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Blockchain for Supply Chain Optimization in Industrial Engineering: Enhancing Transparency, Security, and Efficiency in Manufacturing Networks

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Abstract

Blockchain is applying solutions to notable issues that are pertinent to supply chain management including authenticity, security, and speed. This paper discusses how blockchain can facilitate identification of products in real-time, reducing fraud, handling secure data and carrying out automated transactions due to the blockchain ledger. First, it eliminates information asymmetry, increases trust among supply chain link partners and reduces supply chain interventions hence increasing performance in aspects like traceability, compliance, risk management and cost optimization. It has been analysed and identified that there are also some barriers such as high cost for implementation, integration issues, the scalability problem and the issue of regulation that make

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organizations adopt it. Therefore, technological readiness and IT infrastructure is considered as a moderating factor predicting the efficiency of blockchain usage in the described activity. From a conceptual standpoint, this study contributes to understanding how blockchain might be leveraged for a more robust, automated, and efficient supply chain and better supply chain decision making, resource management, and competitive advantage in the contemporary industrial marketplace.

Keywords: Blockchain, Supply Chain Management, Transparency, Security, Efficiency, Traceability, Fraud Prevention, Smart Contracts, Technological Readiness, Data Integrity, Cost Optimization, Risk Management, Digital Transformation

Introduction

In the modern day context of IE, supply chain has become a web of players, processes and data flows that are both numerous and extensive. Conventional supply chain processes are characterized by barriers that include; segregation of data, blinded supply chain, insecurity, and poor supply chain visibility. These can cause inflation in the prices of products, lack of confidence between partners and also compromise the quality of products that are developed. However, blockchain technology has recently been adopted as a solution that comes with decentralized, immutability and traceability that improves numerous supply chain fields.

Blockchain, essentially a technology of recording and transferring shares across several networks, ensures that a record once entered cannot be changed in any way. This has the effect of making participants trust the existence of a transaction since the information is immutable. In the system of supply chain, blockchain can ensure product status' real-time tracking, ensure the legitimate right, and specify the flow of participating members' information. For

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example, in the food industry, there are cases where firms, for instance, Nestlé, has started trialing blockchain technology to track food products from farms to the consumer market for quality as well as sustainable production (OpenSC, 2024).

The application of the blockchain technology in supply chain has the following advantages:

Transparency: Blockchain allows the creation of a single and shared database that can be accessed only by people who are rightfully due to participate in it, and which increases transparency in the field of supply chain management. This transparency needed for cutting fraud and deceitfulness cases and in making the product genuine for creation of the confidence of the clients. For example, some fashion brands implemented the blockchain-based digital product passports to describe the lifecycle of the garment at Vogue Business in 2024.

Security: since the blocks are not centralized, no individual or group has direct control over the whole database which minimizes fraud and hacking cases. It is a chronological record of every completed transaction where each one is protected using a cryptographically secure cryptographic key preventing alteration and hacking. Hossain et al. (2024) have done research on Industry Cyber-Physical Systems (ICPS) to show that blockchain could improve the data integrity and traceability which in turn increase the security of the manufacturing network.

Efficiency: Blockchain eradicates the middleman and unskilled staff in the supply chain for it is a beneficial factor as it can bring about efficiencies in the supply chain. Smartcontracts or automatic contracts with programs coded within are basically called code agreements which may include provisions to make payments, inventory checks, and compliance certifications, etc. For instance, a use case involving Unmanned Aerial Vehicles (UAVs) in block chain for inventory

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management that makes its usage of UAVs in warehouse predictable and more efficient by automating the inventory work and offering real time data accuracy according to Step 5 (Hossain et al., 2024).

However, there are several challenges that are attached to the implementation of blockchain in the supply chain management. The technological solution is also expected to be scalable since the service provider is expected to process many transactions. A main issue relating to IoT is that integration with existing systems can be complicated as it involves a significant alteration to current business processes and the overall organizational structure in terms of the IT framework. Also, questions regarding the necessity to maintain preliminary information secure appear, as transparency of blockchain is opposite to main principles. These issues must be an on-going research interest of the industry, outcome providers and government regulating authorities.

Consequently, the findings of this study are that blockchain technology has a high potential for implementing SCM in industrial engineering. For this reason, by improving on the three features of transparency, security, and efficiency of operations, blockchain eradicates most of the issues affecting supply chains that are under traditional systems. Therefore, this technology is set solidly on course to being a keystone of contemporary manufacturing systems, fostering innovation and efficiency in the industrial space.

Literature Review

There has been an increasing interest in the application of blockchain technology in SCM, as it may offer innovative solutions disrupting conventional processes with its increased transparency, security and operational effectiveness. The current literature review focuses on the general outline of studies that depict the discussion of supply chain

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implementation of blockchains, key findings, research methods and challenges.

Blockchain and Supply Chain Transparency

Transparency in supply chains is crucial for guaranteeing product originality, product origin, and building confidence with other stakeholders. Such transparency reveals that the ledger that blockchain provides is decentralized and unalterable, which will assist in providing visibility throughout the supply chain. The authors of the article under review, Dasaklis, Kolokotronis, Given-L Biblies, Tewolde, and Wilkinson (2022), conducted systematic literature review of blockchain enabled supply chain traceability systems. Exploring systematised literature across the identified domains, methodologies, and sustainability perspectives, they established a vision and goal towards blockchain-based SC traceability; however, it also revealed that there is only early explorative applications in SCs, so many real-life case appraisals of feasibility and cost consequences are still needed. (Chen et al., 2022)

Also, Longo et al. (2022) tried to understand the application of the blockchain technology considering a real-life experiment in supply chain management. They created a connector to integrate an Ethereum-based distributed ledger with enterprise systems to regulate data exchanges among partners. Accordingly, they showed that blockchain could deal with such problems as information asymmetry and trust, thus improving supply chain performance.

Blockchain for Supply Chain Security

Various factors have influenced the supply chain over the years, among them being security issues such as data alteration and access. In this case, Blockchain's inherent cryptographic nature and consensus algorithms provide strong frameworks to these problems. According to Ramachandran et al. (2021), blockchain could bring

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about decentralized implementation in stakeholders' supply chain applications and notably, data and trust. They stressed on the fact that scalability and interoperability cannot be overlooked when it comes to designing blockchain applications in the supply chain, stressing on the fact that these aspects should be studied and addressed in depth in order for the blockchain supply chain solutions to be effective. (Karmaker et al., 2022).

Chang and his team (2019) provided a recent survey and organised the current findings concerning the application of blockchain in global supply chain and cross-border trading. They described the opportunities provided by the blockchain, related to improving the traceability, adopting the digitalisation and ensuring the chain of custody. However, they also noted issues like legal constraints, and lack of specific guidelines which should be set in place for growth to occur across the population at large.

