed the adoption of ontology-based enterprise modelling in BC design and test it in the food SC provenance traceability. Agrawal et al. (2021) studied the data management when adopting BC traceability in textile and clothing multi-tier SC. Zhu et al. (2022) employed BC as governance mechanism to support product deletion decision makings. Yang et al. (2022) investigated when BC-enabled traceability motivates producers to outsource deliveries to logistics firms. In addition, Ji et al. (2022) suggested manufacturers to adopt BC when consumers' traceability awareness exceeds a certain level.

4.4 Theme 4: BC-enabled manufacturing system

Manufacturing is one of the biggest SC application areas of BC. Karamchandani et al. (2021) studied the perceived role of BC in manufacturing and suggested that BC can significantly improve delivery reliability and mass customisation. Indeed, many studies have been actively seeking new ways to leverage BC capabilities for the development of emerging manufacturing trends. Two key trends being studied the most are cloud manufacturing and digital twin-enabled smart manufacturing.

BC-supported cloud manufacturing (CM) is gaining traction recently. CM is a new smart networked manufacturing model that embraces cloud computing to provide on-demand Internet access to a shared pool of configurable manufacturing resources delivered as services (e.g., software, capabilities, equipment) (Karamchandani et al. 2021). Although CM allows to meet the growing demand for higher product personalisation, it still suffers from issues caused by centralised network operations such as availability, efficiency, flexibility, and security (Yuan et al. 2019). Thus, many researchers have studied decentralised BC as a promising solution to many of these CM problems. Particularly, new system architectures and design principles to effectively integrate and leverage BC into CM system are proposed.

For example, one of the first distributed peer-to-peer CM system was developed by Li, Barenji, and Huang (2018), which used a cryptographic public BC network architecture with five layers (i.e., resource, perception, manufacturing, infrastructure, and application) to improve the security and scalability of CM. Later, Barenji et al. (2020) changed the network layer to a consortium BC network with new BFT-based consensus mechanism to make it more suitable for small-medium enterprises (SMEs). Kaynak, Kaynak, and Uygun (2020) developed the CM system where the network layer is Ethereum-based public BC network, but the application layer is employed in a hybrid public-private structure to allow users to pay only for the manufacturing agreements that need to be secured, hence cutting the intermediary costs. To enhance the system credibility and efficiency, Leng et al. (2018) proposed a public BC with the double chain structure, i.e., *user information chain* to record and store the business user information in public service platform and *transaction chain* to record and store transaction data. Bai et al. (2019) proposed a light-weight BC platform for IoT-based CM which include both the in-chain network for transaction processing and the off-chain network for data storage and other complex tasks. As the distributed decentralised BC network normally requires a consensus algorithm to provide a consistency process of all nodes, several studies aim to improve the consensus authentication mechanism for more effective and reliable service collaborations when developing a CM system architecture (Yuan et al. 2019; Y. Fu and Zhu 2019b; 2019a).

Another research subtopic in this theme is emphasising on how BC supports the digital twin (DT)-enabled smart manufacturing. DT, which was first introduced in 2003 for managing PLC in the virtual space, consists of three fundamental parts, i.e., the physical product, the virtual product, and the data transmission between them. In response to the mass personalisation trend, Leng et al. (2019) developed a decentralised self-organising Makerchain model which uses BC smart contracts for automating transactions between makers in social manufacturing and the workpiece’s DT for lifecycle quality tracking and anti-counterfeiting. Later, Leng et al. (2020) continued to develop a permissioned BC-based model for personalised manufacturing (called ManuChain), of which a smart contract tree model is used at lower-level to proactively decentralise the fine-grained and personalise task execution while a DT model is utilised for holistic optimisation of manufacturing planning at upper-level. Most recently, Leng et al. (2022) built a BC smart contract pyramid-driven multi-agent autonomous process control prototype on ManuChain system to enhance the control timeliness and adaptability towards a resilient personalised manufacturing. Zhang et al. (2020) studied the hardware and software design of the data- and knowledge-driven DT manufacturing cell system which combines IoT with permissioned BC to efficiently facilitate autonomous manufacturing process. Not only during product design and manufacturing stage, BC can also be an effective data management method for the DT of product throughout its entire lifecycle including logistics, sales, return, maintenance, recycling, etc., as proposed in the cryptographic BC-based DT framework by Huang et al. (2020).

4.5 Theme 5: Scheduling in BC-supported cloud manufacturing

While the previous theme studies the technological development of system architectures and design principles of the BC-supported CM, this research stream studies focuses specifically on scheduling problems in such system. Scheduling is the most studied topic in CM, which can be broadly defined as the process of allocating, controlling and optimising resources/services to tasks/workloads. It involves many activities such as task dispatching, task decomposition, service discovery, matching, selection, and composition (Liu et al. 2019).

In this theme, several studies of BC-supported CM system tried to optimise service composition which refers to the matchmaking process of selecting and combining multiple services, atomics or composite, into service bundles to fulfil a set of demanded tasks. Since service composition is often a NP-hard multi-objective, multi-constraint optimisation problem which makes exact approaches (e.g., Branch-and-Bound) computationally expensive to use, most of solution approaches are developed based on evolutionary algorithms to find a near-optimal solution. For example, Yu et al. (2019) used particle swarm optimisation to solve a BC-based service composition model that considers multiple quality of service (QoS) objectives including cost, service availability, reliability, and function similarity. Zhang et al. (2019) improved Memetic algorithm by combining genetic algorithm and simulated annealing to find optimal manufacturing service collaborations for the tasks. However, like many other evolutionary algorithms, these models are only efficient on small-scale problems but often fails to extract solutions in large-scale ones. To overcome this pitfall, Aghamohammadzadeh and Valilai (2020) developed a novel scalable solution approach based on the divide and conquer strategy. More particularly, the original large-scale service composition problem is divided into sub-problems with a smaller fraction of the service/task pool that can be efficiently solved using genetic algorithm. Nevertheless, for practical uses, the performance of this model when considering various QoS attributes such as quality, reliability and availability is still subject to be validated in future research. Taking time-dependent machine availability, Dolgui et al. (2020) presented the BC smart contract design as a flexible flow shop scheduling problem and suggested an event-driven dynamic approach combining continuous and discrete optimisation for the solution of task and service compositions.

A less studied subtopic in this theme is to examine pricing strategies and revenue management for service providers in job bidding (Zhu et al. 2020; Giovanni 2019).

4.6 Theme 6: BC-enabled healthcare SC

A distributed ledger using BC is a promising technology that can offer practical solutions to several SC process-related problems in the healthcare industry. For example, Jayaraman, Saleh, and King (2019) proposed an IoT-BC framework of product traceability and trusted information sharing across the healthcare SC to address some pressing challenges in product recalls, supply shortages, drug counterfeits, and expiration tracking.

