ENHANCING SUPPLY CHAIN TRACEABILITY USING BLOCKCHAIN TECHNOLOGY

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ABSTRACT

Blockchain-based supply chain traceability has become a powerful solution for improving transparency, security, and overall operational performance in modern logistics systems. Using decentralized ledger technology, blockchain creates permanent, time-stamped, and tamper-proof records of every product movement and transaction, allowing authorized participants to access real-time, trustworthy information. This approach helps minimize issues such as fraud, counterfeiting, data manipulation, and inefficiencies that often occur in conventional supply chain processes. Practical applications—including IBM Food Trust, VeChain, and Everledger—show the technology's value in industries that demand strong verification of product origin and regulatory compliance, such as food safety, luxury goods, and diamond tracking. When combined with IoT devices, blockchain further improves data precision by automatically collecting critical environmental and logistical data, though challenges related to device security and data integrity remain. Despite its promise, the widespread use of blockchain is hindered by issues such as scalability, lack of interoperability, significant implementation costs, and uncertain regulatory standards. Overall, evidence suggests that blockchain can greatly enhance supply chain reliability and consumer confidence, provided that organizations effectively address the associated technical and operational barriers.

Key Words : Blockchain, Supply Chain Traceability, Decentralized Ledger, Transparency, Fraud Prevention, Product Provenance, IoT Integration, Consumer Trust, Logistics, Compliance

I. INTRODUCTION

Blockchain-based supply chain traceability refers to the use of blockchain technology to enhance the transparency, accountability, and efficiency of supply chains. In traditional supply chains, tracking the movement of goods and verifying their origin can be complex, prone to errors, and vulnerable to fraud. Blockchain, a decentralized and immutable digital ledger, addresses these challenges by securely recording each transaction and transfer of goods in a transparent and verifiable manner. This enables all stakeholders, from manufacturers to end consumers, to track the entire lifecycle of a product, ensuring authenticity and compliance with regulations.

Because the system is decentralized, there is no longer a need for middlemen, which lowers operating costs and fosters greater participant confidence. Smart contracts, a characteristic of blockchain, automate activities like payments and quality checks, further optimizing supply chain operations. Blockchain-based traceability helps prevent counterfeiting, assure product quality, and satisfy sustainability standards for sectors like food, pharmaceuticals, and luxury products. Blockchain technology transforms the tracking of items by offering real-time data and a single source of truth, ultimately enhancing the transparency and robustness of the supply chain.

II. LITERATURE REVIEW

In [1], the researchers examined how blockchain technology can be utilized to support food supply chains, emphasizing on eliminating transparency issues, waste and especially improving food safety and fighting food fraud. The paper goes on to examine some of possible uses of blockchain and why it is important for the food industries for enhancing efficiency and responsibility. This is elaborated further on on the effects of food wastage in health focus.

In [2], the researchers look into how blockchain technology can help enhance the honesty of supply chains. The discussion in the paper is about supply chains having a higher integrity thanks to the power of blockchain technology as a result of its ability to provide real-time access to all the past transactions that have been recorded in a distributed and tamper proof ledger. There is therefore accountability in every part of the supply chain processes from acquisition of raw materials to ferrying the finished goods. Moosavi points out that incorporating blockchain technology into the supply chains helps to reduce the risk of fraud, assists in making fewer mistakes, and gets rid of wasteful activities making the

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supply chains open, responsible and effective. Other issues that this research tackles include overcoming scalability and interoperability challenges and offers evidence on the various use cases of deployment of blockchain technology with emphasis on building trust and enhancing transparency. As such, with the help of blockchain technology, organisations can create supply chains that are more trustworthy and resilient, which in turn is advantageous to the consumers and helps enhance the brand reputation.

