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The Impact of Blockchain Technology on Transparency and Traceability in the Supply Chain of the Food Industry

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Abstract: This thesis explores the revolutionary potential of blockchain technology, emphasizing its implications for improving transparency and traceability. Food safety, authenticity, and sustainability are major issues that the food industry must deal with. These issues can have a big impact on customer confidence and safety. In order to properly handle these issues, traditional supply chain systems frequently lack the traceability and transparency features that are required. But blockchain technology provides a decentralized, immutable database that safely and transparently records transactions, which is a promising option. This study investigates the theoretical underpinnings and real-world uses of blockchain technology while conducting a critical analysis of the state of the food industry's supply chain using secondary data from published academic articles. It assesses the effect of blockchain technology on improving transparency and traceability in food supply chains by combining findings from other academic publications, taking into account elements like data integrity, information sharing, and stakeholder participation. This thesis emphasizes how blockchain technology has the possibility to revolutionize supply chain transparency and traceability in the food business. Through the utilization of blockchain's intrinsic characteristics, such decentralization and cryptographic security, stakeholders can augment consumer trust, alleviate hazards, and cultivate increased accountability along the food supply chain.
Keywords: Blockchain technology, Food supply chain, Traceability, Transparency, Socio-economic impacts, Stakeholder perspectives, Reliability & security, Immutability, Internet of Things (IoT), Consensus mechanism.

I. INTRODUCTION

A. Blockchain

Blockchain is a complex but increasingly relevant technology. Essentially, blockchain is a distributed database:

1) Consider a digital ledger that is copied and dispersed among a network of computers rather than being kept on a single server.
2) The ledger is fully replicated on every computer connected to the network, and it is updated

and verified continuously.

B. What differentiates blockchain from other technology:

1) Immutability: Once information is added to the blockchain, it can't be altered or deleted. This creates a tamper-proof record of all transactions.
2) Security: Cryptographic techniques secure the network and ensure the integrity of data.
3) Transparency: All participants can access the entire ledger, promoting trust and accountability mostly recognized for securely tracking ownership and transactions using cryptocurrencies like Bitcoin.

However, its applications are not limited to the food business.

Monitoring the provenance and travels of food items

- Enhancing the safety and traceability of food
- Fostering openness and customer trust

C. How Blockchain technology is used on transparency and traceability in the supply chain of the Food industry:

Capturing and Recording Data: Sensors and the Internet of Things: Real-time data such as temperature, humidity, and position can be obtained by sensors installed in industrial plants, transportation vehicles, and farms. After that, the blockchain is supplied with this data, producing a verifiable history of every product's journey. RFID tags: Specific RFID chips that hold data on a product's origin, processing stages, and certifications can be attached to it.

Access to this data is possible at any stage of the supply chain by scanning these tags.

1) *Smart contracts:* These self-executing agreements have the ability to take action in response to preset parameters. For instance, a smart contract might pay a farmer automatically when their crop reaches a predetermined spot.
2) *Data Exchange and Availability:* Shared ledgers: A single shared ledger with all product data is accessible to all authorized supply chain actors. Information flow is streamlined as a result of the removal of the requirement for numerous paper-based records and central databases.
3) *Access for consumers:* Through QR codes or specialized platforms, consumers can obtain product information. This enables consumers to make knowledgeable decisions based on criteria such as certifications, sustainability practices, and place of origin.
4) *Regulatory compliance:* To verify adherence to food safety requirements and other laws, regulatory organizations can use blockchain data.

D. The Impact of Blockchain on Transparency and Traceability in the Food Industry:

The food industry continues to face difficulties with traceability and transparency across its intricate supply networks. Blockchain technology offers a promising way to increase transparency and trust in food systems with its distributed ledger and tamper-proof records.

1) *Improved Product Traceability:* All actions are tracked: Food goods can be tracked at every stage, from processing and origin to retail and transit, thanks to blockchain technology. Customers can view comprehensive information such as farm location, harvest date, transportation specifics, and processing techniques by scanning QR codes or visiting internet platforms.
2) *Faster recalls:* The breadth and impact of recalls are minimized when it becomes easier and quicker to identify the contaminated batches in the event of contamination or other problems. Customers are protected, and firms suffer less financial loss as a result.
3) *Enhanced trust:* Blockchain fosters confidence amongst customers, producers, and retailers by offering verifiable and irreversible data. Product openness empowers consumers to make wellinformed decisions, and it enhances the reputation of producers.
4) *Enhanced Openness:* Data democratization: Blockchain reduces information asymmetry and fosters collaboration by giving all stakeholders access to the same data. This encourages a food system that is more cooperative and effective. *Combating fraud:* Data manipulation is made more difficult by the tamper-proof structure of blockchain records, which lowers fraudulent actions such product replacement.