BC in counterfeit drug prevention is a dominant research topic in this theme. Pandey and Litoriya (2020) developed and tested a BC Hyperledger Fabric platform recording medicine logistics data to prevent counterfeit medicines. It found that the proposed system is computationally expensive but can provide a reliable solution to tackle fake medicines. Likewise, Jamil et al. (2019) used the Hyperledger Fabric BC platform to suggest an identity manager procedure that enables the time-limited access to drug and patient health records based on a permission network and smart contract. Nørfeldt et al. (2019) avoid counterfeits by introducing the crypto-pharmaceutical concept where each pharmaceutical product is attached to a patient-specific BC of unique individual dosage units. Kshetri (2017) highlighted how the decentralised, autonomous BC application can strengthen cybersecurity and protect privacy in the cloud and IoT ecosystem with the illustration from the healthcare industry. BC-based digital token can also be used to enhance product tracking and reduce product counterfeit in healthcare. For example, Yanovich et al. (2018) proposed a digital asset named crypto-token stamp to prevent counterfeit caused by physical postal stamps. Of which, every stamp operating activity is attended by subsequent transactions with digital tokens on the Hypeledger Fabric platform. Tseng et al. (2018) used the Gcoin BC-based drug transaction data with the surveillance net regulation model to prevent counterfeit drugs and protect public health.

Another fruitful research avenue is to explore BC applications in healthcare reverse logistics. For example, Debe et al. (2020) proposed the decentralised BC, smart contract and decentralised storage system to reduce the number of wasted drugs by managing the return, redistributing the unused drugs and facilitating the reselling drugs process.

An important but largely understudied research direction is to focus on implementation issues of BC-adopted healthcare applications. Shanley (2017) stressed that using BC in healthcare is a complex matter since anything that involves patient data would trigger different privacy and data regulation. Makhdoom et al. (2020) developed Privysharing - an innovative BC framework that uses a digital token named PrivyCoin for privacy preserving and secure data sharing in smart cities, which is also applicable to smart healthcare. Other issues in finance, security, expertise, and government policies are among the most important barriers of BC implementations in healthcare, as Govindan et al. (2022) revealed.

4.7 Theme 7: BC-enabled anti-counterfeiting SC system

In the theme of developing the BC-based anti-counterfeit SC system, two research branches have been identified: (1) developing track-and-trace systems, and (2) utilising cryptography to detect counterfeiting attacks.

In the first stream, Radio Frequency Identification (RFID) tags are widely adopted in the track-and-trace SC system as an effective anti-counterfeit measure. However, these tags can be easily cloned in public spaces like in the post SC. Therefore, Toyoda et al. (2017) developed an RFID-enabled anti-counterfeits schemes with a BC-based product ownership management system that allows customers to reject the purchase of counterfeits even with genuine RFID tag records. Similarly, Sidorov et al. (2019) proposed a robust ultra-lightweight mutual authentication protocol to successfully connect RFID protocols with the secured decentralised BC database. This system has been proven to efficiently reduce the costs of storage, computational and communication among SC members. Cui et al. (2019) proposed a permission BC and Hyperledger Fabric platform to track and trace every electronic part in SC, as well as preventing illegitimate device registration, transfer, and off-chain distribution.

In the second stream, Islam and Kundu (2019) proposed the framework combining BC and embedded physically-unclonable-function-based (PUF) public key cryptography for authentication in the Integrated Circuit (IC) SC. It uses BC's smart contract and cryptography to provide ownership transfer record, while PUF provides a unique identification for an IC allowing it to be connected uniquely to a BC. Cryptography is also significant in developing rewarding system to encourage honest behaviours from SC members. Alzahrani and Bulusu (2020) used game theory to develop a truly decentralised anti-counterfeit SC which encourages honest consensus nodes' behaviours by providing the rewards or penalties for members. Likewise, Zulfiqar et al. (2021) proposed EthReview - a product review system based on the Ethereum platform which uses the ERC20 tokens to create the incentive rewarding and penalty system for honest and fraudulent behaviours.

4.8 Theme 8: BC-based logistics and transportation

After manufacturing, logistics and transportation are another prominent research domain in BC-SC literature. There is a growing interest in studying BC application in developing Intelligent Transport System (ITS) with Internet of Vehicle (IoV). Labrador and Hou (2019) developed a novel BC-based ITS technology which uses the public-key cryptography as a security mechanism for vehicle identification and transaction authentication in IoV scenarios. Hu et al. (2019) proposed the ITS which uses the Byzantine consensus algorithm based on time sequence and gossip protocol to improve both communication security and the fault tolerance of the system. Based on the BC-based decentralised structure, Lei et al. (2017) proposed the secure and dynamic key management framework for ITS to enhance securities and reduce operating times. Mu, Rezaeibagha, and Huang (2020) suggested the BC application in policy management for transportation systems by applying a lightweight policy-driven signature scheme under the permission and private BC scenario.

Recently, BC has increasingly been exploited to solve existing challenges in modern logistics services. For instance, Yang et al. (2019) developed a BC-based steel logistics architecture with the improved practical Byzantine-fault-tolerant (PBFT) algorithm to enhance the system performance (i.e., security, delay, throughput and fault tolerance). Yi (2019) designed a BC-based logistics model with an information undeniable scheme to secure logistics for personal privacy protection.

Not just logistics, some studies also develop the BC system for managing information and capital flow across the whole SC process. Xiong et al. (2019) designed a BC private-key distribution scheme allowing secret sharing for lost key recovery to guarantee payment security and protect digital assets in the construction SC. Gao et al. (2018) proposed a novel SCM system based on a BC decentralised ledger with a two-step block construction mechanism. Designed with efficient storage scheme and information protection, the system can securely support various logistics activities such as cargo tracing, bills of lading, international trade compliances, and customs clearances. Du et al. (2020) developed a SC financial platform with the BC homomorphic encryption to improve efficiency of logistics, capital and information flow while protecting sensitive data privacy. Liu and Li (2020) is one of few studies exploring BC applications in global SC and logistics. It provided a product traceability framework for cross-border e-commerce SC, integrating a series of BC-models including multi-chain structure, data management and block structure.

4.9 Theme 9: BC-based SC system architecture development

This major research stream shifts the focus more on technological aspects of implementing and integrating BC system into SC system. Most of studies under this research cluster proposed the holistic system architecture with the sequence diagram that explicitly demonstrates how system agents/entities connect and interact in the sequence of processes to carry out the specific SC functionality.

System architectures with BC integrations are proposed for different SC processes and contexts. For example, in manufacturing, Shahbazi and Byun (2021) developed a private Hyperledger Fabric BC system for machine learning-based fault diagnosis prediction of equipment and machinery. In warehouse, Fernández-Caramés et al. (2019) designed and evaluated an automated inventory system that uses a BC distributed ledger to securely store RFID-tagged inventory data collected by unmanned aerial vehicles (UAV). In procurement, Thio-Ac et al. (2019) introduced an online BC-integrated system architecture and web design for the whole procurement execution process starting from procurement posting to order placement and contract signing. Agrawal et al. (2022) designed a BC-based procurement and distribution system where smart contracts are used to support stakeholders' collaborations and resource sharing.

In wholesale trading, Yoo and Won (2018) created a transparent price tracking system based on Ethereum BC and smart contracts to grant customers access to information about the distribution cost of each transaction, thus discouraging wholesalers from extracting excessive profits while protecting companies against Distributed Denials of Service (DDoS) and data forgery attacks. In shipping logistics, Wu et al. (2017) developed a hybrid BC architecture for a crowd-validated, real-time shipment tracking system, of which a set of private ledgers are used for private sharing of shipment information between each trading partner while a single public ledger is used as an independently validated, tamper-proof records of online shipment status. In quality control, Mondal et al. (2019) adopted the PoW protocols in cryptocurrencies to develop an IoT-BC architecture allowing real-time quality monitoring in food SC by having the RFID-based sensors at physical layer and BC at cyber layer. Likewise, Figorilli et al. (2018) developed a BC decentralised and distributed ledger system for RFID-based traceability of product quality throughout the whole wood SC process. Wang et al. (2020) built a novel BC-based information management system to facilitate on-time delivery and track quality problems of precast components in the construction SC.