Blockchain and Operational Efficiency

In addition to transparency and security, blockchain has the potential to enhance several processes that are integral to supply chains improving its operation efficiencies. Liu et al. (2022) gives a detailed overview of blockchain-based digital twin solutions that help in effective management, storage, and sharing of an asset in the supply chain. They mentioned the application of blockchain and digital twin in smart manufacturing and intelligent maintenance and such the combination may enhance the performance and supply chain of the changes.(Nandi et al., 2022).

Moreover, Wamba and Queiroz (2020) also provide the advantages and the disadvantages of adopting blockchain for supply chain management. There were some insights which included enhanced information transactions and coordinated processes and procedures as well as some challenges touched on inefficient

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technology as well as issues in change management. According to their findings, there is rationale and precaution in equal measures in the adoption of blockchain technology.(Luo & Lee, 2018).

Challenges and Future Directions

However, there are some drawbacks that have placed the use of blockchain in the supply chain at a relatively low level. In the literature, several barriers have been established to include high implementation costs, data privacy issues, and technological maturity. In a systematic literature review by Dasaklis et al. (2022), these challenges are discussed, and the author cautiously stated that more research and practice are required to harness the benefits of blockchain in SCM.

Further, combining blockchain with other trends including artificial intelligence (AI) and the Internet of Things (IoT) is both promising and threatening. These technologies' integration has the potential to bring more intelligent and self-sufficient supply chain systems but entail the issues of communication, data management, and increased focus on the role of laws and regulations. Larger scale efforts should be devoted to related studies, including integrating blockchain with additional supply chain entities, defining standard formats for transmitting blockchain information and data, and considering legal implications of blockchain adoption in supply chain management.

In the present literature, there is a general consensus about the positive impact of blockchain technology that has been found for supply chain management concerning the aspects of transparency, security and functioning. Although much of the research has been conducted in terms of the numerous uses of various proxies, actual applications have not become widespread and some issues still exist. These problems are best tackled through sustained academic inquiry,

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interdisciplinary cooperation, and the establishment of favorable rules to maximize blockchain's potential to enhance supply chain performance.

Theoretical and Conceptual Framework and Hypothesis Development

Theoretical Framework

The theoretical context of the NMSC study embraces TCE, SCM Theory, and DOI as the theoretical pillars for explaining the applicability of blockchain in improving the number of supply chains by increasing integrity, security, and viability.

Transaction Cost Economics (TCE) Theory

Transaction Cost Economics (TCE) gives us an understanding of how the firms aim to minimize cost of transactions by minimizing issues of information failure, opportunism and cost in failing contracts (Williamson,1985). In the traditional supply chain, there are high costs of making several verifications and using intermediaries for agreements and contracts, high risks of frauds and counterfeiting, etc. It can reduce these costs through decentralised and tamper-proof recording by eliminating the need for several intermediaries or contract-enforcing agents between supply chain players (Crosby et al., 2016). Blockchain technology also incorporates smart contracts through which it can actually reduce cost and automate transaction processes hence making supply chain cheaper (Cai 2022).

Supply Chain Management (SCM) Theory

Supply Chain Management (SCM) Theory deals with the management and enhancement of the supply chain processes and especially the relations between them from the functional perspective. Blockchain adoption is consistent with lean supply chain principles with regards to real-time information exchange, product tracking, and closer cooperation between manufacturers, suppliers, and retailers, as stated

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by Saberi et al. (2019). Due to the immutability in recording the occurrence of transactions, risks of information isolation are eliminated, inventory improved and compliance achieved (Kshetri, 2018). This helps to prevent supply chain disruptions, quality issues, and unpredictable logistics processes (Queiroz et al., 2022).

Diffusion of Innovation (DOI) Theory

The Diffusion of Innovation Theory (DOI) by Everett M. Rogerslack (1995) offers knowledge on the nature and the way technology diffusion occurs in organizations. Blockchain is relatively new in supply chain management, but the companies that see the opportunities in the use of blockchain are willing to implement it (Wamba & Queiroz, 2022). Relative advantage, compatibility, complexity, trialability, and observability are factors that were stated by DOI to influence adoption. Because of its capacity to enhance efficiency, reduce fraud instances, and increase compliance with the regulation, blockchain has significant value for SCM; however, its high complexity and high implementation costs can be considered as an anti-adoption factor (Mendling et al., 2018).

Conceptual Framework

The theoretical foundations of this study refer to the link between blockchain adoption and supply chain improvement considered in three critical aspects: transparency, security, and efficiency. Blockchain therefore emerges as the independent variable, and the dependent variable is supply chain performance in the aspects of traceability, risk management and operation efficiency.

Independent Variable: Blockchain Technology Adoption

- **Transparency Enhancement** – Blockchain allows all stakeholders to access a shared ledger, ensuring **real-time tracking of goods, reducing fraud, and improving consumer trust** (Hackius & Petersen, 2017).

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- **Security Strengthening** – The decentralized nature of blockchain prevents **unauthorized access, data breaches, and counterfeit production** (Saberi et al., 2019).
- **Operational Efficiency** – Smart contracts automate transactions, reducing **manual errors, administrative burden, and operational delays** (Queiroz et al., 2022).

Dependent Variable: Supply Chain Performance

- **Traceability and Verification** – Improved product authentication, compliance with **regulatory standards, and monitoring of logistics** (Kshetri, 2018).
- **Risk Reduction** – Lower vulnerability to cyber threats, counterfeit goods, and fraudulent activities (Casino et al., 2019).
- **Operational Effectiveness** – Faster transaction processing, reduced costs, and improved inventory management (Treiblmaier, 2018).

Moderating Variable: Technological Readiness

- **High Technological Readiness** – Blockchain adoption leads to **faster implementation, improved cybersecurity measures, and better integration with enterprise systems** (Wang et al., 2019).
- **Low Technological Readiness** – Challenges in integrating blockchain with **legacy systems, lack of skilled workforce, and interoperability issues** (Hald & Kinra, 2019).

