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Enhancing Supply Chain Management with Blockchain Technology: An Analytical Review on Transparency, Traceability & Security

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ABSTRACT: In recent years, the world of supply chain management has seen exceptional challenges driven by the factors like globalization, intricate networks of stakeholders, and an increasing demand for real-time information. Transparency has become an indispensable element in modern supply chains, where stakeholders demand real-time visibility into the entire value chain. Block chain's immutable ledger ensures transparency by providing a secure and tamper-proof record of transactions. This transparency is much essential when it narrows down to building trust among firms. By combining both Supply chain & Blockchain we can enhance transparency, security, and traceability, ensuring accurate and tamper-proof data. This paper investigates how blockchain technology enables end-to-end visibility, traceability, and transparency through theory and architecture thereby increasing the trust among all participants in supply chain.

KEYWORDS: Blockchain, Supply chain management, transparency, traceability
SOURCE: Website (Google Scholar, Investopedia)

I. INTRODUCTION

In an era where consumers demand more accountability and regulatory requirements for supply chains are becoming increasingly stringent, transparency and traceability have become paramount in logistics and commerce. Blockchain technology, renowned for its decentralized and immutable ledger, is emerging as a powerful tool to bring unprecedented levels of transparency and traceability to supply chain operations.

Blockchain technology is a distributed ledger system that allows secure, low-cost transactions and asset transfers without the need for third-party authentication. Blockchain, originally conceptualized as the underlying technology for cryptocurrencies, has evolved beyond its initial financial applications to become a disruptive force across various industries. Unlike conventional method, which is the centralized business process, Blockchain technology performs in decentralized manner that provides enhanced transparency, sturdiness, auditability, and security. It eliminates intermediaries, improves efficiency, reduces costs and settlement times, and supports new business models by increasing revenue and savings. The decentralized network approves transactions through consensus mechanisms, such as proof of work or proof of stake, making data tampering difficult. Transactions are recorded indelibly in blocks, ensuring data integrity and transparency. Blockchain technology's architecture facilitates interoperability, allowing different organizations to interact, share digital assets, and form partnerships, driving better business value across various sectors, including banking, healthcare, and government. Beyond its foundational benefits, block chain serves as a platform for the integration of emerging technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI).

Blockchain Technology has a significant impact on various sectors and industries like banking, government, healthcare, etc. as follows:

- Removes mediators, improving efficiency, and speed.
- Streamlines operations by reducing cost and time associated with settlements and disputes.
- Empowers new business models by growing revenue and savings.

Transparency has become an indispensable element in modern supply chains, where stakeholders demand real-time visibility into the entire value chain. Block chain's immutable ledger ensures transparency by providing a secure and tamper-proof record of transactions.

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Supply chain management is the monitoring and optimization of the production and distribution of a company's products and services. It seeks to improve and make more efficient all processes involved in turning raw materials and components into final products and getting them to the ultimate customer. Effective SCM can help streamline a company's activities to eliminate waste, maximize customer value, and gain a competitive advantage in the marketplace. The fundamental idea following the supply chain management is that different associations include themselves in a supply chain by trading data concerning market varieties and production abilities. This information exchange improves the management of inventory, information, and money flow among supply chain stakeholders. Accurate demand forecasts resulting from shared information led to reduced inventory levels and overall costs. Exchanging information diminishes vulnerability and smoothens supply chain activities, which is vital because of the intricacy of supply chain coordination and strong contest. In global supply chain management, sharing information benefits all stakeholders by increasing overall profit and execution. Deloitte's digitalization structure changes traditional supply chain processes into a digital supply network (DSN), enhancing efficiency and integration. Regardless of these benefits, challenges such as data tampering, faulty entries, scams, outdated data, and definition misunderstandings persist. Digital technologies play a significant role in integrating and enhancing SC processes. Enhanced information sharing among SC partners improves coordination and performance. The overall focus is on leveraging digitalization and efficient information management to optimize supply chain operations.

In an attempt to build resilient supply chain management, blockchain technology has become a prominent tool, which is a novel technology using distributed and decentralized ledger to trace the real-time movement of goods and services in a supply chain, thus bringing transparent and robust connectivity in the process.