In the development of smart cities, Botello et al. (2020) built a BC system (so-called BlockSIEM) to securely store and access security events for a range of smart services (e.g., manufacturing, transport, health, education). For smart transports, Elagin et al. (2020) and Jabbar et al. (2020) developed the BC-based IoT system architectures to establish secure information exchange and address Vehicle-to-Everything communication problems. To leverage BC technology for overcoming SC collaboration and trust issues, Longo et al. (2019) designed a software connector to connect the enterprise's information system with an Ethereum-like BC, allowing firms to share information with partners at different levels of visibility, as well as checking data authenticity, integrity and invariability.

4.10 Theme 10: BC-based food and agriculture SC

As agriculture goods or food sources can be fraud easily and hard to track, quality assurance remains the utmost challenges for the chain members in this sector. Recent studies have focused on the research theme that explores the BC-application benefits on sustaining the agriculture and food SC.

For example, Zhang et al. (2020) proposed a four-layer security management system based on BC technology in grain SC, which allows the combination of chain storage, data security, information intercommunication, real-time sharing information and traceability for the whole process operation. Sander, Semeijn, and Mahr (2018) also highlighted BC benefits in meat SC by simplifying the certification process to facilitate the customers' purchasing decision making. Behnke and Janssen (2020) standardised the traceability process in the food-ingredient SC by indicating eighteen boundary conditions that SC-system needs to fulfil to optimize the BC-based traceability. Surjandari et al. (2021) designed a permissioned BC network with three channels and raft consensus algorithm in Halal SC and concluded that the system can efficiently secure Halah food transactions.

BC-based smart contracts have been widely used to enhance the traceability system in agriculture SC. For instance, Salah et al. (2019) emphasised the usefulness of Ethereum BC and smart contracts in developing tracking-and-traceability system for soybean products, where all interactions and transactions are governed, controlled and stored with the immutable ledger. Lin et al. (2019) developed a BC food traceability system which divides the data management tasks into on-chain and off-chain networks to prevent data explosion and uses smart contracts to avoid data counterfeit and sensitive information disclosure. Mao et al. (2018) proposed a BC-based credit evaluation system from the integration of smart contract and LSTM system to provide traders' credit results.

Dealing with the counterfeit problem in the production and operations process subject to strict supervisions by the State Food and Drug Administration, Yong et al. (2020) combined the virtual currency-based BC and machine learning technologies to enhance the supervision function and provide intelligent recommendation functions. In another study, Ding et al. (2020) proposed a permissioned BC-based, double-layer framework applicable for agri-food SC, of which the main layer provides traceability information directly to customers by using consortium BC while the sub-layer consists of several immutable private BCs for secure data entry and storage.

5. Suggested future research directions

Based on the discussion in the previous section, some future research directions can be identified in the BC-SC literature. Overall, the radar chart in Figure 8 summarises the subtopics in ten key themes identified by LDA topic modelling and suggests some possible pathways to stimulate the BC-empowered SCM towards five future research directions.

[Insert Figure 8 here]

5.1 Direction 1: Integration of BC and other emerging technologies for global, scalable SCM

Current research focuses mainly on BC applications in the local and regional SCM, however, its benefits and challenges in a more complex, large-scale global supply chain system are largely underexamined. The revenue management and cost-benefit analysis in theme 1 serves as a good starting point for future research of the BC-based international SCM as the findings can motivate more business uptakes of BC.

Furthermore, as the cross-border SCM often deals with big data, it is essential to integrating BC with other emerging technologies (e.g., cloud computing, physical internet, DT) to enhance the system scalability. In this regard, future studies can consider adapting the BC-SC system architectures discussed in the research theme 9 to the international context.

5.2 Direction 2: Exploring applications of BC-based crypto-X in SCM

There are a few of crypto-X applications (e.g., crypto-currency, crypto-asset, crypto-anchor, crypto-token) that deserve future research attentions. It is a fruitful research stream to explore new values of Crypto-X in SCM.

For example, crypto-currencies and crypto-assets can be used in smart contracts to enable automated payments and proof of delivery. However, there is an ongoing controversial argument about whether they can be used as the global currencies/assets for international trades. While some countries like Japan recently allow crypto-currency trading for public procurements, others like France and China are more sceptical and even impose a ban on this asset. The inconsistency and absence of standard regulations and governances are the main barriers to their global adoptions.

Contributing to research stream in theme 3 and theme 7, future research should also exploit the benefits of using crypto-anchor and crypto-token for product tracking and anti-counterfeit between SC members. At the same time, some challenges in their system architecture design, implementation and operationalisation are also worthwhile to investigate (theme 9). For instance, one of the main challenging tasks is to optimise the number of locations of crypto-anchor devices in the SC network to maximise the return on investment.

Arguably, manufacturing (theme 4), logistics and transportation (theme 8), and food SC (theme 10) are among the areas that are most likely to be interested in the crypto-X applications for the advancement in tracking, traceability, and anti-counterfeit capabilities.

5.3 Direction 3: BC-enabled development of closed-loop SCM

While extant literature mainly focuses on the application of BC-technology in traditional forward SC structure, its benefits in reverse logistics and closed-loop SC development has been much less discussed. Thus, we call for further investigations on exploring the efficacy of BC-application in circular economy and identifying unique modifications or benefits on different industries and SC stages. The call could be involved in several research themes identified in this review.

For instance, as BC allows product lifecycle tracking (theme 3), its data on the used or end-of-life products could be explored to improve reverse logistics operations (theme 8) such as predicting quality and timing of product returns, and hence, optimizing recycling and remanufacturing planning and control (theme 4 and theme 5).

In addition, future researchers could also conduct the feasibility study of how new BC applications such as NFT (non-fungible tokens) can reconfigure the whole closed-loop SCM in the context of circular economy. For example, some fashion brands have initiated the adoption of NFT royalties which use BC-based smart contracts to authenticate the second-hand products and automatically collect royalties from resales, thereby stimulating fashion reuse behaviours and reducing wastes. However, the system architecture development (theme 9) and the feasibility of such new business models in terms of economic performance (theme 1) and sustainability impacts (theme 2) are yet subject to be further investigated.

5.4 Direction 4: Assessing the environmental and social impacts of BC-based SCM

There is a long-standing debate over the environmental impact of BC technologies which largely hinder their adoptions in the large-scale. People share a growing concern that BC operations in data centres often consume a huge amount of energy and cause greater carbon footprints than conventional technologies. Hence, apart from investigating the economic viability (theme 1), it is also worthwhile for future research to develop the lifecycle assessment with metrics and measures to quantify the environmental impact (theme 2) of adopting BC in SCM.