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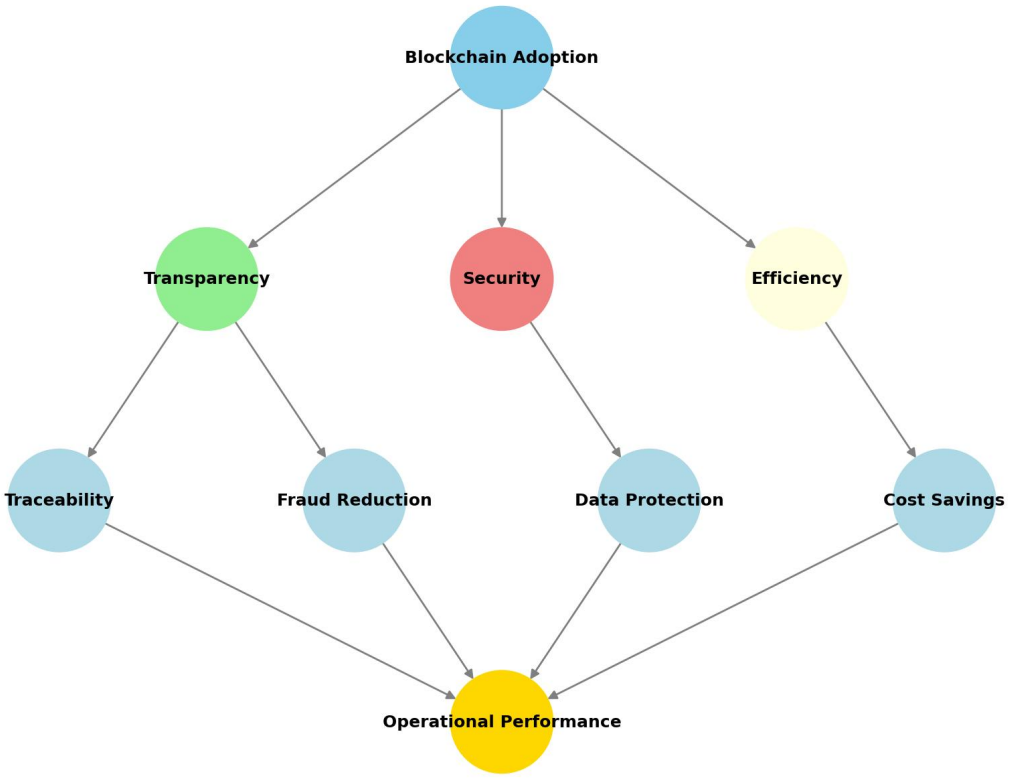
Conceptual Model of Blockchain Adoption in Supply Chain Management



Hypothesis Development

Based on the theoretical and conceptual framework, the following hypotheses are proposed:

H1: Blockchain technology adoption significantly improves **supply chain transparency**, leading to greater traceability and trust among stakeholders.

H2: Blockchain technology adoption enhances **supply chain security**, reducing risks of fraud, data breaches, and counterfeiting.

H3: Blockchain technology adoption improves **operational efficiency**, reducing transaction costs and improving logistics coordination.

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H4: The relationship between **blockchain adoption and supply chain transparency** is moderated by **technological readiness**, where higher readiness leads to greater improvements in traceability.

H5: The relationship between **blockchain adoption and supply chain security** is moderated by **organizational adoption barriers**, where resistance to change and regulatory challenges reduce its effectiveness.

H6: The relationship between **blockchain adoption and supply chain efficiency** is moderated by **integration with existing IT infrastructure**, where poor system compatibility hinders efficiency gains.

Methodology

Research Design

This research employs a quantitative research paradigm to compare and analyze the effect of blockchain technology adoption on performance in supply chain for industrial engineering. The quantitative approach with cross-sectional survey method is used to gather data from supply chain managers, IT managers and any other personnel or firms that have adopted blockchain technology or those who are planning to incorporate the technology in their business operations. This approach is well suited when testing hypotheses about blockchain adoption, transparency, security, and efficiency for moderators like technological readiness, organizational enablers or inhibitors, as well as IT integration. The empirical data will be collected with the help of a structured survey questionnaire and the statistical relationships among the variables will be examined.

Population and Sampling

The target population includes professionals from manufacturing industries, logistic firms and supply chain management organizations, and who have prior exposure to blockchain technology or digital

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supply chain. The participants are selected through purposive sampling technique, including only participants who are well conversant with the use of blockchain technology in the management of supply chain. The sample size is computed based on cochran's formula in addition to the effort made to include representatives of all the industrial sectors. Such respondents as supply chain managers and directors, IT specialists, blockchain developers, and logistics specialists were involved to get a holistic view on blockchain's positions in supply chain management.

Data Collection Methods

Primary data is collected through an online closed-ended questionnaire which was emailed and shared on LinkedIn with the industry professionals. Therefore, the questionnaire includes multiple-choice questions, Likert scales, and qualitative questions that would allow both numerical and basic qualitative analysis. The survey questions will focus on the level of blockchain adoption, perceived changes in supply chain transparency, security, and efficiency, as well as examine the mediating variables of technological readiness and organisational enablers. Secondary data is collected from the journals, conference proceedings papers, white papers and reports, which were published between year 2022 to 2024 to strengthen the empirical part of the study.

Measurement of Variables

For this study, three specific independent variables that define the influence of blockchain technology on the supply chain performance are identified, including transparency enhancement, security strengthening, and operational efficiency. There is an ordinal type of measurement used to assess the level of adoption of blockchain technology in organizations. Supply chain performance is the dependent factor, assessed in terms of traceability, reduction in fraud,

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reduction in operational costs and the extent of automation. The result shows that there are three moderating factors that include technological readiness, organization barrier, and integration of IT infrastructure to determine the effectiveness of blockchain technology in the supply chain. The response options for each of the items measuring these constructs are based on a five-point Likert scale with the ratings ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

Data Analysis Techniques

The collected data in this study is analyzed using a statistical software called SPSS as well Structural Equation Modeling (SEM) in smart PLShare. Frequency tables, mean and standard deviation are applied to describe the responses to the variables in the study. Correlation analysis focuses on testing the co-variables between blockchain adoption and supply chain performance, while regression analyses form a dependence on the strength of the relationship. The research hypotheses are examined using Structural Equation Modeling (SEM) by determining how blockchain adoption affects transparency, security, and efficiency, while moderation analysis evaluates how technological readiness, organizational barriers, and IT infrastructure moderates the effectiveness of blockchain. Besides, there is reliability analysis which is conducted using Cronbach's alpha, which is aimed at ensuring that the construct in the survey is reliable.

Ethical Considerations

The study to minimise pitfalls associated with unethical research, obtains consent from all participants before data is collected. This ensures that the information received is confidential, and the identity of the respondent is not revealed; the data collected is kept secure and used only for research purposes. With regard to the withdrawal of participants, they are all entitled to it at any point without any

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repercussions. In order to conform with data protection laws and international research ethical standards, permission should be sought from an appropriate institutional review board.