II. LITERATURE REVIEW

The literature review encompasses various studies exploring the application of blockchain technology in enhancing supply chain management across different sectors. Authors such as Bowen Tan, Jiaqi Yan, Si Chen, and Xingchen Liu (2018) conduct thematic analysis to elucidate blockchain's implications in food supply networks. Miguel Pincheira Caro et al. (2018) introduce AgriBlockIoT, tailored for agricultural product supply chains, while Shahid et al. (2020) propose a smart contract solution to enhance agri-food supply chain management. Kamilaris et al. (2019) scrutinize blockchain's potential in agriculture, highlighting obstacles and prospects. Casino et al. (2020) and (2019) emphasize dairy industry traceability, utilizing blockchain-based architectures. Yadav et al. (2021) focus on blockchain-driven factors for sustainable food security in India.

Toufaily et al. (2021) delve into blockchain adoption barriers and socio-economic benefits. Viano et al. (2022) explore CommonsHood's impact on local economies using blockchain. Ge et al. (ongoing since 2017) present outcomes from the "Blockchain for Agrifood" initiative, particularly focusing on South African table grapes. Ghode et al. (2020) rank variables influencing blockchain integration in supply chains, while Wang et al. (2021) investigate blockchain's role in supply chain cooperation, focusing on New Zealand. Hackius and Petersen (2017) gauge logistics experts' perceptions of blockchain technology, urging more use case research.

Sadouskaya (2017) interviews industry experts to foresee blockchain's transformation of logistics. Lim et al. (ongoing) provide a comprehensive analysis of blockchain's impact on supply chains, aiming to guide future investigations. Wu et al. (2021) assess blockchain implementation approaches in fresh product supply chains. Paliwal et al. (2020) emphasize traceability and transparency advantages through blockchain. Mukherjee et al. (ongoing) advocate for blockchain's role in advancing sustainability in agricultural supply chains. Nandi et al. (2020) explore BCT integration from a resource-based theoretical standpoint.

Lastly, Batwa and Norrman (2021) conduct a systematic review on the correlation between supply chain management trust and blockchain adoption, proposing future research directions. These studies collectively shed light on blockchain's multifaceted implications, from enhancing traceability to fostering sustainability, across diverse supply chain contexts.

III. STUDY REVIEW

Interpretation from data that has been analyzed:

Traceability	**Reliability and Security**
Added Value	**Immutability**
Trust	**Internet of Things**
Quality Cost	**Consensus mechanism**
Time Cost	**Social Sustainability**
	Environmental Sustainability

Table 1 Framework of the study

A. *The independent variables used in the study are:*

1) *Reliability and Security:* It relates to the reliability and consistency of blockchain technology in precisely documenting and validating food supply chain transactions. Security is about keeping private information safe and guarding against unwanted access or manipulation. It's about making sure blockchain-based systems are reliable and honest.
2) *Immutability:* It refers to the built-in feature of blockchain technology that data cannot be removed or changed once it has been recorded. This guarantees that data about food supply chain transactions recorded on the blockchain is unchangeable and impenetrable over time. By offering an unalterable record of product origin and transaction history, immutability strengthens transparency and confidence and improves the ecology of the food supply chain's dependability and integrity.
3) *Internet of things:* The network of linked devices, sensors, and objects included into the food supply chain is referred to as the Internet of Things (IoT) in the context of the master's thesis. The supply chain ecosystem can benefit from improved traceability, quality control, and operational efficiency thanks to these IoT devices' real-time monitoring and data gathering capabilities.
4) *Conseus mechanism:* It is the process by which members of the food supply chain network come to a consensus about the legitimacy of transactions that are registered on the blockchain. By guaranteeing that all parties involved come to an agreement over the distributed ledger's current state, it improves traceability and transaction processing efficiency, transparency, and trust.
5) *Social Sustainability:* In the context of the master's thesis, social sustainability refers to treating stakeholders fairly and morally when blockchain technology is implemented throughout the food supply chain. In order to improve the wellbeing of people and communities involved in the food sector, it includes social responsibility, ethical labor practices, community participation, and the promotion of inclusive decision-making processes.
6) *Environmental Sustainability:* It refers to the potential for blockchain adoption in the food supply chain to reduce harmful effects on the environment, encourage resource conservation, and support environmentally friendly behaviors at every stage of the process—production, distribution, and consumption.