Finally, the social impact (theme 2) of BC-adopted SCM is largely neglected in the current SCM literature. For the sustainability development, future studies should also explore how BC adoptions could affect social issues in SCM such as employee satisfaction, training and skill development, job creations/losses, etc.

5.5 Direction 5: Development of Decentralised Autonomous Organisation (DAO)-based SCM

DAO is one of the most interesting technologies emanated from BC, which refers to a new form of organisations where cooperation and coordination between members are automatically enforced by a set of predefined, tamper-resistant rules encoded in smart contracts (Zhao et al. 2022). Operated by a distributed governance among members rather than by a central government/manager, DAO can offer huge benefits in increasing operation efficiency, transparency, privacy, reliability, resilience and reducing transaction cost (Saurabh, Rani, and Upadhyay 2022).

DAOs have been gaining fast-growing tractions in the fintech research, but largely overlooked in SCM (Philipp, Prause, and Gerlitz 2019; Zhao et al. 2022). Therefore, it is essential for future research to investigate the impacts of DAOs, compared to other BC types, in various SC application areas such as manufacturing (theme 4), cloud manufacturing (theme 5), healthcare (theme 6), logistics & transportation (theme 8), and food & agriculture (theme 10).

Additionally, future studies should develop new system architecture approaches (theme 9) to transform the existing SCM system into a fully DAO, thereby stimulating its uptakes in practices. The proposed system design needs to provide solutions to key concerns of the automatically distributed governance such as cybersecurity threats, group consensus management, legal duties, political and social issues.

6. Conclusion

The decentralised, immutable mechanism of BC technologies offers the unprecedented opportunities to enhance visibility, traceability, accountability and transparency across the entire SC. Therefore, BC in SCM is a fast-growing literature which requires to be regularly reviewed and systematically synthesise to unveil key research themes and fruitful future research directions.

In this work, we thus develop an efficient, scalable data-driven reviewing approach that uses text mining and LDA model to extract latent topics from the full-text content analysis of 108 relevant journal articles. Our proposed approach overcomes the drawbacks of traditional systematic literature reviews using either human coding practices or bibliographic analysis for article classifications, which are highly time-consuming and biased when dealing with big textual data.

As a result of LDA, ten key research themes have been discovered, including revenue management, sustainability, traceability, cloud and DT-based manufacturing systems, scheduling in cloud manufacturing, healthcare, anti-counterfeit system, logistics and transportation, system architecture development, and agricultural SC. Our study calls for more studies on five future research directions to stimulate the adoption of BC in SCM. They include (1) the integration of BC and other emerging technologies for large-scale global SCM, (2) exploring applications of BC-based crypto-X in SCM, (3) the BC-enabled development of closed-loop SCM, (4) assessing the environmental and social impacts of BC-based SCM, and finally, (5) the development of DAO in SCM.

Although our literature review analyses one of the largest sample sizes in the field, new publications continue to emerge. Consequently, some latest studies may have been unintentionally missed in our study. Furthermore, as the LDA approach is still in its early adoption stage in systematic literature review, it has certain drawbacks, such as the tendency to overlook topical correlations and not being able to indicate the evolution of research trends over time. Other text mining techniques may also be applied in literature synthesis to explore their effectiveness an improve upon the LDA-approach employed in this work.

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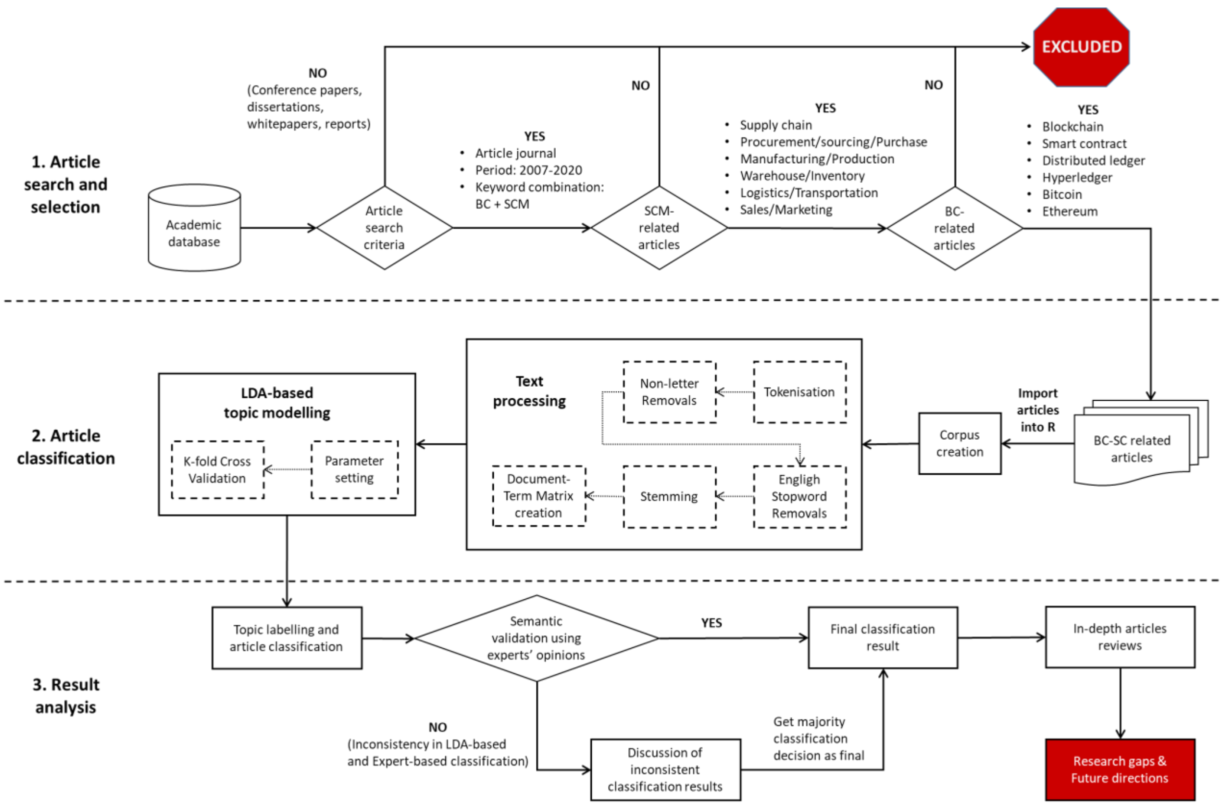


Figure 1 Caption: Review methodology framework
Figure 1 Alt Text: Describing the proposed data-driven literature review methodology consisting of three fundamental stages.
Figure 1 Long Description: The first stage is the process of searching by keywords and selecting the relevant journal articles to be reviewed in this study. The second stage is to develop the article classification framework where the LDA-based topic modelling cluster the selected literature into key research themes. The final stage involves the in-depth content analysis of each research cluster which leads to future research agenda.