In [3], the authors examine some of the technical issues and their solutions for the optimization of a blockchain-based traceability in a supply chain. The paper studies the challenges presented by supply chain's drawn in with the use of blockchain, with specific regard in improving the functionality of traceability systems. One of the challenges that the authors discuss concerns the expansion of the concepts of the blockchain and its networks - clamoring for enormous amounts of data spread across different geographical regions-along the supply chain. In their work, the authors also consider a number of technical solutions to these problems, which include the enhancement of the consensus mechanisms and the creation of a hybrid model of blockchains integrating public and private blockchains. The aims of these proposed system changes are to shorten transaction processing times, lower costs and improve the traceability system as a whole. The paper further discusses IoT enhancements which cloud augment blockchain capabilities towards improved real-time tracking capabilities and accuracy in the data. In doing so, Wu et al. argue the ways in which addressing these issues assist in the aim of using a blockchain system in ensuring visibility and traceability of items across the complex supply chain.

In [4], undertook a detailed scoping review of scholarly literature on the blockchain-based supply chain traceability, and its applicability investigates different factors that are likely to hinder or cause its acceptance. The paper also shows the extent to which the demand for transparency, traceability, and accountability within every supply chain in various industries is the driving force behind the adoption of block chain technology. One of the main issues mentions is the use of blockchain in achieving the sustainability, and therefore specifics on how the technology aids in fair trade, waste management and resource use in the supply chains are provided. The review also highlights the aforementioned regulatory and standardization challenges but address several operational issues including scalability and acceptance. On top of that, Casino proposes possible directions of future research, mainly aimed at enhancing the performance of the blockchain or its combination with other technologies such as the Internet of Things or artificial intelligence. The paper also contains the discussion on the particular aspects of the sustainability issue in blockchain and calls for the research of this problem in connection with sociotechnical factors related to the global supply chain management systems where blockchain should be used. The expense of using blockchain technology presents another difficulty, particularly for smaller businesses. Businesses with low resources may find it prohibitive to engage in blockchain infrastructure due to the initial costs involved and the requirement for technological skills. Moreover, the legislative landscape surrounding blockchain technology is still developing, and it is unclear how various nations will control the application of this technology in supply chains. Additionally, real-world case studies highlight blockchain adoption. IBM Food Trust, used by Walmart, improves food safety by enabling farm-to-store tracking within seconds. VeChain has been deployed in luxury goods to authenticate designer products, reducing counterfeiting. Everledger applies blockchain to track diamond provenance, ensuring ethical sourcing and compliance. These examples demonstrate both the feasibility and sector-specific challenges of blockchain-enabled supply chains.

III. METHODOLOGY

The increasing demand for traceability and transparency in international supply chains has led to the development of blockchain technology as a potentially effective solution. Due to the participation of several middlemen and disjointed data systems, traditional supply chains sometimes lack visibility, making it challenging to track the source of items, identify fraud, and guarantee standard compliance. A supply chain traceability technique that is based on blockchain technology takes advantage of the decentralized and unchangeable characteristics of blockchain technology to establish an open, safe, and verifiable record of each transaction that occurs within the chain.

With this technology, a blockchain network connects every link in the supply chain, including manufacturers, distributors, retailers, customers, and suppliers of raw materials. Every time a product passes through a supply chain stage, a transaction is documented on the blockchain with important details like the product's origin, its past processing, and its present state. Since blockchain records are unchangeable, information entered into them cannot be removed or changed, guaranteeing the accuracy and consistency of the data. Smart contracts, which are blockchain-based self-executing agreements, can also be used to automate certain tasks like enforcing regulatory compliance or initiating payments upon the delivery of products.

There are numerous important advantages of using

blockchain technology for supply chain tracking. By giving everyone involved access to a common understanding of the truth, it improves openness in the first place. In sectors where product authenticity and safety are crucial, such as pharmaceuticals, food, and luxury items, this can help lower fraud, counterfeiting, and the chance of product tampering. Second, by providing a transparent audit record of each transaction, blockchain enhances accountability by facilitating the identification of the root cause of any problems or anomalies in the supply chain. When there is a recall or a quality control lapse, this can be extremely helpful because it allows for the prompt and precise identification of the impacted products. [5]