All participants can access detailed transaction information in real-time. In the past, transaction data were stored in a centralized hub system and shared information with direct transaction participants. However, blockchain technology enables people to share all information based on decentralization, security, and smart execution. In other words, all participants can access to transaction details one after another through peer-to-peer networks (refers to decentralization). Moreover, if transactions are performed by signatures, security is enhanced, and ultimately, transparency is secured. Therefore, if any operational problems occur, they can be cooperatively processed promptly.
D'heur highlights that end-users often require information about the provenance and sustainability of their purchased goods. Organizations can improve branding and system efficiency through sustainability features, enhancing stakeholder morale. Blockchain technology ensures data integrity, as transaction data shared with all supply chain stakeholders cannot be manipulated. This transparency boosts customer and organizational confidence. A study by Kairos Future shows blockchain technology's potential in the food industry's supply chain for auditing product quality, labour conditions, and environmental features. However, verifying product-related data like photos requires arbitrary audits. Research indicates limited work on blockchain technology architecture in supply chain is to enhance transparency.

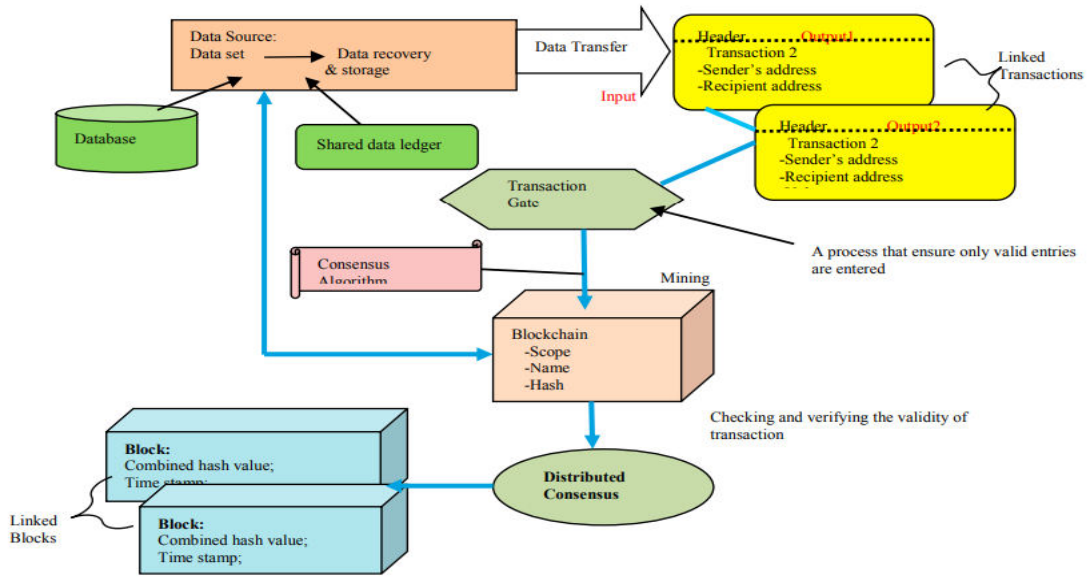

Fig. 1: Blockchain technology architecture

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II. ANALYSIS

2.1 Transparency & Traceability:

Supply chain trust is critical. Once partners in the supply chain face a crisis of trust, sensitive data and information required for cooperation cannot be shared in time, which can easily lead to a bullwhip effect. High trust partnerships can reduce coordination costs and enhance knowledge sharing and information flow between cooperative firms. Supply chain trust helps firms build a flexible supply chain that can improve the ability to deal with uncertainty and allow firms to respond quickly to form a core competitive advantage and meet market needs more flexibly and in a targeted manner. Trust can be gained though visibility i.e. through transparency.

Transparency offers a window into the inner workings of supply chain processes, essential for businesses to build trust among all the participants and stakeholders and maintain brand integrity. At the heart of blockchain's impact is its immutable ledger, ensuring reliable and trustworthy information. Blockchain's decentralized nature allows all stakeholders to access a single, shared source of truth, enabling real-time monitoring.

Traceability is hindered when material information is incomplete or missing; however, the merits of traceability are limited by the complexity within the supply network. Blockchain enables traceability, creating an indelible record of every transaction and movement. This helps in identifying the source of issues and demonstrating compliance with regulations. Blockchain's impact on transparency and traceability is reshaping business operations and consumer perceptions, empowering businesses to build trust and showcase their commitment to ethical practices.

