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SURVEY

Blockchain Technology for Global Supply Chain Management: A Survey of Applications, Challenges, Opportunities and Implications

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ABSTRACT Supply chain management depends on a complex, interconnected network of suppliers, manufacturers, transportation companies, distributors and customers with the goal of predicting, monitoring and controlling operations and processes. Globalization has introduced fierce competition, forcing supply chains to innovate and enhance their performance and capabilities. Centralized management systems are prone to attacks, disruptions and malfunctions. A potential solution to these known issues is the adoption of blockchain technology. The blockchain offers an immutable ledger that allows for a trustless, decentralized system without reliance on third parties. It can provide new features, improve performance, advance network visibility and strengthen the four flows of a supply chain. To survive and compete on the global stage, supply chains must adopt emergent technologies to develop new business strategies. In this paper, a comprehensive survey of academic literature and research works relating to blockchain platforms for global supply chain management is presented. This survey will provide an overview of blockchain technology for supply chain management, summarize industry applications, highlight persistent challenges, and identify research opportunities to enhance the current state of research in the past six years. The contribution of this survey is to also provide a list of available blockchain solutions for global supply chain management and to elaborate on future advancements in the field. New solutions will be proposed and explained.

INDEX TERMS Blockchain, blockchain applications, blockchain technology, global supply chain management, literature review, supply chain management, survey.

I. INTRODUCTION

Supply chain (SC) management is defined as a proactive measure of four flows: materials flow, process flow, case flow and information flow. Logistics form the backbone of the SC and are responsible for planning, implementing and controlling the flow and storage of goods, services and information [1]. Today's globalized markets have created tighter competition due to the elimination of international boundaries [2]. To survive and maintain sustainability, it is necessary for organizations to identify and develop new business strategies based on the adoption of emerging digital technologies [3]. Global supply chains need to find new ways to design their supply chains to take advantage of opportunities that offer more flexibility [4]. Systematic smart implementations must be made to remain competitive. Today's SC applications follow the Industry 4.0 concept to expand internal processes and to promote the digitalization of products and processes [5].

Blockchain technology (BCT) has seen a proliferation in current literature as it transforms business processes by building trust without an intermediary, providing stakeholders with enhanced visibility, applying smart contracts

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to oversee applications, introducing disintermediation and simplifying digitalization and optimization of supply chain operations [6]. Blockchain technology has expanded to include cryptocurrency, healthcare, advertising, insurance, copyright protection and energy [7]. Most industries today have a supply chain with facilities distributed across the globe. Despite technological advancements and recent developments, globalized SCs have seen a plethora of challenges before, during or after blockchain adoption. These categories are laws & regulations, data management & provenance, governance & traceability, interoperability & standardization, lack of awareness, education & innovation, performance & scalability, trust & stakeholder management and transparency & visibility.

This survey will present a deep dive into the available literature spanning from 2018 to 2023. The purpose is to provide a detailed overview of blockchain applications, adoptions and implementations in global SCs. A strong emphasis was placed on the current challenges and research gaps that hinder BC progression. Solutions were organized into tables that are meant to provide a roadmap for future researchers. The survey is a one-stop shop for all current industrial researchers to pick and choose which parts may be necessary for their own research, while adding to the literature regarding blockchain solutions for supply chain management. This paper also serves as a basis to create a conceptual framework that will be used in a future implementation. The survey is split into sub-categories and these sections follow this structure. Section I introduces blockchain technology. Next, Section II lists applications by industry. Section III presents the challenges and open issues that exist in today's global market. It also contains any notable gaps in research and opportunities to correct them. Blockchain solutions will be briefly proposed in Section IV. Lastly, Section V summarizes the research implications of successful implementations and proposes future work.

II. BLOCKCHAIN TECHNOLOGY

Blockchain is a digital ledger technology (DLT) that provides a tamper-proof ledger that utilizes cryptographic mechanisms to improve resiliency without the use of a central authority. These ledgers contain cryptographically signed transactions that are organized into blocks that are chained to one another with their own unique hash. Modification becomes more difficult for older units as newer chains are added and resistance is increased [8]. The blockchain uses two kinds of encryption: asymmetric and symmetric. Asymmetric uses public or private keys, while symmetric uses a one-time generated code for decoding and encoding. Blockchains have three different types of nodes: simple, full and mining. Simple nodes send and receive transactions. Full nodes store copies on the ledger process of generating a new block [9]. A node initiates a transaction by employing a digital signature using private key cryptography. A single transaction represents a transfer of digital assets which include the timestamp, block ID and address. Once transactions are verified and confirmed by miners, they are included in the block. Each miner competes against each other to solve a computational problem. Incentives are given to the miner and network peers to verify the new block using consensus mechanisms [10].

Once on the block, the transactional data is safely stored and easily retrieved for future examination. The immutable ledger eliminates the need for a trust authority, as trust is created through the blockchain's architecture. The key characteristics of blockchain architecture are decentralization, immutability, transparency, traceability, trustless, persistency, anonymity, auditability, automatic contract execution, validity and tamper-resistance.

- **Decentralization:** Blockchain transactions do not require the assistance of a trusted central agency for transaction verification [10]. Consensus mechanisms ensure transactions are processed and validated by the nodes. Each node is equivalent and stores the data on the digital ledger.
- **Immutability:** Blockchain transactions are verified and stored in the ledger. It provides a record of all previous transactions on the chain, increasing visibility and auditability.
- **Transparency:** Once majority of nodes reach consensus, transactions are stored, and the ledger is updated. Any changes to the network are publicly visible ensuring transparency [9].
- **Traceability:** Records are permanently stored on the blockchain along with transaction information [11]. Each update can be traced back to its origin, resulting in a more efficient and transparent network [9].
- **Trustless:** Blockchain provides transactions between unfamiliar parties who don't trust one another. Consensus mechanisms ensure the validity of transactions through the distribution and updating of the ledger [9].
- **Persistency:** Blockchain's infrastructure ensures network data is authentic and not modified [10]. Transactions recorded on the ledger are considered persistent as they spread across the network, where each node maintains and controls its records [12].
- **Anonymity:** Each actor on the network can be assigned a virtual identity [13]. No outside agency is responsible for monitoring sensitive data. A certain amount of anonymity is provided through the trustless environment [10].
- **Auditability:** All recorded transactions are timestamped and stored on the immutable ledger which can be traced at any time due to the fact the information is considered persistent. The degree of auditability depends on the type of blockchain [12]. Public has the highest, while private has the lowest.
- **Automatic Contract Execution:** Smart contracts can be programmed to start when a certain number of conditions are met. The blockchain will automatically determine when these conditions occur and enforce the terms of the contract [14].

- **Validity:** Broadcasted transactions are validated by nodes and do not require executions from each. Falsification or inconsistencies can be easily detected [12].
- **Tamper-resistance:** Transactions are considered tamper-proof during and after the block generation process [13]. Since all blocks are linked to the previous in a chain, alteration would change too many parameters which would be easily detectable.

There are three types of blockchain; permissioned, permissionless and consortium/federated. In a permissionless (public) blockchain, anyone can run a node, participate in mining, access a wallet and write transactions. Public blockchain is the most common digital currency application [15]. A permissioned (private) blockchain is a closed platform where only certain actors are granted permission to perform specific tasks. These systems are often owned by a corporation or person [15]. In a consortium or federated blockchain, power is divided between a group of people or a person who forms groups called federated or consortium [15].

Blockchain technology uses consensus models to enable a group of mutually distrusting users to work together [8]. When a new user joins, they must agree to a predetermined set of principles. Consensus models remove the need for a trusted outside agency to maintain the system, as anyone can verify the blockchain's integrity by verifying each block independently.

Forks make changes to permissionless blockchain data or protocols. Forks are divided into two categories, soft and hard forks. A soft fork is a change to a blockchain implementation that is backwards compatible, while a hard fork is not backwards compatible [8]. In soft forks, upgraded nodes can communicate with those non-updated nodes. In hard forks, there is no communication, nodes will be severely impacted, and a diversion will occur from the existing technology [16].

Smart contracts are implemented on top of the blockchain, where contracts are deployed through cryptographically signed transactions. Hence, smart contracts are self-enforcing and autonomous executable programs that enforce the terms and conditions of an agreement or contract using code and computational infrastructure. The key features of smart contracts are decentralization, immutability, transparency, accuracy and availability [17]. Smart contracts extend and leverage blockchain technology, as they are tamper resistant and can be used without a trusted third party [8].

Smart contracts ensure appropriate access control and contract enforcement. The life cycle of smart contracts follows four steps: creation, deployment, execution and completion. During deployment, execution and completion, a sequence of transactions will be executed and stored on the blockchain [18].

III. GLOBAL SUPPLY CHAIN MANAGEMENT

Global supply chain and logistics management have been focused on the performance of business operations. They focus on similar concepts but are two separate ideas. Logistics focused on the work required to enhance inventory management, while SCM focuses on integration of activities to increase the operating efficiency [1].

The growth of international business has led to enhanced supply chains, capable of using sustainable SC practices. Large supply chain networks today are efficient operations and able to standardize their processes. They are able use current developments to their advantages and use new forms of technology as new options appear as technology evolves [2].

Globalization had to led to a rise in having a distributed SC that has facilities and suppliers from across the world. Offshore suppliers have lowered the overall price suppliers can offer their products. Corporations can keep their prices high while always looking to gain competent, low-wage workers [3].

Operations Management (OM) research and applications have given researchers the ability to formulate new models satisfying supply chain strategies and allowing SCs to adapt to change or the introduction of new government policy. Strategies allow for a global division of an SC to plan accordingly by considering goals, flows, capacities and capabilities [4]. OM has evolved strategies into what supply chains are known for, well-oiled machines that are more than capable of handling global demand.

The digital age has taken previous advancements and transformed them into what we call today as smart production. Smart systems have the necessary personnel and processes to comply with demand and remain ahead of the competition. To succeed, they must maintain the four attributes: production connectivity, performance visualization, process optimization and system autonomy [5]. A current supply chain is a complex network that generates, monitors and controls the four flows. It is the complete pathway of a product from raw material to a consumer good on the marketplace. The goal is to consistently compete against other global SCs, lower expenses and augment daily operations to produce goods quicker & cheaper [19].

A supply chain is a system of people, events, data, resources and departments with the sole objective of moving products to generate capital. Supply Chain Management (SCM), in a global sense, is complete real-time monitoring of every division's operation within the SC, no matter where they may be in the world [20].

IV. RELATED LITERATURE

Blockchain technology for supply chain management research is in its infancy. Consequently, there is a lack of peer-reviewed sources and most focus on conceptual rather than practical implementation. Each source will be summarized along with their key contributions to this field of research in Table 2.

Chang and Chen [21] provided an overview of the use of blockchain and smart contracts in the field of supply chain management (SCM). The purpose of their research was to bridge the gap between the existing knowledge regarding blockchain applications and future work.

TABLE 1. Acronyms.

Abbreviation	Definition
AI	Artificial Intelligence
API	Application Programming Interface
B2B	Business to Business
B2G	Business to Government
BaaS	Blockchain as a Service
BC	Blockchain
BCT	Blockchain Technology
dApps	Decentralized Applications
DLT	Distributed Ledger Technology
EHR	Electronic Health Record
EMR	Electronic Medical Record
ERP	Enterprise Resource Planning
GPS	Global Positioning System
HC	Healthcare
HMM	Hyundai Merchant Maritime
IoT	Internet-of-Things
IP	Intellectual Property
IT	Information Technology
ITS	Intelligent Transportation System
JIT	Just-in-Time
P2P	Peer-to-Peer
PHR	Personal Health Record
OM	Operations Management
RFID	Radio-Frequency Identification
RT	Real-Time
SME	Small-to-Medium Enterprise
SC	Supply Chain
SCM	Supply Chain Management
WWF	Worldwide Fishing

The work Dutta et al. [22] focused on blockchain technology for supply chain operations. The blockchain can be applied to major SC functions such as provenance, resilience, SC reengineering, security enhancement, business process management and product management. Kawaguchi [20] emphasized that blockchain technology needs to be studied more extensively and listed the top adoption challenges: organizational requirements, company readiness, data collection & management, interoperability, transition & integration costs, security, privacy and legal concerns.

