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 SURVEY

Blockchain Technology for Secure Supply Chain Management: A Comprehensive Review

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ABSTRACT Supply chain management (SCM) is a core corporate activity responsible for moving commodities and services from one point to another through a variety of stakeholders. The traditional SCM is based on a centralized approach managed at the central headquarter, and all other sub-offices get instructions from the main office. Some major issues with present SCM systems are security, transactional transparency, traceability, stakeholder involvement, product counterfeiting, additional delays, fraud, and instabilities. Blockchain (BC) emerges as a technology that can manage the data and build trust efficiently and transparently. It can also aid in transaction authorization and verification in the supply chain or payments without a third party. To address the present SCM issues, BC technology is a feasible solution. Motivated by the aforementioned considerations, in this paper, we present a survey on the adoption of BC in SCM. This paper undertakes a comprehensive analysis of the literature on BC characteristics, implementations, and business consequences in various SCM. This Blockchain-centered study, in particular, discloses the research state and delineates future research directions by studying and analyzing 97 up-to-date publications highlighting BC's supply chain uses. Transparency and traceability, information sharing, product anti-counterfeiting, and building trust are the major aspects propelling BC's implementation in SCM. Further, we analyzed various applications of SCM in which BC can be used as a probable technology to secure all transactions. Then, we have highlighted open issues and research challenges for adopting BC technology in SCM that open the doors for beginners eager to start work in this amazing area.

INDEX TERMS Blockchain, security, supply chain management, traceability, transparency.

I. INTRODUCTION

SCM is defined as the movement of goods from producer to consumer. It is a network that is made up of independent or semi-independent business entities such as producers, suppliers, retailers, and clients who are involved in the manufacturing and distribution of goods. It covers all from item improvement, sourcing, generation, coordination, and the data frameworks required to facilitate these exercises. Since early times, supply chains have occurred, starting with

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the first item shaped or service formed and sold. But with industrialization and globalization, SCM got to be more refined, permitting companies to do a more proficient work of creating and conveying merchandise and administrations. Organizations can now identify failure before it occurs and take proactive measures to prevent it. They make an exact estimate that supports meeting client requests and monetary goals simultaneously. Every node in the supply chain network must be concurred upon and flexible in response to the needs of the consumer and competent in dealing with issues such as tracking, exchange approaches, shipping modes, and so on. Consumers also have various options for purchasing

products, including in-store, online, and more, putting them in the driver's seat when it comes to defining SCM priorities. So, while discussing the primary issues in today's SCM, we discover that

- 1) Today's supply chain is centralized. However, a centralized supply chain is often time-consuming and expensive to manage, and it lacks essential functionality for market analysis.
- 2) The complexity of supply chains and value networks adds a high cost to supply chain players, which the customer eventually absorbs. The data in the majority of the documents are kept on BC, which is an expensive procedure.
- 3) The present supply chain architecture does not deliver the requisite level of transparency and traceability.
- 4) In the current supply chain, stakeholders and consumers face dilemmas relating to coordination, inventory management, human resource reliance, order management, stock management, expiry date, etc. As a result, stakeholders cannot evaluate demand and hence are unable to optimize output and storage.

The traditional SCM is based on a centralized approach. A single business headquarters and a single warehouse full of departmental managers in different areas like logistics, distribution, and procurement, and these managers are responsible for overseeing their specific location during the complete supply chain. They keep track of the information in a centralized database stored nearby. When the data on the record is not beneficial to the company's growth, it may be misrepresented secretly. As a result, mistrust between ventures has progressively noticeable, resulting in higher communication expenses. Also, there is no pricing transparency in the supply chain because of the middlemen. Furthermore, because of the high risk of data manipulation inside the venture, the data across supply chain entities is incompatible; as a result, the product tracing procedure has been delayed.

In Today's supply chain, there is no encrypted mechanism to store consumers' private information. Cyber-attacks will be able to access this data, revealing important public and personal information. Another key issue is that goods only travel in one direction in today's supply chain management. As a result, if a product is faulty, the customer is responsible for the consequences. He didn't have an option but to accept the chance. As a result, in traditional SCM, enabling the reverse flow of products and transactions for each customer is a major challenge. Supply chain attacks are another key issue in Today's SCM. Instead of directly attacking a single organization, supply chain attacks target vendors and providers. It is a cyber-attack that targets a reputable third-party vendor who provides critical services or software to the SC. Unsecure suppliers in a chain are attacked to obtain access to their bigger trade partners in a supply chain assault. Some well-known supply chain attacks are discussed in Table 1.

Now, there has been a considerable increase in the need for SC's fairness, security, and efficiency. The stakeholders have begun to demand a more transparent SCM process. End users

want to know the complete information on the provenance of the items. To address such a problem, a tamper resistant tracking method must be created. Infrastructure decentralization and the development of a trust layer for business logic may be revolutionized using BC technology. BC is an immutable, permanent record system created by covering encrypted information in chronological order. Decentralization, traceability, tamper-proofing, and cryptographic security are all important elements of the BC system. Besides, smart contracts can be created, permitting transactions to be done safely between commonly un-trusted parties. Smart contracts are a type of digital contract or agreement. When a certain goal is fulfilled, a smart contract can be configured to do a task without the participation of a third party. BC can also support automatic payments, quality control, and stakeholder trust, among other things. Real-time data handling with monitoring and regulating data in a virtual environment, less paperwork, increased efficiency with faster response times, increased supply chain visibility, and reduced geographic limits are several advantages of adopting BC in supply chains [17]. It also reduces the risk of SCM attacks.

A. COMPARISONS WITH THE EXISTING SURVEYS

Several industries outside of finance, such as the supply chain, are among the most extensively discussed BC applications. BC technology is ideal for addressing supply chain concerns. The possibility of adopting BC technology in SCM has been a topic of investigation, and several reviews have been published so far that gives an overview of the current situation and a research path forward. Motivated by these facts, we have reviewed various supply chains in the proposed survey. This section compares state-of-the-art works that focus on the BC and SCM and their integration. Table 2 shows a relative comparison of the existing surveys with the proposed survey. It also highlights their primary objective, key contributions, and limitations, which can be useful insight for beginners who want to start research in this emerging area.

B. MOTIVATIONS AND CONTRIBUTIONS

1) MOTIVATIONS

In response to the expansion of industries, SCM has emerged as a management approach. With several stakeholders and business transactions, supply chains are naturally difficult. Many disputes exist in traditional supply chain networks during COVID-19, including the lack of transparency and traceability, entering counterfeit products such as fake drugs, difficulty in managing risks and disruptions, and the need to build trust and reputation. The adoption of BC technology has answered the requirement for a safe, transparent, and traceable platform. Most existing tracking and traceability system, which is used by most supply chain networks, has problems with centralized management and data privacy. BC, the fundamental technology, has gotten a lot of interest from academics and business in the last several years due to its nature of immutability and decentralization. The introduction

TABLE 1. Recent attacks on supply chain.

Company Name	Year	Description
Mimecast [139]	2021	Mimecast provides email security services that require clients to securely connect to Mimecast servers to utilize their Microsoft 365 accounts. The attackers discovered credentials that enabled them to breach the provider and access their certificates. Then they use the certificates to access customer data after the customer-validated and trusts the certificate .
SITA [140]	2021	SITA is a company that specializes in air and transportation information technology. Attackers had compromised SITA servers and stole passenger data from SITA's customers.
Kaseya [141]	2021	Kaseya is a software service supplier specializing in remote monitoring and management technologies. Attackers obtained access to Kaseya software by exploiting a software vulnerability. Attackers used this access to install ransomware on customers' infrastructure .
APPLE XCODE [142]	2021	Apple Xcode is a programming environment for creating OS X and iOS applications. A single malicious Xcode project was used to infect Xcode developers with a backdoor.
CLICKSTUDIOS [143]	2021	ClickStudios is a provider of business password management solutions. Their main product is a password management solution called Passwordstate. The 'upgrade director' online interface used by Passwordstate to update the program was hacked, leading users to download malware rather than the intended upgrades. The deployed virus was meant to steal data from the infected systems. [143].
BIGNOX [144]	2021	BigNox is a provider of emulation software. Their flagship product, NoxPlayer, is a well-known Android emulator for Windows and Mac computers. The infrastructure of NoxPlayer has been hacked. It might exploit the tool's update system to distribute malware instead of updates.
VERKADA [145]	2021	Verkada serves over 5,000 clients with cloud-based security surveillance solutions. Attackers hacked into the production server. This allowed attackers who gained the privileged credentials to access the security cameras installed on customers' premises .
SOLARWINDS [146]	2020	SolarWinds is a provider of management and monitoring software. SolarWinds' network management system (NMS) is called Orion. Orion had been jeopardized. Attackers got access to the SolarWinds network, which was then utilized to acquire and steal data.
ABLE [147]	2020	Able is a Mongolian company that provides software solutions to government bodies and enterprises in that region. The malware was introduced to the "Able Desktop" program by attackers. Then this program was utilized to steal data from the compromised devices of the consumers .
Ledger [148]	2020	Ledger is a company that manufactures hardware wallets. The attackers employed open-source intelligence tools to identify acceptable credentials for accessing Ledger records and stealing client data. Using such information, the attackers exploited users' faith in Ledger by sending phishing emails .

of BC in the supply chain with advanced technologies will modify existing supply chain systems and remove control of third-party systems. It can overcome various supply chain difficulties. The potential of this technology to track all types of transaction more transparently and securely motivate us to explore the possibilities BC offers across the supply chain. However, the application of new and emerging technology in any sector can give rise to some issues and challenges. The use of BC technology in the supply chain field is still in its early years, which limits an understanding of its potential. Small and Medium-Sized Enterprises (SMEs) would be affected financially and socially by BC technology. So, BC solutions need to be evaluated in terms of their scalability and cost-effectiveness to address the concerns of business managers. This is a serious challenge, and a big question is what would happen to the existing operating system and how much time it would take to develop a new BC-based system.

2) CONTRIBUTIONS

This paper investigates the current status of BC technology implementation in various supply chain network areas. We comprehensively surveyed the application of BC in Food and Health supply chain networks. This study makes several significant contributions, including theoretical advances related to the adoption of BC in the supply chain.

Following are the research contributions of this paper:

- 1) To explore the opportunities and benefits of using BC to enhance various functions in different supply chain networks.

- 2) To present various areas of application in the supply chain where BC can be applied.
- 3) To explore and present various challenges in implementing BC technology in the present and future supply chain networks.

The author's contribution to performing the survey is to clearly understand the implementation and adoption of BC technology in current supply chain networks during COVID-19.

C. METHODS AND MATERIALS

As part of the research technique for the proposed survey, a systematic analysis and study were carried out to provide a full analysis of the adoption of BC in the SCM. We started the study suggested by analyzing review articles on BC-based supply chains from reputable conferences and databases such as Springer, Science Direct, ACM, Taylor Francis, Wiley, IEEE Explore, and Google Scholar. After that, we looked at a few BC-based system applications. This research aims to see how BC technology may be used to improve current supply chain networks. In this criterion, search using BC Technology, Supply Chain Management, BC Use in SCM, Provenance, and Supply Chain Traceability. Finally, we examined the abstracts and conclusions of the collected publications and determined the relevant techniques and ideas for the proposed survey.

1) RESEARCH QUESTIONS

Research questions reflect the ultimate objective of a research paper and play a key role in the selection of primary studies.

TABLE 2. Comparative analysis of the existing surveys with the proposed survey.

