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**RESEARCH ARTICLE**

# Enhancing Supply Chain Transparency, Traceability, and Efficiency through Blockchain and IoT Integration

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**Abstract**
Blockchain and IoT has been a subject of much research interest in supply chain management because it tends to improve traceability and visibility of products. It enables them to address some concerns with data such as data quality or the trustworthiness of the data and the kind of issues with data compatibility that are highly relevant in present day supply chains**.** The main aim of this study is to understand the benefits of combining blockchain and IoT in improving the supply chain's transparency and traceability and also the levels of supply chain optimization attainable with this technology. Both quantitative and qualitative methodology has been implemented for this study where content analysis has been implemented to discuss the study's aim and objectives. 40 were sampled for the quantitative analysis. Descriptive statistics, correlation, and regression analysis were tested. Blockchain and IoT devices are observed to be effective and important for improving transparency and supply chain traceability. Regarding the quantitative analysis; statistically significant relationship has been determined between the variables, implying a strong and positive influence and association between the variables.

**Keywords:** Supply chain; Blockchain; IoT; Efficiency; Performance; Traceability

## Introduction

Blockchain and the Internet of Things (IoT) have emerged as transformative technologies in supply chain management, receiving growing scholarly and industry attention due to their potential to enhance product traceability, transparency, and operational efficiency. Blockchain, a decentralized and tamper-resistant ledger technology, ensures secure, immutable records of transactions, while IoT provides real-time data acquisition through interconnected devices and sensors (Saberi et al., 2019; Min, 2019). When integrated, these technologies address critical data-related challenges such as data integrity, quality, and interoperability that plague traditional supply chain systems (Rejeb et al., 2022). In centralized systems, issues like tampering, data silos, and single points of failure persist; however, blockchain's distributed structure mitigates these risks, while IoT enhances the

granularity and immediacy of data collection (Sunny et al., 2020; Sharma et al., 2020). For example, blockchain facilitates end-to-end traceability by allowing all stakeholders within a supply chain network to monitor product flow and verify product authenticity. This is especially crucial in sensitive sectors such as agri-food and pharmaceuticals, where trust and safety are paramount. Complementarily, IoT technologies offer real-time monitoring of environmental conditions, such as temperature and humidity, ensuring that perishables like food or medicine maintain required standards throughout the supply chain (Miguel Pincheira Caro et al., 2018; Kshetri, 2018). Moreover, blockchain enhances transparency and trust among supply chain partners by reducing opportunities for fraud and ensuring that shared data is tamper-proof and verifiable (Piera Centobelli et al., 2021; Kouhizadeh et al., 2021). This trust-building aspect has implications for strengthening supplier-buyer relationships and improving collaborative decision-making. The primary objective of this study is to examine the synergistic impact of integrating blockchain and IoT in improving the transparency, traceability, and optimization of modern supply chains. Specifically, the study aims to: (1) evaluate the potential of blockchain in securing supply chain-related data; (2) assess the role of IoT in facilitating real-time monitoring and predictive analytics; and (3) explore how the convergence of these technologies can reduce inefficiencies, mitigate risk, and enhance overall supply chain performance.

The study is well structured, where the Introduction provides an overview of the problem, research objectives, and the significance of integrating Blockchain and IoT in supply chain management. The Literature Review Reviews the existing body of knowledge on blockchain and IoT technologies, their individual roles in the supply chain, and their combined potential. It also highlights research gaps. Methodology describes the research design, data collection methods, analytical approach, and limitations of the study. Results and Findings Presents the analysis and key outcomes derived from the study's methodology, showcasing the impact of blockchain and IoT integration. Discussion Interprets the findings in the context of the literature, discussing their implications for theory and practice. Conclusion and Recommendations Summarizes the main insights, answers the research questions, and offers recommendations for practitioners and directions for future research.