Gonczol et al. [23] sorted the existing literature into three large groups; theoretical analyses, conceptual systems, and implemented systems. They concluded there was a lack of technical papers due to limited knowledge and not enough interest from sectors outside of business and finance. Their work sorted challenges into two types: technical limitations and digitalization issues.

Wan et al. [24] identified industries in which BCT can have a significant impact on information sharing, investigated current challenges or deployment barriers and classified the future development of information sharing using BCT within a SC. Their work focused on understanding the nature of the supply chain as a part of the future development of blockchain and emphasized the need for more research regarding blockchain-based information sharing in SCs.

Pournader et al. [25] investigated blockchain applications across supply chains, transportation and logistics. Four clusters were included to provide a picture of each sector: technology, trust, trade & traceability/transparency. The authors distinguished the lack of combination technology available despite the increased interest from literature.

Lim et al. [26] gave a comprehensive analysis of blockchain technology applications in SCs. Their work encompassed agriculture, forestry, fishing, manufacturing, construction, and mining industries. Four research gaps hinder the combination of blockchain and supply chains were mentioned: ignored themes in supply chains, applied methodologies in research, academic theory and practice in different industrial sectors.

Shakhbulatov et al. [27] reviewed six challenges hindering supply chain management and linked their solutions with blockchain frameworks in the available literature. These challenges were provenance, performance improvement, quality assurance, quality control, sustainability transparency, data privacy and confidentiality. Their work identified new opportunities and challenges of blockchain for supply chain management highlighting the need for new solutions.

Paliwal et al. [28] investigated the role of blockchain technology in sustainable supply chain management using the What, Who, Where, When, How and Why (5W+1H) pattern. Their research indicated there is a strong trend in awareness for blockchain technology due to increased academic attention.

Juma et al. [29] provided a detailed overview of blockchain technology in international trade supply chains. They discussed the practicality of using blockchain technology from a customs perspective.

The following survey is a comprehensive compilation of literature reviews published in the last six years that provides a detailed map of today's global landscape. It differentiates itself by organizing challenges, opportunities and solutions that could be potentially enhanced using blockchain technology as a tool. Table 2 categorizes each literature review or survey by their key contributions to the advancement of blockchain technology for global supply chain management.

V. MATERIALS & METHODS

The purpose of this survey is to assimilate current literature centered around blockchain technology for global supply chain management. The survey aims to provide answers to the following research questions:

RQ1: What challenges & vulnerabilities in global supply chain management need to be addressed?

RQ2: What gaps in research exist?

RQ3: What opportunities exist for future research based on the current gaps in research?

*RQ4:*What successful solutions can be built upon to advance blockchain implementations for global supply chain management?

To better understand the current state of research and future research opportunities, a survey paper was employed with a three-step methodology to gather relevant cited works that directly relate to the research questions. The

TABLE 2. Related literature.

Paper	Focus Area	Key Contributions
[21]	Blockchain for Supply Chain Management	Classified four major SC pain points: traceability & transparency, stakeholder involvement & collaboration, SC integration & digitalization and common frameworks & blockchain-based platforms Provided blueprint for future applications
[22]	Blockchain Technology in Supply Chain Operations	Categorized six major SC functions that BCT can be applied to: resilience, provenance, SC reengineering, security enhancements, business process management and product management. Summarized real world BCT applications for SCM. Listed blockchain adoption challenges, such as organizational requirement & readiness, data collection & management, interoperability, transition & integration and cost, security, privacy and legal concerns.
[23]	Blockchain Implementations for Supply Chains	Indicated the food, pharmaceutical and shipment sectors are the industrial SCs with the most use cases. Concluded that blockchain applications struggle with scalability and interoperability. Cited main supply chain issues as missing link between physical product & digital record, standardization procedures and a lack of educational awareness.
[24]	Blockchain Information Sharing In Supply Chains	Healthcare & medical, smart construction & smart city, bank loans for SMEs and textile supply chains listed as having the most potential for blockchain-based information sharing system. Summarized challenges & deployment barriers: unwillingness to share information due to conflict of interest, organizational misconceptions from lack of knowledge or understanding Focused future development using smart contracts to mask sensitive data, performance evaluation analysis and using Digitalization for increasing speed while eliminating regulatory costs.
[25]	Blockchain Applications in Supply Chains, Transportation & Logistics	Introduced the 4T structure, an interconnected conceptual model that uses Technology, Trust, Trade & Traceability/Transparency. Stressed the usage of blockchain technology in coupling IoT, managing complicated transportation networks and streamlining transparent operations to combat the rate of globalization and expansions of SCs.
[26]	Blockchain Technology Applications in Supply Chains	Addressed applications regarding the combination of blockchain and supply chains. Identified four research gaps: (1) ignored themes in supply chains, (2) applied methodologies in research, (3) academic theory and industrial practice and (4) practice in different industrial sectors.
[27]	Blockchain Enhancements for Supply Chain Management	Cited six challenges in supply chain management: provenance, performance improvement, quality assurance & quality control, sustainability, transparency and data privacy & confidentiality. Countermanded the challenges by proposing solutions found in literature. Summarized seven challenges of BCT for SCM: immutability, tracking accuracy, provenance, new supply chain management models, throughput, cost & complexity and security. Classified six key features of BCT frameworks for SCM: confidentiality & data privacy guarantees, light-weight consensus algorithms, deterministic smart contracts, fast information retrieval and flexible verification algorithms.
[28]	Blockchain Technology for Sustainable Supply Chain Management	Provided a classification framework (ETLCL) by combining TRL and Grounded Theory. Identified numerous gaps in research, such as legacy system integration requirements, lack of a governance structure, stakeholder behavior in a blockchain-based information system and determining the need to use blockchain in sustainable supply chain management projects.
[29]	Blockchain in Trade Supply Chain Solutions	Categorized proposals: electronic trade solutions, validation solutions and supply chain management optimization. Discussed topics from a customs perspective: type of blockchain to use, the combination of BCT with other technologies, validating the performance of the blockchain, scalability & number of transactions, accessibility & user privileges and customs administration.

last six years were selected, 2018 through 2023, to focus on current advancements. IEEE Xplore & Google Scholar were utilized to promote robust research, capable of reproduction & repeatability. The three steps are as follows; selection criteria, source evaluation and full text read & interpretation.

A. STEP 1: SELECTION CRITERIA

Journal selection criteria used a group of keywords relating to blockchain models, applications & challenges for global supply chain management (SCM). The goal was to include meaningful sources while excluding ambiguous references. Academic journals and conference articles are compared to inclusion/exclusion parameters. If one exclusion condition existed, the journal was removed. Strings were used to narrow sources based on keywords or phrases. The full list of selection criteria can be found in Table 3.

String 1 (''blockchain'' OR ''industry'' OR ''applications'' OR ''logistics'' OR ''manufacturing'' OR ''supply chain management'')

TABLE 3. Selection criteria.

Criteria	Rules
Inclusion	Academic publications within the last six years only Blockchain applications & challenges for logistics, manufacturing or supply chain management
Exclusion	Papers published before 2018 No less than 10 total citations

String 2 ("global" or "supply chain" OR "blockchain" OR "challenges" OR "research gaps" OR "opportunities")

B. STEP 2: JOURNAL EVALUATION

Sources that passed inclusion criteria and contained no exclusion criteria were gathered into a database for review. During the journal evaluation phase, each paper's abstract, discussion and conclusion were assessed for compatibility. Unreliable sources were removed to prevent scope creep and encourage a cohesive body of work.

C. STEP 3: FULL LITERATURE READING & INTERPRETATION

Each source was thoroughly reviewed, findings were generalized and results analyzed. Research questions were aligned to each selected journal's contents. Sources were then categorized and labelled for future examination. Selected journals were grouped by section or keyword and inserted into the literature review. Figure 1 summarizes the outcome of the selection criteria.

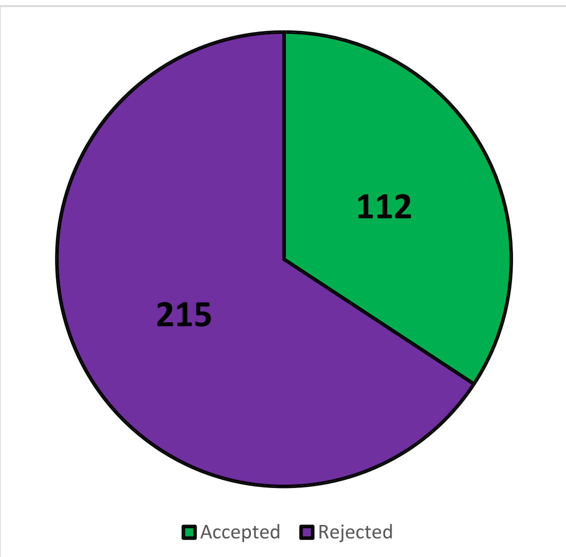

FIGURE 1. Outcome of selection criteria.

VI. RESULTS

Figure 2 displays the distribution of total number of sources per each section of the survey. It is meant to show how many journals went into each part of this research paper. Figure 3 shows publication by year. Figure 4 references publication by type of research. Figure 5 sorts publications by application industry. Figure 6 splits publications by challenge with their corresponding opportunities while Figure 7 focuses on the solutions derived from said challenges and opportunities. Table 3 groups blockchain applications by industry. Table 4 organizes sources by their challenges and opportunities for future research. They are meant to show the overall distribution of sources and which sections were given the most attention. Blockchain models, applications and challenges received the most sources to highlight the current state of blockchain in the supply chain management field in the past six years.

TABLE 4. Blockchain applications by industry.

Industry	Total Number of Papers
Agri-Food	12
Healthcare & Medicine	11
Logistics & Cross-Border Trade	14
Energy	11
Other	4

TABLE 5. Blockchain challenges & solutions.

Category	Total Number of Papers
Laws & Regulations	18
Data Management	18
Governance & Traceability	16
Interoperability & Standardization	16
Lack of Awareness, Education & Innovation	9
Performance & Scalability	20
Trust & Stakeholder Management	16
Transparency & Visibility	10

VII. DISCUSSION

A. INDUSTRY APPLICATIONS

Today's blockchain systems can be tailored to fit a specific sector using a combination of available options such as type of BCT, consensus algorithm and what characteristics a company hopes to gain. Blockchain applications will be presented for different sectors with emphasis on global supply chain management, logistics and transportation. A minimum of ten

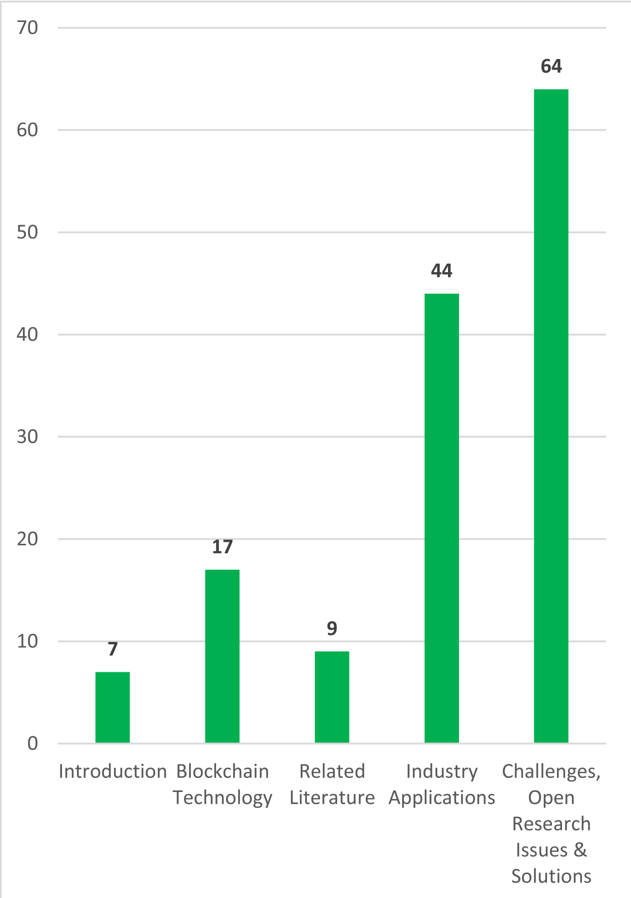

FIGURE 2. Publication distribution by survey section.