Related Survey	Year	Objective	Key Contributions	Limitations and Open issues
[135]	2022	The purpose of this paper is to examine the elements impacting the application of blockchain in supply chain management in order to tackle the present difficulties in the supply chain ecosystem.	For the implementation of blockchain in supply chain, technology, intracompany synergy, intercompany collaboration, extrinsic factors, and innovation structures are rigorously analyzed.	There were no qualitative methodologies employed in this study, such as concentrated group discussions with industry experts.
[136]	2022	This research is to investigate and examine the use of blockchain technology in agrifood supply chain management (AFSM).	As key applications in the agrifood industry, this paper emphasizes food safety, traceability, transparency, removing middlemen, and combining Internet of things (IoT) with blockchain technology.	This research is only limited to Agrifood supply chain. There is no real execution of the proposed blockchain-based honey traceability system.
[1]	2021	In this study, stakeholders from various pharmaceutical companies and drug regulatory agencies in Nigeria were interviewed to determine the feasibility of incorporating BC technology into the Nigerian pharmaceutical supply chain to reduce the supply of counterfeit drugs.	The prospect of implementing BC technology into the Nigerian pharmaceutical supply chain to reduce the supply of counterfeit pharmaceuticals is being investigated.	This research is only limited to the Nigerian pharmaceutical supply chain.
[2]	2021	Review various BC-based approaches that can help prevent drug counterfeiting	Examine several BC-based ways to combat medicine counterfeiting.	There is no real execution of the method.
[3]	2021	This article aims to learn how using BCT in SCM might affect trust. Trust in BCT is based on the sub-dimensions of provision, certification, delegation, and infrastructure (for the platform) and dependability and authenticity (for the records).	This paper aims to understand how applying BCT in SCM can influence trust.	Other benefits of BC for the supply chain (such as security, dependability, and so on) were not considered.
[4]	2021	A survey of numerous BC-based systems proposed for implementation in various domains of SCM.	A thorough review of 15 research publications was conducted in order to offer a better knowledge of how BC works and how it may be used in supply chain applications.	They did not conduct an in-depth assessment of the available literature for the discussed applications.
[5]	2021	To show a multi-dimensional trend, conduct statistical analysis in terms of year of publication, top research institutes and research, and article classification	In this survey, the authors declared that BC has the potential to encourage data exchange, enhance business operations, minimize operational costs, and boost collaboration efficiency.	The author does not provide any practical implementation.
[6]	2020	A total of 106 review articles were examined to provide an overview of the use of BC and smart contracts in the supply chain.	In this, four major issues were identified: traceability and transparency, stakeholder involvement and collaboration, supply chain integration and digitalization.	The procedure has yet to be put into action.
[7]	2020	As a case study, use ten distinct applications from the logistics sector to construct an explanatory model for the interaction of players in an operational supply chain utilizing BC technology.	This research offers insights into the business model idea and how BC technology and (dis-)intermediation will alter existing notions in Operations and Supply Chain Management.	They have not conducted a complex logistics industry with many different players worldwide.
[8]	2020	271 BC initiatives were evaluated based on their origin dates, BC kinds, status, industries applied to, and the type of company that created the project.	This survey examines how BC initiatives in the supply chain are progressing.	They did not conduct an in-depth analysis of various projects, such as funding data.
[9]	2020	The authors of this survey review the benefits and limitations of distributed supply chain organization and management in order to evaluate the applicability and existing uses of BC in the supply chain area.	This paper provides the groundwork for practitioners and researchers to focus future studies on enhancing BC technology and its applications in the supply chain sector.	Implementation in complex supply chains is still missing.
[10]	2020	This study attempts to show the use of BC technology in the dairy industry. It primarily focuses on using BC technology to improve the dairy supply chain system.	This paper discusses how BC technology may be employed in the dairy supply chain system and the possible benefits to various stakeholders and the dairy sector as a whole.	The author does not provide any practical implementation.
[11]	2020	This paper identifies the various organizational theories used in BC literature in logistics and transportation (LSCM).	BC literature is organized around six organizational theories: agency theory, information theory, institutional theory, network theory, resource-based view, and transaction cost analysis.	The research did not comment on or address relevant tools and approaches that might aid in understanding the relationship between LSCM and organizational theories.
The Proposed Survey	2022	Study applications of BC in secure SCM.	This study fully examines the present academic research state and application scenarios by combining the features and technical principles of BC technology.	

The goal for doing this research is to comprehend and assess BC technology, as well as to investigate its usefulness in tackling the issues of existing supply chain systems in a cost-effective manner. Several study problems prompted us to investigate the potentials of BC in safe SCM. These are as follows:

RQ1: What are the advantages of implementing BC-based supply chain systems?

RQ2: Recently, have there been any BC uses in the supply chain industry?

RQ3: What primary issues has BC adoption brought to supply chains?

RQ4: Is BC usage in SCM likely to grow in the future?

2) DATA SOURCES

We studied standard reviewed journal database, i.e. IEEE Xplore, Elsevier, ScienceDirect, Springer to find the current literary studies and the information available on the internet. We also took advantage of other resources i.e., technical

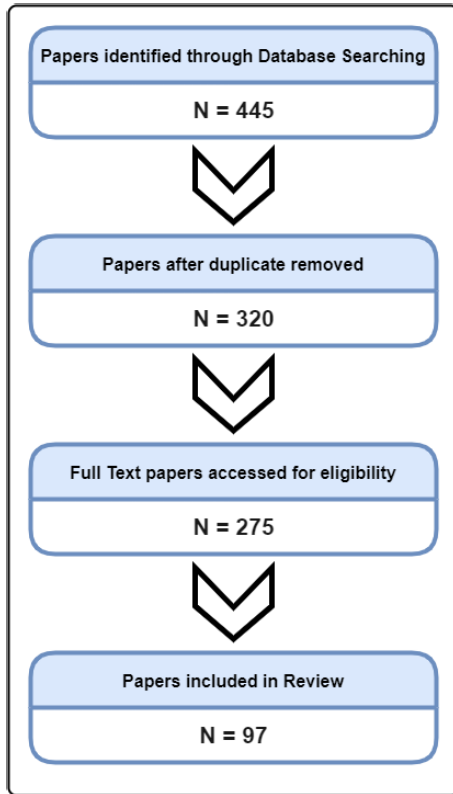


FIGURE 1. Survey criteria [N = No. of Papers].

books related to the case, concessions, envisioning websites, and online journals pertinent to the current survey.

3) SEARCH STRING

To formulate the search string, particular keywords and their synonyms are selected from the identified research questions. The keywords are then arranged with the conditions of ‘AND’ and ‘OR’ in a particular sequence to form the following query:

((“Blockchain” OR “Blockchain Technology” OR “Distributed Ledger” OR “Decentralized Ledger”) AND (“adoption in” OR “acceptance in” OR “use in”) AND (“Supply Chain Management” OR “SCM” OR “Secure Supply chain Management”)).

4) INCLUSION CRITERIA

Following is the inclusion criteria.

- 1) Papers published from 2016 until early 2022.
- 2) Papers presented/published in Peer-reviewed journals, conferences, conferences proceedings or published as book chapters.
- 3) Papers focus on secure supply chain management
- 4) Papers focus on adoption of Blockchain Technology in Supply chain Management. Preference is given to the latest papers.

5) EXCLUSION CRITERIA

Following is the exclusion criteria.

- 1) Papers published before 2016.

- 2) Papers that are not in the English language.
- 3) Papers that do not focus on application of Blockchain technology in SCM are also excluded.

Figure 1 shows total of 445 papers were extracted from the database till early 2022 and finally, 97 papers relevant to our review paper were shortlisted and analyzed after an in-depth review.

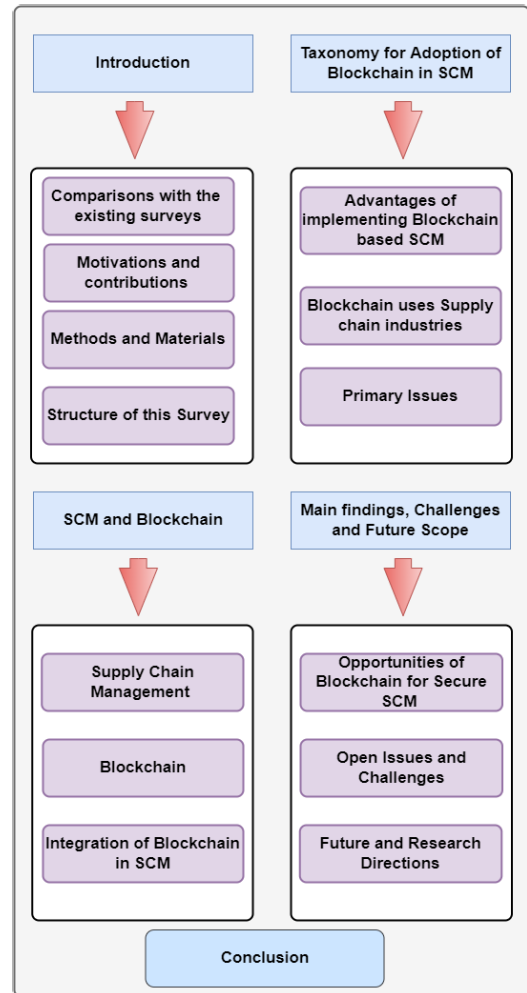


FIGURE 2. Structure of the proposed survey.

D. STRUCTURE OF THIS SURVEY

The structure of the paper is as follows. Section II covers the fundamentals of supply chain operations and BC technology. Section III addresses the usage of BC technology to manage various supply chains based on a review of the literature, Section IV gives the research gaps, and section V gives the ultimate conclusion. Figure 2 shows the structure of the paper.

II. SCM AND BLOCKCHAIN TECHNOLOGY: BACKGROUND, DEFINITION, AND MOTIVATION

This section focuses on the background of the supply chain and BC Technology. There are three subsections in

this section. First, we'll discuss supply chain management. Second, we'll go through the basics of BC Technology, including how it works. In the third part, we focused on the usage of BC in supply chain systems.

A. SUPPLY CHAIN MANAGEMENT

SCM is a core corporate activity responsible for moving commodities and services from one point to another through a variety of stakeholders. Dissimilar groups, resources, behaviors, and organizations are concerned with converting raw materials into completed products and satisfying consumer orders, which are referred to as supply chains. It is an interconnected network of corporations, individuals, activities, information, and resources that are included in fabricating and transferring a product or service from the seller to the client via a planned flow of information, physical dissemination, and payment. It starts with the delivery of raw materials to a manufacturer and stops with the delivery of the completed product or service to the consumer. Control of the stream of products and services to maintain the quality of sensitive commodities throughout the shipment, eliminate unnecessary expenses, and better satisfy customer expectations is known as supply chain management [19]. Agri-food sectors, pharmaceutical industry, Textile industry, Automobile industry, manufacturing industry, high-tech industry, service trade, and so on all have supply chain management. Each product in supply chain systems goes through a life cycle that includes states like Processing, Stored, Manufacturing, Shipped, Arrived, and consumed. There are a few issues with present supply chain administration such as the need for straightforwardness (clarity), disturbances, additional delays, data twisting, and instabilities. The present supply chain usually relies on a central entity to maintain data, which could be problematic for transparency and trust. When the data on the ledger is not beneficial to the company's growth, it may be counterfeited tactfully. There's exceptionally minute information about the item's starting point, handling, or distribution to the end customers. The customers were usually only given access to a portion of the information released by big brands. Lack of sufficient knowledge of a product can cause trouble confirming numerous characteristics of a product. Customers could have trouble authenticating many product ingredients claimed by the company. As a result, there is a growing mistrust between ventures, resulting in higher communication expenses. Furthermore, because of the company's high risk of data manipulation, information between supply chains is unpredictable, causing the product traceability process to be easily disrupted. When using a regular supply chain, we might face other issues, including delayed delivery, misplaced shipment, corruption, tampering, and fraud or counterfeiting products. As a result, traditional supply chains have failed to match customer demand for a low-cost, high-quality product [20].

The main aim and challenge of effective SCM is to optimize supply chain presentation containing external effects such as customer focus and internal efficiency, which means analyzing and removing all waste, problems, and

complexities across the internal supply chain. Integration of supply chain modules needs Blockchain commitment, confidence, collaboration on decisions, and exchanging true information.