## Literature review

Blockchain implementation in conjunction with IoT is regarded as one of the promising approaches in supply chains because the characteristics of the considered models regarding efficiency, transparency, and traceability have improved. Blockchain, a digital distributed ledger technology with records being unquestionable and unchangeable, is secure from many problems such as falsification and rigging. Some of them point to the growing use of the blockchain in supply chain automation with the help of IoT gadgets for tracking activities in the supply chain in real time. These devices, connected to the blockchain, allow for constant updates on the flow and status of commodities, making it simpler to track and analyse issues with the supplies in the chain (Wu et al., 2022). In the adjustment of the agro-food sector especially, the use of blockchain has been revealed to possess promising capabilities concerning the safety of food items and the general eradication of contamination and fraud. Since IoT sensors are always compounding data and sending this information, blockchain guarantees that the data is protected while being shared with everybody and is more transparent and traceable (Babu et al., 2023). Besides, their capability to record permanent data also provide a robust ground to enhance reliability among the chain members and to make them more liable (Langat, and Guo, 2023).

However, there are some constraints which hinder the implementation of B2B commerce. One of them is with scalability problem because the blockchain may have a problem to handle a lot of data that pertains to the supply chain processes. Some of them include zero-knowledge proofs, cryptographic solutions, sharing but one main

hitch is compatibility (Saxena et al., 2023). For block chain to work optimally in managing supply chains, the following challenges have to be addressed.