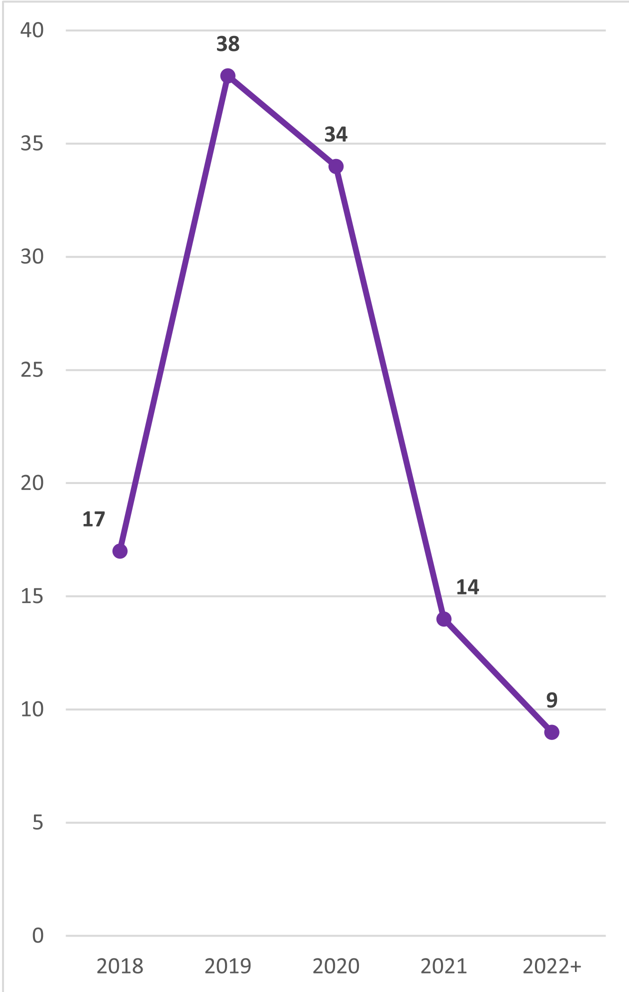

FIGURE 3. Publication by year.

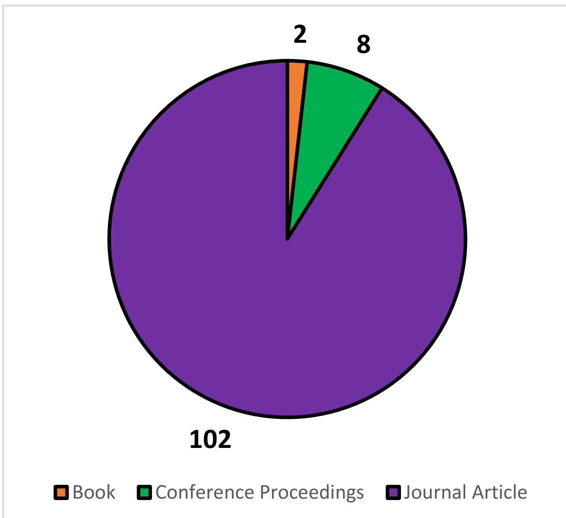

FIGURE 4. Publication by type.

sources were applied to each section to provide a current view of the global landscape.

1) AGRICULTURE & FOOD

The agriculture and food industry has evolved from traditional processes to precision-based systems. Smart agriculture dominates the industry making it possible for blockchain to be used as a tool for promising solutions, but network performance problems need to be addressed prior to adoption. Latency, bandwidth, physical storage limit, power consumption, and communication speed between devices play a critical role in the development of new BCT solutions. Blockchain, used in combination with IoT devices, can maintain a secure, transparent, and tamperproof system [30]. BCT can be used to solve technical problems and optimize communication and SC processes. Currently, BCT solutions exist for agricultural insurance, smart farming, traceability, land registration, food supply chain governance, farm security and agriculture product e-commerce safety [31]. Ferrag et al. [32] focused on green, sustainable practices for IoT devices, developing them into smart systems capable of making decisions on the fly with RT data. This was accomplished by separating the network into layers with each layer serving a specific purpose such as the quick transport of data and the coordination of electronic devices across the entire SC. Demestichas et al. [33] provided a detailed overview of traceability applications

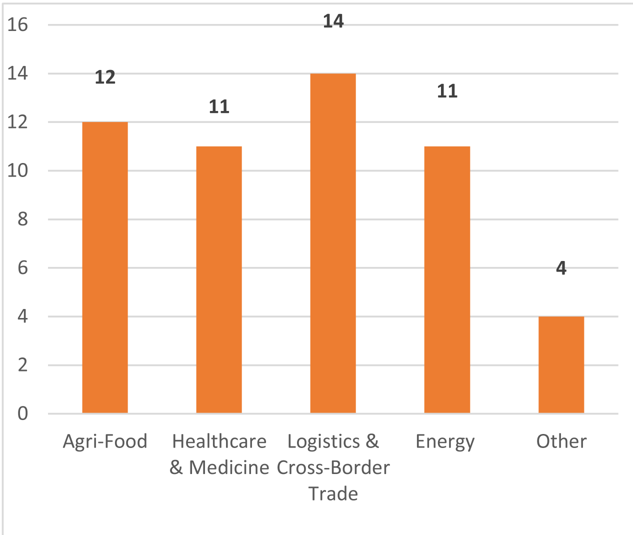

FIGURE 5. Publication by application industry.

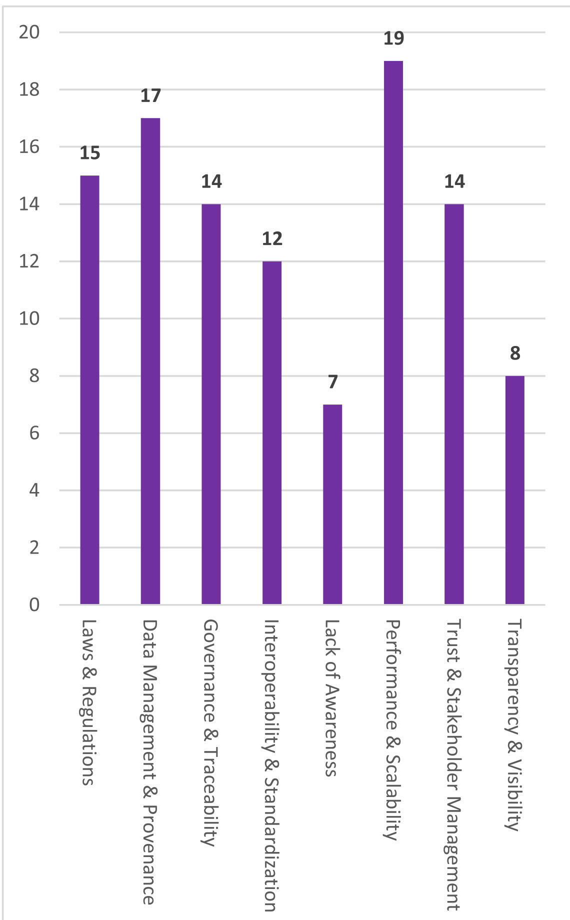

FIGURE 6. Publication by challenge & opportunity.

in the agri-food industry. Traceability can provide agriculture SCs with higher levels of visibility, real-time location and inventory data and product provenance [34].

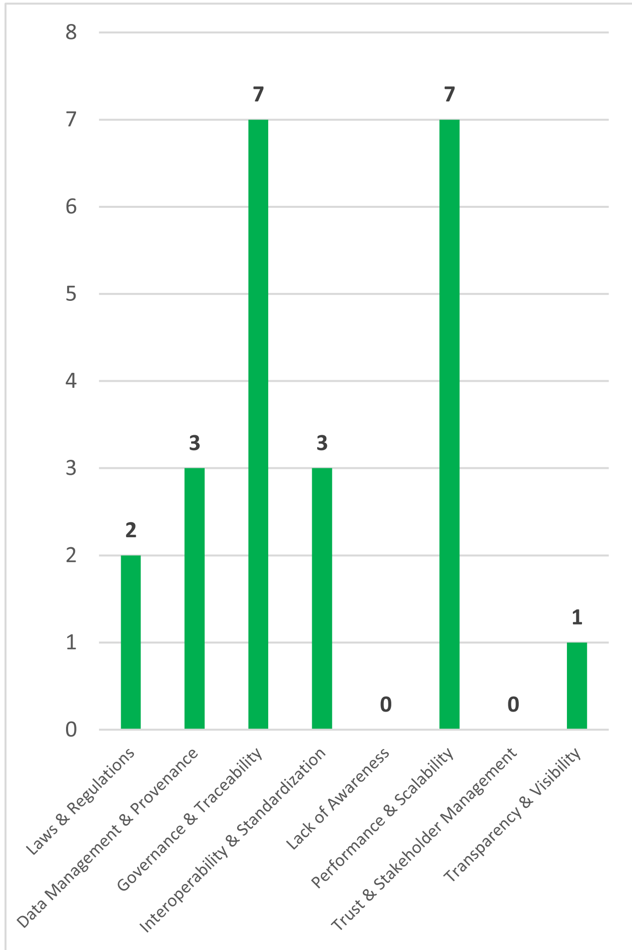

FIGURE 7. Solutions by challenge category.

Lin et al. [35] defined smart agriculture by expanding on the work of Demestichas et al. [33] and Tripoli and Schmidhuber [34]. Smart agriculture is defined as the application of technologies such as IoT, Big Data, Global Positioning Systems (GPS), Cloud Computing, and Artificial Intelligence (AI) into a smart system that can predict outcomes, make intelligent decisions, and amalgamate numerous technologies into a single, unified platform [35].

Zhao et al. [36] focused on creating solutions to worldwide challenges from a holistic perspective. The agriculture and food sector's primary objectives are the circulation of products from creation to consumption. The work emphasized the need for agri-food value chain management that adopts new technologies to streamline operations and overcome barriers.

Feng et al. [37] stressed the importance of sustainable standards & practices that can operate throughout the agri-production process. Real time data must be available twenty-four seven to make informed decisions through human interaction and automation, which can be addressed through traceability in blockchain applications.

Khan et al. [38] linked IoT and BCT to ensure product provenance which is critical when dealing with perishable food. A BCT-IoT platform can enhance provenance, payment methods and management practices. The goal of IoT applications in the agri-food industry is incorporation of automation and intelligence into a smart system. Kim and Laskowski [39] classified the major agriculture applications into three categories: food safety, sustainable agriculture practices to foster relationships with co-op farmers and agriculture finance. Food safety is a combination of provenance and tracing. Sustainability leaves a smaller carbon footprint and supports local co-ops by contributing to smaller farms. FarmShare is an Ethereum-based platform that provides a communication platform for farmers and consumers. Tokens are exchanged between parties when a transaction is finished and posted on the network. In finance, smart contracts can be employed to keep contractual agreements between parties through automated actions.