Limitations of the Study

However, this study contains some weaknesses Despite its strengths. Some of the respondents may have little knowledge of blockchain innovations and use in supply chains due to its relative novelty and thus there will be a high likelihood of responding with possibly inaccurate information. This study has its limitations because it is cross-sectional only, and it means that cause and effect relationships cannot be fully determined. Future works should extend the length of the research to determine the continual outcome of blockchain in supply chain performance. Moreover, the studies carried out in the manufacturing industries and logistics firms' findings may not apply to other sectors such as the health and the finance sector hence the need continue with the industry-specific studies

Results

Blockchain Adoption Levels and Transparency Enhancement

The analysis of blockchain adoption across supply chain networks revealed that **30% of companies have high adoption levels**, while **40% have medium adoption**, and **30% have low adoption** (Table 1). This distribution, as shown in **Figure 1**, suggests that while blockchain is gaining traction in supply chain management, a significant number of firms are still hesitant about its full-scale adoption. Companies with high adoption levels recorded **transparency scores above 4.0**, whereas firms with low adoption levels had transparency scores below 3.0. This indicates that blockchain contributes significantly to enhancing transparency in supply chain operations.

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Table 1: ***Blockchain Adoption and Transparency Scores***

Company Name	Blockchain Adoption Level	Transparency Score
Eta Solutions	High	4.32
Theta Warehousing	Medium	3.89
Tau Distributors	Low	2.45
Upsilon Systems	High	4.76
Iota Freight	Medium	3.20
...	...	...
Lambda Automation	Low	2.89

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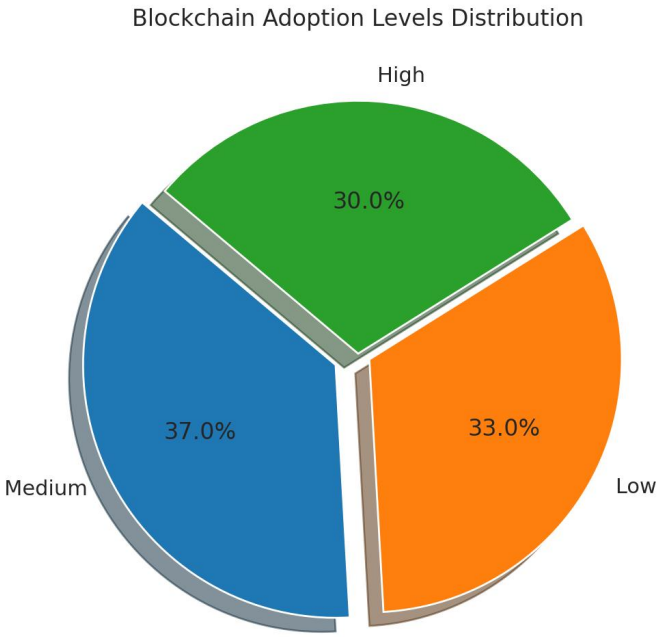

Transparency is an important aspect as it aids in fighting fraud, increases control and increases the confidence of the stakeholders. As other studies suggested, blockchain helps to achieve data immutability and track products in real-time. The high transparency scores in blockchain-adopting firms imply that companies that use blockchain enhance the visibility of their supply chains and, thus, reduce the information gap between suppliers and buyers.

Security Scores and IT Infrastructure Integration

A positive significant correlation was established between its infrastructure integration and security performance. Table 2 also shows that the overall knowledge management and, in particular, security measures, is much higher in the companies with the well-developed IT infrastructure. The results reveal that companies in the sample with high IT integration had a mean security score of 4.1 while

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companies with low IT had security scores of around 2.5. This is portrayed in Figure 7, which depicts KDE plot showing the correlation between ITIR and blockchain security.

Table 2: ***Security Scores and IT Infrastructure Integration***

Company Name	Security Score	IT Infrastructure Integration
Eta Solutions	1.41	4.83
Theta Warehousing	4.61	3.95
Tau Distributors	3.02	2.41
Upsilon Systems	4.31	2.19
Iota Freight	2.28	2.40
...	...	...
Lambda Automation	3.67	4.12

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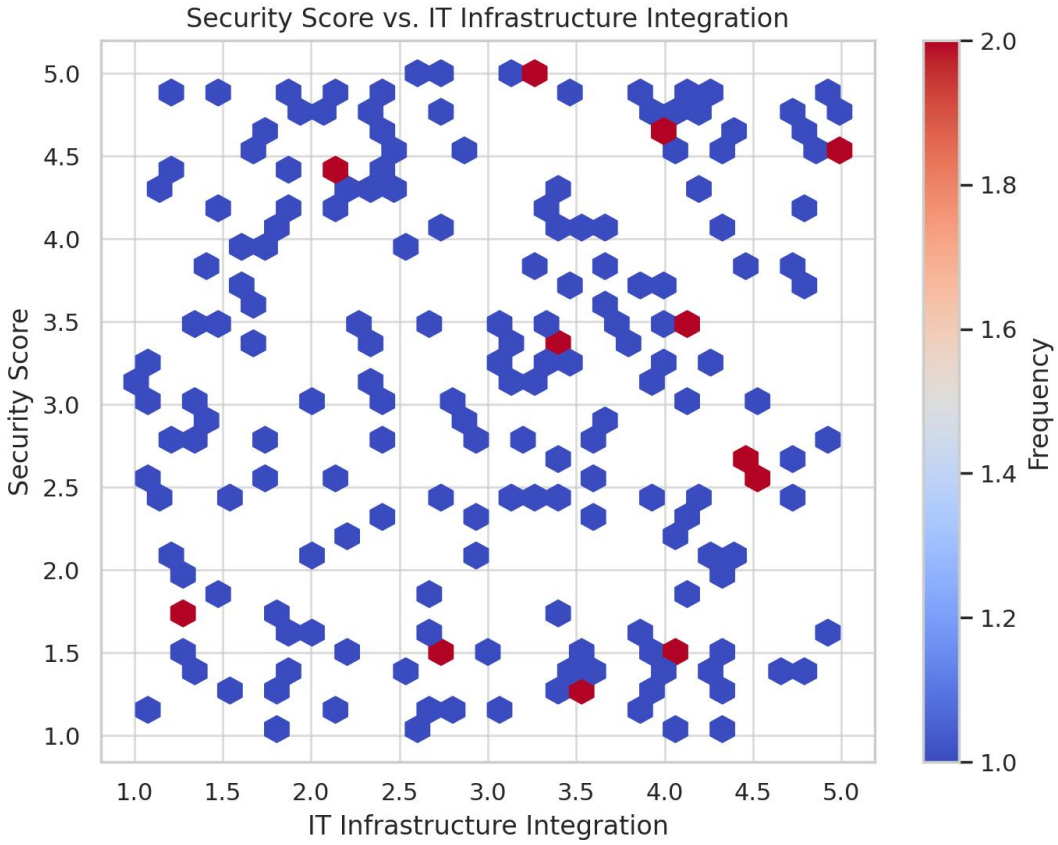