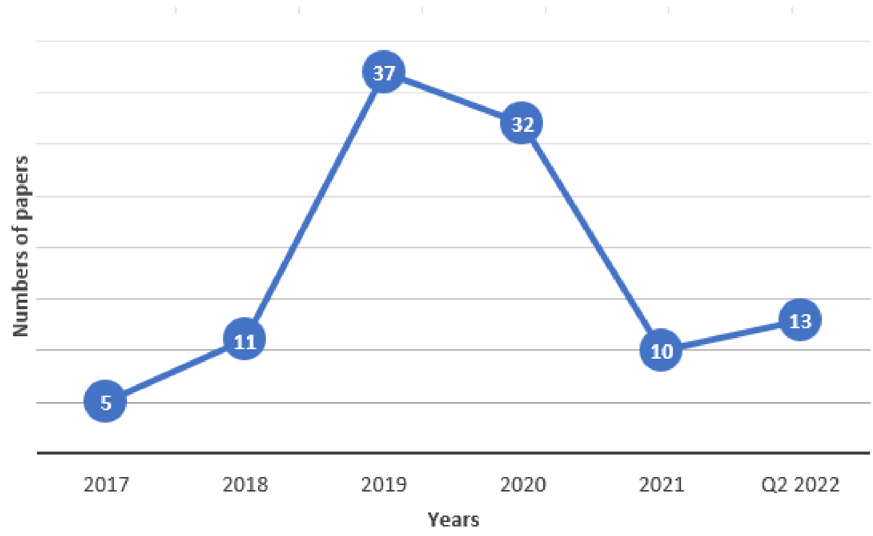


Figure 2 Caption: Distribution of publications by year

Figure 2 Alt Text: Number of journal articles in the selected literature by year of publication. Research interests in BC-SCM had soared dramatically since 2019, implying that that the topic has begun ascent into mainstream

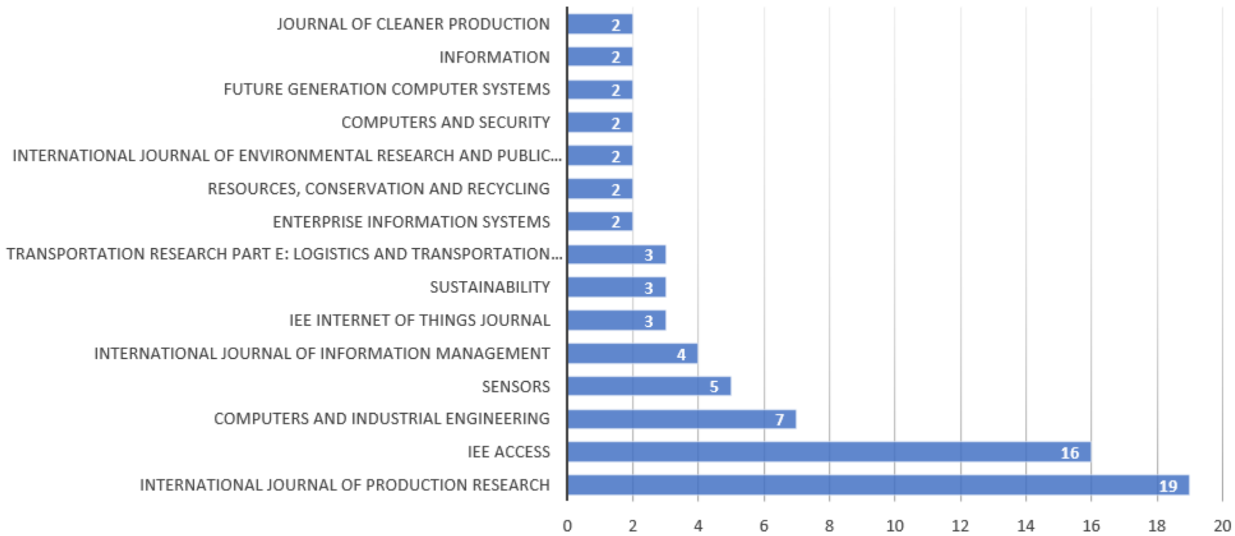


Figure 3 Caption: Distribution of publications by journal

Figure 3 Alt Text: Top 15 journals publishing most of the BC related research in the selected literature (74 out of the 108 papers)

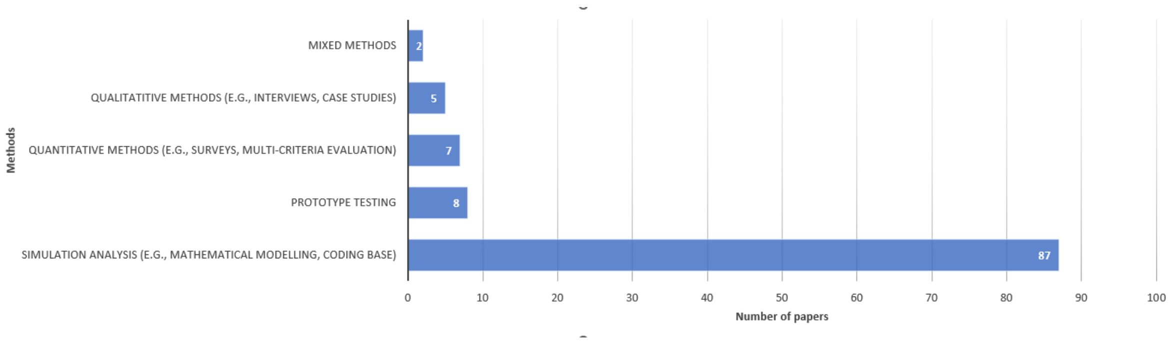


Figure 4 Caption: Summary of research methods used in reviewed articles

Figure 4 Alt Text: Five main research methods have been identified among the reviewed papers. Simulation analysis accounts for about 85% of all reviewed papers.

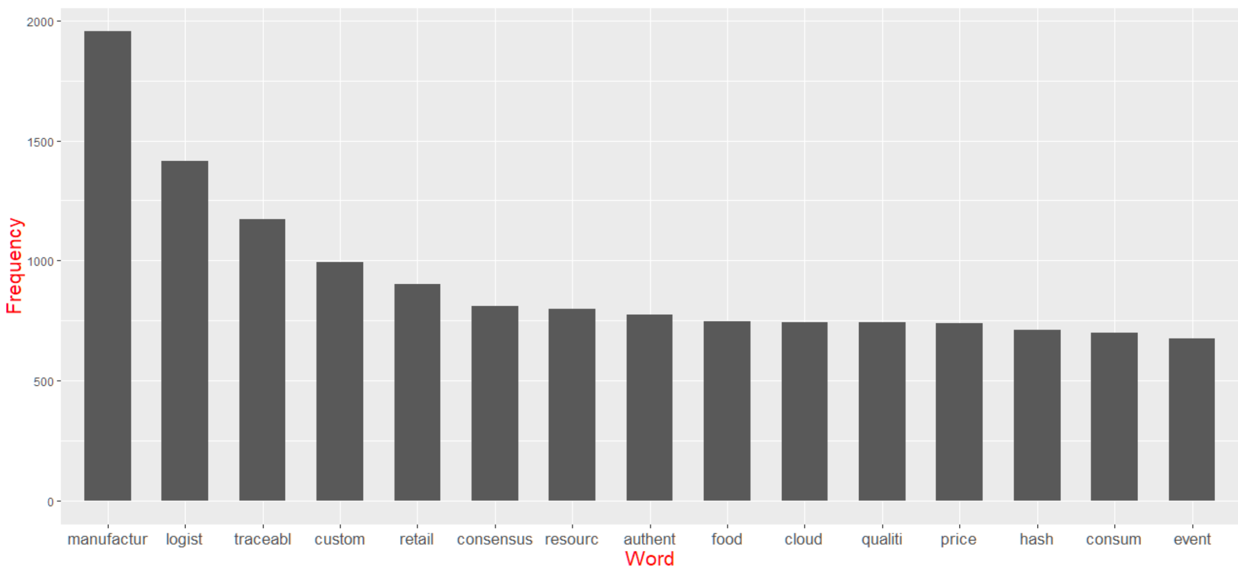


Figure 5 Caption: Frequency of top 15-word frequency in the DTM

Figure 5 Alt Text: The occurrence of top 15 words in the DTM derived after processing the full text of the 108 selected publications. It is noteworthy that these words are presented in its stemmed form (e.g., reducing “*logistics”* into “*logist”*) to avoid miscalculating the term distribution.