An example of a use case in the agri-food industry is worldwide fishing (WWF) seafood traceability. The BC-based system regulates rules and regulations regarding fishing and ecosystem conservation. Items are scanned and important data attributes are stored with their respective ID tags, which prevents the purchase of illegally caught seafood. A second use case is the Walmart & IBM food safety solution that utilizes BCT to upload SC information and retail data. The tracing of food helps detect contaminated food and prevent E. coli outbreaks, as well as providing data for risk prevention and management [40].

Uddin et al. [19] presented a model for blockchain in the food supply chain. The proposal helps managers determine if BCT is appropriate (or not) for their business. It works for SC networks of all sizes and has a solid framework.

2) HEALTHCARE & MEDICINE

The healthcare (HC) industry has a need for blockchain technology. Electronic health records (EHRs), data management, access control, auditing, medical billing and anti-counterfeiting are applications in industry. All sensitive data must be secured and consolidated to promote interoperability between different systems [41].

Farouk et al. [42] focused on three major applications in healthcare and pharmaceuticals: intelligent healthcare systems for patients, enhancing the protection of patients' personal data and strengthening drug credibility in the pharma industry. The blockchain improves security, management and the analysis of big data.

Dimitrov [43] examined big data management, the evolution of records and pharma research and development. BCT is responsible for maintaining all three types of patient data records: electronic medical records (EMR), electronic health records (EHR) and personal health records (PHR). The Ethereum framework was implemented for management and access control through virtual private networks (VPNs) since blockchains can easily manage and abide by environmental protections & regulations. Decentralized applications (dApps) allow doctors to conduct telemedicine with low fees and IoT sensors can ensure patient data is up to date to ensure an accurate history of health.

Konstantinidis et al. [44] discussed effective Blockchain applications in HC. High data volumes and throughput transaction processing are two benefits of a decentralized system. Current efforts focus on patient data management and record keeping. Doctors and healthcare providers have access to patient information, stored on a distributed ledger, for monitoring and alerts.

Zhao et al. [45] emphasized the importance of blockchain applications in the healthcare industry to create a smart healthcare system. A patient can maintain their personal records, while the blockchain can store, monitor, and distribute sensitive information via wireless sensors. The result is a comprehensive, personalized summary of a single patient's health records that are available to any medical center, physician's office or hospital with patient permission to protect privacy [45].

Leeming et al. [46] introduced numerous early-stage solutions to audit private data and to give patients the power to manage consent of their private information. A linkage between records, insurances and medical centers will streamline consumer applications and create a data repository. A patient's record will form the basis of the health plan while smart contracts can be utilized to tweak meta-information.

Agbo et al. [47] summarized BCT applications in the healthcare & pharmaceutical sectors. In pharma, fraud and counterfeit detection are two pillars to maintaining and controlling drug authenticity. Applications to healthcare include record management, insurance claim reporting, patient-centered health plans and uniformity among major medical management software. The decentralized nature of BCT allows for a distributed system without the need for an authoritative.

Khatoon [48] stressed the use of BCT with smart contract applications in medical workflows and healthcare management systems. Multi-organizational data exchanges rely on easily accessible information that is interoperable with research initiatives and physician requests. Ethereum smart contract development & applications for healthcare & medicine were discussed. Smart contracts conditions are programmed and offer many options including stakeholder access, data authorization & ownership, viewership permissions and actor credentials.

Siyal et al. [49] analyzed six applications of BCT for HC: EHR, clinical research, medical fraud detection, neuroscience, pharmaceutical & research. The blockchain can provide SCs with more functionality than legacy systems. It is used for digitalization, highly sensitive information storage & retrieval, record immutability, smart contract facilitation, data accessibility, transparency, confidentiality, system integration, medical product validity and research and development.

Haq and Esuka [50] reviewed applications in the pharmaceutical industry. Application areas include drug discovery & pharmaceutical research, SC & counterfeit drugs detection, prescription management and billing claims management.

Telemedicine, with BCT, enforces trust between HC professionals & patients. Combined with AI, remote diagnostic services use medical data derived from quantitative and qualitative statistical methods.

Uddin et al. [19] displayed another model for blockchain in the vaccine supply chain, which combines machine learning, IoT and BCT with SCM. This combination of technologies gives customers increased security, opens up the SC to be completely transparent and network maintenance.

3) LOGISTICS & CROSS-BORDER TRADE

The logistics and transportation industry is reliant on integration of activities across suppliers, distributors, wholesalers, and retailers. Current literature shows that the logistics industry is employing BCT applications.

Al-Jaroodi and Mohamed [51] addressed blockchain applications for logistics management and synchronization of multiple companies' actions including planning, scheduling, coordinating, monitoring and validating performed activities. Logistics traceability gives stakeholders the ability to trace goods with BCT adoption with consistent and reliable sets of data. Vehicles can be optimized by providing the best route and energy saving techniques. Collaborative logistics across companies can reduce freight costs and maximize capacity and utilization [52].

Dobrovnik et al. [53] presented the blockchain framework with IoT and big data for logistics management. The key applications are logistics traceability, vehicle routing, energy saving management and collaborative logistics.

Blockchain technology applications for logistics provide a link between the physical & digital world, using IoT for device integration [54]. BCT-IoT applications include logistics management; food traceability, solving logistics inefficiencies, product management and commercial implementation [55].

In the transportation industry, BC can protect reputation when validating a message's authenticity and or protect expensive items from being stolen and duplicated. Blockchain applications are mandatory for product traceability and the integration of SC processes transactions to create dynamic business interactions [56].

Majeed et al. [40] introduced the Intelligent Transport System (ITS) for supply chains with transportation vehicles. This smart platform combines automation, RT monitoring and management systems to streamline operations and coordinate SC activities.

Miglani et al. [57] focused on two separate use case studies: logistics and transportation. The logistics study addressed the success implementation of IoT and BCT integration, while transportation looked at ride-sharing apps.

Blockchain can be a useful tool for cross border trade and e-commerce. It provides a trustless platform which removes the need for third party involvement. Majeed et al. [40] proposed smart electronic commerce and the benefits of adoption, such as proof of delivery for tangible assets, dispute settlement and the removal of third parties for the authentication of transactions. Zhang et al. [58] provided a recap of three distinct applications that are being utilized in finance and economics: cryptocurrency, cross-border payments and digital asset registries.

Chang et al. [59] posed international applications of BCT via smart contracts in cross border trade. IBM, Maersk & Hyundai Merchant Marine have designed and deployed applications on the global stage. Two successful implementations of global applications of BCT for SCM include IBM & Maersk's TradeLens and the blockchain development transaction system (BDTS) from CargoX [60]. Other examples are VGM portal, Agility and Blockchain in Transport Alliance [61].

Ganne [62] posed the question, "Can blockchain revolutionize international trade?" Many applications have had an influence on trade, including business to government (B2G) initiatives, inter-agency coordination, streamlining certification and licensing practices, enhancing customs clearance processes, improving temporary admission of goods, protecting the accuracy of trade data, and allowing advanced auditing methods.

Okazaki [63] concluded that trade-related applications can be developed and implemented with BCT, such as RT exchange of information (EOI), data driven customs programs and financial crimes detection. Two use cases were presented: the IBM-Maersk joint venture for global trade digitalization and Singapore's Global Trade Connectivity Network (GTCN). Uddin et al. [19] talked about logistics for retail SCs. An inventory item can be tracked from start to end point, which guarantees trust, openness and veracity within the SC. It encompasses the shipping pathway from manufacturer to final customer.

4) ENERGY & POWER CONSERVATION

Cohen and Lee [4] summarized prominent BCT applications in the energy industry; renewable energy resource management, token-based energy trading, local energy market scenarios and power gird distribution and intervention.

Al-Jaroodi and Mohamed [51] discussed BCT in energy related applications. Microgrid technology, infused with BCT, not only controls and monitors the electric grid to distribute power to those who need it but also provides surplus credits to those who do not. Smart contracts in the power industry enable constant communication between all devices on the smart grid. Smart home prosumers, small scale prosumers, primary energy source and smart vehicle prosumers are all P2P energy trading that uses a BCT-based system. The two major use cases that are currently seeing commercial implementations are PowerLedger and Bankymoon [55].

Treiblmaier et al. [64] focused on smart energy or the energy related to individuals or groups of organizations. The blockchain is used to protect the privacy of users, deter malicious acts and promote green practices for more sustainable practices.

BCT can be employed to upgrade an existing grid to optimize reliability and efficiency, providing RT sensing and monitoring to the energy management system. It can be used with renewable energy sources, energy trading infrastructures, power distribution systems and analytical software [40].

Bao et al. [65] reviewed how blockchain is applied in the energy sector. Decentralized storage, power grid control, smart grid P2P energy trading, electric vehicles and carbon emissions trading are implementations that have advanced BCT. These applications intend to save energy, provide a decentralized architecture, decrease fossil fuel consumption and reduce the impact of climate change.

BCT can also assist in energy operations with billing, sales & marketing, trading, automation, data transfers and smart grid management. BCT can improve wholesale energy, imbalance settlements, digitalization, IoT integration and P2P energy trading. The Brooklyn MicroGrid is an example of a use-case that utilizes a blockchain-based P2P energy platform. Other areas in the energy sector include metering & billing, tokens & investment, decentralized energy trading, grid management, automation, asset management, electric e-mobility, and general-purpose initiatives and consortia [66].

Kufeoglu et al. [67] analyzed applications in the power industry including AI, machine learning, deep learning and digitalization. In combination, these apps simplify business operations and provide a link between physical and digital objects. Their work indexes global companies that have BCT applications implemented as of today, such as Conjoule, from Germany, a P2P marketplace for renewable energy, and Dajie, a P2P-IoT-BCT trading platform from the UK. Other applications for blockchain in the energy sector are a secure payment mechanism for EV charging/discharging, for P2P energy trading, providing green energy certificates and to advocate for Demand Response Planning. The modern, decentralized architecture allows for expanded security and privacy while having flexibility [57].

Musleh et al. [68] examined decentralized technologies for smart grid applications. The BC is used in P2P energy trading to set a fair price for both seller and buyer, to integrate electric vehicle (EV) charging stations, to control a trustworthy electrical grid and to monitor smart contracts to improve grid resiliency. Additional use cases for BC include competition between P2P power utilities and managing RT supply & demand, energy trading and microgrid maintenance. Currently, there are close to 140 start-ups in the energy sector [69].

5) OTHER INDUSTRIAL APPLICATIONS

Blockchain has uses for both large and small industries. The industries listed below are small-scale sectors with fewer references in the literature:

- **Government:** Blockchain technology fosters innovative applications and handles digitalization of assets, transaction integrity and P2P exchanges. The objective of DLTs in government is to provide transparency while reducing security risks. E-government applications include digital ID management, tax fraud prevention, data access control and voting protocols. The Estonian Blockchain strategy is a use case of an e-government application [40].
- **Manufacturing:** Technical records and other paperwork can be uploaded to the distributed ledger. BCT can be employed as an inventory management tool, displaying the availability of spare parts in RT. In conjunction with IoT, security and privacy techniques will become more fortified [55]. Smart factories are dynamic environments and BC can provide flexibility, which assists with planning and scheduling, making SCs able to adapt on the fly. An autonomous manufacturing system links with IoT devices to make RT decisions that result in smart products [64].
- **Smart Applications:** An application's goal is to provide security and privacy to the homeowner [56]. Smart devices, using BCT, provide homeowners with comfort & convenience by offering new options to better integrate their IoT devices and home security [64].
  Smart home refers to the complex consolidation of information and communications technology (ICT). IoT devices communicate through the router via servers and the local network to prevent privacy leakage. Architecture follows a three-layered taxonomy to ensure security [38]. A use case is the Dubai Blockchain strategy, which is the first smart city power by the Blockchain in 2020, to establish a business ecosystem [40].