B. BLOCKCHAIN

A Blockchain is a form of database or a storage structure that uses blocks and chaining to store data. As new data is received, it is entered into a new block and then chained to the previous Blockchain. Blocks have specific storage capabilities, and when they are filled, they are linked to the previous filled block, establishing a data chain known as a "Blockchain." Stuart Haber and W. Scott Stornetta did the first investigation on the notion of Blockchain in 1991. They wanted to form a system that prohibited altering the contents of the document timestamps. Satoshi Nakamoto, an anonymous individual or group of individuals, originally built the Blockchain in 2008, a peer-to-peer network, and solved the double-spending problem. A year later, Bitcoin, a cryptocurrency, was created based on Blockchain technology serving as the distributed ledger. Blocks are the key concept of Blockchain (BC) technology. To identify the block, a hash value created using the SHA256 hash algorithm is used. The header field of the recent block stores the hash value of the previous block or parent block. The kind and architecture of a BC also influence the structure of a block. Generally, some main attributes can be required for a block in the block header, which is the link to the previous block, i.e., preceding block hash value, the timestamp, the nonce, the Merkle root, with the body of the block, which contains transactions. A nonce is a randomly generated number that is only used once. This number is added to a hashed block to fulfill the difficulty level limitations when it is rehashed. A Merkle tree is a binary tree containing hash pointers named after its creator Ralph Merkle. Data blocks are arranged in pairs in a Merkle tree, and the hash of each of these blocks is kept in a parent node. The hashes of the parent nodes are kept one level up the tree, and they are again arranged in pairs. Continuing in this manner, we reach the root node at the very top of the Merkle tree. Merkle Root refers to the apex of the Merkle tree. Thus, the Merkle root is a hash of all transactions in a block. This implies that instead of checking each transaction individually, just the Merkle root is necessary to validate or verify all transactions in the Merkle tree.

In computing, a BC is a form of distributed ledger that uses a unique technical concept that constructs an immutable ledger of information cryptographically. It is maintained via a decentralized network in which a specific consensus mechanism approves all records. As a distributed ledger, BC does not require a centralized body or an administrator to supervise and control a network. In very easy words, BC is described as a series of blocks that hold information in the form of transactions that are recorded chronologically and openly and that cannot be backdated or tempered. The decentralized nodes verify the transactions (user systems) by a consensus

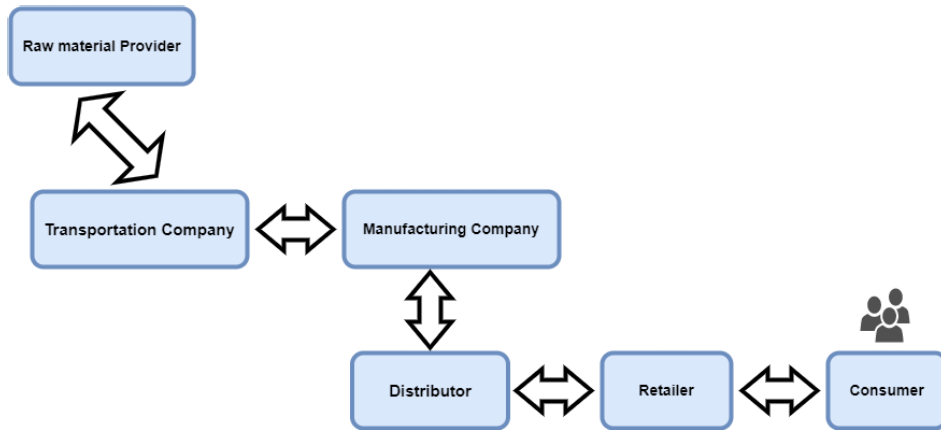


FIGURE 3. Flow of the traditional supply chain.

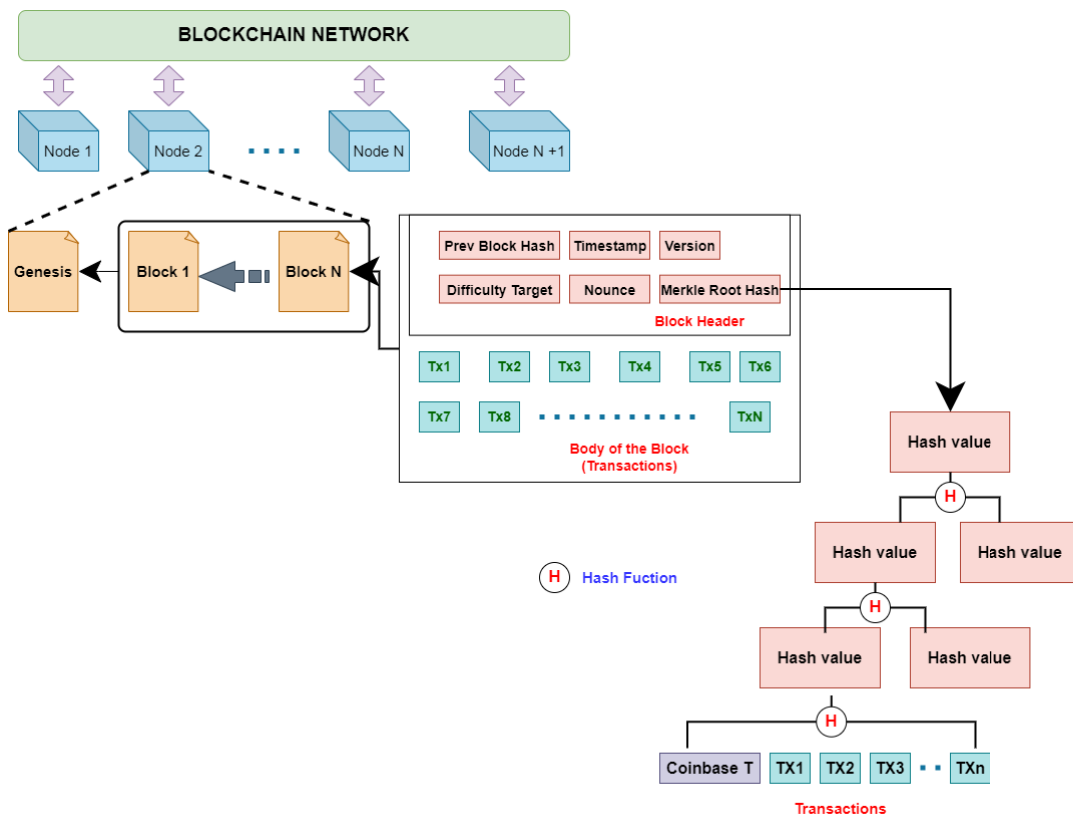


FIGURE 4. Conceptual view of the Blockchain network to be used for supply chain.

algorithm. The ledgers are spread among all parties involved rather than managed by a single body. It is extremely difficult to change information after it has been stored on a BC. A BC is a sort of database that only allows for reading and adding data [104].

1) TYPES OF BLOCKCHAIN NETWORK

A BC network may be built in a variety of ways. They can be public or private, permissioned or made by a group of individuals (consortium).

Public BC Networks: A public BC, such as Bitcoin, is one that anybody may join and participate in. In this type of BC, significant processing power is required and for transactions, there is little or no privacy, and the security is likewise insufficient.

Private BC Networks: One company manages a private BC network for its customers, deciding who is permitted to participate, running a consensus process, and maintaining the shared ledger, i.e., a private BC network governed by an organization. This may include the use of a BC within

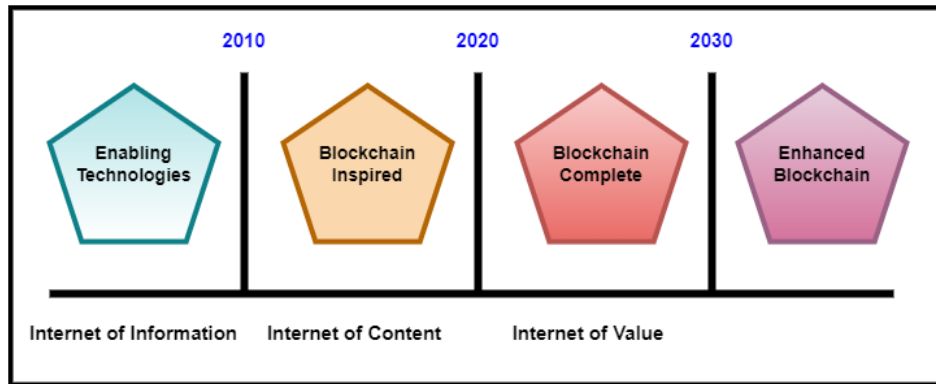


FIGURE 5. Evolution of BC technology.

the company's firewall. In most cases, a permissioned BC network is put up by a firm that wants to build a private network.

Notably, permissions may also be set on public BC networks. In Public, Permissioned BC network validation of blocks by pre-selected nodes but visible to all users. In private Permissioned BC, validation of the block is controlled by an organization, i.e., in a full centralized manner. As a result, a private or permissioned BC controls who is permitted to join the network and what transactions they may do. Participants must first receive an invitation or permission before they may take part in the activity.

Consortium BC: Several companies can maintain a BC by collaborating. In this type of BC, all transactions and data access are controlled by pre-selected entities. A consortium BC is appropriate when all members require permissions and share responsibilities for the BC. Table 3 describes the comparison of two popular blockchain networks.

2) EVOLUTION OF BLOCKCHAIN

Gartner, the research and advisory organization, describes a true BC that consists of the following five components: decentralization, distribution, encryption, and immutability [134]. Based on these five aspects, [134] presents a paradigm that is based on the growth and maturity of BC systems:

a: PHASE 1: BC-INSPIRED SOLUTIONS (2012-2020)

Only three of the five components, namely distribution, encryption, and immutability, are present in the solutions. Most of these services are experimental and not fully deployed, and they are aimed to increase efficiency by simplifying existing procedures.

b: PHASE 2: BC-COMPLETE SOLUTIONS

All five elements are included in this phase's solutions to distribute the entire BC value proposition. At the same time, Gartner predicts that by 2023, only startups will be working on solutions at this level of maturity.

c: PHASE 3: ENHANCED-BC SOLUTIONS

Complete solutions will be integrated with corresponding technologies, including the Internet of Things (IoT), artificial intelligence (AI), and decentralized self-sovereign identity (SSI) solutions in the third phase of BC.

According to [133], BC may improve global GDP by \$1.76 trillion by 2030. According to the research, BC's total impact on the Indian economy is expected to reach \$62.2 billion by 2030. The PwC research also stated that BC technologies that enable provenance and traceability – allowing companies to authenticate the source of items and follow their movement across supply chains – would have the greatest effect (\$41 billion) in India in 2030. The next two categories are solutions for securitization and payments (at \$13.2 billion) and applications to secure one's identity, certificates, documents, and credentials saved online and prevent identity theft (at \$5 billion). According to Gartner, by 2023, BC will support the global movement and tracking of \$2 trillion of goods and services annually [134]. Up to 30% of the worldwide consumer base will consist of things by 2030 and these objects will execute commercial activities, and BC will be the technology that enables them. By 2025, BC will have added a commercial value of approximately \$176 billion. By 2030, this figure would have risen to \$3.1 trillion.

3) WHY DO WE NEED BC?

Here are some of why BC technology has gained so much popularity.

- 1) **Unalterable transactions:** BC guarantees the inalterability of all operations by registering transactions in chronological sequence. When a new block is added to the existing BC, it cannot be withdrawn or customized. This increases openness and ensures that all transactions are permanent.
- 2) **Fraud prevention:** The ideas of shared knowledge and consensus help to reduce fraud and embezzlement losses. BC as a monitoring tool reduces expenses in logistics-based companies.