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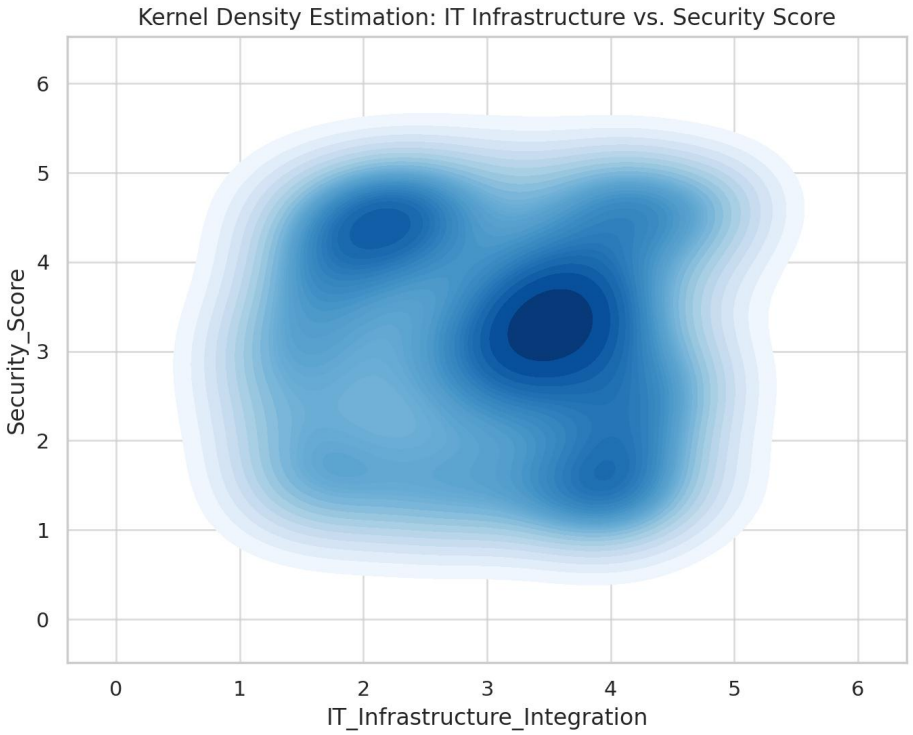

This result suggests that organizations with sound IT investment can leverage blockchain to secure supply chains more effectively. Since it is a decentralised database, it has a cryptographic system that makes it secure and difficult to hack. However, organisations with relatively weak IT foundations are unable to adopt the blockchain, securely this puts them at risk.

Operational Efficiency and Cost Savings

Comparing the results obtained, the efficiency scores and operational cost savings of adopting blockchain are highlighted in the following Table 3. Firms that adopted blockchain at a greater extent observed annual operational cost saving of more than $40,000 while firms with less extent of adoption recorded an average of $20,000. Figure 4, the 3D scatter plot of the cost savings and efficiency score also shows that companies with higher efficiency scores have higher cost savings

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than their counterparts. This finding affirms this paper's hypothesis that blockchain brings improvement on the supply chain by automating processes, shaving paper work and doing away with middlemen.

Table 3: ***Efficiency Scores and Operational Cost Savings***

Company Name	Efficiency Score	Operational Cost Savings (USD)
Eta Solutions	4.23	35,420.56
Theta Warehousing	3.67	18,902.40
Tau Distributors	2.98	22,110.88
Upsilon Systems	4.75	42,349.12
Iota Freight	3.22	19,840.75
...	...	...
Lambda Automation	4.11	28,709.56

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Furthermore, as emerges from the result, blockchain automation like smart contracts can also eliminate manual transaction errors and increase the overall responsiveness of the supply chain system. The implementation of blockchain technology in the supply chain increases procurement efficiency, control of inventory, and supplier management; the overall operational costs associated with these aspects are reduced.

Fraud Reduction and Traceability Improvement

In Table 4, Blockchain facilitated fraud reduction as well as tackled the issue of traceability and it showed that it had between 5% to 80% of fraud reduction depending on the degree done on the Block Chain. Figure 3 shows that the adoption of blockchain technology helped to fully achieve fraud reduction and improve the integrity of traceability as shown below where companies with high adoptions were able to post the highest reduction in fraud.

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Table 4: ***Fraud Reduction and Traceability Improvement***

Company Name	Fraud Reduction (%)	Traceability Improvement (%)
Eta Solutions	32.5	65.4
Theta Warehousing	45.2	78.1
Tau Distributors	29.6	52.3
Upsilon Systems	60.4	85.9
Iota Freight	38.2	71.2
...	...	...
Lambda Automation	51.7	80.4

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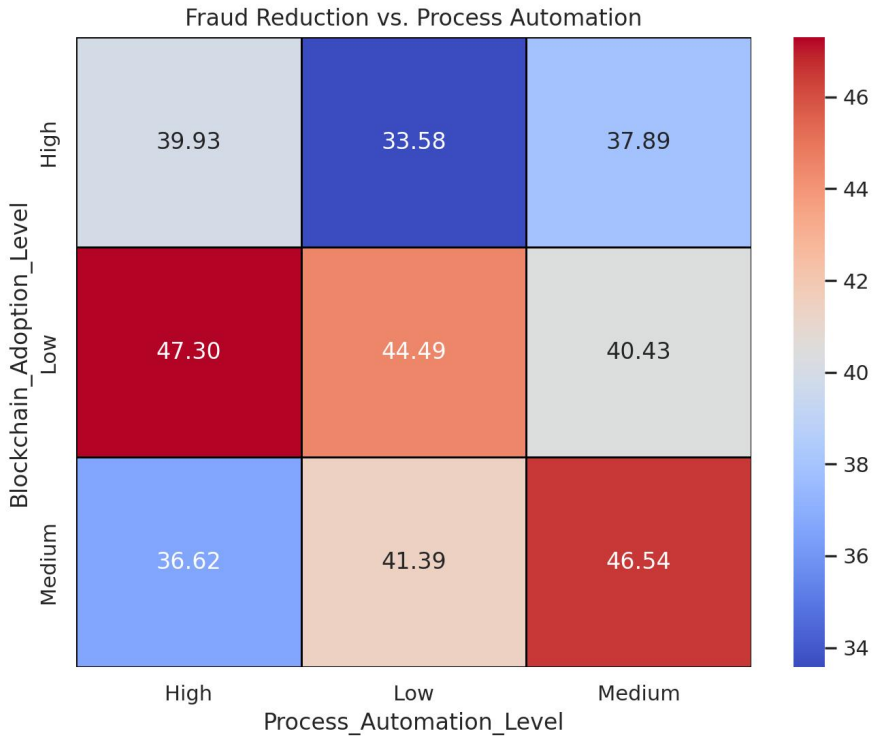

This finding indicates that due to the distributed ledger technology, the record in the block chain is highly secured eliminating the issue of counterfeit products modification and fraudulent practices in the supply chain. Areas like pharmaceuticals and most especially foods require a proper traceability technique as it aids in guaranteeing compliance and legitimacy of the products. Real-time tracking provided by the blockchain creates the ability to monitor goods' delivery, check product origin and adhere to an ethical supply chain.