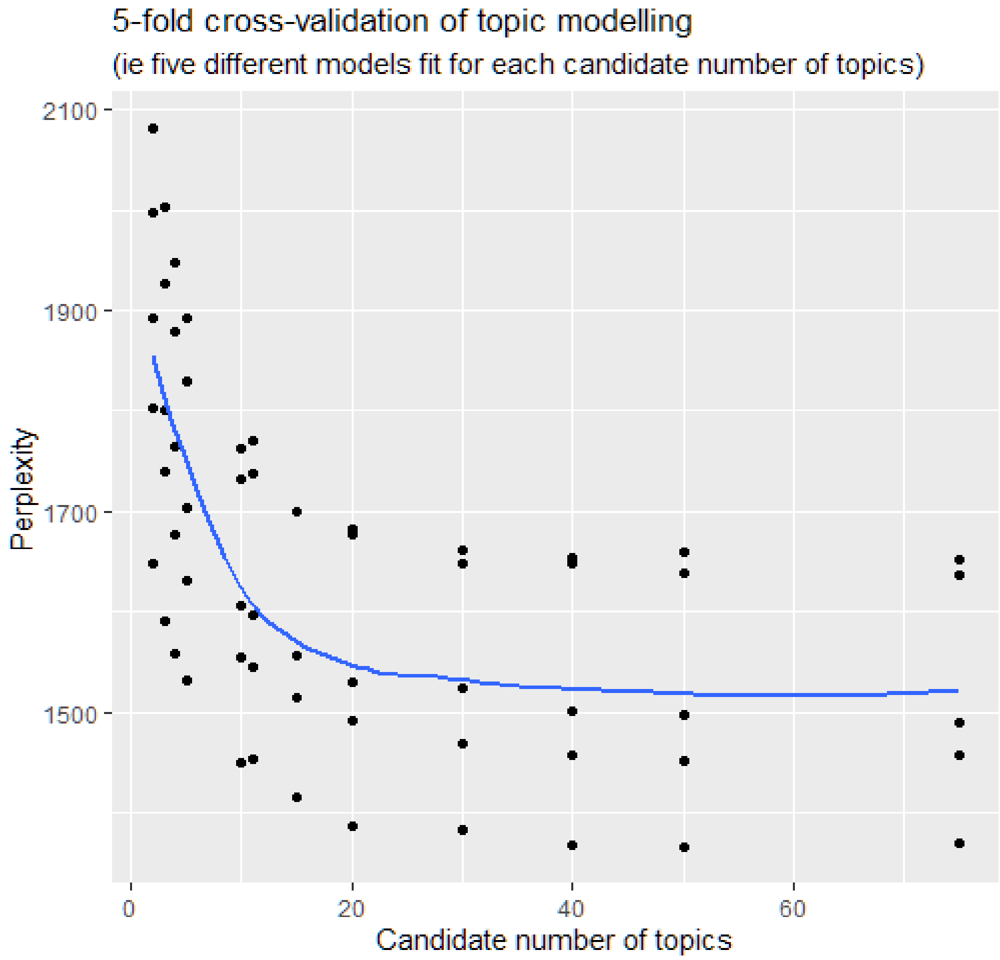
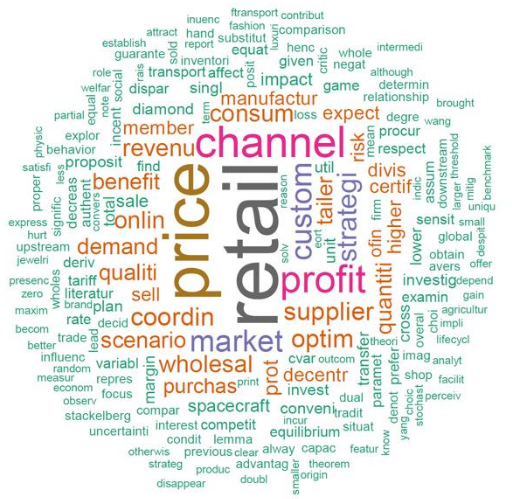
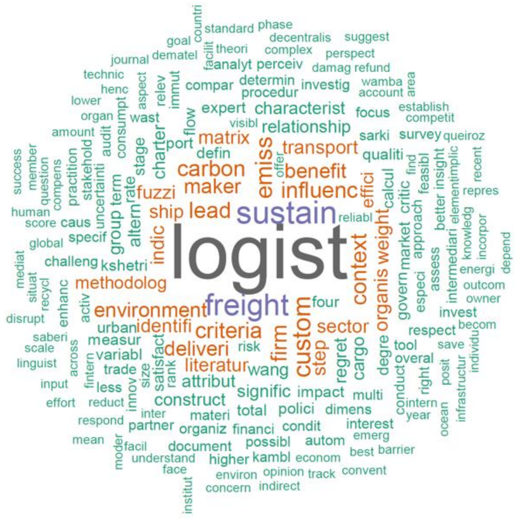


Figure 6 Caption: Optimising number of topics (K) based on perplexity scores
Figure 6 Alt Text: The number of topics K in LDA model is a subject to be optimised, the result of the parameter tunning process of K is calculated by evaluating the perplexity score of the holdout (i.e., unseen) dataset under the five-fold cross validation. Based on the figure, $K = 10$ is selected as the perplexity score drops the most significantly (i.e., indicating the highest improvement in model performance).