B. CHALLENGES, OPEN RESEARCH ISSUES & SOLUTIONS

Current literature outlines key issues that global SCs encounter before, during or after blockchain adoption: laws & regulations, data management & provenance, governance & traceability, interoperability & standardization, lack of awareness, education & innovation, performance & scalability, trust & stakeholder management and transparency & visibility.

1) LAWS & REGULATIONS ISSUES

Blockchain does not have a set of general legal regulations and standards to follow.

Chang et al. [70] recommends a comprehensive compliance profile to advance the use of standardized regulatory mechanisms. The researchers presented four areas for future research opportunities: distributed jurisdiction and laws, legal framework to ensure validity, responsibility/accountability, and data privacy.

Zhao et al. [36] stressed the necessity to introduce new standards to regulate BC applications. Large SCs have multiple manufacturing facilities with their own set of laws and regulations. Regulation authorities must stay vigilant and continuously improve regulatory measures to strengthen the international supervision of the SC [51]. Governments need to draft new laws to allow innovative technologies to thrive and not be slowed by barriers due to legal constraints in the implementation of a blockchain-based system [38].

Haq and Esuka [50] identified one of the biggest challenges as integrating BCT solutions with existing regulations and compliance with global standards. Stringent requirements hinder advancements but smart contracts can write and enforce rules which automate SC processes and reduce costs.

Kassem et al. [71] cautioned that mistakes and vulnerabilities in smart contracts due to human error can be rescinded but waste resources and time and present unforeseen risks. On the other hand, not all the smart contract stipulations are being followed and may be overregulated [60]. All facets of the smart contract must be followed to avoid issues regarding regulations from different countries and unclear jurisdiction. Bekrar et al. [72] summarized legal and regulatory issues that arise from lack of jurisdiction or when localized regulations limit certain SC actions.

Other barriers for BCT adoption are issues during transformation related to regulation, efficiency and security. These are focus areas for current and future research initiatives. Creating and redefining business models that incorporate an official legal framework is an effective way to cope with the transformation process [73].

Okazaki [63] emphasized the use of Application Programming Interfaces (APIs) for the creation of BC solutions for technical challenges and regulatory disparities. Lack of standardization is prevalent in world trade and disrupts digital solution development and application.

Laws and regulations need to be updated in consideration of the current global landscape. Protecting user's rights and their data poses a gap in research [74]. Katsikouli et al. [75] called for action plans to reveal gaps in legal regulations regarding fair trade. The implementation of fair-trade strategies in BCT is immature and presents a research gap.

Tezel et al. [76] identified the need for blockchain-based systems compliance with existing accounting systems, regulations, frameworks, standard contracts, and laws. New models are needed to address regulatory structure compliance and its challenges in blockchain adoption. Policy development and regulation is mandatory and a barrier to BCT adoption, practices, and strategies due to the lack of a regulatory framework [77].

Gohil and Thakker [78] detailed blockchain implementations challenges in handling and maintaining legal contracts and document security. An opportunity is present for future research in the storage and retrieval of secure legal documents and legal compliance requirements. Legal and regulatory uncertainties can cloud managerial involvement and decision making in adopting BCT in SCs. Serious effort must be put into the development of new standards capable of dealing with risks [79].

2) LAWS & REGULATIONS SOLUTIONS

Etemadi et al. [90] introduced a solution that aims to increase supply chain resilience. It can help monitor various laws, threats and regulations to avoid disruption and keep a SC running smoothly despite outside interference. An example presented by these authors [90] discussed Cryptocontract, a solution to create, maintain, disclose and dispute contracts. It is a three-fold design using BCT, IoTs, and Smart Contracts. Smart contracts are traditional contracts 2.0, capable of contract enforcement automation.

Polyviou et al. [96] noticed that studies indicated that certain inventory items may have a regulation placed on it. The food industry has many requirements for shipping and receiving meat. If a product doesn't meet these requirements, suppliers will be notified and recommended to increase the quality of their materials.

Mazlan et al. [105] highlighted the lack of innovative operations, procedures and logistics in the maritime industry. Digitalization is a promising solution in this field which serves as the development backbone of the smart technology, such as smart ships or smart logistics with globalization.

3) DATA MANAGEMENT & PROVENANCE ISSUES

Global SCs must manage their data effectively to provide accessibility, authenticity, availability, digitalization, integrity, privacy, protection, provenance, security, sharing and storage. Blockchain and data storage problems in IoT-precision agriculture networks were discussed by Torky and Hassanein [30]. Blockchain-based storage options can alleviate many of the issues associated with cloud-based storage and can improve data availability and security. Other researchers have investigated technical challenges for data accessibility and protection. A lack of standardization has led to unclear rules on how data should be shared and stored between public and private BCs, leading to the need for creating new data management standards [34].

Konstantinidis et al. [44] mentioned privacy as one of their primary issues for BC-SC systems. Data sharing concerns have negatively affected medical organizations as current encryption methods can't fully protect an actor's identity. Users' identity protection is a chief concern and an area for future research. Similarly, malicious attacks, security breaches and compromised data jeopardizes the integrity of patient data and diminishes privacy. Secure solutions are needed that protect users' identities [47].

Siyal et al. [49] indicated that without a trusted third party, data privacy can be compromised if multiple parties are responsible for authorization. Another challenge is the total capacity of data storage. Future efforts should focus on scalability and resiliency to refine record keeping and retrieval speed.

Ahmad et al. [56] discussed identity protection as a barrier to full privacy in IoT networks and suggested that more in-depth research is required to tackle privacy issues by mixing available techniques.

Data provenance can increase customer satisfaction and trust. Smart cities, for example, are dependent on efficient SCs with dynamic business interactions. Track and traceback procedures can upgrade BC solutions by optimizing management processes and ensuring legitimacy of information across the SC [64].

Okazaki [63] raised concerns about the privacy and security of the data storage and accessibility on the shared ledger as transactions are linked to identities.

Traditional logistics systems are outdated and incapable of handling complex situations. Upgrading legacy platforms with new forms of technology, such as BC, IoT or RFIDs, is an important area of research [78].

Chang et al. [70] highlighted the disruption of information flows in global SCs due to the large volume of documents, from bills of lading to certifications. Digitalization is a promising opportunity to streamline administrative practices along with provenance to ensure legitimacy and detect counterfeiting.

Rejeb et al. [85] indicated that human manipulation of data or information in non-IoT scenarios remains an industry challenge and new BC solutions should focus on identification verification and device authentication. The paper emphasizes the importance of data quality and provenance and identified three challenges: data control, authenticity, and monetization. The lack of aggregate IoT data is a gap and potential area for future research.

Bodkhe et al. [84] identified areas that need further development to address security challenges, including data modification and unauthorized access, in HC. Other areas include increased data volume and information processing complexity, data provenance and integrity, and protection of users' data when stored in a centralized database.

Different privacy policies relating to information and data usage, sharing and release may hinder successful implementations of BCT in SC. New IT tools are necessary to mitigate limitations in RT information accessibility and to enhance storage management [86].

Two major technical challenges to modern SCs, access control and data retrieval, were outlined by Wu et al. [87]. New approaches are required to pull the desired data efficiently and reliably from the BC while preserving data privacy. Kumar et al. [88] indicated another storage challenge was deciding which data gets stored on the blockchain or off-chain.

Blockchain transactions are not well suited for sensitive data since they are transparent and irreversible. New approaches need to be flexible enough to change transaction parameters using smart contracts and be versatile enough to oversee large amounts of data [83]. Kamilaris et al. [77] listed accessibility as an open issue to agriculture blockchains. The information infrastructure required to operate and maintain BC systems might prevent access to markets for new users.

Etemadi et al. [90] focused on authentication security protocols in blockchain to ensure department privacy and security from potential attacks. New solutions need to focus on safeguarding privacy while enabling connectivity, increasing the effectiveness of IoT devices. More attention needs to be devoted to data storage methods in BC implementations in end-to-end SCs. Other authors have cited privacy risks as a main barrier to BC adoption. More secure consensus algorithms are required to improve system security and privacy [79].

4) DATA MANAGEMENT & PROVENANCE SOLUTIONS

Zhao et al. [36] looked at the challenges in applying BCT in agri-food value chains. Privacy leakage is a significant barrier to transparency and trust building, thus encryption (i.e., obfuscation) is a promising area for BC solution research.

Al-Farsi et al. [80] presented three solutions that have been created from academic efforts. The first solution's target was to preserve information privacy. It allowed for auditability, ownership and authenticity of goods. Potential attack mechanisms, such as breach of data integrity, can be prevented and stopped altogether with this option. The second solution is secure data sharing which introduces a decentralized file system, BCT integration and storage schemes. The third and final solution's topic was data provenance, which allows accurate product tracing and enables provenance. Both solutions two and three prevent attacks such as data integrity breach, tampered input data and false data reports.

Chang et al. [70] presented a solution regarding port container operations. Data access and control is limited by credentials, digital rights exist between parties, rights can be transferred, and operations can be digitized without a third-party source.

Afanasev et al. [83] examined Blockchain as a Service (BaaS) as a solution for data management. Supply chains can build and operate applications and their functions, which increases flexibility. Cloud-based storage is the best option for databases within the BaaS since companies wanting to adopt this service will pay and sign a contract for a certain amount of time.

Litke et al. [89] proposed a data management solution for data exchange. Input data is mandatory and must be entered to give a larger level of detail than most solutions. The system boasts better tracking methods and faster identification processes.

Etemadi et al. [90] proposed a solution for product provenance for cyber risk identification & mitigation. Essential product information, credentials, rights are stored on many IoT devices in case of a security issue.

Everledger, part of the Hyperledger Fabric framework, is an implementation that tracks the provenance of assets with high costs [99].

5) GOVERNANCE & TRACEABILITY ISSUES

Traceability and governance are key challenges in global SC due to increasingly complex systems. Katsikouli et al. [75] indicated that when traceability is decreased, vulnerabilities appear, and compliancy becomes lax. Agarwal et al. [91] mentioned traceability as a major challenge which can become an industry inefficiency causing delays, errors and increased costs. Demestichas et al. [33] concluded that complex SCs tend to have issues with traceability. Opportunities exist by leveraging big data and machine learning to yield a more efficient production process.

Feng et al. [37] addressed five major challenge areas in blockchain for sustainable traceability practices, including technical challenges, blockchain infrastructure, social, institutional and system performance. A blockchain-based traceability system lacks the public key infrastructure needed for quality control, inter-domain policies, and to authenticate products.

Friedman and Ormiston [92] looked at the possibilities for blockchain to approach food traceability sustainability issues. Contamination and spoilage occur frequently due to lack of safety and quality standards which negates public health. BCT promotes trust in an environment with strangers by keeping data secure, verifiable and manageable. Track and trace methodologies can become more effective via blockchain intervention.

Haq and Esuka [50] discussed four challenges to BC adoption: technical, legal, business and trust. Governance is the establishment of trust without the need for a central authority. Regulatory and legal requirements can slow governing models by forcing stakeholders to perform the role of regulator. The work of Ariningsih and Sundara [93] partially examined the traceability and governance of SC flows during natural disasters. The new model uses blockchain implementation, along with Vendor Managed Inventory (VMI) to create an alliance among SCs and to provide trust when it is lacking. Information sharing and consensus are two BCT features that are suitable for disaster relief efforts in the future.