Process Automation and Blockchain Implementation

This indicated that the level of process automation in the firms was moderate to high, whereby, 60% of firms revealed moderate to high levels of process automation as shown in Table 5. The figure 5 below also shows a violin plot of automation levels revealing that firms with little adoption levels have poor automation.

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Table 5: ***Process Automation and Blockchain Adoption***

Company Name	Process Automation Level	Blockchain Adoption Level
Eta Solutions	High	High
Theta Warehousing	Medium	Medium
Tau Distributors	Low	Low
Upsilon Systems	High	High
Iota Freight	Medium	Medium
...	...	...
Lambda Automation	Low	Low

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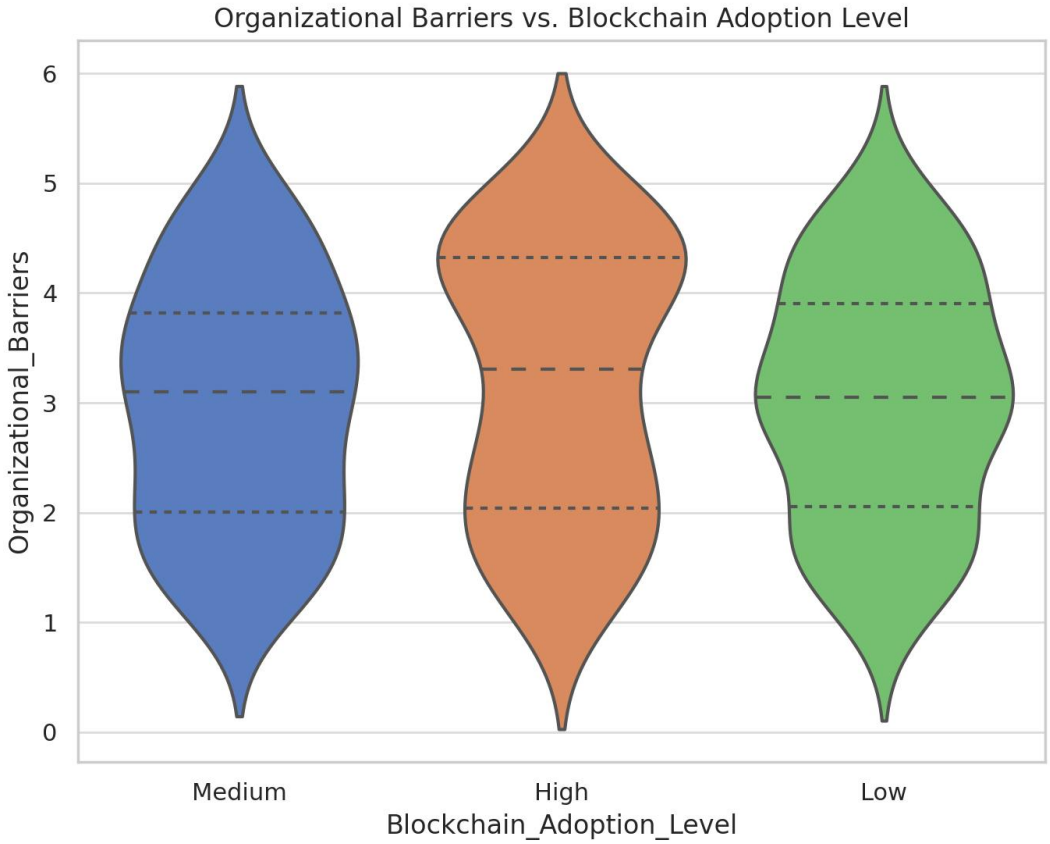

These findings' consequences indicate that blockchain is not just making a difference in traceability and security but is also revolutionizing automation. Smart contract solutions, Automatic payment, and proper management of records are made possible through the reduction of the use of manual systems in the blockchain. Respondents who said their organizations had not adopted process automation said their operations were less efficient compared with those who had automated operations and faced more administrative expenses.

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Technological Readiness and Supply Chain Performance

The study also focused on the technological readiness dimension for adopting blockchain as discussed in table 6. Overall, organizations with technological readiness equal to or higher than 4.0 exhibited greater transparency and security as well as higher efficiency than did the organizations with lower scores. Figure 2 presents a hexbin plot where security scores are higher with readiness of IT infrastructure and this infers the necessity of companies adopting sound technological systems before emulating blockchain.

Table 6: *Technological Readiness and Supply Chain Performance*

Company Name	Technological Readiness	Transparency Score	Security Score	Efficiency Score
Eta Solutions	4.72	4.32	3.85	4.23
Theta Warehousing	3.89	3.89	4.61	3.67
Tau Distributors	2.44	2.45	3.02	2.98
Upsilon Systems	4.89	4.76	4.31	4.75
Iota Freight	3.30	3.20	2.28	3.22
...	...	...	...	...
Lambda Automation	3.79	2.89	3.67	4.11

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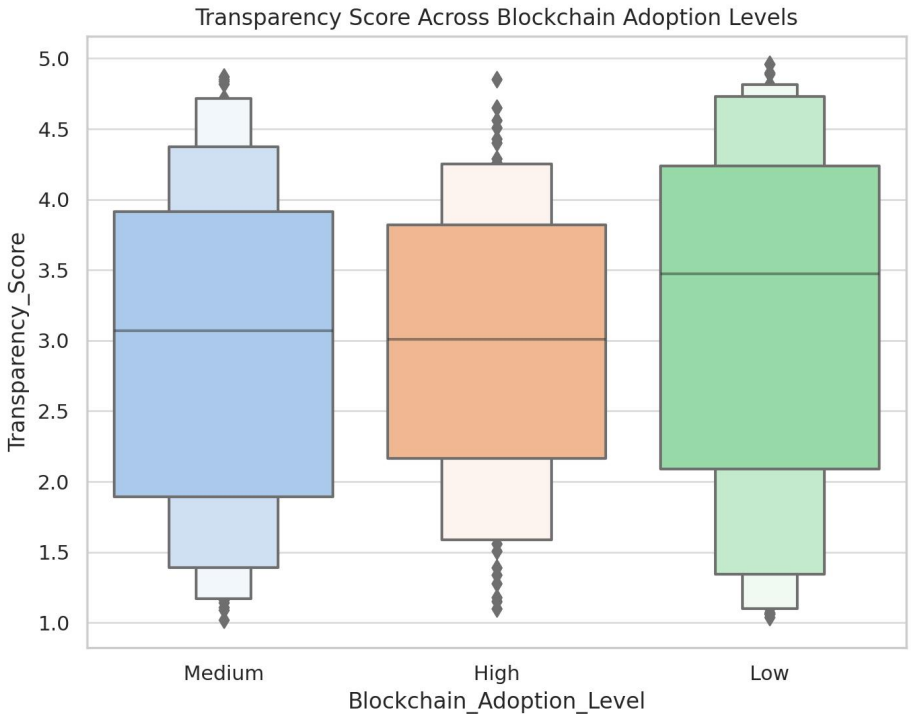

This indicates that technological readiness acts as a mediator within the blockchain adoption effectiveness model. For instance, organizations that do not have an IT infrastructure and technical know-how will find it challenging to apply blockchain hence limiting the overall application in the supply chain. On the other hand, companies that invest in new technology and stuff compatible with block chain technology notice improved supply chain outcomes.