**Conceptual framework**

**Figure 1.** Conceptual framework for the study variables

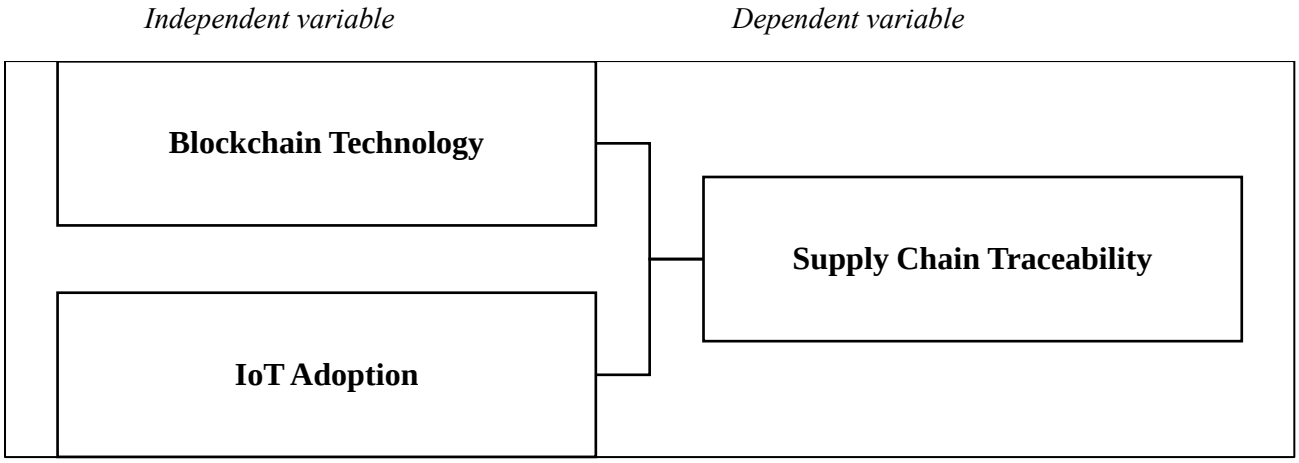



Figure 1. Conceptual framework

Source: Authors construct, 2025

**Hypotheses development**

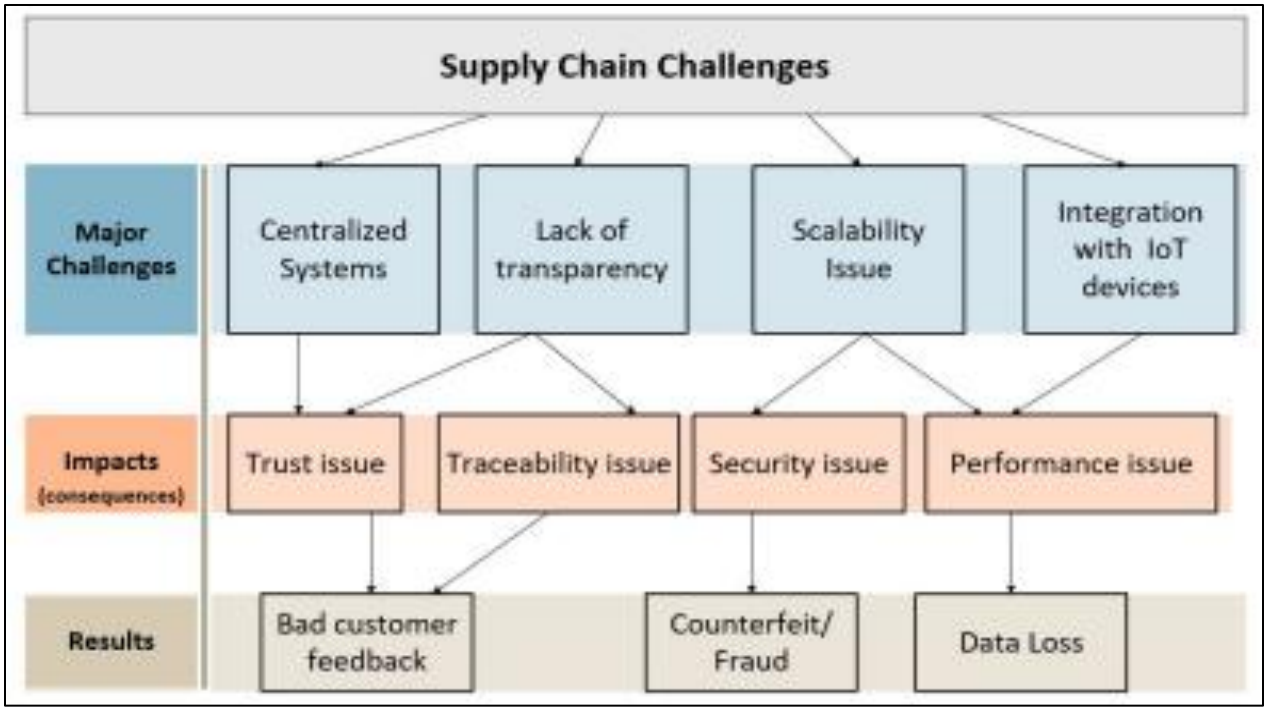
*$H_1$: Blockchain Technology has a strong and positive association with supply chain traceability*

*$H_2$: IoT adoption has a strong and positive association with supply chain traceability.*

Figure 1 highlights the conceptual framework of the study variables. Based on the innovation techniques used for maintaining transparency in supply chain; it is described by Wong et al. (2024) that supply chain traceability has been increased using technologies and it is being used for ensuring safety and also preventing any manufacturing and distribution of counterfeit materials. This is important since it helps in improving the overall efficiency of the supply chain and it is achieved by the blockchain technology and Internet of Things combined. This is also discussed in Sunny et al. (2020)'s study where the integration of blockchain and internet of things that is being used for improving the supply chain traceability and it is able to improve the end-to-end visibility as well. Moreover; as per Hellani et al. (2021)'s study, it is observed that using the blockchain features such as smart contracts, it is able to secure data sharing and also implementing real time monitoring. This helps I improving the overall supply chain ecosystems and ensure that there are no lapses in the supply chain. This is important since it is used to improve the transparency of such a supply chain and is considered to be a secure and efficient method to improve its operations (Kumar and Pundir, 2020).

As per the description provided in figure 2; it is observed that the current supply chain systems are found to struggle in leveraging its productivity due to the conventional methods still in use. However, this is addressed in Khan et al. (2022)'s study where the use of technologies specifically blockchain technology have been increased and improved transparency and traceability.