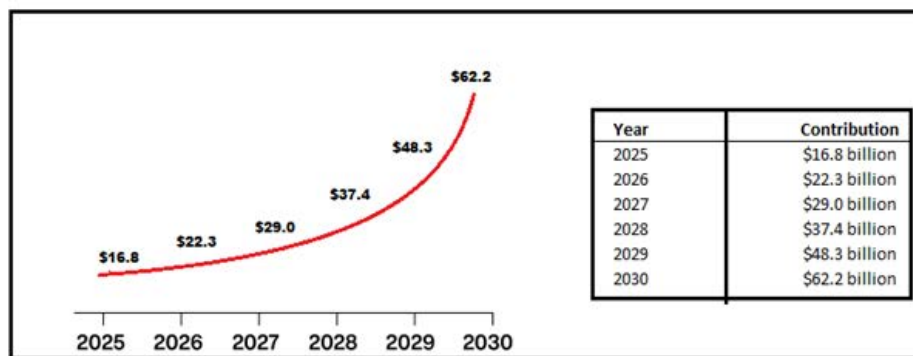


FIGURE 6. Technological impact of BC technology [133].

- 3) Reliability: Because a copy of the original BC is available to each participant, the distributed ledger (DLT) technology stays operational even if a substantial number of other nodes fail.
- 4) Time reduction: BC can play a critical role by enabling faster trade settlement since it eliminates the need for a lengthy process of verification, settlement, and clearing because all parties have access to a single version of agreed-upon data from the shared ledger.
- 5) Collaboration: Facilitates direct communication between parties without the need for a third party to serve as a middleman.
- 6) Security: The identities of the interested parties are certified and verified via BC. This eliminates duplicate records, lowers rates, and speeds up transactions.
- 7) Transparency: The BC provides more transparency, and all transactions are irreversible. We can trace everything from orders to payments to accounts to manufacturing with a BC network. So when we look at the BC, we can see everything about a transaction, from beginning to end, providing us more confidence and additional efficiencies and possibilities.

parties, supply chains have a great potential for BC implementation [17]. BC uses authentication and traceability and transaction security in a distrusted environment. Real-time data handling with monitoring and regulating data in a virtual environment, less paperwork, increased efficiency with faster response times, increased supply chain visibility, and reduced geographic limits are several advantages of adopting BC in supply chains [17]. It’s been recommended that BC might be used to enhance the supply chain’s resiliency, promote transparency, and increase the traceability of products in the supply chain [22], [68]. The system’s average completion time was shortened, the workload was reduced, order traceability was validated, and visibility to multiple supply chain participants increased with BC. As a result, SCM may be improved in many areas, such as procurement, production, transportation, and inventory management.

In BC technology, a block represents each link in the chain of products from manufacture to sale, and these blocks are connected to complete the process [24]. Once the blocks are created, the information cannot be altered, maintaining product safety by ensuring traceability [25], [26] [27]. Immutability and great accessibility are added to the list of evident benefits by [28]. In addition, BC allows for precise product quality monitoring while in transit. For example, a supply chain stakeholder can detect if an item was placed in the wrong location or lingered there for too long by analyzing data on the transmission path and time duration of the item. This is particularly crucial for frozen goods, which cannot be held at room temperature. Consumers may be more ready to purchase a brand if BC-based solutions provide them with greater assurance that the goods are authentic and of top quality. Based on the research [29], six firms on Forbes’ “BC50” list created BC use cases directly connected to supply chain management by the platform Block data. 15 companies out of 50, including IBM, Nestlé, Walmart, and Amazon, have employed BC technology for traceability/provenance reasons, which are closely connected to supply chain management.

Another major area in SCM is the transaction cost. Transaction cost theory has been utilized in [105] study to know

C. INTEGRATION OF BC IN SCM

Moving to a BC-based solution has just one goal: to provide an immutable, irreversible, distributed, robust, and non-centralized ledger system. Very efficiently, BC can be used to monitor and sign contracts, and it can also be used to verify the provenance of goods. Various BC properties are particularly useful in supply chain case studies, according to systematic research as shown in Table 4.

III. ADOPTION OF BC IN SUPPLY CHAIN: A SOLUTION TAXONOMY

In this section, we propose a solution taxonomy for applying BC in the SCM. The supply chain is one of the most extensively discussed BC applications. As a result of the complex network structure of stakeholders, the necessity for information exchange between parties, the difficulty and risk of document transmission, and the lack of trust between

TABLE 3. Ethereum Vs. Hyperledger Fabric Blockchain.



Characteristics		
Governance	Ethereum developers	Linux Foundation
Ledger Type	Permissionless/ Permissioned	Permissioned
Platform	Generic BC platform	Modular BC platform
Transactions per second	15 -20 TPS	Approx 3500 TPS
Consensus Algorithm	Nakamoto based PoW/PoS	Pluggable PBFT / various
BC Forks	Yes	No
State	Account based model	Key-value database
Confidentiality	No (Transparent)	yes
Vulnerability of attacks	51%	grater than one-third faulty nodes
Tamper proof	Difficult	Easy
Data Storage	Swarm	CouchDB, LevelDB
Currency/ Token	Ether	FabToken System
Smart contract Type	ETH smart contracts	Chain-code in fabric
Smart contract language	Solidity,Serpent, LLL	Python,Golang,Java
Tokenization support	Yes	No
Key management	No	Yes (through CA)
Scalability	Difficult	Easy
Suited for	B2C DApps	B2B DApps

TABLE 4. Main characteristics of BC and their potential contributions to SCM.

Characteristics of BC	Description	Contributions to SCM
Immutability	It is also known as irreversibility. The data can hardly be modified or deleted after the nodes have approved the data in BC.	Forged paperwork will no longer be a risk, and auditability is enhanced. Immutability provides security against unfair and fraudulent Practices. [28], [33], [63], [75]
Security	BC provides security through the use of encryption protocols and cryptographic algorithms.	Keeping data from trade transactions and other product-related information very resilient and safe. [21], [32], [69], [99]
Trust	BC creates a trustless network by using sophisticated math.	Business partners can trade together without knowing each other. [17], [34], [40]
Decentralized	Decentralization means no central institution is needed and every node is equivalent.	It removes the requirement for third-party verification for transactions and their costs. [35], [106]
Transparency and Visibility	The data is simultaneously validated and broadcasted to all the nodes. Transactions or records cannot be hidden, creating more trust and adding value to the business system.	BC facilitates firm-to-firm and person-to-person collaboration while also increasing the visibility of organizational procedures and records. [44]
Tamper-resistance	Tamper-resistance means that any transaction information stored cannot be tempered during and after block generation.	By tamper resistance, the supply chain helps to ensure dependability and confidence. [35], [57]
Disintermediation	Disintermediation is described as a reduction in intermediaries between manufacturers and consumers.	Disintermediation leads to an uninterrupted chain of transactions, increasing speed and trust among stakeholders in the process. [35]

how BC may change supply chain interactions such as transaction costs and governance decisions. Researchers found that it is possible that BC technology can cut supply chain transaction costs and governance costs by a substantial amount, particularly in terms of search and information costs. Kshetri *et al.* [30] mentioned BC case studies in different phases of maturity for diverse reasons to see how they influence major SCM goals. According to the study, BC influences the price, worth, speed, trustworthiness, risk reduction, sustainability, and elasticity.

The application of BC, according to [31], may be utilized to build solutions digitally and can improve the capability to exchange operation data in actual time throughout the network to gain a competitive edge. Another significant benefit

of BC technology is security [32], since a shared, permanent ledger with hard-coded rules may minimize or eliminate the need for internal systems and business processes to conduct audits without the need of a third party. Users have the option of remaining anonymous or proving their identity. As a result, BC ensures secure data sharing while also fostering trust. All participants may see the information on a BC, and it can't be changed by a single entity, which builds trust and reduces fraud.

The supply chain may be made more flexible with the help of BC. To be flexible, a supply chain must be capable of responding to changing market conditions to provide goods and services on time and within budget. Making sustainability indicators more quantifiable and meaningful is possible with

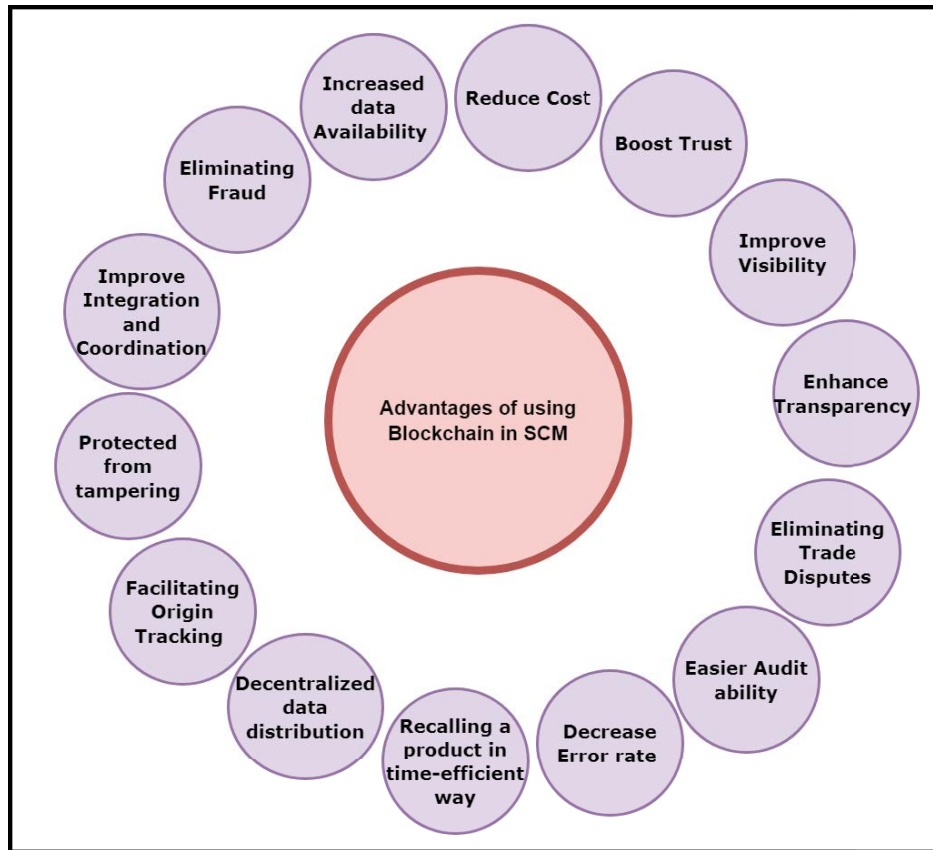


FIGURE 7. Advantages of using BC technology in SCM.

BC. In this sense, BC can end unethical and illegal actions. Using BC technology in the supply chain and logistics sector might help them solve various issues such as cargo insurance, currency risk, liability for items destroyed during transportation, and so on. Data accountability and supply monitoring may be entirely automated using BC-based systems in vaccination distribution [33].