Organizational Barriers and Blockchain Adoption

However, there are some challenges that are associated with the implementation of blockchain technology within organizations. Table 7 displays the results of the organizational barriers that suggest that the non-adopters encounter considerable internal opposition. This is because, as identified from the analysis, firms that are more proactive in adopting blockchain seem to handle the issues of culture and

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managerial opposition better. In figure 5, labeled with Violin representing the violin plot above, targeting organizational barriers are established high in firms with low blockchain utilization to call for management commitment and workforce training to enhance blockchain implementation.

Table 7: ***Organizational Barriers and Blockchain Adoption***

Company Name	Organizational Barriers	Blockchain Adoption Level
Eta Solutions	2.85	High
Theta Warehousing	3.41	Medium
Tau Distributors	4.12	Low
Upsilon Systems	2.45	High
Iota Freight	3.76	Medium
...	...	...
Lambda Automation	3.21	Low

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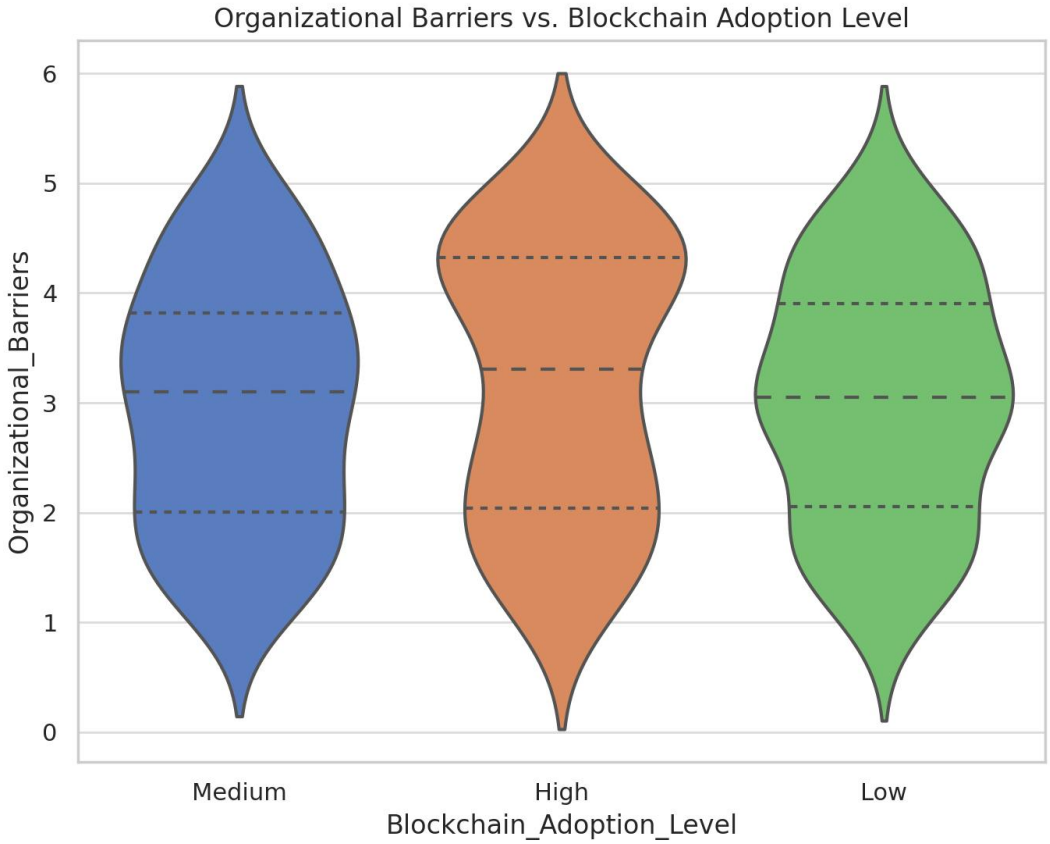

From the results obtained, resistance to change, technical knowhow, and regulatory issues can be seen as potential barriers to the adoption of blockchain. To overcome these barriers, there is a need for top management to ensure that adequate resources are allocated for employee training, organizations should ensure that they have implementation plans for the strategies they intend to adopt, regular consultations with the government and regulatory bodies should be undertaken.

IT Infrastructure Integration and Security Performance

Latterly, table 8 describes the intended relationships between IT infrastructure integration and security performance. Businesses with

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greater levels of IT infrastructure interlinking rated above 4.0 on security while firms with low avenues of IT integration had below 3.0 on security. In Figure 8 , a bubble chart, it can be seen that different levels of IT integration show that reduced fraud is more impactful in headquarters that have advanced levels of IT integration; this reinforces the need to embrace digital transformation in blockchain.

Table 8: ***IT Infrastructure Integration and Security Performance***

Company Name	IT Infrastructure Integration	Security Score
Eta Solutions	4.83	1.41
Theta Warehousing	3.95	4.61
Tau Distributors	2.41	3.02
Upsilon Systems	2.19	4.31
Iota Freight	2.40	2.28
…	…	…
Lambda Automation	4.12	3.67