**Figure 2.** Supply chain challenges and complexities




**Source**: Hellani et al. (2021)

Figure 2 shows the complexities and challenges of supply chain and its major impacts. This known challenge assists in enabling informed decisions and also assists the industry to address any factors that can hinder its supply chain with a lot of ease. The combined use between both the blockchain and the IoT devices also assists in enhancing the accountability and also the difficulty in identifying any wrong information (Brandín and Abrishami, 2024). This is because the method enables data to be gathered in real time and also meets its industry requirements, in this case. It is quite significant and mandatory from the blockchain perspective since it plays a role in distinguishing many problems that cause problems for the organisation (Almabrok, 2023). The combined use of both the blockchain and the IoT devices helps in increasing its accountability and also reduces the possibility of identifying any incorrect information (Ramkumar et al., 2022). This is because of its ability to collect data in real time and also complying with its industry regulations.

**Methodology**

In this research, the strategy is to adopt blockchain and IoT solutions in supply chain transparency and accountability. This needs a decentralised ledger which is crucial in storing secure data that which are irreversible and central to the protection of crucial supply chain information as postulated by Saberi et al., (2018). IoT devices result in real time visibility and tracking of assets in the supply chain which highly enhances the supply chain transparency and efficiency (Raza, and Singh, 2022). Both quantitative and qualitative method and its approach is utilized in decision making to determine the extent of the tool in fostering transparency and sustainability measures and by evaluating the psychosocial factors important to adoption. 40 participants were sampled related to the topic and statistical tests are applied such as descriptive statistics, correlation, and regression analysis to

discern the relationship between the variable. Moreover, the methodology uses smart contracts in blockchain to manage the transactions and ensure that the data between different actors of the supply chain are synchronous. This not only makes the functioning smooth but also reduces many dangers related to the computation of dat

**Table 1**. Inclusion & exclusion search criteria

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| Journal articles published post 2020 | Journals and articles published prior 2020 |
| Articles and journals concern themselves with supply chain transparency, traceability, blockchain | Journals and articles do not focus or mention about blockchain, supply chain transparency, and traceability |
| Journals and articles published in the English language | Published in any other language |

**Source:** Langat, and Guo, 2023

Table 1 shows how literature was sought, themes where carefully analysed by the use of inclusion and exclusion criteria. Since performance issues such as latency and informants could arise in the execution of smart contracts, consensus algorithms are used to ensure the blockchain network can handle a large volume of transactions without compromising on the security of the network or the time it takes to execute that transaction (Langat, and Guo, 2023).

## 4. Results

**Table 2**. Descriptive Statistics of variable

| Metric | Blockchain Technology | IoT Adoption | Supply Chain Traceability |
|---|---|---|---|
| Mean | 4.19 | 4.25 | 4.27 |
| Median | 4.00 | 4.00 | 4.33 |
| Mode | 4.00 | 4.00 | 4.00 |
| Standard Deviation | 0.23 | 0.36 | 0.36 |
| Minimum | 4.00 | 3.67 | 3.67 |
| Maximum | 4.67 | 5.00 | 5.00 |
| Count | 39 | 39 | 39 |

Table 2 shows the descriptive statistics of variables. Blockchain technology has a considerably low standard deviation i.e. 0.23 and indicates that there is a consistent opinion about its role in supply chain traceability. On the other hand; IoT adoption experiences moderate intensity standard deviation of 0.36 and it indicates that there are some variations in responses regarding its role. Similarly, the dependent variable i.e. supply chain traceability also has similar intensity standard deviation that merits similar interpretation. As all the variables' mean values are above 4; it indicates that there is a strong perception attested with blockchain technology and IoT adoption

and it is perceived that these technologies are able to significantly contribute towards the supply chain's traceability.