B. *The dependent variables used in the study are:*

1) *Traceability:* It indicates how food products can be tracked and recorded all the way from manufacture to consumption using blockchain technology. It entails keeping an unchangeable and transparent record of all transactions, allowing interested parties to confirm the provenance, path, and characteristics of food products. This improves quality control, accountability, and customer confidence in the food supply chain.
2) *Added Value:* It relates to using blockchain technology to improve product quality, transparency, and customer trust in the food supply chain. It includes the observable advantages and enhancements brought about by the integration of blockchain technology, such as enhanced market competitiveness, decreased risks, and higher efficiency, all of which eventually support the food industry's general socioeconomic growth.

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3) *Trust:* In the context of the master's thesis, "trust" refers to stakeholders' faith and dependence on blockchain technology to precisely record and preserve transparent information along the food supply chain. It includes the idea that blockchain technologies preserve accountability, security, and integrity, encouraging participant cooperation and raising the general level of industry trustworthiness.
4) *Quality Cost:* It refers to costs associated with preserving and guaranteeing the safety, integrity, and compliance of food products across the supply chain; these costs are impacted by variables including the effect that blockchain adoption has on lowering the frequency of fraud,contamination, and product recalls.
5) *Time Cost:* It refers to the amount of time that is saved or used as a result of the food supply chain adopting blockchain technology. This includes time savings associated with increased efficiency in tasks like supply chain tracking, transaction verification, and regulatory compliance. It calculates how using blockchain technology would affect decision-making, operational workflows, and supply chain performance over time.

C. Considering a scale of 'Strong, Moderate and Weak', where all the independent variables arecorrelating to the dependent variables.

1) Reliability and Security:

- Traceability: Strong correlation, it indicates traceability. Because blockchain technology is more dependable and secure, traceability is improved by guaranteeing the validity and integrityof data all the way through the supply chain.
- Added value: Strong correlation, it indicates improved security and dependability encourageconsumer faith in the legitimacy and caliber of goods, which adds value.
- Trust: Strong correlation, it indicates improved dependability and security protect against fraudand data manipulation, which fosters stakeholder trust.
- Quality Cost: Moderately correlated. While lower chances of fraud and contamination can lower quality expenses through enhanced security and reliability, the exact impact may differ based on particular quality control procedures.
- Time Cost: Moderately correlated. Improved security and dependability can save time spent on audits, data verification, and dispute resolution, which can result in more efficiency.

2) Immutability:

- Traceability: Strong correlation. Immutability makes guarantee that data that has been recordedcannot be changed or removed, which improves traceability and offers a trustworthy history of the product.
- Value Addition:. : Strong correlation, Immutable records increase consumer confidence andtrust by ensuring the validity and integrity of data.
- Trust: Strong correlation, Immutable records provide openness and credibility by ensuring thatdata has not been altered. This promotes confidence.
- Quality Cost: Moderate correlation, by limiting data manipulation and guaranteeing theaccuracy of quality-related information, immutability helps save quality expenses.
- Time Cost: Weak correlation. Although immutable records help maintain data integrity and eliminate the need for laborious verification procedures, they might not have as much of animmediate influence on time expenditure.
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3) The Internet of Things (IoT):-

- Traceability: Moderate correlation. The use of blockchain technology into IoT devices improvestraceability by enabling real-time product condition monitoring and data collection.
- Added value: Moderate correlation. IoT integration creates value by boosting consumerconfidence by continuously monitoring and improving product quality and safety.
- Trust: Moderate correlation. IoT devices' real-time data boosts trust by giving clear details aboutproduct conditions and supply chain procedures.
- Quality Cost: Strong correlation. IoT-enabled monitoring minimizes losses, stops contamination and spoiling, and maintains product quality to lower quality expenses.
- Time Cost: Strong correlation. IoT devices' real-time data lowers time costs by facilitatingprompt interventions and decision-making, which boosts productivity.