Bodkhe et al. [84] stated a key challenge to traceability is the lack of total number of implementations. Current approaches have drawbacks such as no hardware compatibility, lack of privacy, supervision, and transaction speed. Ahmed and MacCarthy [94] noted the lack of standards for traceability in blockchain adoption efforts and the lack of guidance in application implementations. Limited understanding stifles robust initiatives, making business requirements unclear and often confusing. Different SC configurations have different requirements and each project should be looked at differently. The granularity of data and diversity of scope are two areas that need further research to better understand blockchain initiatives and the effects they have on global SCs.

Rogerson and Parry [97] examined issues of governance surrounding BCT. More research is needed to address the lack of standards which creates data inconsistency.

Reliance on centrality and lack of trusted information among SC actors are two gaps in current research [90]. Despite the new frameworks proposed, there are opportunities available for creation and enhancements.

6) GOVERNANCE & TRACEABILITY SOLUTIONS

Venkatesh et al. [14] discussed a BCT solution called the Product Service System (PSS) that combines BCT & IoT. The PSS has been used in many industrial applications including RFIDs and aircraft engines. Offers three services in one package; product, use, result.

Gohil and Thakker [78] talked about practical implementations used today. Hyperledger Sawtooth offers open source solutions to businesses and has seen success in the seafood supply chain. It enforces traceability by recording daily information and storing it in case of review or audit. Research projects have been implemented that focus on IoT integration and the use of open-source frameworks for DLTs. Al-Farsi et al. [80] introduced many BCT solutions. The solution for governance gave SCs ownership rights, compliance directives, data privacy and policy design & analysis. Potential attack mechanisms include data integrity breach and tampered input data can be halted with this promising solution.

Chang et al. [70] reviewed a Just-in-Time (JIT) production solution that aims to monitor a system accurately by using RFIDs, notifications, warnings, and provide visibility through IoT devices. Bodkhe et al. [84] advanced Chang et al.'s [70] philosophy by further advancing operational control. also proposed a solution for operation control which aims to eliminate bottlenecks, optimize planning & scheduling

The compromise between confidentiality and traceability is a significant challenge in BCT [95]. A gap in research exists in finding a balance between the two through the development of new solutions capable of RT updates and tracing. Kamilaris et al. [77] indicated that the long-term impact of blockchain on governance still needs to be assessed. SC monitoring with IoT relies on two main functions, tracking and tracing. Data integrity, tampering and centrality affect tracing. BC implementations can eliminate gaps by reducing human intervention, ensuring data reliability and information system integration [96].

Wu et al. [87] examined Everledger. Their top priority is the transparency of global supply chains. They offer provenance and asset tracking in this digital transparency company. Etemadi et al. [90] briefly discussed anti-counterfeiting to enforce governance over a worldwide SC. Tracing drugs can make it near impossible for dishonest people to sell counterfeit medicines or prescriptions. Finding counterfeit products keeps your supply chain uncompromised.

The authors [90] also recognized Counterchain as a solution for drug governance and origin traceability. Authenticity is protected through this platform through automation, monitoring and regulating.

Walmart, Kroger and other department conglomerates use BCT solutions to keep products unadulterated, erase fraud and getting more suppliers involved in their SC network to achieve better product traceability [104].

7) INTEROPERABILITY & STANDARDIZATION ISSUES

The lack of standardization or a common set of standards has limited blockchain interoperability and a unified set of standards is necessary to streamline interoperability in SCs [34]. A research opportunity is closing the interoperability gap between ledger types.

Another area of research is the formulation of standards and regulations to reduce investment cost and human resource allocation in international trade [36]. Agbo et al. [47] focused part of their work on interoperability difficulties. Without standards, industrial applications experience operation issues. The need for open standards is a promising area for new research projects. An international set of standards is needed to unify services and ensure data integrity when implementing blockchains in HC [49].

Interoperability and standardization challenges have led to integration issues in BCT adoption [50]. The creation of new standards is a research opportunity that could assuage the integration issues between multiple devices. When manufacturers integrate multiple blockchains, there is a heightened need for interoperable systems [55]. The authors noted the significant challenge of interoperability and called for implementations to become standardized.

Kassem et al. [71] summarized interoperability challenges for blockchain applications where requirements differ. Future work could focus on the access layer, developing application-specific functions. Lack of interoperability has also caused issues with data retrieval, resolving collaboration and cross-chain interaction, and wider BCT adoption. An opportunity for future research is the creation of industry-wide standards and practices [98].

Lack of standardization has led to technical incompatibility between large and small suppliers in food SCs [99]. Similarly, in the agricultural industry, a major challenge is the lack of standardization in data format, lending itself to research in the creation of protocols, shared among actors [100].

As with other researchers, Katsikouli et al. [75] promotes standardization as a key issue in BCT adoption. This issue presents a research gap, as there is no common standard for all regions and countries. Mann et al. [101] cited lack of industry standards in mining has disrupted intellectual property (IP) property patents. Opportunities exist in the development and refinement of standard technology for BCT implementation.

8) INTEROPERABILITY & STANDARDIZATION SOLUTIONS

Al-Farsi et al. [80] introduced three distinct solutions for interoperability: between heterogenous systems, seamless operation and among cross-border entities. These solutions allow for secure party interaction, dispute settlement, access control privileges and transparent finances. They prevent attacks like the breach of data integrity, falsified information or results reports and tampered input data.

Afanasev et al. [83] summarized real examples of solutions available to SCs using blockchain. The CONNECT project allows IoT networks to interact with each other without using a network address. Suggested solutions aim to enhance IoT heterogeneity and interoperability. Other practical examples include Ethereum, IOTA and Hyperledger. R3 Corda is a smart contract solution to assist with creating an interoperability network with regulated privacy [86].

Jabbar et al. [98] summarized three blockchain solutions that help increase interoperability. Notary schemes, hash locking, side chains and relays are all examples. These items have limited use & functionality and can be used as a foundation for future work & improvements.

Rauniyar et al. [104] spoke about Skuchain, a company that allows banks to trade digital financial services to their customers or to conduct business. Establishing interoperability between various trade platforms is their main objective and contribution to interoperable solutions development using emergent technologies.

9) LACK OF AWARENESS, EDUCATION & INNOVATION ISSUES

Duan et al. [74] suggested the lack of understanding of BCT's true potential hinders solutions since companies are looking for an easy fix instead of addressing organizational issues. It may be more challenging for SMEs to flourish from the lack of financial resources, skills, and expertise [102].

Chen et al. [99] discussed that unfamiliarity and lack of knowledge of BC adoption has held back and postponed initiatives. Labor and skill shortage are also a factor. Lack of innovation is a challenge for advanced industries that utilize new forms of technology [103]. Operations, procedures, and logistics need improvements to be able to support critical infrastructures to remain globally connected and distributed.

Saberi et al. [86] summarized lack of awareness challenges, like resource allocation and financial decisions. Organizations need to reform old policies, adopt new technology and transform workplace culture for personnel to accept BCT. Lack of managerial commitment to blockchain implementation is a significant barrier as effective SCM relies on support from top management [79]. Sustainable practices are becoming more common as environmental regulations force global SCs to rectify practices and conform to societal rules [86]. Industry sectors, corporate cultures and the behavior of users can be detrimental to the decision to adopt BCT [90].

10) LACK OF AWARENESS, EDUCATION & INNOVATION SOLUTIONS

Blockchain solutions need to be appreciated by all employees to benefit from the technology and to foster confidence in future efforts. Al-Farsi et al. [80] briefly mentioned lack of awareness solutions that ensure the secure exchange of information. These solutions are excellent at detecting any compromises or anomalies. Stakeholders haven't fully committed to the solution since it involves complete trust and no credibility when an error occurs. Improvements need to be made to push the solution to its full potential.

Rauniyar et al. [104] noticed that many implementations lack innovation and awareness to detail. The airline industry has shown interest in using BCT. Airbus, Lufthansa and British Airways all have projects underway but many lack the ability to fully complete the objective. Manual efforts must be made to ensure complexity, which conflicts with automation.

11) PERFORMANCE & SCALABILITY ISSUES

Performance is a primary concern in today's global market, adversely affecting bandwidth, efficiency, latency, throughput, and scalability. Torky and Hassanein [30] discussed the challenges of IoT networks and blockchain solutions. IoT device & sensor communication rules, energy conservation, complex network scaling and limited storage solutions are opportunities for future BC research projects. Several technical, regulatory, institutional, infrastructure and capacity development related challenges that need to be addressed before scalability reaches maturity [34]. A gap in research exists in the trade-off between anonymity and identity.

Challenges for IoT devices in BC include scalability, security, and stability [37]. Rauniyar et al. [104] examined BCT integration with IoT devices. Their findings proved that risk mitigation plays a pivotal role in SC performance through innovation by creating new sub-categories like dispute resolution and fraud prevention. Performance indicators, like storage capacity, and processing ability need more research to improve quality traceability systems.

Latency and scalability are two performance challenges [42]. A barrier to scaling is the response time and system latency that increases with the number of users. Lack of network latency is an opportunity for future BC infrastructure research.

Latency is the biggest limitation of all consensus protocols. Current protocols address the issue, but more work is necessary to speed up the confirmation process [44]. Scalability is a significant barrier to BC in HC. The large volume of data involved introduces latency into the network, affecting transaction speed. Validation mechanisms need to be optimized to store large amounts of transactional data without degrading performance [47].

Jovic et al. [60] explained blockchain challenges due to performance and scalability issues. Conserving processing power since all nodes in a chain must process all transactions is an area of investigation.

BC faces challenges such as scalability, efficiency, and complexity in the use of smart devices in intelligent transportation systems. Architectures need to be flexible enough to deal with large numbers of devices. Future work must focus on adding functionality, such as scalability and simplicity [106]. Rejeb et al. [85] proposed combining IoT with BCT. Scalability is an issue due to the limited number of nodes and the ability of IoT devices. Existing proposals lack the ability to combine decentrality, scalability and security. Refusal to share information, effective incentive mechanisms and lack of trust and collaborative activities are identified as major BC barriers [102]. Bodkhe et al. [84] also explored scalability obstacles. RT scenarios require millions of transactions to be executed posing a significant research gap for scalable transactions.

A prime challenge in BC for SCM is how systems scale and operate with an increasing number of stakeholders and large amounts of transactional data. Reparameterization of the block size and inter-block interval can improve the system, but without a fundamental redesign of the blockchain paradigm, scalability issues will always occur [87].

Jabbar et al. [98] divided scalability into four approaches: on-chain, off-chain, consensus mechanisms, distributed acyclic graph-based. It was noted that a fundamental change is required in BCT architecture to modify protocols and optimize algorithms.

Litke et al. [89] focused on bandwidth constraints due to a network's physical limit. Scalability is limited by the number of transactions each block can take.

Kamilaris et al. [77] concluded that blockchain protocols face serious obstacles since the system is limited by network parameters like transaction block size & interval. Bekrar et al. [72] indicated that BC immaturity has led to a major concern with scalability. The authors supported Wu et al. [87] and Jabbar et al. [98] in reasoning that newer developments and protocols must be designed with scalability in mind. Future work must focus on sharding without losing security. Venkatesh et al. [14] summarized past scalability challenges. Network changes result in slow processing speeds and block size limitations. Future research initiatives must focus on enhancing performance parameters.

12) PERFORMANCE & SCALABILITY SOLUTIONS

Agbo et al. [47] and Alladi et al. [55] looked at the scalable implementation of BC for HC. The large size of data is a practical issue for feasibility and scalability. Data storage and retrieval is a current gap in research, as solutions need to be scalable but efficient. Huge amounts of data increase computation and time, constricting scalable solutions within IoT networks. Storage optimization is a future research area in network infrastructure and node behavior [56].

Block size, high volume, transactions, number of nodes and protocols are barriers to scalable solutions [105].

Redesigning the blockchain and storage optimization are two areas of research needed to gain insight on system performance.