One valuable outcome for the firms from the building of trusting relationships is that such trust-based relationships may represent an opportunity for the firms to access needed strategic assets, such as information, knowledge, and other important resources. Blockchain technology can help firms and their partners build trusting relationships and thus promote mutual trust in the changing process of business relationships. Blockchain technology mainly focuses on generating trust between firms through cooperative relations and interactive processes.

Supply chain transparency drives the adoption of supplier socially responsible practices to both influence customer purchase behaviour and create conditions that force competitors to match their actions, especially for managers with valuable, high visibility brand names. However, high-profile companies such as Apple have followed a policy of secrecy about component sourcing and practices [8] and only released information after extensive social pressure.

2.2 Efficiency and Cost Reduction:

One of the primary sources of inefficiency in traditional supply chains is the involvement of intermediaries, each introducing potential delays and additional costs. blockchain facilitates direct peer-to-peer transactions, cutting out unnecessary middlemen. This not only accelerates the speed of transactions but also significantly reduces costs associated with intermediaries. The introduction of smart contracts takes automation to a whole new level. These self-executing contracts encode and automate complex business rules, ensuring that agreed-upon terms are met without the need for constant oversight. This not only reduces the risk of errors but also enhances the speed and accuracy of transactions, contributing to a more efficient supply chain. Block chain's real-time visibility into transactions provides stakeholders with instant updates on the status and location of goods throughout the supply chain. This transparency not only fosters trust among participants but also enables proactive decision-making. Businesses can respond swiftly to disruptions, optimize routes, and ensure the timely delivery of products. The implementation of block chain in supply chain management yields tangible cost savings. By eliminating intermediaries, automating processes, and reducing the risk of errors, businesses can operate more efficiently and allocate resources more effectively among participants but also enables proactive decision-making. Businesses can respond swiftly to disruptions, optimize routes, and ensure the timely delivery of products. The implementation of block chain in supply chain management yields tangible cost savings. By eliminating intermediaries, automating processes, and reducing the risk of errors, businesses can operate more efficiently and allocate resources more effectively.

2.3 Security:

It is known that the blockchain system helps to reduce the risk of counterfeit or unlicensed products distributed in the region. This is because blockchain is a decentralized record-keeping system. Many industries, such as the food industry, employ this function to their supply chains based on blockchain technology. Particularly, blockchain technology can manage inventory appropriately while tracking cargo and recording and managing cargo history. This makes it possible for consumers to trust the product, because anyone who participates in the transaction can share and verify all the information. Based on these primary functions, supply chain processes and objectives are impacted positively.

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Smart contracts of blockchain technology have an encryption system to ensure a safe user experience, and smart contracts with pre-determined terms remove human judgment from transactions and reduce human risk. After adopting blockchain technology, transaction records are encrypted, considerably reducing the possibility of network attacks and improving the payment security between upstream and downstream customers. Blockchain technology can help consolidate supply chain partnerships.

2.4. Current Blockchain-Enabled Supply Chain Traceability Applications

The first traceability application evaluated is a project enabled by Ethereum. From January to June 2016, yellowfin and skipjack tuna fish were tracked throughout the entire supply chain, from fishermen to distributors. End users could then track the "story" of their tuna fish sandwiches via a smartphone and determine information about the producers, suppliers, and procedures undergone by the end product. Every unit of measure (by fish or by catch) was associated with a digital "token" to confirm a given fish's origin and tracked throughout the supply chain, presenting a viable model for product certification to an end consumer.

Everledger is another blockchain enabled traceability application for the global diamond industry. The company, which partnered with Barclays, created a database of over a million diamonds registered on their blockchain to certify the final cut diamond was ethically-sourced from "conflict free" regions. Similar measures are being used to create an anti-counterfeit database for other valuable goods such as fine wine and art.

