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A Survey Paper on Blockchain Technologies in Supply Chain Management

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Abstract
The supply chain connects organisations, resources, activities, people, and information in order to transform natural resources and raw materials into a finished product for delivery to the ultimate client. The complexity of supply chains and value networks has increased over time. These complexities add a huge cost to the participants of supply chain, which is ultimately borne by the customer. The existing infrastructure also fails to provide desired amount of transparency and traceability into the supply chain. The blockchain technology is a revolutionary concept that can overcome the problems in the existing infrastructure to build trust, provide transparency and traceability across the supply chain value network. This paper is a survey of various blockchain based solutions that have been proposed to be implemented in various fields of supply chain management. This paper also briefly discusses the application of this technology in various sectors.

Keywords
Blockchain, Supply Chain, Hyperledger fabric, Hyperledger Sawtooth, Ethereum.

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I. INTRODUCTION

The growth of industries has led to the discovery of a management technique called supply chain management. Supply chain basically refers to the complete network of people, organizations, resources, technologies, resources and the activities, from the start stage to the final end-product stage. The term supply chain management refers to the management of flow of all the entities who are a part of the supply chain. This covers the flow of goods, services, information, and money between two supply chain members, as well as the movement and storage of raw materials, work-in-process inventories, and finished product flow from point of production to point of consumption, as well as end-to-end order fulfilment. The demand for a safe, transparent, and traceable platform has been answered by the usage of Blockchain technology as more sectors aim to improve the efficiency of their supply chain management processes. Satoshi Nakamoto invented blockchain in 2008 to serve as the cryptocurrency bitcoin's public transaction record. Satoshi Nakamoto invented blockchain in order to overcome the problem of double spending in the first crypto currency, Bitcoin. The decentralised and distributed nature of blockchain solved this problem. A blockchain is made up of blocks that are linked together by cryptography, with each block containing a cryptographic hash of the preceding block, a timestamp, and transaction information. Each new block reinforces the previous block in the chain, forming a chain. This makes blockchain immutable since data in any specific block can't be changed after it's been recorded without affecting the rest of the chain. Because to its decentralised structure, even if someone gets to modify a chain, it only affects that copy; the other copies are unaffected.

The most attractive feature of blockchain technology is its nature of immutability making it a perfect solution for solving the issues of transparency, traceability, counterfeiting and other administrative problems. With the use of blockchain organisations can digitise its physical assets and records, and create an immutable decentralized record of all transactions. The use of blockchain helps organisations enable a transparent and accurate tracking of its supply chain from end-to-end. The records of all transactions, provide an efficient way to

track all assets from production to the end user. This tracking prevents fraud and counterfeiting in many high value goods.

The blockchain technology allows all members of a supply chain to have access to the same data, reducing coordination and data transmission errors. Blockchain also helps increase efficiency of administrative processes and also help reduce cost of audit of supply chain data.

For implementation of blockchain into supply chains, additional technologies are necessary to be integrated for its efficient use.

Some technologies that are prominently used for implementing blockchain:

1. RFID Technology: RFID is a wireless and contactless data transmission method that uses radio frequency waves. RFID technology makes data interchange and access easier. RFID tags enable firms to easily track and collect data about products in transit, which can then be shared with other supply chain partners.
2. Internet of Things (IoT): IoT is an interconnected network of physical devices that can track, share and receive data. IoT devices may be connected to individual shipping/storage containers, as well as raw materials or manufactured goods. The IoT system can send its location to GPS satellites, which can then be used to monitor the movement of products.

II. LITERATURE SURVEY

Harvard Business Review refers to blockchain as an innovative landscape that represents just 10 years of work of an elite group of computer scientists, cryptographers and mathematicians. The rapid rise in blockchain technologies has led to immense research in the implementation of the blockchain in supply chains. The majority of this research has occurred in the last 10 years. This research has slowly drawn the attention of major players in the field of blockchain and it is not far from when blockchain is going to be used as a mainstream technology in the field of supply chain.