Innovative and scalable solutions are under development and need more work. Additionally, developers are working to find a better to solution to extend BC scalability while keeping high security and decentralization within the food SC [74].

Saberi et al. [86] suggested that improvements are needed in storage management and advanced cloud computing to have viable storage options for scalable solutions, an area that needs further investigation.

Rejeb et al. [85] and Jabbar et al. [98] both discussed a scalability solution that is termed off-chain scaling. It runs alongside the blockchain, or in parallel. The primary purpose is to exchange data between both chains. A concern is the compatibility of off-chain scaling with existing business infrastructure.

Jabbar et al. [98] also talked about on-chain scaling too. It requires companies to change their current structures.

Sharding is an example of an on-chain scaling solution. The blockchain is separated into smaller pieces instead of a singular system. The authors also focused on consensus mechanism scaling. VeChain and NEO are two examples of blockchains that utilize consensus-mechanism scaling.

Bekrar et al. [72] and Jabbar et al. [98] discussed distributed acyclic graph-based scaling which is a distributed ledger technology that can process transactions much quicker making them more scalable than other solutions. IOTA and NANO Hashgraph & Byteball are all examples of DAG scaling.

Hyperledger Fabric is a scalable solution that uses smart contracts to with excellent community support [86]. It has been adopted by IBM, Cisco and SAP for its ability to handle financial applications and aims to unify all developments of blockchain technology that crosses industries [104].

Wu et al. [87] briefly mentioned reparameterization as a scalability solution. It causes the inter-block interval speed to increase and block size expansion.

Sharding is a scalability solution. Data partitioning is used to lower transactions fees and wait times. Memory storage is done via horizontal data partitioning [97].

Haque et al. [112] presented a comprehensive framework for addressing scalability issues. Scalable Edge IoT Blockchain (SEB) aims to enhance IoT performance & efficiency within a blockchain network using a combination of sharding, Interplanetary File System (IPFS) and the Delegated Proof of Stake (DPoS) protocol. Resource utilization, latency and throughput are all metrics that improved as a result of EOSIO BC implementation.

13) TRUST & STAKEHOLDER MANAGEMENT ISSUES

Stakeholder management is essential to establishing trust without intermediaries and coordination in global SCs. Poor infrastructure has led to a lack of digital skills and trust. Stakeholder collaboration is crucial to maintaining trust & full interoperability [37]. A considerable level of skepticism exists among stakeholders in the agri-food value chain [36] More work is needed to resolve technical BCT issues by instilling trust in stakeholders.

Chang et al. [70] recognized trust as one of the most important factors in a committed and collaboration environment between stakeholders. Current stakeholders rely heavily on central intermediaries for transactions. The removal of intermediaries is an opportunity for research with BCT. The lack of infrastructure uniformity and stakeholder awareness are two obstacles to BC implementations and SC innovation. The replacement of policy and lack of methodology is a gap in research that must be addressed [95]. Litke et al. [89] realized the significance of stakeholders (actors) relationships to the nurturing of trust. The shift from relational to technological trust is occurring in the construction industry and creates opportunities for future work in policy making. Poor information flow among stakeholders is major challenge across a global SC. A platform for coordinating multiple stakeholders is another research opportunity [108].

Complex SCs have many stakeholders, so RT access of operational data is key to making informed decisions. Accessibility is an area for future work, as it directly correlates to trust in blockchain-based systems [78]. High levels of trust can be more quickly established through digital trust as opposed to traditional SC relationships [102]. Other problems commonly experienced by stakeholders have been articulated [90]. Information sharing, digitalization, response time and low collaboration are obstacles that need further research initiatives. These issues diminish the value of trust in BCT.

14) TRUST & STAKEHOLDER MANAGEMENT SOLUTIONS

The incentivization of current operational and business models is an opportunity for new BC solutions in HC. Stakeholders are more likely to participate if there is a reward for their work [50].

Ahmad et al. [56] split their research into research challenges and future directions. Trust and reputation management is a difficulty for IoT devices. Blockchain solutions can play a pivotal role in node recommendation and reputation, but more research is needed in this area. Lack of trust and limited collaboration is a key issue that hinders BCT adoption. Increased collaboration and trust are needed to ensure all parties are fair and use the same, transparent data [71]. The establishment of BC solutions for developing countries or SMEs is an opportunity for future work [74].

Rauniyar et al. [104] discussed a solution to increase stakeholder management and increase trust. The stakeholders have a complete view of all data as product flows. Moyee Coffee uses tokens to represent the commodity's value. It is created when the product begins and increases in value as it travels toward the end of production.

The authors [104] also summarized the Hyundai Merchant Maritime (HMM) initiative, which utilized the BC to allow secure sharing of data between many stakeholders throughout shipment. The project proved that new solutions, that combine various forms of technology like IoT, can improve maritime vessel monitoring and management.

As the number of stakeholders increases, so does the need for trustworthy, transparent frameworks that allow companies to have successful BCT implementations [107]. New governing policies are essential to changing workplace culture and fostering cross-organizational communication.

15) TRANSPARENCY & VISIBLITY ISSUES

Transparency is a growing concern for global SCs. Transparency is a feature SCs hope to gain from BCT adoption. Accurate data is a challenge that needs to be addressed to keep product information complete. Historical and performance data must be made available in the BC to safeguard sustainable practices while creating new ones [92]. Barriers stand in the way of the acceptance of blockchain technology in supply chains. Organizations need to be fully prepared prior to implementation, infrastructure and expertise must be solved before integration. The blockchain will increase visibility by keeping records transparent for all stakeholders

TABLE 6. Challenges & research gaps.

Challenge	Specific Issue	Reference
Laws & Regulations	Distributed jurisdiction & laws, flexible legal frameworks, regulations,	[60], [70], [72]-[73], [78]
	responsibility and accountability	[36], [51]
	International monitoring and regulation application standards	[38]
	Increased government involvement and new legislation	[50], [71]
	Creation of automated, custom laws through smart contracts	[63]
	Lack of a standardized system for documentation	[60], [74]
	Data and privacy protection	[84]
	Legacy system compatibility limitations	[75]
	Fair trade strategies from BCT immaturity	[78]
	Document security, storage and retrieval	[79]
Data Management & Provenance	Limited data storage and capacity	[30], [36], [49], [86]-[88], [90]
	Data accessibility, privacy leakage and sharing protection	[34], [37], [44], [49], [56], [63], [77], [79]-[84], [87], [90]
	New approaches for data management standards	[64], [70], [84], [90]
	User identity protection	[47], [49], [56], [63]
	Data provenance and integrity	[70]
	Digitalization of paperwork	[70], [85]
	Counterfeiting	[84]
	Data modification	[87]
	Access control and data retrieval	[89]
	Transaction flexibility and versatility	[90]
Governance & Traceability	Traceability-complexity Tradeoffs	[75]
	Traceability-confidentiality Tradeoffs	[33]
	More efficient production processes	[95]
	Blockchain infrastructure and framework renovation	[33]
	Quality control and inter-domain policies	[37], [90]
	Governance consensus mechanisms, requirements and standards	[37]
	Lack of successful implementations	[50], [77], [95], [97]
	Approaches for hardware compatibility, privacy, supervision and	[84], [94]
	transaction speed	[84]
	Guarantee of product authenticity	[95]
	Data integrity, tampering, consistency and centrality	[90], [97], [100]
Interoperability & Standardization	Selection of the correct regulatory frameworks, governance structures and standards	[34], [36], [45], [55]
	Interoperability between blockchain ledger types	[47], [50], [75], [98]-[101]
	New, open standards for industrial applications	[49], [76], [98]-[100]
	Lack of international set of standards	[94], [101]
	Lack of blockchain technology regulation	[71]
	Refinement of standard technology for blockchain implementations	[101]
Lack of Awareness, Education and Innovation	Lack of misunderstanding of blockchain adoption	[74], [104]
	Lack of resources for Small-Medium Enterprises	[102]
	Perception of blockchain technology	[103]
	Labor and skill shortage	[103]
	Lack of experts/expertise	[103]
	Digitalization	[103]
	Resource allocation and financial decisions	[86]
	Creation of new positions for blockchain implementations	[86]
	Decision-making obstacles	[90]
	Lack of managerial commitment	[79]
Performance & Scalability	IoT device and sensor communication rules	[30], [112]
	Energy conversation & computing resources	[30], [60], [98], [112]
	Complex network scaling	[30], [112]
	Limited data storage capacity, optimization and retrieval	[30], [47], [55]-[56], [89], [104], [112]
	Storage management & advanced cloud computing	[87], [112]
	Block size restrictions & reparameterization	[14], [84], [86]-[87], [106]
	Speed and finality algorithms	[34]
	Anonymity-Identity Tradeoffs	[34]
	Processing ability with large transaction sizes, latency & time interval	[14], [37], [47], [56], [77], [87], [89], [101], [104]-[105], [112]
	System longevity	[47]
	Performance degradation	[44], [112]
	Optimization of validation mechanisms	[72], [87], [105]-[106]
	Flexibility infrastructure renovations	[60], [72], [86]
	Blockchain immaturity	[85]
	Limited number of nodes	[85], [112]
Trust & Stakeholder Management	Poor infrastructure	[37]
	Lack of a collaborative network, coordination and digital trust	[37], [70]-[71], [78], [89]-[90], [107]-[108]
	Stakeholder skepticism	[32], [95]
	Stakeholder training and education programs	[36], [74]
	Incentivization of operational and business models	[50]
	IoT device trust and reputation management	[56]
	Removal of intermediaries	[70]
	Stakeholder Indifferences	[85]
	Utilization of IoT devices for specific functions	[85]
	Infrastructure uniformity	[74]
	Blockchain solutions for developing countries and Small-Medium Enterprises	[74]
	Supply chain relationship difficulties	[102]
	Policy replacement and lack of methodology	[85]
	Real time operational data availability & information sharing	[89], [105]
	Digitalization	[78], [90]
Transparency & Visibility	Accurate data availability	[90]
	Use of collaborative, open-source networks	[34]
	Infrastructure improvements	[84], [109]
	Policy, regulation and tracking system enhancements for increased visibility	[84]
	Lack of organizational trust	[95]
	End-to-end visibility & procurement	[78], [90], [109]

TABLE 7. Blockchain solutions for global supply chain management.