III. METHODOLOGY

3.1 The Unified Theory of Acceptance and Use of Technology – UTAUT (Theoretical basis):

The Unified Theory of Acceptance and Use of Technology (UTAUT) was developed through the review and integration of eight dominant theories and models,

#	Theory	Source	Description
1	The Theory of Reasoned Action (TRA)	Ajzen & Fishbein [22]	TRA is used to predict individual behavior based on pre-existing attitudes and intentions
2	The Technology Acceptance Model (TAM)	Davis [23]	End user use and acceptance model
3	The Theory of Planned Behavior (TPB)	Ajzen [24]	TPB is the first model to mention psychological factors related to technology acceptance
4	A combined TBP/TAM	Taylor and Todd [25]	These authors added two factors (subjective norm and perceived behavioral control) to TAM which gave a more complete test of important determinants of technology usage
5	The Model of PC Utilization	Thompson [26]	A competing perspective to TRA and TPB used to predict usage behavior rather than intention to use
6	Diffusion of Innovation Theory (DIT)	Rogers [27]	DIT describes how technological innovation moves from invention to widespread useage
7	Social Cognitive Theory (SCT)	Bandura [28]	Stipulates environmental influences (e.g., social pressures) or unique personal factors (e.g., Personality) are equally significant in determining behavior
8	The Motivational Model	Davis [29]	The core constructs of the theory are extrinsic and intrinsic motivation

Table 1.1. UTAUT Theories

Individually, each theory has been used extensively within several academic disciplines to research individual use and acceptance of information technology. The study revealed that the contributing models explained between 17 and 53 per cent of variance in user intentions; however, UTAUT was found to outperform the eight individual models. For a comprehensive literature review see Williams, Rana, & Dwivedi who examined 174 existing articles on the UTAUT model. These authors empirically demonstrate its soundness as a methodology for explaining individual technology acceptance and use in organizations across a variety of organizations, geographies, and applications.

The UTAUT model presents four main effects for end intention and usage which are performance expectancy, effort expectancy, social influence, and facilitating conditions. The UTAUT identified the four moderators of gender, age, experience and voluntariness of use, but these associations were based on empirically observed correlations rather than on theory and are not included in the resulting conceptual framework. The original four core determinants and respective associations were maintained for this article as they have proven to be reliable determinants in prior research.

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The model provides theoretical guidance for the development of research propositions for the adoption and use of blockchain technologies applied to supply chain traceability. The conceptual model utilizes six of the influential variables from UTAUT.

Additionally, this research introduces two trust constructs of IT innovation adoption which are germane to exploring the promise of blockchain's inherent qualities of supporting transparency via "trust less" trust.

3.1.1 Performance Expectancy
P1. Performance expectancy positively impacts the behavioural intention of using blockchain technology for supply chain traceability.