Third, by eliminating the need for middlemen, cutting down on paperwork, and lowering the price of cross-system data reconciliation and verification, blockchain can simplify processes. Blockchain-based supply chain tracking is not without its difficulties, though. The requirement that all parties embrace and incorporate blockchain technology into their current processes is one of the main obstacles. This can be an expensive and complicated procedure, particularly for smaller companies that do not have the funding or technological know-how to put blockchain into practice. Additionally, the correctness and integrity of the data being entered into the system determines how successful blockchain traceability will be. Should false or erroneous information be entered at any stage across the supply chain, [6]

The validity of the record will remain on the blockchain, potentially compromising the system's credibility. To sum up, supply chain traceability based on blockchain technology provides a strong and safe foundation for raising the level of responsibility, efficiency, and transparency in supply chain management. [7] The potential advantages of risk reduction, cost reductions, and increased consumer trust make blockchain an increasingly appealing solution for contemporary supply chains, notwithstanding the obstacles to its broad implementation.

IV. PROPOSED BLOCKCHAIN-BASED SOLUTION

In today's international economy, supply chains are increasingly complicated, including various parties, regions, and procedures. Problems including a lack of transparency, inefficiency, and fraud susceptibility are frequently brought on by this complexity. [8] A blockchain-based approach to supply chain traceability is put forth in order to overcome these difficulties, taking use of the decentralization, immutability, and transparency that are intrinsic to blockchain technology.

The suggested remedy is to establish a permissioned blockchain network that links producers, suppliers, distributors, retailers, and customers, as well as all other participants in the supply chain [9]. A consensus-building process will verify each participant's distinct digital identity, fostering stakeholder trust. Upon joining the network, each party will be able to record transactions relating to the transfer of commodities, including timestamps, amounts, quality checks, and position data. All authorized participants will have access to a transparent and unchangeable ledger that is formed by these transactions, which will be kept in blocks that are safely connected to each other.[10]

The capacity to trace the provenance of goods from their point of origin to the end user is one of the primary characteristics of this blockchain technology. For example, the blockchain can be used to record the sourcing details of raw materials, including their provenance, quality certifications, and safety standard compliance[11]. Every transaction involving these products will be recorded as they go through the several phases of the supply chain, including processing, packaging, and distribution, building a thorough audit trail. Improved consumer trust and overall product safety will result from this traceability, which will help speed up the process of identifying the cause of any problems, including recalls or quality issues.[12]

Moreover, the blockchain can be used to automate certain supply chain procedures through the use of smart contracts, which are self-executing agreements with stipulations encoded directly into code. [13] For example, a smart contract can be designed to automatically initiate payments, update inventory levels, and notify relevant parties of the completion of a transaction when a cargo reaches its destination. A more efficient supply chain results from this automation, which also shortens processing times, eliminates the need for middlemen, and reduces human error.

Improved data security is a key benefit of this blockchain approach. Sensitive data is encrypted and spread across numerous nodes in the distributed ledger that powers the blockchain, protecting it against manipulation or unwanted access. [14] Multiple parties agree on each transaction, guaranteeing the accuracy and reliability of all recorded data. Furthermore, different stakeholder access levels to the blockchain guarantee the protection of private company data while preserving the transparency required for accountability.

The suggested solution also contains a user-friendly interface for all stakeholders to engage with the blockchain. With the use of this interface, participants will be able to track the path of their products, ensure that regulations are being followed, and examine performance indicators in real-time.

Furthermore, consumers would benefit from this solution by having access to precise product information, such as origin, handling procedures, and sustainability certifications, thereby empowering them to make informed purchasing decisions.[15]

In conclusion, a solid framework that tackles the issues of transparency, efficiency, and security within the supply chain is presented by the suggested blockchain-based solution for supply chain traceability. Utilizing the decentralized and unchangeable characteristics of blockchain technology, this approach improves stakeholder collaboration, streamlines procedures, and eventually increases consumer trust. Supply chain management might be dramatically improved by implementing such a solution, which would increase its adaptability and resilience to the demands of a market that is changing quickly.