The authors of [1] talk about the drawbacks of the present supply chain management systems and also give an overview of how blockchain can solve these drawbacks. The present nature of supply chain is centralised, this leads to many issues. The main issue is transparency, the supplier can increase taxes at free will and other members of the supply chain bear these taxes for self-demand and the effects of this is passed to the next person in the supply chain. Another issue that arises is tampering of the information for self-gain by members. Blockchain is proposed a solution to these issues. Blockchain is a decentralized ledger and provides transparency throughout the chain to all its members. Blockchain's nature of immutability provides a perfect solution to tampering of information. For supply chain tracking, blockchain can be connected with IoT using technologies such as RFID and smart tags. This integrated blockchain system encompasses the process of data collecting and management for every node of information that comprehends the tracking and tracing system using IoT devices.

[2] proposes a system for tracking dairy products from farmer to consumer. The Hyperledger Fabric framework, which has a modular architecture and supports pluggable consensus protocols, is used to build this system. This paper also gives an overview of Hyperledger Fabric and its components.

The following are the eight important considerations for building Hyperledger fabric:

1. Blockchain Developer: They create both applications and smart contracts on the blockchain. These contracts are utilised by Blockchain users to interact with the Blockchain.
2. Blockchain Regulator: In a business network, they are the authority and may have broad access to the ledger's contents.
3. Blockchain Operator: A blockchain's operators are in charge of identifying who is allowed to participate in the blockchain, distributing blocks to participants, and so on.
4. Blockchain Architect: Creates the blockchain solution's architecture.
5. Blockchain User: A business user who is not aware of the Blockchain and operates in a business network. They use an application to interface with the Blockchain.
6. Traditional Data Coordinator: This is an established data system that delivers data that could influence smart contract characteristics.
7. Traditional Processing Platform: This is a pre-existing computer system that the Blockchain might employ to simulate processing.
8. Membership Services: This section manages the many sorts of certificates required to run an authorised Blockchain.

In literature [3] they propose a system that implements blockchain for tracking the carbon-footprint of food transportation and production stages. This system uses a Raft-like census technique to construct a scalable and lightweight blockchain that runs on a private cluster. Transportation, which consists of transportation trucks, is the most important aspect of the carbon footprint cycle. Each truck is equipped with an "Electronic Logging Device" (ELD), which captures data directly from the vehicle via a "Heavy Duty On Board Diagnostics" system (HD OBD). A food product identification number, timestamp, truck vehicle identification number, stage the

truck is coming from, amount of transported food and the network address of the previous block are among the data acquired by this device. A blockchain block is then formed by applying a single way hash function like "SHA256" to the contents. There are three nodes in this carbon footprint chain: 1) The node that sends the blocks to remainder of the network is the Leader. 2) listener: a node that receives the broadcast. 3) candidate: a node that starts a leader election. The leader that has been elected sends across a request to remainder of the network after all nodes have reached census. Only a single block of transactions is broadcast by the leader node, and it is duplicated throughout the state machines of all nodes. The census determines whether or not the new stage/cluster is the first. The algorithm verifies the trucks and freights by looking at where they came from, which is validated by the prior block's address and the prior cluster's name. In this method, a random node is chosen from the previous cluster and a request is sent to check if the block exists. If the block exists, the current transaction is copied across all nodes in the current cluster at the same time. If the information is not authenticated, it is rejected and not published to the blockchain.

According to literature [4,] blockchain can be used to tackle another critical component of the supply chain: transactions. Because of its paper-based and semi-digitalized character, the transaction process in today's supply chains has trust and security challenges. This study proposes using blockchain smart contracts to automate supply chain transactions. Smart contracts are a type of computer code agreement between two parties that is run on the blockchain and hence cannot be changed. Because the transaction only occurs when the smart contract's requirements are completed, there is no need for a third party, therefore there are no trust difficulties. They offer an approach based on three smart contracts: Logistic Smart Contract (LSC), Supplier Smart Contract (SSC), and Buyer Smart Contract (BSC) in the article (BSC). These smart contracts also function as a state machine, monitoring and updating changes in logistics details. Contracts are programmes that initiate a payment transaction and are designed to communicate with one another. On the blockchain network, they also provide product delivery notifications and information updates. When the required criteria are met, a smart contract is automatically executed. As a result, interactions between supply chain parties such as suppliers, logistics, and buyers are fully visible and immutable in a decentralised manner. Suppliers and logistics can receive their compensation in the form of crypto on the blockchain at the conclusion of these transactions. This smart contract feature aids in the creation of a secure and automated framework that eliminates current transaction difficulties.