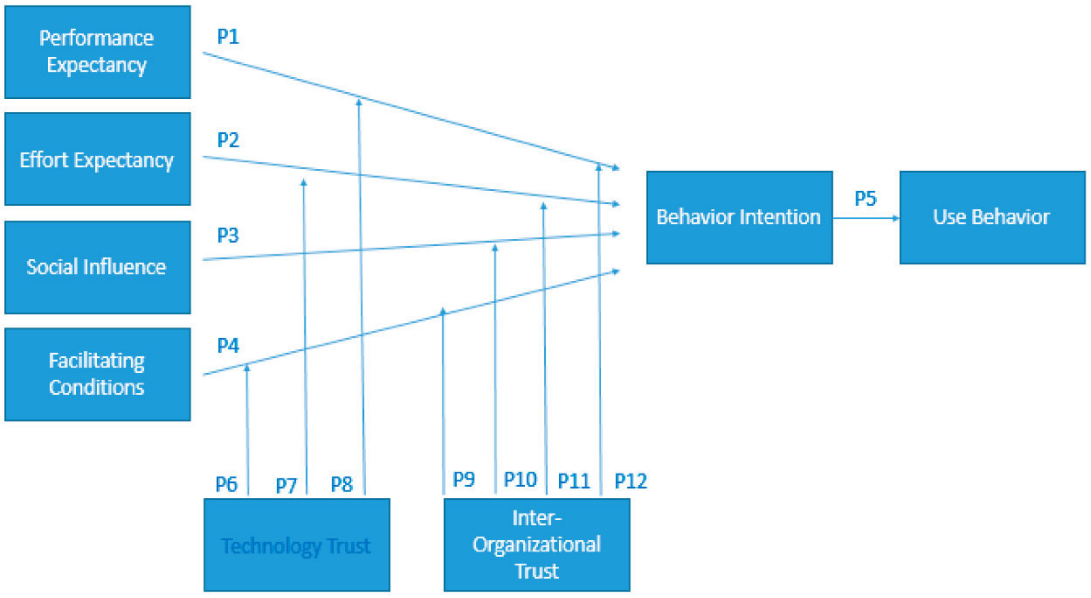

Fig 2. Research Propositions

3.1.2 Effort Expectancy
P2. Effort expectancy positively impacts the behavioural intention of using blockchain technology for supply chain traceability.

3.1.3 Social Influence
P3. Social influence positively impacts behavioural intention to use blockchain technology for supply chain traceability.

3.1.4 Facilitating Conditions
P4. Facilitating conditions (i.e., technical resources and organizational support) positively impact behavioural intention to use blockchain technology for supply chain traceability.

3.1.5 Behavioural Intention and Use Behaviour
P5. Behavioural intention will positively influence the use of blockchain traceability applications.

3.1.6 Technology Trust
P6. Trust in technology positively moderates the relationship between Performance Expectancy and Behavioural Intention.
P7. Trust in technology positively moderates the relationship between Effort Expectancy and Behavioural Intention.
P8. Trust in technology positively moderates the relationship between Facilitating Conditions and Behavioural Intention.

3.1.7 Inter-Organizational Trust
P9. Inter-organizational Trust positively moderates the relationship between Performance Expectancy and Behavioural Intention.

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P10. Inter-organizational Trust positively moderates the relationship between Effort Expectancy and Behavioural Intention.
P11. Inter-organizational Trust positively moderates the relationship between Social Influence and Behavioural Intention.
P12. Inter-organizational Trust positively moderates the relationship between Facilitating Conditions and Behavioural Intention.