4) Consensus Mechanism:-

- Traceability: Strong correlation. Consensus techniques preserve a consistent and trustworthy record of product movements and improve traceability by ensuring agreement on the legality oftransactions.
- Added value: Strong correlation. Consensus methods are valuable because they facilitate consensus on shared facts, encourage collaboration, and promote transparency and confidenceamong participants.
- Trust : Strong correlation. By guaranteeing agreement among participants and lowering thelikelihood of disagreements and conflicts, consensus procedures increase confidence.
- Quality Cost: Weak correlation. Consensus procedures improve data consistency and correctness, but they may not have as much of an immediate effect on quality expenses.
- Time Cost: Moderate correlation. Consensus procedures expedite the decision-making processby cutting down on the amount of time needed to reach consensus and resolve disagreements.

5) Social Responsibility:

- Traceability: Weak correlation. Initiatives centered around social responsibility mightencourage moral sourcing, but their direct influence on traceability might be restricted.
- Added value: Moderate correlation. Initiatives centered around social responsibility bring valueby satisfying consumer desires for products made ethically, improving brand recognition, and increasing market competitiveness.
- Trust: Moderate correlation. By showcasing a dedication to moral principles and conscientious corporate behavior, open communication regarding social responsibility initiatives fosters trust. Cost of Quality: Weak correlation. Depending on the particular procedures used, social responsibility programs may or may not have a direct impact on quality expenses.
- Time Cost: Weak correlation. Social responsibility programs might not have a significant direct influence on overall time expenses, even though they might add to the time required forcompliance monitoring.

6) Environmental Sustainability:

- Traceability: Weak correlation. Although tracking sustainability practices with blockchain technology may yield more information, traceability may not be directly impacted by it.
- Added Value: Moderate correlation. Initiatives promoting environmental sustainability create value by satisfying consumer desires for environmentally friendly goods, improving brand recognition, and creating a unique market niche.
- Trust: Moderate correlation. By showcasing a dedication to environmental responsibility and accountability, transparent information regarding environmental sustainability measures fosterstrust.
- Quality Cost: Weak correlation. Depending on the particular procedures used, the direct effect of environmental sustainability measures on quality prices may differ.
- Time Cost: Weak correlation. Initiatives for environmental sustainability may not have a significant direct influence on overall time expenses, even though they could need more time forcompliance monitoring.

D. Variables that have strong correlation are :

1) Reliability & Security:

- Strong correlation with all dependent variables: Traceability, Added Value, Trust, Quality Cost,Time Cost.

2) Immutability:

- Strong correlation with all dependent variables: Traceability, Added Value, Trust, QualityCost, Time Cost.

3) Internet of Things (IoT):

- Strong correlation with Quality Cost, Time Cost.
- Moderate correlation with Traceability, Added Value, Trust.

4) Consensus Mechanism:

- Strong correlation with Traceability, Added Value, Trust.

- Moderate correlation with Time Cost.

Strong correlations between these independent variables and a number of dependent variablesshow how much of an impact they have on the efficiency, transparency, and traceability of thefood supply chain.

E. Significance of the strongly correlated variables :

1) Reliability, Security, and Immutability: These characteristics are essential to guaranteeing thesecurity, integrity, and validity of data stored on the blockchain. When evaluating the socio- economic effects, a trustworthy and safe blockchain system increases transparency, fosters stakeholder trust, and lowers the possibility of fraud or other wrongdoing. This boosts market competitiveness, builds consumer confidence, and advances socioeconomic growth in general.

2) Internet of Things (IoT): IoT integration makes data collection and real-time monitoring easier, improving supply chain visibility and quality control. This leads to higher consumer satisfaction,lower quality costs, and better product quality—all of which have a beneficial socioeconomic impact.

3) Consensus Mechanism: In the food sector, consensus methods are essential for tackling important issues including trust, transparency, and coordination. Consensus techniques enhance data integrity, dispute resolution, and decision-making by guaranteeing agreement among network participants. This helps to handle issues with supply chain coordination, data sharing, and stakeholder alignment.

4) Immutability: The immutability of blockchain records solves issues with fraud, data manipulation, and authenticity confirmation. This addresses issues with product provenance, quality control, and regulatory compliance while fostering accountability, transparency, and confidence in the supply chain.

IV. CONCLUSION

1) By addressing issues with trust, traceability, and regulatory compliance, blockchain use in thefood sector may improve supply chain integrity overall and boost consumer confidence.

2) The success of blockchain adoption is greatly influenced by stakeholder perspectives, which influence decision-making by taking into account variables including perceived benefits, risks,and technological maturity.