Number	Challenge	Solution	Description	References
1	Data Management & Provenance	Port container release operations	Data are gathered in the database and is restricted by party Digital rights are transferred between parties Rights transferred to receiver from sender Securely digitized the operation process without any middlemen or third parties	[70]
2	Governance & Traceability	Just-in-Time (JIT) production operations	Radio Frequency Identification Devices (RFIDs) trigger situational alerts Warnings for supplier replenishment and delivery Visibility is increased through IoT applications	[70]
3	Governance & Traceability	Operational control	IoT devices control processing capacity, throughput and set-up time Bottleneck alleviation Production planning & scheduling optimization	[90]
4	Laws & Regulations	Digitalization	Conversion of physical data into a digital format Digitizes all data & paperwork removed Forms the foundation for smart systems	[105]
5	Performance & Scalability	Off-chain scaling	Run in parallel with blockchain Exchange and transfer of value Business infrastructure compatibility Off-loading transactions are done privately	[85], [98]
6	Performance & Scalability	On-chain scaling	Require structural change Examples include Sharding & SEGWIT	[98]
7	Performance & Scalability	Consensus mechanism-based scaling	Upgrades to consensus mechanisms in place VeChain and NEO are two blockchains that have successfully used this method	[98]
8	Performance & Scalability	Distributed Acyclic Graph-based scaling	Another distributed ledger technology Topological structure for ordering Examples include IOTA, Byteball, NANO Hashgraph	[72], [98]
9	Performance & Scalability	Reparameterization	Block size expansion Inter-block interval speed increase	[87]
10	Data Management & Provenance	Blockchain as a Service (BaaS)	Cloud-based data storage Build, host and utilize applications and functions Flexibility	[87]
11	Governance & Traceability	Everledger	High-value asset tracking Origin to owner provenance	[87]
12	Interoperability & Standardization	Notary Schemes	A group of witnesses confirm the blockchain state to permit operation	[98]
13	Interoperability & Standardization	SideChain & relays	Applied to many solutions Examples include Polkadot and ChainLink	[98]
14	Interoperability & Standardization	Hash Locking	Limited functionality Original hash value is guessed for a limited amount of time	[98]
15	Data Management & Provenance	Data Exchange	Faster identification & tracking methods Mandatory data input for each item produced	[89]
16	Transparency & Visibility	Product Labelling	Higher levels of visibility Mislabeling and counterfeiting will be more difficult Product recalls can be deployed faster	[96]
17	Performance & Scalability	Sharding	Partitioning used to shorten confirmation time and lower transaction fees Horizontal data portioning used for memory storage	[72]
18	Governance & Traceability	Anti-counterfeiting	Tracing drugs using a combination of encrypted quick response (QR) and blockchain technology Origin & traceability protect authenticity	[90]
19	Data Management & Provenance	Cyber risk mitigation	Store information safely using IoT devices on blockchain architecture Product provenance, credential and rights are stored to counter future security issues	[90]
20	Laws & Regulations	Cryptocontract	Ethereum-based blockchain used for automation Smart contracts replace standard, traditional contracts Combination of IoT, blockchain and smart contracts	[90]
21	Governance & Traceability	Counterchain	Safeguards drug authenticity Regulates consumer confidence in products	[90]
22	Governance & Traceability	Product Service System (PSS)	Successful in many applications such as aircraft engines, RFIDs and photocopiers. Three types of services: result, product and use Combines IoT and blockchain to mitigate high costs	[14]
23	Governance & Traceability	Hyperledger Sawtooth	Open source solution to businesses Enforces traceability using daily recordings	[86]
24	Interoperability & Standardization	R3 Corda	Offers a decentralized solution for finance Tokenized system	[86]
25	Interoperability & Standardization	The CONNECT Project	Allows IoT network to connect and interaction with each other increasing accessibility and connectivity Enhances IoT heterogeneity	[83]
26	Interoperability & Standardization	Skuchain	Allows financial institutions to trade digital finance services to their customers and other businesses (B2B) Development aims to establish interoperability between trading services	[104]
27	Trust & Stakeholder Management	Moyee Coffee Initiative	A tokenized system is used to add value to commodities A commodity's worth gains value as it travels through the SC to its destination	[104]
28	Trust & Stakeholder Management	Hyundai Merchant Maritime (HMM)	Allows the sharing of data securely for marine activities Blockchain with IoT to improve vessel monitoring and management	[104]
29	Transparency & Visibility	Privacy by Layers Approach	Allows for a transparent SC while maintaining the privacy of information Uses a data controller to allow access to authorized materials	[81]
30	Performance & Scalability	Scalable Edge IoT Blockchain (SEB)	Sharding showed remarkable improvement in CPU & resource utilization Delegated Proof of Stake (DPoS) has better performance capabilities than that of Proof of Stake (PoS) and has shown to be promising for scalability solutions	[112]

in the SC network [109]. Orenstein's [110] research looked at creating transparency in SC networks. Using a dashboard, a visualization tool, Key Performance Indicators (KPIs) were used to identify several information dimensions to a particular business process. Once a layered map is created, network metrics can be acquired and analyzed to see the impact of removing or redistributing key nodes [110]. It can theoretically be used to examine a traditional system versus a new blockchain-based platform to a before and after look of the implementation process.

IoT devices experience open issues including lack of transparency in blockchain deployment. An opportunity exists for the establishment of BC solutions to improve infrastructures. When systems have issues, visibility is decreased across the SC. Future work should spotlight ways to improve policies, regulations and tracking systems for connectivity [84]. Lack of transparency has led to low trust among SC members. A major opportunity is present to overcome trust within an organization prior to adoption [95]. End-to-end visibility is the chief concern for SCs. The visibility of the complete product lifecycle is an opportunity for future research work [78]. Etemadi et al. [90] briefly analyzed adoption, benefits and challenges in SCs. The main issues were visibility and transparency of SC assets.

16) TRANSPARENCY & VISIBILITY SOLUTIONS

A promising research area is the use of collaborative, open-source platforms with new, transparent solutions [34]. Blockchain solutions can allow global supply chains to address challenges and overcome obstacles. Table 7 lists 30 potential solutions that provide a distinct research opportunity. The objective is to advance blockchain technology for global supply chain management applications.

Riva [81] introduced the Privacy by Layers approach which combines the need for a transparent SC with the protection of individual privacy rights using a side chain. The objective is to install a data controller, to govern the e-ledger, be responsible for accessibility and to grant permissions to access block content.

Sunny et al. [82] focus on supply chain transparency enabled by BCT. One section of their research focused on the food and agricultural SC. Specifically, traceability solutions that are focus on the quality of food, stringent food requirements for religion or by government and origin tracing.

The authors [82] also showed that there is a common combination of IoT, RFID, GPS & BCT in the literature. It has a multitude of uses by has been seen to have success in advocating the adhered to environment and social sustainability standards, RT tracking and tracing, counterfeiting items and preventing food safety hazard.

VIII. IMPLICATIONS, LIMITATIONS & FUTURE WORK

A. THEORETICAL IMPLICATIONS

The effectiveness of smart contracts can be improved by expanding functionality and improving accuracy. SCs have undergone a transformation in recent years, combining BCT with other technologies such as machine learning, AI, IoT devices, APIs, big data, GPS, and advanced cloud computing. Blockchain has gained attention in recent years due to its applicability in a variety of industries. Current infrastructures need to be renovated with flexible frameworks and uniform architectures [79]. BC's true potential has yet to be reached and current literature is mainly conceptual.

The concept of globalization has become more prevalent in supply chains and logistics. With the advent of new forms of technology, monitoring and controlling becomes mandatory, as processes become more complex and geographically dispersed. A collaborative network is difficult to achieve [34], [90], [108] due to stringent requirements, lack of resources and financial constraints. Developing nations and SMEs lack the capability, expertise or monetary support to compete effectively. Empirical studies leave out smaller SCs purporting disproportionate growth, inequality and trade imbalances.

B. PRACTICAL IMPLICATIONS

The most promising areas in BCT for immediate applicability are governance, traceability, performance and scalability. In BC-based global supply chains, IoT devices are used in conjunction with RFIDs to provide RT product tracing and governance. They increase visibility by increasing the level of operational control. Situation reports provide accurate alerts and warnings. IoT devices control processing capacity, throughput and set-up time to optimize production planning and scheduling in Just-in-Time (JIT) production operations. These solutions have experienced success but can be further advanced by focusing on productivity, operational costs and customer satisfaction [85]. Additional devices can be used to increase accuracy pertaining to inventory management, replenishment and delivery.

Off-chain scaling solutions, or sidechains, are transactions that are done privately, off the blockchain network. They run in parallel to normal operations and transfer value between them [85]. The data stored off-chain has reference numbers tied to them and can be pulled at any time and sent to the main blockchain. Adding functionality to this solution can decrease congestion, increase throughput [98] and diminish storage complexity.

Sharding is a blockchain solution that partitions data to shorten confirmation time and lower transaction fees. It partitions data horizontally to assign storage in memory [72]. Ethereum aims to increase security by distributing both system storage and smart contract executions. Anti-counterfeiting solutions have been applied in the pharmaceutical industry to enhance medicine traceability. Using a combination of BCT and encrypted quick response (QR), all information is transmitted to the chain, where smart contracts examine and diagnose medicine properties [90].

C. POLICY-MAKER IMPLICATIONS

Policymakers must encourage the use of blockchain technology as a singular technology or combined with new forms of technologies to enhance global supply chains. From the policy perspective, launch plans and initiatives must have BCT implementations, promoting the shift toward decentralized technologies [111].

There are many benefits of training and planning programs for employee opportunity & advancement. Costs can be offset or replaced completely if the relevant resources are there. Employees will be more comfortable with the switch to BC and have confidence from the hours of education.

D. RESEARCH LIMITATIONS & FUTURE WORK

Limitations in blockchain technology research are immaturity, globalization infancy, blockchain implementations restrictions, lack of specialty sources, sources published within the last six years and lack of practical solutions for open issues and gaps in research. Global SCs must innovate to remain relevant while facing fierce competition and demanding customers. There are also additional limitations within this survey research. First is the lack of sources that specialize in a single topic. Research needs to shift from including a multitude of concepts to concentrating on a specific area. Second, the survey's scope was confined to papers published in the last six years. Older papers that contain pertinent information will be left out in favor of up-to-date sources.

Blockchain implementations are restricted to supply chain management, logistics and manufacturing. Sources that did not meet the selection criteria were eliminated from the survey, creating an environment where exclusions limit the breadth of work. The final limitation is the lack of practical solutions with working examples that are applicable to global SCs. Tools are needed to solve many problems associated with BCT adoption. Conceptual papers provide a blueprint for future implementations but lack the ability to propose and construct solutions.

The lack of practical solutions is also a limitation to this survey leaving a significant gap in the understanding applications. The lack of practical solutions with working examples was included in this survey but more examples could have been reviewed to provide a bigger picture of current and future implementations. The lack of case studies, proof of concept and good examples has placed a constraint on the overall body of work.

Future research should promote extensive deployment strategies, detailed case studies and open code repositories. Explicit implementations are needed for researchers to gain a better understanding of what blockchain solutions offer and how they can affect industry applications and practitioners. It will aid in the creation of new materials that will assist with education and awareness of emergent technologies while allowing for more advanced solutions from academia.

The aim of the survey was to provide a detailed summary of the most relevant and current research articles pertaining to BC applications, challenges and vulnerabilities in SCM. The objectives were to find opportunities for future work, based on known research gaps, to define available opportunities, to list successful approaches and to make suggestions for future research projects to advance the global landscape in blockchain technology development.

Future research will focus on the use of blockchain technology as a tool for improvement. Researchers look for new applications within the sphere of supply chain management. A prospect for future research involves the improvement of current ERP systems. Enterprise Resource Planning (ERP) software uses closed, centralized systems to conduct business and maintain their databases. Ethereum allows for dApp development and can be applied to an existing ERP system to provide a decentralized option for data storage. Using Tryton ERP, an open source ERP available for all operating systems (OS), a new model is required to provide ERP systems with decentralized options. The new framework will be developed and proposed to provide equivalent parts between both systems and to see if there are any benefits over a centralized system.

A decentralized version of Tryton ERP will be modified to insert a new application programming interface (API) and smart contracts to replace the traditional, centralized client-server database. Web3 API will replace the base Tryton ERP due to its decentralized nature. It communicates between the ERP and the BC by calling smart contracts or parts of smart contracts. It also sends data to the metrics GUI, which will be developed to show a visual representation of the data during testing.

Smart contracts will be developed and deployed to an Ethereum Test Network database. There are two programming languages that will be used in the experiment. Python is used for Tryton modifications, API operation and GUI data display. Solidity is responsible for smart contract mediation using the Truffle framework.

A group of metrics will be collected during the experiment for a comparative study. Each metric is a mathematical formula that is directly derived from the data acquired. The metrics will determine which system performs better. Once enough tests have been run to acquire a large enough sample size, conclusions can be inferred to see which system is the better option. Decentralized databases can offer companies more options with data security and storage.

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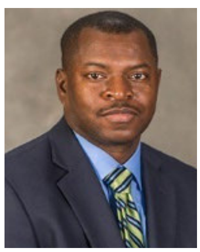

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