The authors of [5] propose a system that enhances traceability in the Pharmaceutical supply chain with help of blockchain and integrated IoT edge devices. The data in the block includes the timestamp, version, Nonce, Merkle root, previous block's hash, and the current block's hash, as well as a header with metadata. This structure makes sure that the blocks are arranged chronologically and that each one refers to the preceding one, making it impossible to update any data without also updating the following blocks. In order to automate the process of data collection, data processing, and validation, IoT edge devices like barcode scanners, RFIDs, weighing scales, GPS trackers, temperature sensors and so on are used. This data is kept in edge devices as blocks in chronological sequence, which will be uploaded to the cloud later. The cloud-based storing of data on blockchain allows for a secure platform.

The blockchain has the following advantages over traditional data security measures:

1. Decentralized database: This prevents a single point of failure in data storage. If a node is attacked and compromised, it can be purged and restored to the latest "golden copy" of the blockchain.
2. Continuously reconciled and immutable data: A peer-to-peer network in which all nodes are identical or equal and the new blocks are propagated, vetted, and accepted across nodes.
3. Peer-to-peer network consensus: Consensus techniques ensure that data between nodes is consistent.
4. Authenticated users on a private network.

The literature in [6] suggests that blockchain technology be used to track counterfeit medications across the supply chain. Pharmaceutical manufacturers contribute information such as name of the drug, timestamp, location, components, usage of the medicine, and the side effects for each drug in this system. A smart contract is used to approve this. For these details, the manufacturer creates a unique encrypted QR code, which is connected to the blockchain as a transaction along with the manufacturer's public key and the hash value of the preceding transaction. If a participant requires further information about a drug, he can provide the producer with his public key and he/she will transmit it to them after encrypting the QR code. With their valid private key, they can now decrypt this QR code. The blockchain is inaccessible to illegitimate users, and it can only be accessed by legitimate users who have a public key. The sender cryptographic signature is used to ensure non-repudiation verification in this structure.

The authors in [7] propose the mainstream implementation of blockchain in agricultural supply chain. The current agricultural supply chain contains a number of flaws, such as intermediaries and middlemen who tap into marketing channels to benefit and pass on losses to producers. Producers lack access to timely, accurate information on market trends, seasonal fluctuations, pricing, quality, and quantity needs. Misinformation, misconceptions, and a lack of confidence among different levels can be overcome if blockchain can be utilised

to deliver reliable information about the supply chain. Producers can make well-informed decisions, resulting in more profits and lower losses overall.

The Benefits of Blockchain in the Agri-Food Supply Chain:

1. Producers will be protected. They would be able to make well-informed judgments if they are aware of the numerous elements affecting their crops.
2. Losses can be distributed and held accountable among members of several tiers, increasing traceability and transparency.

The literature [8] examines the problems that arise at each point of the supply chain and assesses their suitability for use with blockchain technology. Based on its trust and decentralisation properties, the authors have established a preliminary framework to analyse the application of blockchain in various supply chain stages such as supplier relationship management, order fulfilment, production flow management, and demand management. An overview of the fields in which blockchain interacts with supply chain management, which will assist further research and development, is a main purpose of the paper.

In order to handle the retailers' orders securely and efficiently, the authors of literature [9] suggest a Consumer Ordering Consensus Protocol for Business-to-Consumer online retail businesses. The protocol is implemented using smart contracts and blockchain technology. The consumer submits an order request via smart contract in this system. The smart contract is then sent to the Ethereum blockchain network. The order request is saved in a block as transaction data. The order request is sent to all network participants, including the shop and carrier. The order information obtained by each node is then verified. If there is an exception or an order request that is invalid, a reject warning is provided to customers based on the consensus mechanism. The customer can then select whether or not to place another order. The procedure shall continue until the next step in which the request for order is processed. After all nodes have allowed an order request, the products will then be supplied from the trader to the consumer.