3) The successful and long-lasting integration of blockchain technology in the food supply chain will depend on stakeholder collaboration, technology infrastructure investment, and the creationof industry standards and best practices.

4) The identified variables have shown major significance in the adoption of blockchain technology in food industry.

V. LIMITATIONS OF THE STUDY

1) Because the food supply chain varies by geography and industry, findings might not beapplicable to all situations.

2) The accuracy, consistency, and availability of secondary data sources could differ, whichcould affect how reliable the results are.

3) Only using data and literature that already exists; relevance may be impacted by additionalfindings after the study.

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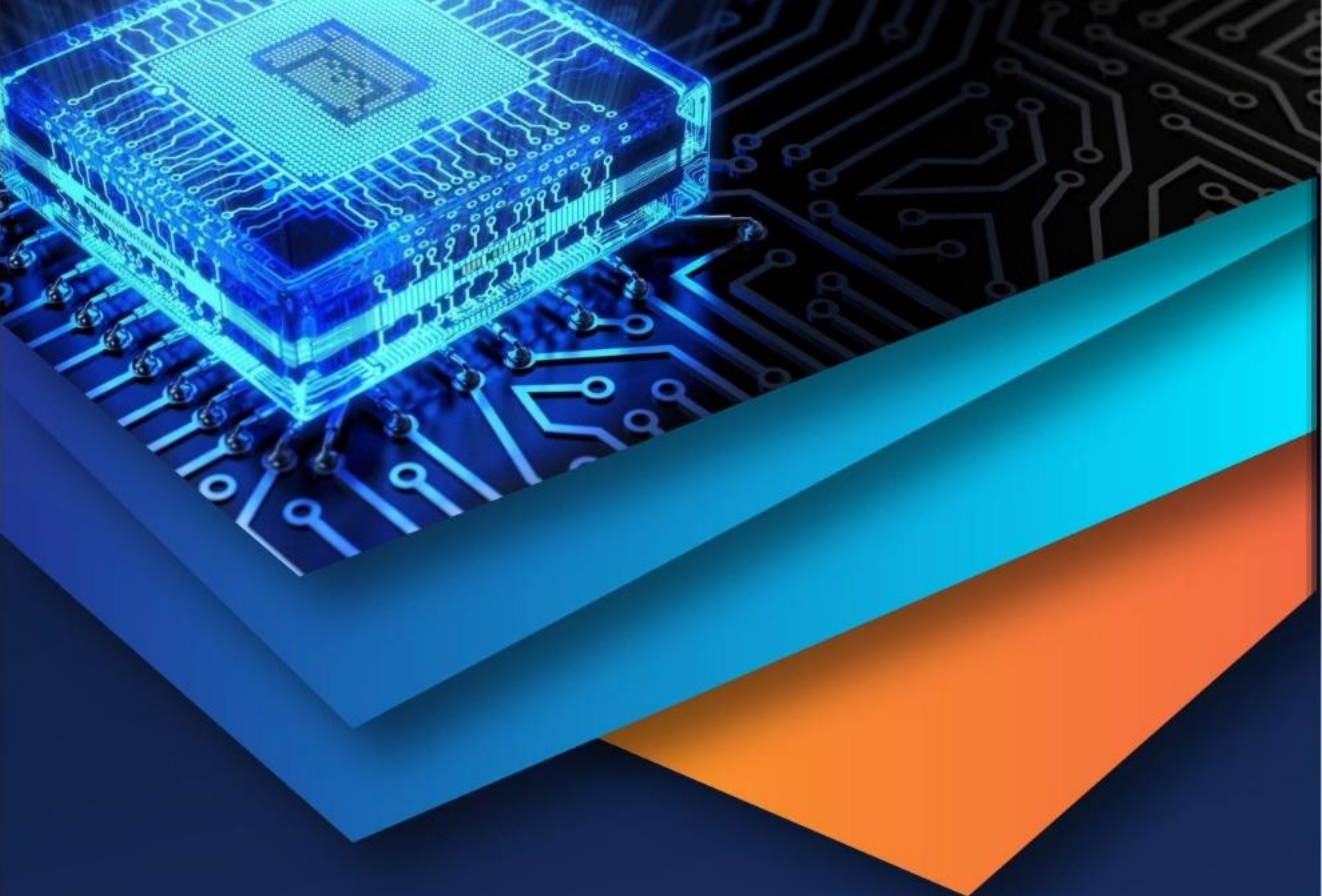

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