Topic 1



Topic 2



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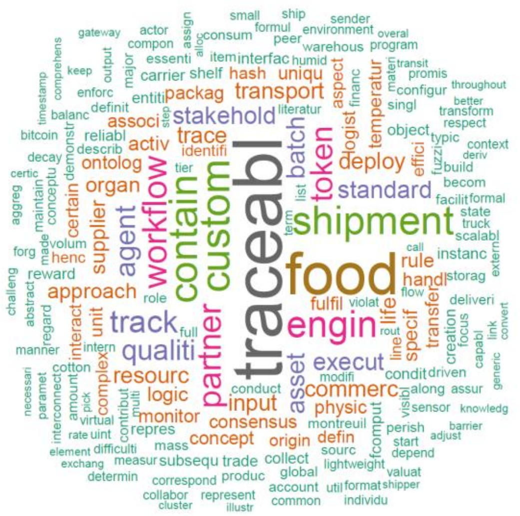
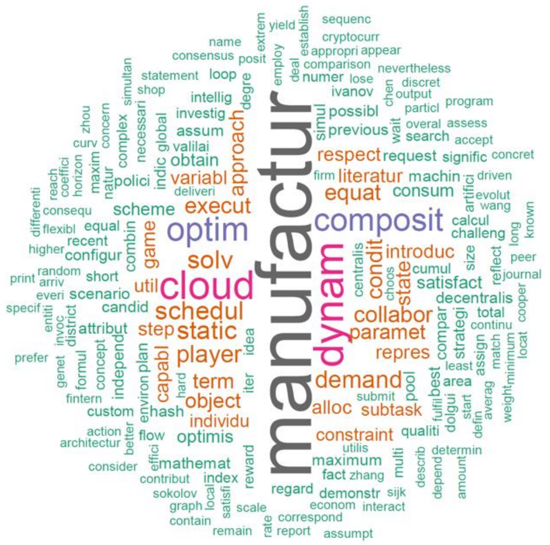
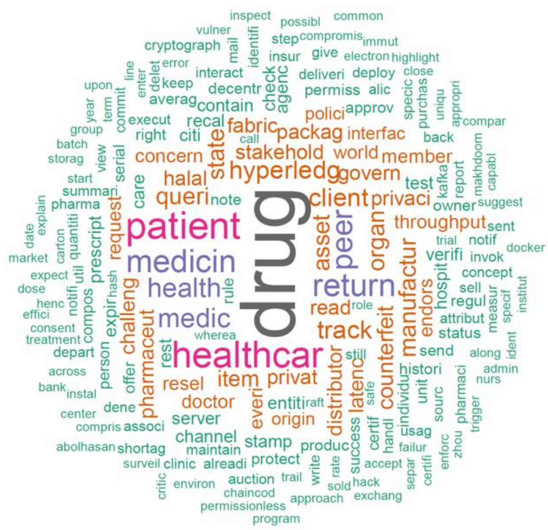


Topic 4

Topic 5



Topic 6



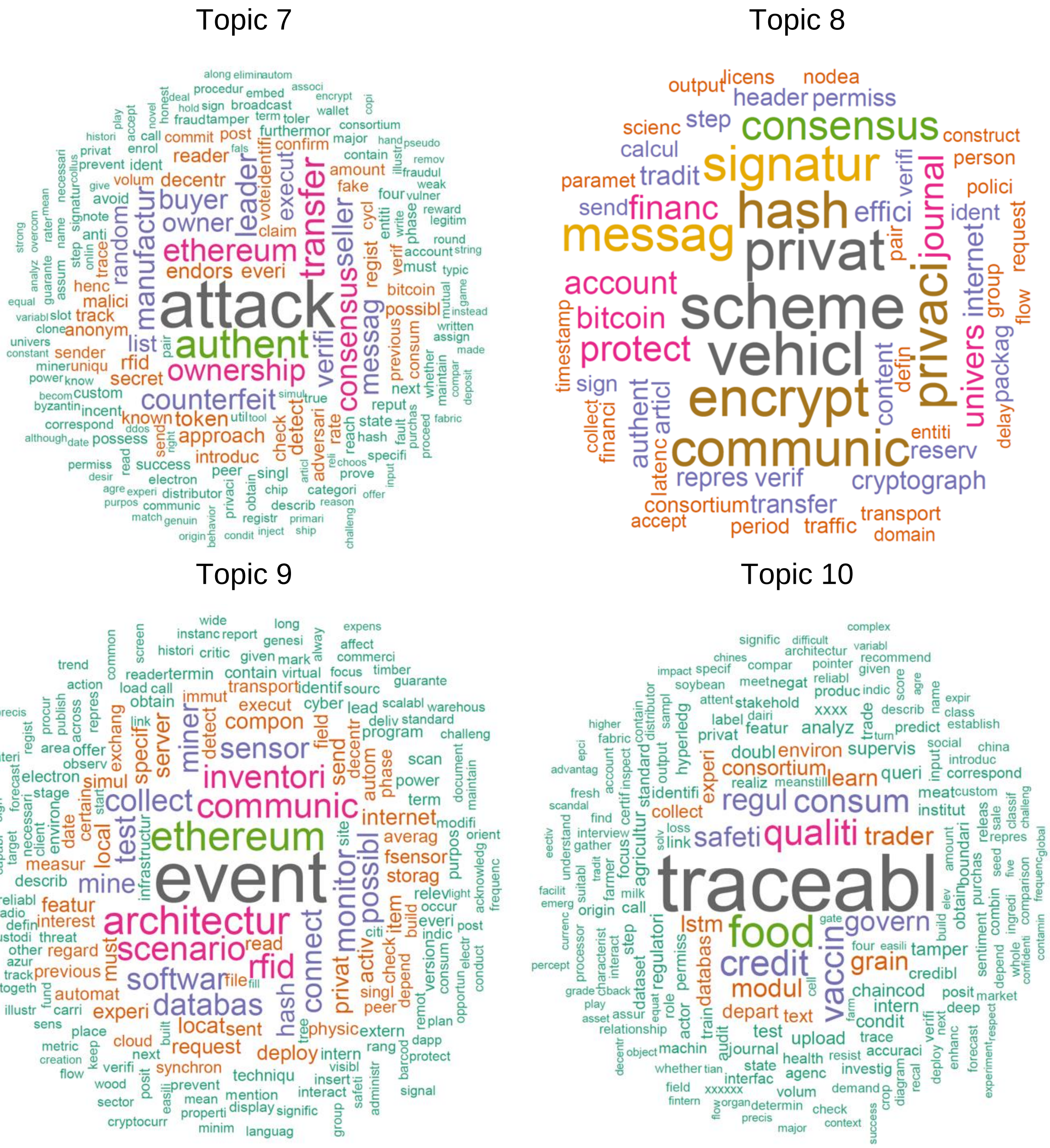


Figure 7 Caption: List of keywords in each LDA topic

Figure 7 Alt Text: A visualisation of the identified LDA topics using the word clouds in which the size of the word corresponds to its importance (i.e., the probability of the word in the topic).