V. IMPLEMENTATION DETAILS

Blockchain technology, which offers data immutability, security, and openness, has completely changed how companies track and manage their supply chains. To guarantee that a blockchain-based supply chain traceability system is reliable, scalable, and industry-adaptable, it must be implemented with a number of essential parts and procedures.

Blockchain Framework Selection: Choosing the right blockchain platform or framework is the first stage in the deployment process. Businesses may select among public, private, or consortium blockchains, depending on the size, complexity, and particular requirements of the supply chain. Decentralization is facilitated by public blockchains like Ethereum, although they may be slower and cost more because of transaction fees. Private blockchains, like Hyperledger Fabric, are suited for enterprise-level applications since they provide a single point of control and a higher transaction throughput. Consortium blockchains offer a compromise by preserving efficiency and privacy while enabling several reliable parties to keep control over the network.

Automation and Smart Contracts: Smart contracts are essential to the blockchain's tracking process automation. These self-executing contracts make sure that certain things happen when circumstances are met—like money starting to roll in after a product delivery confirmation—by automatically enforcing predefined constraints. By implementing smart contracts at crucial supply chain checkpoints (such as the procurement of raw materials, production, and distribution), manual intervention is decreased and reliability is raised. Programming languages like Solidity (for Ethereum) or Chaincode (for Hyperledger Fabric) are used by developers to generate these smart contracts.

Integration with IoT and Sensors: By integrating blockchain technology with Internet of Things (IoT) devices and sensors, blockchain traceability is improved. Real-time data on product variables like temperature, humidity, and location can be obtained from Internet of Things (IoT) devices that are integrated into goods or affixed to shipments. By uploading this data to the blockchain, an unchangeable history of the product's travels is ensured. For instance, it is possible to keep quality control throughout transit by closely monitoring perishable items like food or medications. Products can also be scanned at different places using QR codes or RFID (Radio Frequency Identification) tags, which guarantee automation and accurate data. Data collected from IoT devices (temperature, humidity, GPS) is transmitted via secure gateways to blockchain nodes. Smart contracts can validate sensor inputs and trigger automated actions. However, ensuring that IoT devices themselves are tamper-resistant is vital, as inaccurate or manipulated data can undermine the blockchain's integrity. Comparative studies suggest that while traditional ERP and RFID systems offer faster processing, blockchain provides stronger immutability and cross-party trust.

Data Security and Privacy: Blockchain's decentralized structure guarantees data integrity, however for sensitive supply chain data, further privacy precautions could be required. Encryption methods must be implemented by businesses to safeguard sensitive information, particularly in sectors like finance and healthcare. Zero-knowledge proofs (ZKP) can be exploited to ensure that parties validate information without disclosing sensitive data. To balance openness and privacy, role-based access control (RBAC) can be used to limit data visibility to authorized users only.

User Interfaces and Data Visualization: Suppliers, manufacturers, and customers must all be able to easily navigate the blockchain traceability system's user interface in order for it to be successful. Through dashboards, front-end applications can show real-time supply chain information, providing insights into product origin, transit periods, and conditions throughout transportation. These tools facilitate the tracking of goods, the settlement of conflicts, and the maintenance of accountability across the supply chain.

Interoperability and Standards: Several parties are usually involved in the supply chain, and they all use distinct systems and standards. Interoperability between blockchain systems and current supply chain management instruments, such as Enterprise Resource Planning (ERP) software, should be supported. The blockchain technology can be connected with industry standards, such the GS1 system for product identification, to facilitate stakeholder

communication and guarantee uniform data formatting throughout the supply chain. By integrating blockchain's inherent capabilities with IoT, encryption, and smart contracts, firms can construct a highly trustworthy and transparent supply chain tracing solution. To satisfy industry-specific requirements, the blockchain architecture, integration points, and security measures must be carefully considered during deployment.