A. ADVANTAGES OF IMPLEMENTING BC-BASED SUPPLY CHAIN SYSTEMS (RQ1)

Since each stakeholder system's ledger contains all records; therefore the BC platform for the supply chain avoids the uncertainty that comes with traditional supply chain systems' separate databases [19]. According to the interviews conducted by [34], due to automatic data validation, BC lowers the need for double-checking in the supply chain in addition to tracking and tracing services. BC allows transaction monitoring by providing proof of provenance for transactions. BC enables higher volume and data accuracy while speeding up end-to-end supply chain operations. Data is distributed across the whole network in seconds with BC-enabled applications. Consensus techniques provide data truthfulness and intuitive foundations for smart contracts, enabling supply chain automation and operational benefits. So, in supply chain management, BC might improve transparency,

traceability, efficiency, and data security [21]. According to [134], using BC to prove provenance could generate US \$962 billion for global GDP over the next decade. Figure 6 shows the probable advantages of using BC in the SCM. Adding BC to the supply chain system has several advantages, such as:

- Integration and coordination of supply-chain functions should be improved.
- Facilitates the transmission of information between all stakeholders in the supply chain regarding manufacturing, assembling, distribution, and product maintenance.
- By allowing consumers to find out where a shipment or order is in a given time. With BC, the supply chain may be more trustworthy and transparent.
- Continuous monitoring is more clear and precise (Facilitating origin tracking)
- Because BC technology is decentralized and cryptographically secured, data transportation, possession, and ownership may be more safeguarded against manipulation or hacking.
- Improving visibility and product conformity with international standards to increase confidence between the manufacturer and the customer
- lowering administrative and paperwork costs (management and verification costs)

- By checking the authenticity of the product certification, fraud and counterfeit items can be reduced or eliminated. For example, to track if a given item meets quality requirements, this might be utilized.
- Recalling a product promptly (Enables easier trace back to find flaws in products or processes)
- Keeping track of product quantities and their transfer between partners.
- Minimize or eliminate the need for internal systems and business processes to conduct audits. (Easier audit ability)
- Decentralized data distribution
- More flexible system
- Increased data availability
- Improved watch over the data flow (Keeping track of all business-related documents such as purchase orders, modifying orders, paying receipts, etc.)
- By incorporating BC technology into the payment system, it may be possible to reduce friction in commercial finance and therefore eliminate trade disputes.
- Adoption of BC technology in the supply chain systems might help them solve various issues such as cargo insurance, currency risk, and liability for products destroyed during transportation.
- Using BC would significantly reduce the number of errors that occur at various levels of the supply chain and significantly enhance customer service.

According to a review of the literature, there are four major areas of BC usage throughout the supply chain (Figure8).

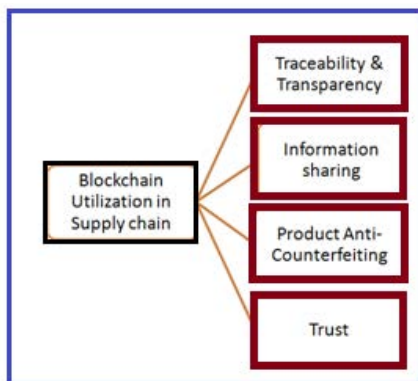


FIGURE 8. Impact areas of BC utilization in supply chain.

1) TRANSPARENCY AND TRACEABILITY

Ahmad *et al.* [35] defines transparency and traceability as; when discussing high-level information in a supply chain, the term “transparency” is frequently used. To map the whole supply chain, data such as product components, facility locations, supplier names, and so on will be collected. Traceability, on the other hand, is linked to rough data in that it includes the selection of a definite element to trace, establishing mutual criteria for communication with associates, implementing ways to create and acquire correct records,

picking a way to store traceability data, and defining how to exchange data on the platform.

Traceability is referred to the capability to obtain any or all information about the thing under examination through documented identifications at any time during its life cycle. Recent BC projects have a primary goal of increasing supply chain transparency [36]. One of the most favorable uses for BC Technology in SCM is to increase product transparency and traceability by allowing transactional data to be exchanged between two or more supply chain partners, to save transactional data in an immutable format, and to preserve only one version of the transactional database. Visibility & disclosure are both required for transparency. Businesses must first identify and collect data from their supply chain suppliers. The knowledge must then be circulated to all internal and international stakeholders. [37] divided the traceability system into

- Internal entities of the supply chain, for example, production, processing, sales, cold chain logistics firms, etc.
- External entities of the supply chain such as customers and regulatory agencies etc.

To improve the traceability of mangoes, Wal-Mart created a method that cuts the time it takes from seven days to just two seconds to trace mangoes from farm to store in the food business [38]. When it comes to cross-border supply chain difficulties, Maersk and IBM have worked together in the trade business to deploy BC technology, which increases information transparency and allows trading partners to share information [39]. Using RFID and BC technology, [40] have created a traceability solution for the Agri-food supply chain. There are several ways RFID technology can be used in the logistics industry to collect data and manage it for Agri-food quality and safety. Agri-food quality and safety are ensured by this method since it fosters trustworthy information interchange and allows for traceability, but it remains mute on overall process automation.

Authors in [41] looked into the use of IPFS and secondary databases to create a traceable storage strategy. IPFS is an open-source distributed file system technology used to store distributed data. A secondary database transaction hash must first be obtained, followed by an IPFS blockchain hash to retrieve data in IPFS. A BC and EPCIS-based shared food safety traceability system was proposed by [34], and data tampering and trust transfer were dealt with using smart contracts at the organization level. Parallel to this, the system employs a dynamic data management system on and off-chain to address the issue of BC data burst. By using Hyperledger Sawtooth technology, [43] have developed a supply chain traceability solution for agricultural products. The system creates the EU’s “farm-to-fork” concept. By scanning QR codes, consumers can learn more about a product, check its quality and safety.

Authors of [44] investigated a technique of executing business transactions utilizing BC and smart contracts to improve soybean supply chain transparency and traceability. By using smart contracts, the solution abolishes the necessity for a trusted centralized specialist, keeps track of businesses, and

controls and monitors interactions between soybean supply system players. These conversations are kept on the BC and linked to IPFS, providing transparency and traceability throughout the soybean supply chain. 15 conditions must be met before BC can be used to resolve the problem of traceability and data sharing in the dairy food supply chain, according to [32].

The Ethereum BC network was used by [45], [46] to recommend a reputation system for Agriculture and food supply chain. Each transaction is written to a BC, subsequently uploading them to the Interplanetary Network (IPFS). The storage system generates hashes of data stored on BC to ensure that it is secure and reliable. According to the proposed system, traceability schemes and trade and delivery methods are included in the Agri-Food supply chain. Authors of [149] present a concept for a BC-based stainless steel tracking system that would trace the whole supply chain from stainless steel factories to end-users. The hyperledger fabric is used for this suggested design.

Authors in [33] demonstrated a BC-enabled system for monitoring COVID-19 vaccination registration, storage, distribution, and self-reporting unfavorable effects. This system protects against identity theft and impersonation by ensuring the information truthfulness and immutability of vaccination beneficiary registrations. To ensure that vaccines are distributed safely, smart contracts are being created to supervise and track safe handling requirements set out by vaccine manufacturers. Moreover, the authors of [69] show a smart contracts-based BC system for agricultural food supply chains that may be used to monitor and trace food items. To store environmental and agricultural development data IPFS is used by the farmers, and IPFS file hashes are stored in smart contracts. This solves the problem of BC storage and also enhances data security. ShanweiLv fengyuan Modern Agricultural Development Co., Ltd has implemented this structure.

BC-enabled traceability architecture for multi-tier Textile and Garment supply chain is proposed by [47]. It abstracts supply chain partner interaction at the organizational level, while smart contracts and operation validation standards are summarized at the operational level. Authors of [35] created and tested an Ethereum-based BC system for effective drug traceability in the Pharma supply chain, using smart contracts and decentralized off-chain storage. The smart contract secures the provenance of data, removes the requirement of middlemen, and shows all participants a secure, immutable transaction record. Then, the Authors of [37] create a BC-enabled traceability system for storing and retrieving product information in the agricultural supply chain. An off-chain traceability information system and an on-chain information system are used to decrease chain load strain while achieving efficient information queries. This traceability of agricultural products is divided into four categories: production, processing, logistics, and sales.

Luisanna *et al.* [107] devised a system in which nodes are prepared with a variety of sensors that send data straight to

Raspberry Pi units, which then transfer it to the IPFS and the Ethereum BC. This system would also benefit from ad hoc RFID/NFC tags, which would quickly provide whole information about the products and their batches to the proposed system. Then, [48] presents a shopping platform for clients to buy source-verified goods, as well as the traceability of the food's reliable resume. The environments in which the meal's ingredients are sourced and the logistics and distribution environment that the food supply chain travels are also discussed in this article.

2) INFORMATION SHARING

Information exchange in a supply chain is difficult and fragmented because of the large amount of data created by its participants. To make knowledge exchange more convenient, members of a supply chain can communicate information, including product specifications, status, ownership, data location, and even environmental effect [34]. Members of the supply chain are frequently dispersed internationally due to globalization and complexity in nature, resulting in highly fragmented information. Furthermore, stakeholders' large volume of data makes information exchange difficult. Real-time information sharing provided by BC promises to change the way information is exchanged and dispersed across many people. It has the potential to contribute value to several supply chains, including health and medical, construction, and smart city.

bcBIM is a BC-based architecture created by [49] to tackle the integrity of shared data. In this model, data is kept in chronological order and is guaranteed to be free of falsification. When someone adds to or changes the BIM model, the records are saved in the BC, and all of the BIM data is vetted and confirmed. Users will be able to see who made the modifications. Displaying ownership of changes transparently increases confidence in information and cooperation.

Magdi *et al.* [106] projected a BC-enabled architecture in which all supply chain information is stored in the BC to increase product provenance transparency. All manufacturers throughout the supply chain, according to [50], must register a BatchID and retain it on the BC to obtain data such as certification and validation of their production units. Every step of the process will be more visible due to this, which will help to Because of BC's decentralized nature, information transparency is increased. Then, Ilhaam *et al.* [51] presented an Ethereum BC-based system for automating procedures and information exchange, as well as capturing the detailed algorithm of supply chain stakeholder interaction. There is no one point of failure in Vendor Managed Inventory operations. Vendor Managed Inventory processes are made easier with its small, safe, trustworthy, and transparent communication method.

For privately exchanging information in the supply chain of pharmacy, a BC-based system with smart contracts and a consensus mechanism was introduced by [52]. Intelligent contract technology distributes cryptographic keys safely and securely to all parties. BC technology assures that members

of the supply chain can get confirmed information, which improves mutual relationships. While reducing security concerns, BC-enabled platforms with smart contracts might facilitate information exchange across trusted and untrustworthy entities.

3) PRODUCT ANTI-COUNTERFEITING

Counterfeit products are delivered to end-users because of a lack of transparency and outdated information-sharing systems in the supply chain system, affecting both the economy and the users' lives [52]. Counterfeit products have been purposefully and fraudulently manufactured and mislabeled in terms of uniqueness and basis to appear to be real. According to an Economic Cooperation and Development Organization report, the SCM process wastes half a trillion dollars every year. The topic of counterfeit goods was examined by [53]. Here authors formed a BC-based method for identifying and preventing counterfeit items that takes advantage of Near Field Communication (NFC). They use two authentication techniques, local and global authentication, to authenticate transactions. When the tag and product information is tampered with during the transaction, local authentication is used to verify it. In global authentication, legitimate nodes track each shipment's full chain of transactions to guarantee that the present transaction is acceptable and as expected. Using a consensus protocol, a subset of nodes is selected for validation to reduce the number of validators to save energy. If you want to reduce energy consumption, the consensus protocol chooses a subgroup of the nodes as validators to validate a current block. These two authentication processes operate together to verify the agreement. When it comes to consensus latency and detection rate, simulated experiments were used by the developers to evaluate the performance of the projected system.

BC technology might be used to monitor counterfeit pharmaceuticals across the supply chain, according to [55]. For each drug in this system, pharmaceutical makers submit data such as the drug's name, date, location, components, dosage, and adverse effects. This is approved via a smart contract. The manufacturer produces a unique encrypted QR code for this data, linked to the BC as a transaction along with the manufacturer's public key and the previous transaction's hash value. If a participant needs further information on medicine, he may offer his public key to the manufacturer, who will encrypt and transmit the QR code to them. Using their valid private key, this QR code may now be decoded. Illegitimate users cannot access the BC, and only legitimate users with a public key may access it. Non-repudiation verification is ensured in this structure by using the sender's cryptographic signature.