**Table 3.** Correlation of variables

| | Blockchain Technology | IoT Adoption | Supply chain traceability |
|---|---|---|---|
| Blockchain Technology | 1 | | |
| IoT Adoption | 0.624 | 1 | |
| Supply chain traceability | 0.719 | 0.700 | 1 |

Regarding the correlation analysis in table 3 above, it is observed that the variable blockchain adoption shares a strong and positive association with IoT adoption i.e. its coefficient value is 0.624. It indicates that an increase in blockchain technology tends to increase IoT adoption as well. Similarly, the relationship between blockchain adoption and the dependent variable i.e. supply chain traceability is also strong and positive. With the coefficient value being 0.719, it is signified that an increase in blockchain adoption strong influences the supply chain traceability as well. On the other hand, similar level of association and strength is observed between the dependent variable and IoT adoption but with a slight reduction in its strength i.e. coefficient value is 0.700.

**Table 3.** Model Summary

| Regression Statistics | |
|---|---|
| Multiple R | 0.999 |
| R Square | 0.997 |
| Adjusted R Square | 0.970 |
| Standard Error | 0.225 |
| Observations | 39 |

Table 4 shows the model summary of the study. Ozili (2023) states that the acceptable R-square value is higher than 0.50, highlighting the statistical significance of the relationship shared between the independent variables. As per the model summary; the R square value is 0.997 or 97% that shows the amount of variability provided by the predictor variables on the supply chain traceability.

**Table 4**. Analysis of variance

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 2 | 715.24 | 357.62 | 7069.63 | 0.00 |
| Residual | 37 | 1.87 | 0.05 | | |
| Total | 39 | 717.1111 | | | |

Sig. value of 0.00

Table 5 indicates that since the model's significance value is 0.00; it is determined to be a goodness of fit model and its causal relationship between the variables can be determined through the model. In other words, the model's explanatory power is adequate and can be used for the regression analysis.

**Table 5.** Relationship of variables

| | Coefficients | Standard Error | t Stat | P-value |
|---|---|---|---|---|
| Intercept | 0 | #N/A | #N/A | #N/A |
| Blockchain Technology | 0.612205 | 0.130 | 4.702 | 0.000 |
| IoT Adoption | 0.402786 | 0.128 | 3.144 | 0.003 |

Sig. value of 0.00

Per the coefficients in table 6, blockchain technology is found to share a statistically significant relationship with the dependent variable i.e. supply chain traceability as its significance value is 0.00. This shows that an increase in blockchain technology is also bound to increase the supply chain's traceability. Similarly, IoT adoption with its significance value 0.003, it is claimed that it also shares a statistically significant relationship with the dependent variable.

**Discussion**

As per the findings observed in the results; it is observed that there is a significant influence and impact observed on the supply chain traceability and transparency. It is in line with Biswas et al. (2023)'s study where traceability has been improved due to effective use of blockchain technologies. Moreover, Azevedo et al. (2023)'s study also observed that supply chain transparency and traceability experienced a substantial improvement through blockchain use as the industries are able to become assured of both the products and processes to ensure sustainability and are able to communicate better with its logistics base, which reduces the traceability loss. Regarding the blockchain and IoT in supply chain; it is observed to provide substantial benefits to the agricultural firms since the blockchain technology is able to provide a decentralised ledger while the IoT devices helps in collecting real time data. This is important since it helps in identifying each stage's visibility and also assess the supply chain from the initial process to its execution. On the other hand, the use of blockchain is also effective in improving its traceability since once the data is stored, it helps its stakeholders to track its origin and also the movement and condition of its productions (Ada et al., 2021). This helps in maintaining quality controls and also helps in optimising its supply chain as well. This is quite imperative for the organisation in general and its supply chain in particular since it helps in implementing predictive maintenance and also establishing smart contracts (Centobelli et al., 2022). This is because blockchain helps in powering its automated payment process through smart contracts and also helps in confirming its delivery as well.