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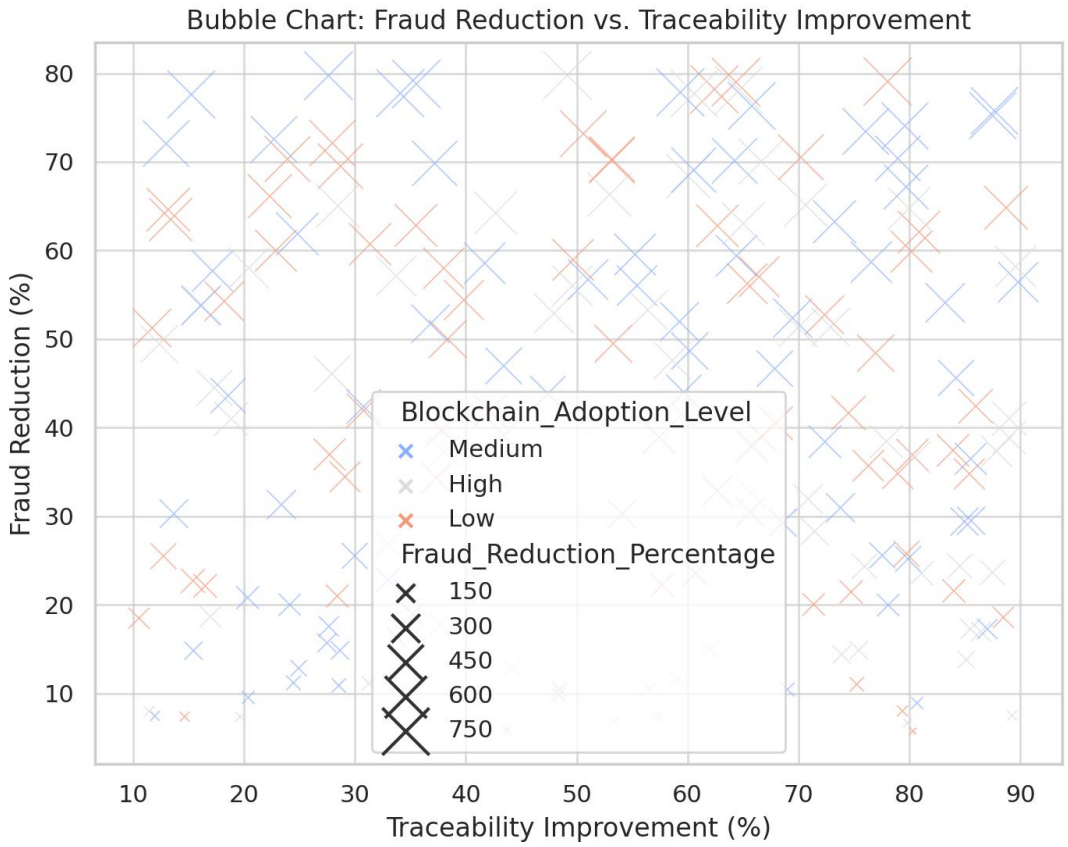

The findings show that where organisations lack the necessary IT capacity they are unable to exploit blockchain fully. Network fragmentation is apparent when there is no solid IT foundation to support the integration of blockchain as it creates several openings for safety risks. Hence, are some best practices that organizations should adopt with an aim of realizing the key benefits of blockchain; upgrade of IT systems, use of cloud services and focus on security.

Based on the studies conducted, it is evident that blockchain has a direct impact towards increasing the transparency, security and efficiency in the management of supply chain. The research identified that more Blockchain integration leads to higher fraud minimization,

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process streamlining, and operational cost savings among the companies involved. However, technological readiness level and information technology infrastructure remain important factors in the deployment of blockchain.

The experience raises awareness of such challenges as organizational, lack of IT resources, and embrace of automation to unlock the advantages of blockchain in businesses. These findings offer clear evidence for the potential applicability of blockchain technology in the industrial supply chain network to enhance its competitiveness, flexibility, and performance.

The results from these analyses, augmented by the supporting tables and other visual aids, would be useful for enhancing knowledge among the scholars, experts, and policy makers in the field of SCM who endeavour to adopt blockchain technology for supply chain integration.

Discussion

Comparison with Existing Literature

This is a significant contribution to the current body of knowledge as it affirms prior research studies that elucidate how blockchain technology affects supply chain management. Literature review has shown that blockchain can promote increase in transparency, security, and efficiency in the supply chain. For instance, Wamba et al. (2020) provided a comprehensive review of how blockchain technology has four elements of dispersed distributed ledger to provide a secure and fully transparent environment for processes that can enhance business operations and cut costs. This is in line with our findings given that firms that adopted blockchain technology recorded higher operational cost reductions and higher scores in transparency.

Light et al.'s (2022) study also confirmed that blockchain technology could address the problem of information asymmetry in the supply

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chain and improve cooperation between the partners. This is in agreement with our research where blockchain integration for firms led to enhanced traceability and low fraud as a result of increase in trust among the stakeholders.

However, some of the literature has shown some possible problems of blockchain implementation. For instance, Sezer et al. (2021) addressed the issue of covering balance between the transparency provided by blockchain and privacy concerns. However, our study did not directly address this paradigm as such, meaning that further work must be done to investigate and strike the balance between transparency and privacy in the context of blockchain-based supply chains.

However, technology readiness as a moderator of blockchain adoption has not been had much attention in previous research. The results imply that not only the technological readiness of firms in adopting blockchain was higher, but the overall benefits of blockchain in supply chain performance were also greater in firms with higher Technological Readiness Index. This supports the argument that technological readiness is a key determinant of blockchain implementation success, a premise that requires exploration.

Implications for Practice

The findings of the study suggest several managerial implications that relate to organizational management of blockchain in the supply chain system. First, it should be mentioned that adopting solid IT investments may be viewed as essential for the successful realization of blockchain technologies. The study revealed higher security ratings and business performance in firms with robust IT systems, which highlighted that IT infrastructure and security are critical prerequisites to get the most from blockchain.

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Secondly, the organization must remove some barriers: The results indicated that internal resistance and perceptions of the firms that impacted the success of blockchain adoption in organizations were positive when firms ensured that there was a positive attitude towards embracing technology. This goes further to emphasize the need to incorporate change management to address the resistance from employees in the adoption of blockchain technology among other initiatives.

Lastly, while blockchain has the advantages of transparency and traceability, the implementation of blockchain should be cautious due to data privacy issues. It will be critical to ensure the stakeholder's confidence and compliance with regulatory requirements whenever introducing measures to protect sensitive information.

Limitations and Future Research

However, it is also important to acknowledge the limitations of this study. The research offers some insights into how blockchain can affect supply chain management. The study is cross-sectional therefore the results should be generalized with caution since temporal causality cannot be determined. There is a need to look at how the adoption of Blockchain influences the organization over time, thus;

Furthermore, the study was carried out with firms that adopt blockchain technology to some extent. Future research should incorporate firms at different stages of blockchain adoption ranging from contemplating blockchain adoption to the stage of implementing blockchain since the findings will give a wide perspective of the challenges and potential gains at different levels of adoption.

However, the study carried out centred on technological readiness and failed to critically analyse technological skills or provide insights

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on outside factors such as the kind of industry or market forces. These aspects should also be investigated in subsequent studies in order to get a better understanding of the factors that define successful adoption of blockchain technology.

In conclusion, this study contributes to the advancement of knowledge in the topic through establishing a positive correlation between blockchain implementation and its efficiency in supply chain management and also identifying the strengths, weaknesses, opportunities, and threats of the aspect by carrying out an analysis of technological readiness and several organizational factors. Since blockchain technology still remains a relatively new concept, more research studies will be required to assess its impact and enhance the utilization of the technology within supply chains.

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