Jinhua *et al.* [110] presented a fully working Ethereum BC system to prevent goods counterfeiting by paying a small transaction fee. SMEs can implement this proposed application system to obtain safe and anti-counterfeit confirmation. Khizar *et al.* [54] suggest a BC-enabled medicine

SCM system that incorporates a machine learning recommendation engine. This system uses Hyperledger Fabric to track and monitor the drug distribution process in real-time while proposing the best medicines to clients; the N-gram and LightGBM models are used.

Jayaprasanna *et al.* [56] designed a Blockchain-based Management (BCBM) system. Counterfeit products are detected via a barcode reader in this system, and the product's barcode is linked to a BC system. It uses blocks in the database to hold product information and its unique code. It obtains the customer's unique code and compares it to the database of the BC. If the code is equivalent to the database, the consumer is notified; if not, information about where the client acquired the goods is obtained to discover a counterfeit product. Sudhan *et al.* [58] presented a BC system that employs BC technology to promote transparency about the status of commodities, resulting in a healthy connection between the producer and the customer. All of the procedure is transparent to both the farmers and the officials engaged in the transportation by keeping the details in the BC.

4) BUILD TRUST

Trust has been characterized in several ways in the supply chain literature, including an assumption that an individual's supply chain partner will operate consistently and execute what they promise [59]. One of the most commonly referenced definitions of trust is "The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" [60].

When it comes to managing supply chain connections, trust has always been a vital factor, and it has a direct influence on supply chain efficiency [115]. Moreover, according to research, mistrust among supply chain partners is a major barrier to collaboration [19]. The first step in establishing trust is transparency. BC technology is a novel concept that can solve problems in existing infrastructure by establishing trust, transparency, and traceability throughout the supply chain value network [4]. By assuring the validity of digital resources and identities, BC Technology has built trust in cryptocurrencies like Bitcoin and Ethereum. Cryptocurrency, or BC technology, has been labeled "trust-free" since it eliminates the requirement of a third-party trust and provides an independent source of data without relying on other peers [116]. BC has been adopted to increase transparency, authenticity, and trustworthiness when it comes to supply chains. BC technology improves visibility and transparency by reducing the drawbacks of trust-related problems in a supply chain. Due to finance-related redundancy in record storing, trust-related concerns are common. BC Technology efficiently improves internal trust and collaboration among supply chain members. In the implicit contract between buyer and seller, BC has the potential to bring a new degree of trust. Since each network transaction updates the distributed ledger

in real-time, it develops trust between the client and provider. BC makes data and information available to all parties, yet they can't be changed by a single party, which builds confidence and reduces fraud. By eliminating counterfeiting, BC's immutability characteristic enhances confidence.

BC has been implemented in supply chain sectors to improve transparency, authenticity, and trustworthiness. Using BC, all supply chain processes may be integrated into a single source of information. This information may be made quickly available to customers and other supply chain members that require it. Through transparent transactions, BC technology has proven the ability to promote confidence in SCM, resulting in the delivery of higher-quality products [117]. The World Economic Forum has released a BC deployment toolkit called "Redesigning Trust," which may help businesses "create a new BC solution." In the agriculture sector, [61] presented a conceptual structure to improve the degree of trust between clients and distributors by using BC technology. By creating a BC-IoT application, [118] looked at the best ways to increase trust relationships amongst the various participants in the Agri-Food value chain. The authors of [119] employed the [120] supported extended BC framework. This framework primarily dealt with trust from two perspectives:

- From the sharing economy, where Trust in peers and Trust in the platform are two objects of the trust
- From BC Technology, where trust-free systems and trust-building procedures were examined

Wahyuni *et al.* [122] create a model to conceptualize belief in construction-based SCM and distinguish between micro and macro trusts. With the help of the BC, critical supply chain participants may be held responsible, and transparency concerns might be resolved, decreasing the impact of competing interests and enhancing supply chain trust [121]. Organizations should invest in BC technology to make their supply chain more visible and flexible and establish confidence among supply chain participants.

B. APPLICATIONS OF BC-BASED SUPPLY CHAIN SYSTEM (RQ2)

Now, BC technology is employed in nearly every industry that involves supply chains. This paper discusses two of the most prominent applications of BC in the supply chain, such as the Food supply chain and the Pharmaceutical supply chain.

1) FOOD SUPPLY CHAIN

The World Health Organization (WHO) states that contaminated food causes illness in one out of ten persons. Farmers, manufacturers, certifying/government agencies, logistics, distributors, retailers, and consumers are among the various players engaged in the food supply chain. Each of these individuals sits on their private server and communicates important information about the food item. Because other participants do not have access to this information, food fraud

is higher. When a customer wants to buy anything, they depend completely on the claims on the label. The supplier of raw materials and processors is important to the product producer. The processor relies on the farmer's or farmer association's claim or organic certification. Both consumers and other participants are cheated if they offer inaccurate or changed information. BC creates a protected environment in which every member of the supply chain network has access to all data, which cannot be edited or removed once recorded and confirmed. As a result, it may not only eliminate middlemen, save prices, and increase speed and reporting but also give consumers greater visibility and monitoring. BC technology has increased acceptance in recent years to address traceability and transparency challenges in the Food supply chain. BC will also improve information security and help with long-term traceability management for agri-food goods through IoT-enabled devices for data gathering and persistence. The food sector offers a lot of promise for BC when combined with the newest data capture technology.

Wahyuni *et al.* [122] discovered dangers in source to supply food SCs by reviewing a case study for the seafood (fish) sector. All stakeholders are accountable for avoiding biological and chemical pollution over the total food supply chain operations. Participants are urged to utilize ICT tools to control better and monitor all 'source-make-deliver' processes to safeguard perishable goods and minimize quality variations that violate food safety necessities. Feng *et al.* [40] created a RFID and BC-based agri-food supply chain traceability system. According to the findings of this study, RFID technology may be utilized in the logistics business to gather data which should be managed for tracing and tracking. This method encourages reliable data interchange and facilitates traceability, ensuring the quality and safety of agri-food products.

Pincheira *et al.* [123] demonstrated the use of Ethereum and Hyperledger to implement BCT Agri BlockIoT. In the BCT ecosystem, devices that are connected to the Internet of Things (IoT) accumulate and transmit data, while sensors ensure that smart contracts are executed. To update the condition of perishables as well as the SCM with a focus on transportation, the authors of [124] construct an IoT-based secure monitoring and reporting system without the use of humans. Malik *et al.* [125] developed a consortium permissioned BC model to enhance consumer confidence by eliminating a single node with the highest power. In this system, there are four sorts of nodes: non-participants, participants, governing board, and validators. Customers and other non-participating members can only investigate the BC. The food supply chain stakeholders that makeup participating members are the source of transactions. Several government entities make up the governance board, and they are in charge of setting the access limitations for the contributing members. The sharding method is used to enhance the network's scalability. In a sharding method, data is split into several shards, and the work of verifying transactions is split across various nodes simultaneously. In addition, the network is split into geographical zones, with each zone having its validating node

that processes transactions that originate inside that zone. The transactions of the participating members are kept in their shard once they have been validated (local ledgers). A legal transaction must have a predetermined set of fields and follow the governance board's regulations. Native ledgers are replicated and regularly sent to the global validator to update the product ledger, which consumers may access through the query manager.

In the agriculture area, Hossein *et al.* [67] suggested a conceptual model based on BC to enhance the degree of trust between clients and distributors. Registration, verification, and tracing are the three activities in this framework. The administrative node is in charge of registering the participants. The verification of the uploaded data is handled via Smart Contracts. The end-user (customers) typically performs tracing to trace the items' history information. Mao *et al.* [126] projected a BC-enabled food supply trade system. As a result, they proposed a dynamic programming algorithmic technique to find a tie between vendors and consumers that maximizes transaction profits. Depending on the circumstances, BC can be used to optimize the monitoring component in this application domain. An appropriate credential scheme must be created if a public BC is utilized since the origin of data on the BC must be readily recognized.

Feng *et al.* [40] suggested a shared food safety traceability system based on EPCIS and BC, which leveraged smart contracts to address problems such as data corruption and trust transfer. Simultaneously, this model also employs dynamic data management such as on-chain and off-chain to address the issue of data explosion. Perboli *et al.* [50] investigated a technique to accomplish transparency and visibility in the soybean supply chain using BC and smart contracts. Smart contracts are used to perform business transactions. So, instead of relying on a trusted centralized authority, smart contracts will be used to govern and control all transactions between partners in the soybean supply chain. These communications are saved in the BC, which is linked to the IPFS. Due to the connection between IPFS and the BC, the soybean supply chain is transparent and traceable in a safe and trustworthy manner.

Yasmin *et al.* [127] presents simplified BC architecture with an IoT network for food industry automation named Smart Food Chain (SFC). Compared to the traditional BC system, this model presents the Sub-BC concept, which focuses on reducing resources and processing complexity. Then, Shivendra *et al.* [128] present a strategy for tracking crop prices and traceability that uses the blockchain and effectively conducts business operations through the agricultural supply chain. Then, Ilhaam *et al.* [51] suggested Ethereum-based agriculture and food supply chain reputation system.

The food supply chain has been proven to be more sustainable due to BC, which allows for more efficient operations and targeted product recalls. When product information on BC is recorded in real-time, stakeholders will have a better understanding of product flow and will be able to respond to events more quickly. Wal-Mart has created a mango-tracking

system to improve product traceability that can track mangoes from farm to store in two seconds instead of seven days [38]. Several other IT giants have also developed various BC platforms or solutions for the food sector. By adding smart farming and precision agricultural methods with BC, farm production may be increased, which ensures data privacy and integrity; It makes the food supply chain more efficient by creating confidence among interested parties and simplifying the whole procedure; and, last but not least, it allows farmers to maximize their income through a trusted medium [129].

2) PHARMACEUTICAL SUPPLY CHAIN

The pharmaceutical supply chain is how prescription medicines are supplied to patients. Before reaching the final recipe, ingredients for medicines are typically collected from various sources. The medicine can be distributed once the final formula is determined. The drug will move through several separate entities, including the manufacturer and the patient, along the supply chain life cycle. In each transaction, counterfeit or falsified commodities may be inserted into the supply chain and the industrial sector. The difficulty of preventing counterfeits from accessing the drug distribution supply chain is due to the industry's complexity. As a result, while designing technology-based solutions for the pharmaceutical supply chain, there is a significant demand for surveillance in producing and distributing false, substandard, counterfeit, and grey market pharmaceuticals. In the worldwide pharmaceutical medication trade, counterfeit items make up about 3.3% of the total, according to the Organization of Economic Cooperation and Development (OECD). A significant concern, according to experts, is the selling of counterfeit medications. In the pharmaceutical supply chain, BC-enabled medicine tracing might be used to build a distributed, shared data platform for an immutable system that is reliable, responsible, and transparent [57]. BC can improve the pharmaceutical supply chain's functionality because of its transparent, immutable, and auditable. It can also help control inventory while also reducing counterfeiting and theft in the supply chain.

Bocek *et al.* [130] introduced the Pharma supply chain traceability system Modum.io, which combines the advantages of IoT and BC. IoT sensor devices, back-end, and a user interface create the system's architecture. As part of the back-end, there is an Ethereum BC and a server node responsible for monitoring the BC and implementing smart contracts. This server can also be used to store sensitive data. The front-end is made up of Android-based smartphones that link with the back-end server. [131] developed Gcoin, a BC-enabled pharmaceutical supply chain conceptual framework to track medicine shipping and distribution. Tahseen *et al.* [114] propose using IoT devices to track the carrier's position, temperature, and humidity to optimize and increase vaccination coverage in distant areas while maintaining transparency in the process. For vaccine expiration concerns as well as vaccine record fraud, [25] developed "vaccine BC" technology

TABLE 5. Comparative analysis of state-of-the-art approaches to be adopted in food supply chain industry.