This mitigates the use of third-party involvement and thus also ensures that there is a decrease in human errors and simultaneously improves its efficiency as well. Combing both the IoT devices and the blockchain technology helps in implementing real time data collection since it helps the agricultural sector to assess and evaluate the market changes and also reduces disruptions (Biswas et al., 2023). In other words, the industry gains a higher amount of agility and thus is in a position to maintain a strong control over its supply chain. It is quite important and imperative from the blockchain's perspective since it helps in identifying major issues that can create issues for the organisation. This in turn makes supply chain more flexible to change and its capacity to identify significant disruptions can also be easily avoided (Khan et al., 2022). It is also observed that the use of blockchain is also used for better decision making and also minimising any delays in the production process. This helps the organisation to respond better to any changes in the industry and the market and thus can make incremental changes substantially. With regards to the data integrity; both the blockchain technology and the IoT devices are important because it ensures its data is protected and secured permanently and cannot be compromised. This is quite important for the data integrity since blockchain helps in safeguarding its accuracy along with the data's

authenticity as well. It is also important for providing real time data authentication since data is stored securely on blockchain and thus mitigates any possibility for any unauthorised changes to the data.

**Practical Implication for business**

Businesses can provide stakeholders, including consumers and regulators, with real-time, verifiable data on the origin, movement, and status of goods throughout the supply chain. Blockchain's immutable ledger combined with IoT sensors enables end-to-end visibility, allowing businesses to track a product's journey from raw material to the end user. IoT devices capture real-time data (e.g., temperature, location, and condition), while blockchain ensures the secure and transparent sharing of this information, leading to optimized operations. Blockchain creates a single source of truth for all participants (suppliers, manufacturers, logistics providers, retailers, etc.), fostering trust and collaboration. Businesses can monitor and report on the environmental and social impact of their supply chains, as blockchain ensures data integrity and IoT provides granular tracking.

**Conclusion and Recommendations for business**

The combining of blockchain and IoT for supply chain has revolutions that lead into increase aspect that cover the following aspects; transparency, traceability and data validation. Blockchain provides for secure and unalterable record keeping as its ledger is not changeable, whereas IoT guarantee timely tracking of products as they transit through the supply chain process. Such integration eliminates fraud and inefficiencies and enhances stakeholders' responsibilities and reliability in order to make the supply chain process stronger and more efficient. It is also suggested that to derive the optimal value from combining blockchain and IoT in supply chain industries, businesses should first employ smart contracts which are automated transactions hindering efforts from human interference such as payments, shipments and delivery. IoT investment is crucial in order to obtain information on the state of products as well as their flow in real time. Organizations should also go slow on the blockchain technology adoption, initially testing solutions within compliance segments or supply chain tracking, to gain credibility in the software. Including Interoperability to make partners organizations work in efficient manners is a priority while improving cybersecurity for IoT devices reduces vulnerability.
The second of the suggested strategies for blockchain and IoT integration in supply chains is to concentrate on scalability. Consequently, the supply chain slows down when the data load and transactions increase as businesses evolve. Therefore, it is favourable for the blockchain networks to be scalable without negatively affecting the speed and security. The same applies to IoT systems since the number of connected devices is continuously growing while data transmission should not be interrupted. This way, when the chain of supply market evolves the supporting technology can grow along with it providing high operational performance and integrity of the network.

**Direction for further research**

Further research areas in the field of enhancing supply chain transparency, traceability, and efficiency through blockchain and IoT integration span several technical, operational, and socio-economic dimensions. These areas aim to address existing challenges, unlock untapped potential, and refine the application of these technologies in real-world settings. Below are some promising directions for future research: Scalability and Performance Optimization, Interoperability and Standardization, and Smart Contracts and Automation.

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**Authors contribution:** All the authors contributed in the preparation of the paper. The first author handled the concept, helped in write-up and review as well as conducted the data analysis. The second author worked on the literature review, and the third author handles the methodology

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