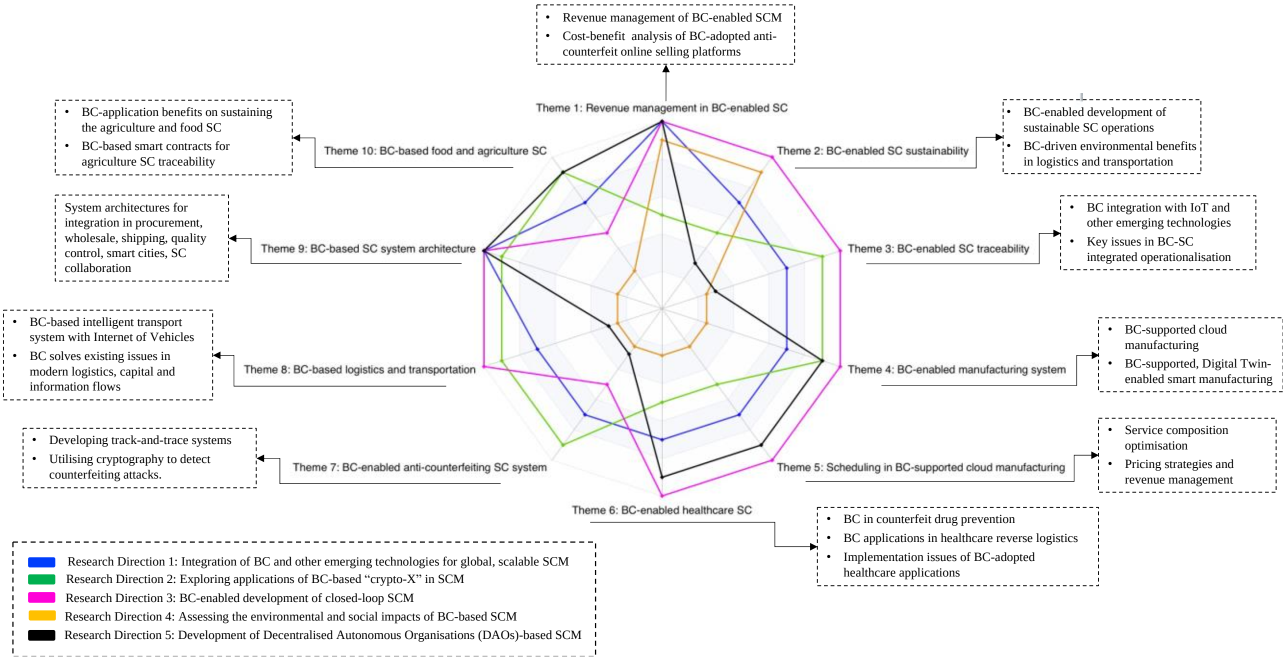


Figure 8 Caption: Summary of findings including ten key research themes and five future directions

Figure 8 Alt Text: Subtopics in ten key themes identified by LDA topic modelling and suggests some possible pathways to stimulate the BC-empowered SCM towards five future research directions.

Table 1: Summary of review articles in BC-SCM literature

Review article	Review focus	Number of articles reviewed	Review methodology	Future research directions
Pournader et al. (2020)	SC, transport, logistics	48	Co-citation analysis	Technology; Trust; Trade; Traceability/transparency
Astarita et al. (2020)	Transportation	371	Co-occurrence analysis	Track and traceability; Regulatory compliance; Smart vehicles' security; Supply-demand matching.
Queiroz et al. (2020)	BC-SC integration	27		Level of maturity of BC-SC integration in emerging countries; More empirical research needed.
Saberi et al. (2019)	SC sustainability	-	Narrative review	Inter-organisational barriers; intra-organisational barriers; Technical barriers; External barriers for BC adoption
Babich and Hilary (2020)	Strengths and weaknesses of BC applications in operations management	-	Narrative review	Information; Automation; and tokenization
Oguntegbe et al. (2022)	BC implementation in agri-food SC management	39	Manual coding thematic analysis	Technological benefits; Organisational adoption strategies; Environmental barriers to BC implementation; Implementation intention
Wu et al, 2022	Construction industry	141	Manual coding thematic analysis	Efficient integration of BC and other digital technologies; BC adoption; Barrier analysis and incentive mechanism
Zhu et al, 2022	BC application in SCM, transportation and logistics	125	Manual coding thematic analysis	Impact of BC on transnational relations; Impact of BC on capturing and evaluating circularity performance and contribute to circularity capabilities at the organizational and operational level
Our study	BC in SCM	100	Data-driven topic modelling	Integration of BC and other emerging technologies for global and scalable SCM; Crypto-X applications in SCM; BC-enabled closed-loop SCM; Environmental and social impacts of BC-based SCM; Decentralised autonomous organisations in SCM.

Table 2: Research theme for each LDA topic

LDA topic	Number of papers	Research theme	Papers
1	10	Revenue management in BC-enabled SC	Hayrutdinov, Saeed, and Rajapov 2020; Zheng et al. 2019; Liu, Li, and Qi 2019; Li, Wang, and Yang 2019; Niu et al. 2021; Choi 2019; Dong et al. 2021; Yang et al. 2022; Wu and Yu 2022; Tao et al. 2022
2	16	BC-enabled SC sustainability	Fu, Shu, and Liu 2018; Kamble, Gunasekaran, and Sharma 2020; Rane and Thakker 2019; Wu, Fan, and Cao 2021; Zhang et al. 2020; Philipp, Prause, and Gerlitz 2019; Yoon et al. 2020; Manupati et al. 2020; Orji et al. 2020; Bai and Sarkis 2020; Yadav and Singh 2020; Ar et al. 2020; Tian et al. 2021; Yousefi & Mohamadpour Tosarkani, 2022; Wang et al. 2022 Zeng et al. 2022
3	13	BC-enabled SC traceability	Tsang et al. 2019; Rachana Harish et al. 2021; Meyer, Kuhn, and Hartmann 2019; Li, Shen, and Huang 2019; Papakostas, Newell, and Hargaden 2019; Westerkamp, Victor, and Küpper 2019; Kim and Laskowski 2018; Agrawal et al. 2021; Hasan et al. 2019; Khan and Ahmad 2022; Zhu et al. 2022; Ji et al. 2022; Yang et al. 2022
4	14	BC-enabled manufacturing	Li, Barenji, and Huang 2018; Barenji et al. 2020; Kaynak, Kaynak, and Uygun 2020; Leng et al. 2018; Bai et al. 2019; Yuan et al. 2019; Fu and Zhu 2019b; 2019a; Leng et al. 2019; 2020; Huang et al. 2020; Zhang et al. 2020; Karamchandani et al. 2021; Leng et al. 2022
5	6	Scheduling in BC-supported cloud manufacturing	Yu et al. 2019; Zhang et al. 2019; Aghamohammadzadeh and Valilai 2020; Dolgui et al. 2020; Zhu et al. 2020; de Giovanni 2019
6	11	Blockchain-enabled healthcare SC	Jayaraman, Saleh, and King 2019; Tseng et al. 2018; Jamil et al. 2019; Nørfeldt et al. 2019; Kshetri 2017; Yanovich et al. 2018; Debe et al. 2020; Shanley 2017; Makhdoom et al. 2020; Pandey and Litoriya 2020; Govindan et al. 2022
7	6	BC-enabled anti-counterfeiting SC system	Toyoda et al. 2017; Sidorov et al. 2019; Cui et al. 2019; Islam and Kundu 2019; Alzahrani and Bulusu 2020; Zulfiqar et al. 2021
8	10	BC-based logistics and transportation	Labrador and Hou 2019; Hu et al. 2019; Lei et al. 2017; Mu, Rezaeibagha, and Huang 2020; Yang et al. 2019; Yi 2019; Xiong et al. 2019; Gao et al. 2018; Du et al. 2020; Liu and Li 2020
9	13	BC-based SC system	Shahbazi and Byun 2021; Fernández-Caramés et al. 2019; Thio-Ac et al. 2019; Yoo and Won 2018; Wu et al. 2017; Mondal et al. 2019; Figorilli et al.

		architecture development	2018; Wang et al. 2020; Botello et al. 2020; Elagin et al. 2020; Jabbar et al. 2020; Longo et al. 2019; Agrawal et al. 2022
10	9	BC-based food and agriculture SC	Zhang et al. 2020; Sander, Semeijn, and Mahr 2018; Behnke and Janssen 2020; Salah et al. 2019; Lin et al. 2019; Mao et al. 2018; Yong et al. 2020; Ding et al. 2020; Surjandari et al. 2021