Author	Year	Description	Implementation	Platform	Application Area
Yang <i>et al.</i> [37]	2021	To address the issues of high data load pressure and poor private security of the BC traceability model as the information accumulates, an on-chain and off-chain data entering approach employing “database + BC” is used.	Yes	Hyperledger Fabric	Food Chain Supply
Wang <i>et al.</i> [69]	2021	Create a BC and smart contracts-based system for tracking and tracing the process of agricultural food supply chains. Farmers use the IPFS to record environmental information and agricultural growth data, and smart contracts are used to store file IPFS hashes.	-	-	Food Chain Supply
Chen <i>et al.</i> [70]	2021	Design BC-based ASC framework to present product traceability.To make successful decisions about agri-food product production and storage for profit maximization, a Deep Reinforcement Learning-based SCM(DR-SCM)technique was used.	-	-	Food Chain Supply
Iftekhar <i>et al.</i> [71]	2021	This paper presents a BC-enabled supply chain architecture that provides a tamper-proof audit trail to reduce the threat of various bacteria, fungi, and parasites in the frozen meat supply chain. It also discusses the risk of Covid-19.	Yes	Hyperledger Fabric	Food Chain Supply
Daniel <i>et al.</i> [72]	2020	Egg distribution is traced from farm to consumer in the mid-western United States.	Yes	Hyperledger Sawtooth	Food Chain Supply
Gao <i>et al.</i> [73]	2020	A complete food supply chain can be established by combining all sources to enable trustworthy food traceability.	Yes	Hyperledger Fabric	Food Chain Supply
Zhang <i>et al.</i> [74]	2020	To increase BC storage efficiency, a multimode storage method was created. It may also give participants, customers, and third-party supervisory agencies trustworthy industrial chain information and danger review, guess, and early warning.			Food Chain Supply
Ferdousi <i>et al.</i> [75]	2020	Designed a BC-based SCM system for the beef cattle industry in the United States that provides data immutability while maintaining data ownership. The system also supports animal traceability, user anonymity, and data aggregation. It achieves consensus through the use of proof of authority (PoA).	Yes	Ethereum	Food Chain Supply
Shahid <i>et al.</i> [45]	2020	For the Agri-Food supply chain, it was proposed to use a BC-based reputation system concerning traceability, trade, delivery, and reputation issues.	Yes	Ethereum	Food Chain Supply
Pradana <i>et al.</i> [76]	2020	Features relief F algorithm was used to identify the most important coffee quality indicators needed for establishing the origin. Using BC-based smart contract architecture, a safe and unalterable way of storing distributed data was shown. There were two methods used to demonstrate the rules in the tracing process: A decision tree and a pseudocode algorithm.	Yes	Ethereum	Food Chain Supply
Ekawati <i>et al.</i> [77]	2020	Proposed an Intelligent Decision Support System (IDSS) based on BC technology to decrease errors and enhance consumer confidence.			Food Chain Supply
Lin <i>et al.</i> [34]	2019	A BC and EPCIS-based food safety traceability solution was proposed to resolve data tampering, data disclosure, and trust transfer concerns. It uses On and Off data management to address the data explosion problem.	Yes	Ethereum	Food Chain Supply
Mondal <i>et al.</i> [78]	2019	With IoT devices and BC technology, a system for monitoring food supply networks has been suggested. The 900 MHz RFID gives the product a unique identity and sensor data, which aids in real-time quality monitoring.	-	-	Food Chain Supply
Salah <i>et al.</i> [44]	2019	Researchers investigated the smart contract-based BC system to accomplish transparency and visibility in the soybean supply chain.	Yes	Ethereum	Food Chain Supply
Baralla <i>et al.</i> [42]	2019	In the Sardinia Region, to manage and protect the products made in Sardinia and advance the whole food supply chain, a BC-based system was created.	Yes	Ethereum	Food Chain Supply
Huang <i>et al.</i> [79]	2019	To address issues including data tampering, data disclosure, and trust, developed a BC system in the Food supply chain.	Yes	Ethereum	Food Chain Supply
Tsang <i>et al.</i> [80]	2019	A BC-IoT- fuzzy logic-based food traceability system (BIFTS) is advocated for perishable food management.			Food Chain Supply
Sun <i>et al.</i> [81]	2019	Creates an Ethereum and RFID based liquor anti-counterfeiting traceability system	Yes	Ethereum	Food Chain Supply
Arena <i>et al.</i> [82]	2019	It offers a BC-enabled method for enforcing EVOO product certification by tracing the product’s full supply chain from the ground to the store. A tamper-proof record of the product, including cultivation, harvesting, making, packing and preservation, and transportation and storage, is provided to the client.	Yes	Hyperledger fabric	Food Chain Supply
Bechtsis <i>et al.</i> [83]	2019	With a farm-to-fork BC platform, the proposed system integrates the operations of numerous parties in a global containerized food supply chain.	Yes	Hyperledger fabric	Food Chain Supply
Baralla <i>et al.</i> [43]	2019	A BC-based system was proposed to apply the EU “farm to fork” method to trace agricultural products. Buyers can learn more about a product and verify its quality and safety by scanning the QR code.	Yes	Hyperledger Sawtooth	Food Chain Supply
Jaiswal <i>et al.</i> [84]	2019	Suggested a theoretical framework for secure and motivated P2P food grains trade, employing smart contracts such as food grain supply, bidding, trading, and utilization. Use the Vickrey-Clarke grove (Vickrey auction) approach to encourage farmers and consumers to exchange information.	Yes	Ethereum	Food Chain Supply
Koirala <i>et al.</i> [85]	2019	A BC-based supply chain model is described in this study to demonstrate how openness is preserved in a carrier procurement bidding process, creating the system more well-organized and safe. The reverse auction bidding process is handled by a smart contract called ‘Bidding,’ which is constructed in Solidity and deployed on BC.			Food Chain Supply
Madumidha <i>et al.</i> [86]	2019	This paper introduces a “Provider- Consumer Network,” a dispersed BC-based food traceability system that permits developers to create agricultural building blocks that interface with IoT devices from supplier to customer. The goal is to establish a distributed ledger available to all network users and provides transparency.	Yes	Ethereum	Food Chain Supply
Moudoud <i>et al.</i> [87]	2019	Propose BC architecture for use in a food supply chain that includes multiple dispersed IoT devices. The suggested design uses Oracle’s network and smart contracts to provide product traceability and system transparency. It also proposes a Lightweight Consensus for the Internet of Things (LC4IoT), which minimizes processing power,storage capacity and latency.			Food Chain Supply

that makes use of the traceability property and smart contracts provided by BC technology.

Yaoming *et al.* [113] utilize BC technology to evaluate and create a comprehensive life cycle SCM approach for medical equipment that covers the entire process of manufacturing, supply, tendering, procurement, storage, application, export, usage, destruction, and traceability. In Indonesia, a BC-enabled Medicine SCM system (MSCM) was projected by [62] for the distribution of medicines between public health centers. JMeter tool is used to test the system performance regarding transactions per second (TPS), latency, and resource consumption to determine if the suggested solution would work. Kumiawan *et al.* [62] created a BC enabled Management System for identifying counterfeit products in the Supply network. Musamih *et al.* [35] created an Ethereum-based BC system for the pharmaceutical supply chain and decentralized off-chain storage to monitor and trace medicines in a decentralized way. Uddin *et al.* [57] Hyperledger Fabric and Hyperledger Besu are two viable BC-based decentralized architectures that can fulfill security, privacy, accessibility, and transparency criteria.

IV. MAIN FINDINGS, CHALLENGES AND FUTURE RESEARCH DIRECTIONS

A. OPPORTUNITIES OF BC FOR SECURE SCM

In this subsection, we discuss some of the main opportunities of BC for secure SCM. Due to its unique qualities, for instance, real-time data exchange, transparency, reliability, traceability, immutability, and visibility, BC has emerged as the instrument of the modern-day [63]. According to Allied Market Research, BC's global supply chain market will expand at 80.2 percent through 2025. Reports from Market Watch show that the global market for BC-enabled supply chains is estimated to reach \$9.8 billion by 2025. According to industry estimates, BC's global contribution to the supply chain industry is estimated to reach \$424 million by 2023. In the near 5 to 10 years, SCM is likely to be among the most successful implementations of BC technology, and BC is likely to become the standard in SCM [64]. Figure 9 shows the SWOT study regarding adoption of BC in supply chain.

1) REDUCED ANTI-COUNTERFEITING PROBLEM

BC may be utilized to enhance transparency and visibility of the source and combat counterfeiting. For example, the Food Standards Agency in the United Kingdom utilizes BC to track the circulation of meat to improve food traceability (Ministry of Electronics and Information Technology, India, January 2021). Walmart, a retail giant, puts a premium on food safety, monitoring, and traceability by implementing BC technology. It has previously conducted testing utilizing this technology to track food goods from Mexico and China, such as mangoes and pigs. In addition, Walmart can ensure quality and food conditions throughout transit by using sensors to monitor the temperature in a BC system. Unilever, Nestlé, and Dole all use similar techniques.

2) SECURITY

The Food and Drug Administration, United States, is utilizing BC to solve the lack of openness and security in the processing of health data.

3) INCREASE TRUST

From BC: The India Strategy (2020), BC can transform India's agriculture sector by giving an inventory trace of every farmer's production and reducing the distrust between kishans and arhatiyas (mandi intermediaries), redesigning the eNAM service.

4) COMPETITIVE ADVANTAGE

Many experts have emphasized BC's potential to change corporate operations by making supply chain data more accessible and transparent and enhancing the overall consumer experience.

5) REDUCED COST

Incorporating BC technology has a favorable influence on decreasing costs and increasing asset turnover [112].

B. OPEN ISSUES AND CHALLENGES (RQ3)

In this subsection, we discuss some of the challenges in integrating BC with SCM. Because several obstacles and restrictions have already been recognized, acceptance of BC into supply chain processes won't be as easy as anticipated. In a 2017 poll conducted by ABI Research, 93 percent of those making decisions across nine industrial areas stated they were unfamiliar with BC, while 7% said they were conducting preliminary research on the technology. The most significant obstacle to BC implementation in the supply chain is an image problem. Many people associate BC with cryptocurrencies like Bitcoin, and cryptocurrency has a bad reputation owing to its usage in illicit activities. As a result, individuals are hesitant to embrace it. Many businesses have no idea what BC is or what it can achieve.

The second major issue is the lack of interoperability across several BC networks. Interoperability refers to the capacity to share data, operate, and transact across several BC platforms. Organizations are building their own BCs and apps to operate on top of them due to the lack of a common standard. Thousands of projects are now using various BC systems, the majority of which are standalone. They employ a variety of protocols, coding languages, consensus methods, and privacy protections. The issue is that the BC sector is chaotic since there are so many different networks.

Another major issue is a scarcity of qualified developers. As a result, companies cannot access the necessary pool of BC capability to connect in BC adoption. The widespread execution of BC in worldwide supply chains faces significant regulatory and legal obstacles. Because each stakeholder in a BC ledger might be in a different world, it's impossible to say which jurisdiction a BC would fall under. Choosing which law(s) to follow and which courts have the authority

TABLE 6. Comparative analysis of state-of-the-art approaches using BC in pharma supply chain.