3.2. Implementation of Architecture of Blockchain technology

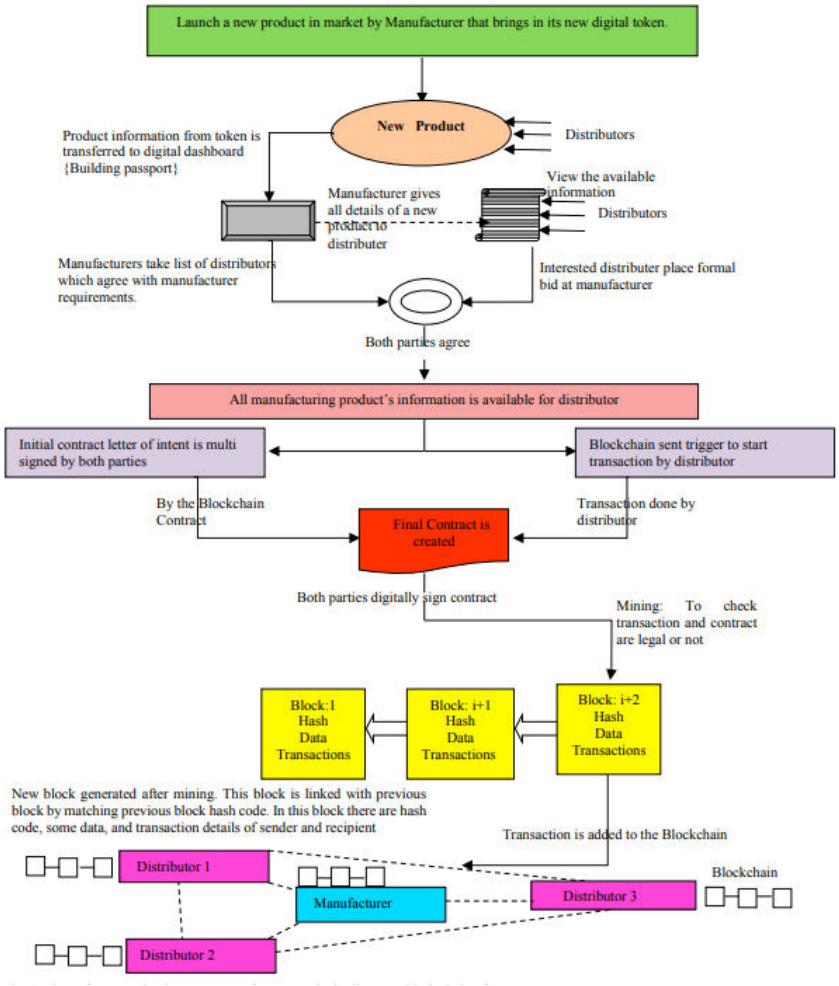

Fig.3 Flow of transaction between manufacturer & distributor with Blockchain

The framework presented in Fig. 3 is an implementation of Blockchain in any manufacturing firm. The manufacturer wants to launch a new product through the distributor to the retailer and then to the customer. Initially, the transaction of the product is done between manufacturer and distributor. At the first stage, the manufacturer brings in digital token required to launch a new product in the market. Every distributor who registered with the manufacturer, can see the digital token of the new product launched by the manufacturer. To have a transaction between the manufacturer and distributor, each party should agree with the requirements mentioned in consensus. When transaction will be processed between them.

Then, blockchain sent a trigger to start the transaction by the distributor. On the other hand, the blockchain contract is generated. After that, mining will be processed after successful transactions. Mining is required to check the authenticity of the transaction. Subsequently, a new block is generated after mining. This block is linked with the previous block by matching the previous block hash code. In this block, the hash code, some data, and transaction details of the sender and recipient are stored. Each block in the blockchain is linearly connected as per time-stamped,

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having transaction data. Thus, blockchain technology enables every stakeholder in the supply chain network to see every transaction. Similarly, blockchain technology can be applied to the transaction between distributor to retailer. Fig. 3 shows the flow chart of the processes to perform the transaction between manufacture to the distributor with the help of blockchain technology. Every node in the supply chain network can see the transaction. In the same manner, transactions can happen between distributors to retailers. Fig. 4 shows the transaction done between manufacturer to distributors and distributors to retailers using blockchain technology.

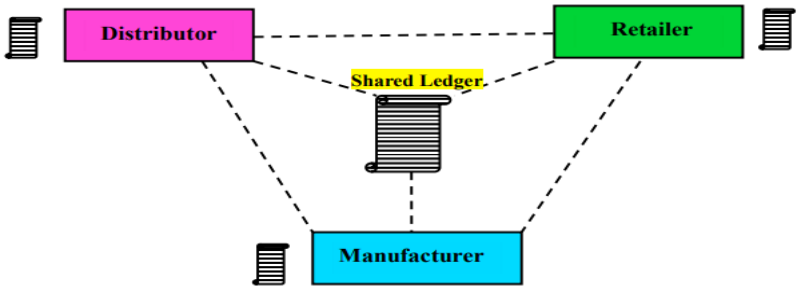

Fig. 4 Blockchain Transactions between Manufacturer, Distributor and Retailer

IV. CONCLUSION

The development and implementation of novel technology does not guarantee that it will be used and otherwise succeed. A theoretical insight is required to better understand the underlying motivators and barriers that will lead companies, or discourage them, from adopting blockchain technologies for supply chain traceability and transparency. This paper introduces the Unified Theory of Acceptance and Use of Technology (UTAUT) to expand the explanation of end user technology acceptance for blockchain traceability applications. This theory provides a robust conceptual framework to explain these relationships and support the development of blockchain tools.

Results after implementation of blockchain architecture shows that transparency is increased, as all the information of transactions done by stakeholders was visible to all partners of supply chain. Further, the trust of every member of the supply chain network was enhanced due to the impact of blockchain technology. The proposed blockchain technology-supply chain architecture upgraded the records of the supply chain process so that the product to the customer within the price and delivery time promised by the manufacturer. Therefore, blockchain technology-based supply chain can be adopted by manufacturing firms to lower the cost of the product and increase the market share in the current competitive scenario. Here, the generalized architecture of blockchain technology in supply chain is proposed. In the future, if a manufacturer shares all the sensitive and private data on the blockchain network, then all parties can access these data that can be misused by other parties in the supply chain network. This will be a serious security issue. Hence, it is necessary to maintain the balance between transparency and confidentiality of information within the supply chain network. Further research could focus on the quality of encryption used to improve the level of security of data.

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