In literature [10], the authors explore the applicability of blockchain technology in the composite materials supply chain, specifically in the manufacturing of components and structures that rely on semi-finished materials like prepregs where temperature-controlled transportation and storage are necessary. The authors explore how blockchain technology may be used to establish an anti - theft history in composite materials of produced items, their transit, handling and storage. The usefulness of blockchain has been addressed in businesses that have rigorous requirements, including aerospace sectors in where the traceability of components or materials is of essential importance.

The authors provide a Supply Chain Management model that increases logistical tracing and reliability, and may, through safe export and import scenarios, automate market transactions and commercial contacts inside the worldwide networks of enterprises without depending on third parties in the traditional Supply Chain model. Hyperledger Fabric is used to implement this concept. In this Supply Chain Management model, the import export scenario is used to demonstrate the basic transaction of selling things from one party to another. This transaction demonstrates the benefit of blockchain by allowing for an open and secure exchange. The importer's bank makes a two-part payment pledge to the exporter's bank. The exporter receives a regulatory clearance certificate before handing over the merchandise to the courier and receiving a receipt. The initial payment instalment from the importer's bank to the exporter's bank is induced by the receipt's output.

Literature [12] lists out the challenges in the existing supply chain systems and introduces blockchain technology as the solution to overcome those challenges by eliminating intermediaries and providing transparency to all the stakeholders participating in the supply chain network. However, implementation of blockchain in certain scenarios will increase the computational cost. To overcome this, the authors of literature [13] propose a hybrid solution by providing a blockchain and off chain mechanism. This hybrid approach initially permits users to search for integrity, traceability, and data source via an intermediary server which facilitates communication between the blockchain and the supply chain, in hashed form, for all occurrences or supply chain records in the blockchain.

Implementation of blockchain technology in organic food supply chain and pharmaceutical supply chain has been discussed in [14] and [15]. In [14], the researchers implement a solution based on blockchain to verify the origin of agricultural food supply chain and the food quality using Ethereum which is a public blockchain. For each physical product, instances of the smart contract were created and further deployed to Blockchain network. The virtual product reference was a QR code. Transparency is provided by the ability to engage with the system by all players in the supply chain. The authentication or validation of all events and transactions associated with a product is done by Blockchain's peers. The farmers' reputation with their products was indicated by a token-based mechanism.

In [15], the authors have proposed a framework to achieve drug safety using blockchain technology. In the pharmaceutical supply chain, this framework creates a secure channel for drug safety across multiple network players, including hospitals, patients, manufacturers, distributors, and regulatory of smart contracts. Every transaction contains information on the manufacturer and the goods. This information is verified and

distributed to all parties engaged in the medical supply chain. The participants can communicate with each other in a transparent manner because of this framework. The proposed architecture also assures trust in the system because it uses a private blockchain for implementation, and the authorities are given by a Regulatory Body's membership and a certificate authority's digital signature.