Author	Year	Description	Implementation	Platform	Application Area
Musamih <i>et al.</i> [35]	2021	To improve the effectiveness of product tracking in the healthcare supply chain, this paper shows a BC-enabled solution that relies on smart contracts and a decentralized off-chain storage method. All parties have an immutable history of transactions, and it guards against counterfeit pharmaceuticals. The proposed system is cost-effective in how much gas is consumed to complete the tasks that are triggered by the smart contract.	Yes	Ethereum	Healthcare Supply Chain
Antal <i>et al.</i> [33]	2021	COVID-19 vaccination registration, storage and administration may be traced transparently with the proposed BC-based system.	Yes	Ethereum	Healthcare Supply Chain
Subramanian <i>et al.</i> [88]	2021	Present the notion of crypto medicine, a cryptocurrency to buy and sell medicines. NEM cryptocurrency XEM is attached to all medical products by a QR code. The IoT integrated monitors were also used to test the time monitoring of liquid medicine.	Yes	NEM	Healthcare Supply Chain
Alkhoori <i>et al.</i> [89]	2021	Crypto Cargo, a BC-based smart container system, will use smart contracts to examine the position of cargo and recognize any violations that may cause harm to contents.	Yes	Ethereum	Healthcare Supply Chain
Qiu <i>et al.</i> [90]	2021	Anti-counterfeiting and tracing of vaccines were developed using a proposed double-chain hierarchical system, in which both the public and private chains were employed in the Ethereum ecosystem.	Yes	Ethereum	Healthcare Supply Chain
Ahmad <i>et al.</i> [91]	2021	Combining COVID-19 medical utensils forward supply chain procedures and protocols into a decentralized Ethereum-based BC system and enabling information exchange among all waste management stakeholders. In the event of a violation, the stakeholders will face penalties.	Yes	Ethereum	Healthcare Supply Chain
Omar <i>et al.</i> [92]	2021	Propose a smart contract-powered BC model to automate the Group Purchasing Organizations (GPOs) procurement process in the healthcare supply chain.	Yes	Ethereum	Healthcare Supply Chain
Mendonça <i>et al.</i> [93]	2021	Propose a cold chain solution based on BC for vaccine cooling.	Yes	Ethereum	Healthcare Supply Chain
Saranya <i>et al.</i> [94]	2021	Using BC, IoT, and Cloud Technologies, create a Go-Win web application for COVID-19 medication Supply Chain System for efficient approved vaccine distribution, tracking Covid-19 patients, post-vaccination safety, and generating awareness to combat vaccine hesitancy and Covid-denial.			Healthcare Supply Chain
Uddin <i>et al.</i> [57]	2021	Propose Hyperledger Fabric and Besu as two viable BC-based decentralized architectures that satisfy essential needs for successful medication tracing.	Yes	Hyperledger Fabric and Hyperledger Besu	Healthcare Supply Chain
Zhu <i>et al.</i> [95]	2020	Proposes a BC-enabled system for storing, querying, and anti-counterfeiting pharmaceutical information across a drug supply chain. The smart contract-based access control policy approach is intended to stop pharmaceutical data from being changed or exposed at BC nodes. It enhances PBFT by providing a scoring system and an up/downgrading method.			Healthcare Supply Chain
Pandey <i>et al.</i> [96]	2020	Propose a robust electronic health network to combat the problem of counterfeit medications in India.	Yes	Hyper ledger fabric	Healthcare Supply Chain
Abbas <i>et al.</i> [54]	2020	This project has a machine learning recommendation system coupled with a BC medication supply chain system. This system tracks and monitors the medication delivery process in real-time, and N-gram and LightGBM models are utilized to suggest suitable drugs to consumers.	Yes	Hyperledger fabric	Healthcare Supply Chain
Kumiawan <i>et al.</i> [62]	2020	In Indonesia, a BC-enabled Medicine SCM system was projected for the distribution of medicines between public health centers. JMeter tool is used to test the system performance concerning transactions per second (TPS), latency, and resource usage.			Healthcare Supply Chain
Singh <i>et al.</i> [52]	2020	A sensor-based IoT and BC Distributed Network (BDN) based on bloXroute servers and the RAFT consensus algorithm architecture is used to monitor medicines as they move through the supply chain.	Yes	Hyper ledger	Healthcare Supply Chain
Saxena <i>et al.</i> [97]	2020	Feedback from 30 professionals working in the pharmaceutical sector, either directly or indirectly, was utilized to develop criteria for PharmaCrypt, a new BC-based platform.	Yes	Ethereum	Healthcare Supply Chain
Shaoliang <i>et al.</i> [98]	2020	Propose a two-tiered BC-based vaccine manufacturing supervision strategy. The first level consists of private data, which comprises manufacturing records and their hashes, and the second level consists of public data, which includes production records, hashes, and vaccination information. This article discusses a consensus technique for multi-node cooperation to increase time efficiency. It also suggests a vaccination data cutting strategy to minimize the amount of space wasted due to the BC's redundancy.			Healthcare Supply Chain
Chen <i>et al.</i> [99]	2020	Propose an IoT-based anti-counterfeiting management system for tracing counterfeit drugs. The framework fulfills data integrity, replay resistance, irreversible information, and non-repudiation information security criteria, but it also accomplishes the aim of automated supply chain management.			Healthcare Supply Chain
Debe <i>et al.</i> [100]	2020	Propose a BC-based solution that uses smart contracts and IPFS to monitor the origin of returned, reusable medications from manufacturing through the resale.	Yes	Ethereum	Healthcare Supply Chain
Shi <i>et al.</i> [101]	2019	Information transparency is promoted by IoT and BC technology, which automates processes, improves safety, and even prevents the proliferation of counterfeit drugs on the market.	Yes	Hyper ledger fabric	Healthcare Supply Chain
Jangir <i>et al.</i> [102]	2019	Using DLT and smart contracts, the authors suggested an original paradigm for the pharmaceutical supply chain network. Consumer privacy, drug transparency, monitoring of the drugs, and quality control, in addition to demand and supply management, are all aided by this architecture.	Yes	Ethereum	Healthcare Supply Chain
Kumar <i>et al.</i> [103]	2019	Propose that the Indian government maintains a private, permissioned BC database that may be used as a distributed medicine inventory that keeps track of supply chain transactions organized into blocks.	Yes	Hyper Ledger	Healthcare Supply Chain

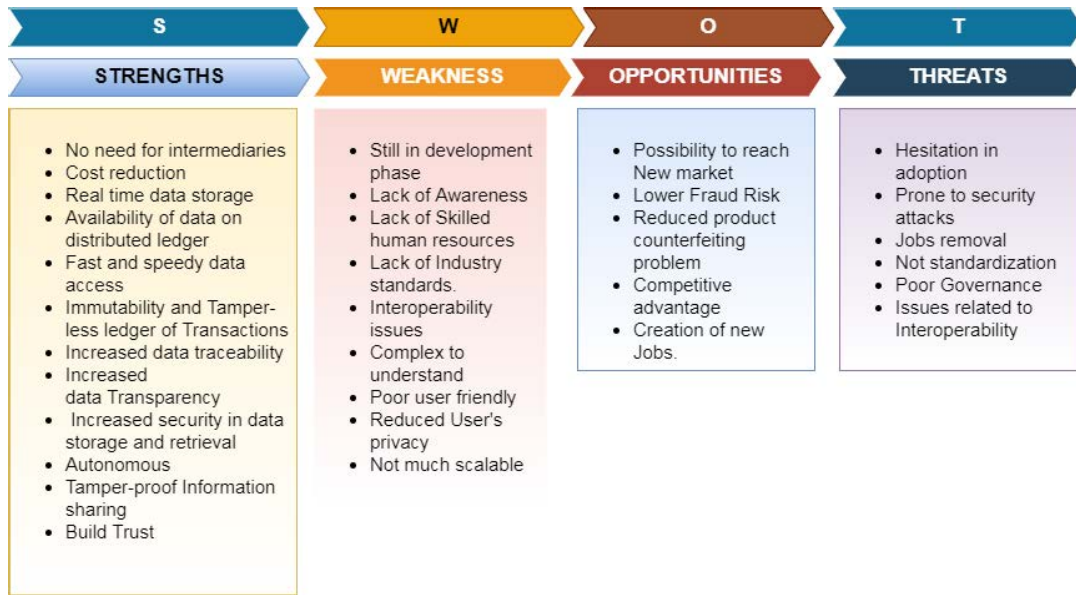


FIGURE 9. SWOT study regarding adoption of BC in supply industry.

to decide on certain issues may be a complex and sometimes contradictory process. A BC system has no one owner due to the nature of BC. As a result, it's not always apparent who should be held accountable, and assigning blame for BC technology is difficult [111]. If BC is unable to comply with legal oversight, it will not be broadly used [5].

The cost of using BC-powered SCM solutions will put off Most small and medium-sized business owners. BC systems' non-trivial operations and installation costs should never be underestimated [65]. BC adoption is further hampered by the need to transfer and integrate people, processes, and technologies [65]. Cyber-attacks appear to be a further substantial obstacle to BC adoption [17]. Security flaws in BC code or cryptographic algorithms – like the DAO breach on Ethereum in 2016 and the rearrangement of a sequence of BC records on Ethereum Classic in early 2019 – may lead firms to discard BC solutions in favor of more traditional procedures. A rising concern is that quantum computers will be able to crack the basic encryption algorithm, posing a serious threat to the security of BC technology [108]. BC mostly employs elliptic curve public-key encryption techniques to produce digital signatures for safe transactions. With the use of Shor's quantum computing technology, we can perform prime factorization of bigger numbers in polynomial time, making it easier to break the RSA algorithm so, in the post-quantum era, digital signature methods such as DSA, ECDSA, and EdDSA will be rendered worthless [5].

Transactions per second (TPS) is a common metric for determining the scalability of different BC models. TPS is the maximum number of simultaneous transactions that may be supported per unit interval. Some of the issues that influenced the scalability of BC models were the architecture and configuration of the BC platform, different block size

limits, different consensus and transaction validation mechanisms, changeable requirements for processing power, network bandwidth, file system, and data storage [132]. For the BC framework to work, the TPS must be considerably large. The present TPS of BC models, on the other hand, is still a long way from meeting this criterion. Finance, for example, needs hundreds of TPS for companies with big operations and businesses. Currently, available BC systems cannot attain this amount of TPS [5]. BC technology does not solve the problem of inputting inaccurate or fraudulent data, which is also a major barrier to SCM adoption.

C. FUTURE AND RESEARCH DIRECTIONS (RQ4)

This subsection explores some of the future directions of BC usage in SCM. Supply chain risks are minimized when BC is utilized with cutting-edge information tools such as 5G, IoT, machine learning, and Cloud computing. Several techniques such as secure tags, seals, or sensors are integrated into the BC-based solutions to confirm the authenticity of items. The developers need to be extremely cautious in designing the complex smart contracts, taking all those codes into account, which makes the smart contract cumbersome.

The present storage costs connected with BC are quite high, with 1MB of data costing 550 USD. So, to adopt BC-based solutions, the cost of storage must be minimized. Cooperation, cooperative collaboration, and proper consensus methods would be critical components in implementing BC for SCM in practice. More strong consensus algorithms and security enforcing methods are required. Reward all supply chain players with incentives to correctly follow the BC-based supply chain protocols. The incentive-based technique of rewarding will pave the path for a long-term, stable

future [66]. Altering the exact implementation of BC protocols may solve the scalability problem, such as Lightning Network and State Channels, which maintain the core BC protocols but perform transactions off-chain. We may also utilize BC sharding, which allows each node to handle only a portion of transactions, decreasing node calculation and storage and improving performance. Another possibility is to use a digital currency on the BC network to fund the supply chain [67].

V. CONCLUSIONS AND DISCUSSIONS

This study attempts to investigate briefly how BC technology works and when it should be utilized to address supply chain challenges. BC technology is employed in SCM in a variety of sectors. The present state of use of BC and Smart Contracts in numerous major industrial domains is studied in this paper. The survey delivers academically sound data on the overall state of BC deployment for various supply chains. The study's findings and conclusions show that research on BC-based supply chains is a growing topic garnering a lot of attention. The majority of the reviewed papers that were evaluated agreed on the prospective benefits that BC may offer to the supply chain.

Furthermore, the obstacles, possibilities, and future perspectives of using BC in the supply chain are thoroughly examined to identify open research questions on utilizing BC realistically in the future. There is a lack of in-depth understanding of BC technology, which might jeopardize its benefits. We think that our study gives academics, engineers, educators, and general readers a proper orientation on the theoretical insights of BC. It also identifies future study goals in areas that combine future technology and BC.

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