TABLE I
SUMMARY TABLE

SL. No.	Authors (Years)	Proposed System	Domain	Topics of interest
01.	S. Madumidha, P. S. Ranjani, S. S. Varsinee, P. S. Sundari (2019)	A blockchain system for tracking and tracing in food supply chain using IoT devices.	Food Supply Chain	Blockchain integration with IoT devices.
02.	S. Bhalerao, S. Agarwal, S. Borkar, S. Anekar, N. Kulkarni, S. Bhagwat (2019)	A blockchain system to track dairy products.	Food Supply Chain	Hyperledger Fabric, Hyperledger Composer.
03.	D. Shakhbulatov, A. Arora, Z. Dong and R. Rojas-Cessa (2019)	A blockchain system for tracking of carbon footprint on food production and transportation stages.	Food Supply Chain	Block structure, transaction structure, Census Algorithm.
04.	M. A. Habib, M. B. Sardar, S. Jabbar, C. M. N. Faisal, N. Mahmood and M. Ahmad (2020)	Proposed a blockchain system to solve transaction issues with smart contracts of automation of transaction.	General Supply Chain	Transactions, Smart contracts.
05.	K. M. Botcha, V. V. Chakravarthy and Anurag (2019)	Using Internet of Things (IoT) edge devices and Blockchain, proposed a method to improve traceability in the pharmaceutical supply chain.	Pharmaceutical Supply Chain	Block and transaction's structure and Advantages of blockchain.
06.	R. Kumar and R. Tripathi (2019)	The goal of this article is to use Blockchain and encrypted QR codes to address the issue of drug safety (quick response) code protection	Pharmaceutical Supply Chain	Blockchain integration with IoT devices
07.	B. Hegde, B. Ravishankar and M. Appaiah (2020)	Proposes a blockchain-based solution for resolving disputes in the agricultural supply chain.	Agricultural Supply Chain	Issues that can be solved and advantages of blockchain in supply chain
08.	S. Yousuf and D. Svetinovic (2019)	Provides a conceptual overview of how blockchain can be used to improve supply chain management.	Supply Chain Management	Suitability of blockchain in various supply chain stages
09.	F. Qu, H. Haddad and H. Shahriar	Using Ethereum, created an application to showcase the role of smart contracts in completing order transactions.	Business-to-Consumer Supply Chain	Smart Contracts, Business to consumer supply chain models
10.	A. E. C. Mondragon, C. E. C. Mondragon and E. S. Coronado	Investigates the use of blockchain technology in the composite materials supply chain.	Manufacturing supply chains in composite materials industry	Blockchain technologies in composite materials, Distributed ledger
11.	Rajashekaragouda G S and M Dakshayini	Proposed and constructed a trading system in the supply chain domain, which used Hyperledger fabric to create a permissioned Block chain network.	Letter of Credit based Trading system in Supply Chain Domain	Letter of Credit, Hyperledger Fabric, Smart Contract, Permissioned network.
12.	S. Nasih, S. Arezki and T. Gadi	Proposed Blockchain technology as a solution for supply chain decentralisation and disintermediation, as well as its implications for the maritime industry.	Supply chain in maritime industry	Digitalization of maritime industries using Blockchain
13.	J. C. López-Pimentel, O. Rojas and R. Monroy	In the supply chain area, a hybrid blockchain-off chain system was proposed.	Audit Issues in Supply Chain Systems	Blockchain-off chain, intermediate server, architecture

TABLE II
SUMMARY TABLE (CONT.)

SL. No.	Authors (Years)	Proposed System	Domain	Topics of interest
14.	B. M. A. L. Basnayake and C. Rajapakse	Implemented a Blockchain-based solution to certify food quality and agriculture supply chain provenance.	Organic food Supply Chain	Public blockchain, Quick Response Code, Token-based mechanism
15.	R. Kumar and R. Tripathi	Proposed a framework for eligible participants to represent blockchain-based safe infrastructure for medical chain supply.	Counterfeit medicine supply chain	Blockchain, QR Code

III. APPLICATIONS

Blockchain technology can be applied to various supply chains. In this section we talk about a few important supply chains and the advantages and issues that blockchain technology can solve.

i) Pharmaceutical Supply Chain:

- End-to-End tracing: The use of blockchain enables data to be added to the chain at every level and streamline the visibility of movement along each stakeholder through whom the drugs flow in the supply chain. The data stored can be validated and cannot be altered at any node.
- Reduction of counterfeiting of medicines: Blockchain provides a clear path of the drugs flow from manufactures to the end users with all transaction stored in the blockchain. Therefore, it is easier to monitor the parts of the supply chain and reduce fraud and counterfeit.
- Efficient and reliable record keeping: The immutable nature of blockchain makes it a perfect solution for storing records in a secure and reliable method.
- Increase accountability: The nature of blockchain allows easy identification of the previous stakeholder in the chain at any stage. Therefore, if any problem arises the previous stakeholder can be held accountable.

ii) Food Supply Chain:

- Transparency: Data is captured at every stage of the supply chain and is accessible to all the members of the supply chain, therefore blockchain increase the transparency of the data. This transparency in turn reduces the chances of food frauds and also other illegal activities.
- Efficiency: Since blockchain stores data at each stage in digital form and this data is immutable and therefore is more efficient the typical paper-based record keeping system that was not immutable. This provides end-to-end traceability which helps in case of a problem and the accountability is easier.
- Secure: The transfer of information on blockchain is validated and once validated it is replicated at every node of the network making very hard to alter any data.
- Food Safety: Since permanent data is stored in the blockchain, it reduces the chance of adulterating and contamination, it also helps make sure of the food quality by storing details regarding its manufacturing and processing. Blockchain makes it easier for a consumer to verify the source of a product before consumption.

iii) Diamond Supply Chain:

- Preventing Blood Diamonds: The use of blockchain based applications lets every stakeholder store specific detail at each level of the supply chain, the miner stores the region and time when it was mined. This once entered in the blockchain cannot be changed therefore subsequent stakeholder have complete information on the source and thus can prevent buying blood diamonds.
- Prevent theft and Insurance Fraud: The information regarding each diamond is stored on a blockchain making it immutable to change chain. Every purchaser can verify the source and retailer of the diamond therefore making theft diamonds easy to track. This also prevents insurance frauds.
- Prevent Fake diamonds: No information can be added to the blockchain without other stakeholders validating it therefore, it is not possible to include any fake diamonds into the blockchain at any stage of the blockchain.

iv) Manufacturing Supply Chain

- Traceability: The information stored on the blockchain is time-stamped and cannot be manipulated / altered by any third party, which aids in adding traceability to the supply chain. This enables accurate tracking of materials in the supply chain.
- No involvement of Middlemen: The blockchain based solution will allow the merchants to order directly from registered and verified manufacturers to receive orders easily without requiring intermediaries.

- Quality Control: Smart Contracts are used by blockchain based solutions to ensure quality and technical capabilities of products and automatically execute the payments if terms and conditions are satisfied. This prevents the manufacturers from convincing the merchants to use products with low quality control standards.
- Payment: Smart Contracts allow quicker and more automated payments to producers and vendors, resulting in increased cash flow as compared to the traditional system which requires 30-120 days and also involves third parties to make and verify the payment.
- Marketing and Sales Cost: Merchants or buyers can communicate directly with the small vendors who can provide premium goods at fair value quotations and fulfilment in time through the blockchain manufacturing network. This reduces the expenses made for advertisements and hence allows more competitive prices.

v) Automotive Supply Chain:

- Automotive producers can experience frictionless supply chains, reduction in distribution costs, improved lead times, faster delivery and easier supply chain paperwork and management through blockchain based solutions.
- Blockchain will boost the enterprise of all global supply stake holders in the automotive sector by offering increased traceability, enabling digitalization and securing the chains of custody.
- Blockchains in automotive supply chains will not only speed up the innovation but also reduces the frictional costs and provides a decentralized platform which will allow the vendors worldwide to access information about any automotive part just by clicking a button.
- A smooth payment will be ensured by seamless integration of local legislation on the country of origin and destination of the shipments.

vi) Oil and Gas Supply Chain:

- Blockchain based distributed ledger platform enables digitisation of crude oil transactions with enhanced security, optimised efficiency and improved transparency.
- A blockchain based solution will reduce the thread of fraud, cybercrime and tampering. Overhead costs and cash cycle times are also reduced.
- In addition, collaborative interactions can be strengthened via blockchain. Joint venture partnerships with many companies involved in the same project are popular in the petroleum and gas industry.
- Any activity on the blockchain is distributed across all nodes in an immutable manner, allowing regulators to track it.

IV. CONCLUSION

Blockchain technology is gaining popularity due to its ability to improve existing systems in a secure manner while maintaining complete transparency. This article conducts a thorough investigation of the use of blockchain technology in supply chain management. We review the available literature to evaluate possible blockchain applications in the supply chain industry. The application of Blockchain technology to supply chain management is a significant advancement that benefits all parties participating in the supply chain network. A thorough evaluation of existing research is the key contribution of this study to provide a deeper understanding of working and applications of blockchain in supply chains. This paper also discusses some of the applications of blockchain based solutions for important supply chain industries to increase transparency, traceability and achieve decentralization in the network.

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