VI. ENHANCING TRANSPARENCY AND EFFICIENCY

Supply chain management has been transformed by blockchain technology, which provides previously unheard-of levels of security, transparency, and traceability. In traditional supply chains, information regarding product origin, handling, and shipping can be compartmentalized, fragmented, or distorted, leading to inefficiencies, fraud, and lack of confidence among stakeholders. Every transaction in the supply chain is recorded in a decentralized, immutable ledger by blockchain, giving all parties involved a single, shared source of truth. A chain of records that can be followed back to the point of origin is created by securely encrypting each transaction, or block, and connecting it to the one before it. Particularly in sectors like food, medicine, and luxury goods where product origin and compliance are crucial, traceability aids in confirming the legitimacy and integrity of products.

The capacity of blockchain to lessen counterfeiting is one of its main advantages for supply chain traceability. Businesses may give products distinct, unchangeable identifiers by integrating blockchain technology, guaranteeing that all parties involved in the supply chain—from suppliers of raw materials to retailers—can verify the product's legitimacy. For instance, blockchain enables customers to confirm the source of their food, including details on how it was grown, processed, and delivered, in the food business, where quality and safety requirements are crucial. In addition to enabling quicker recalls in the event of contamination or other safety issues, this enhanced visibility contributes to the development of consumer trust.[15]

Blockchain further improves efficiency by doing away with the need for paperwork, manual audits, and middlemen. Transactions between stakeholders are streamlined via smart contracts, which are self-executing agreements with pre-defined conditions inscribed into the blockchain. By automating procedures like quality checks and payments after specific requirements are satisfied, these contracts lower human error and speed up the flow of commodities through the supply chain. Furthermore, the accuracy of all recorded data is guaranteed by the immutable nature of blockchain, which further boosts the trustworthiness of information shared amongst members.

Supply chain traceability is further enhanced by the integration of blockchain technology with Internet of Things (IoT) devices. IoT sensors have the ability to track location, temperature, and humidity in real time, which is important for perishable commodities like food and medicine. When blockchain technology is used, this data is captured in an unchangeable ledger, guaranteeing complete transparency throughout the life of the product. Any irregularities, like variations in temperature or delays, are continuously documented, enabling prompt resolution of possible problems.

Nevertheless, supply chains face obstacles in implementing blockchain technology. Since the technology is still relatively new, many businesses are having trouble integrating it with their current setups. Furthermore, blockchain networks need a lot of processing power, and scalability issues still exist, particularly for big, international supply chains. Obstacles include the requirement for industry-wide cooperation and regulatory compliance, since the success of blockchain technology depends on its broad acceptance and collaboration among all supply chain players.

In summary, supply chain traceability based on blockchain technology has the power to revolutionize international trade by boosting efficiency, lowering fraud, and enhancing transparency. Blockchain has the potential to become a vital instrument for guaranteeing the security and integrity of supply chains around the globe as more industries learn to understand its advantages and tackle its problems. In a world that is becoming more interconnected, supply chain management will probably change in the future due to its capacity to promote responsibility and trust.

VII. FRAMEWORK FOR T&C SUPPLY CHAIN

An developing architecture called blockchain-based supply chain traceability aims to improve efficiency, security, and transparency in the textile and garment (T&C) supply chain. This system uses decentralized ledger technology to track, document, and validate each step of the supply chain, from the procurement of raw materials to the delivery of the finished product. Every transaction involving the transfer of products is permanently documented on a distributed ledger via blockchain technology, preventing data manipulation and offering a trustworthy and dependable audit trail. For businesses like T&C, where sustainability, ethical sourcing, and provenance are gaining traction with consumers and authorities, traceability is essential.

Real-time data on the origin, processing, and handling

of materials can be accessed by manufacturers, suppliers, retailers, and consumers in a blockchain-based architecture that encompasses the T&C supply chain. Smart contracts are self-executing contracts with the terms encoded directly into code. They can automate a variety of supply chain tasks, including regulatory compliance checking, payment execution upon fulfilment of predetermined criteria, and certification verification. These agreements minimize the need for middlemen, lessen the possibility of fraud, and simplify processes.
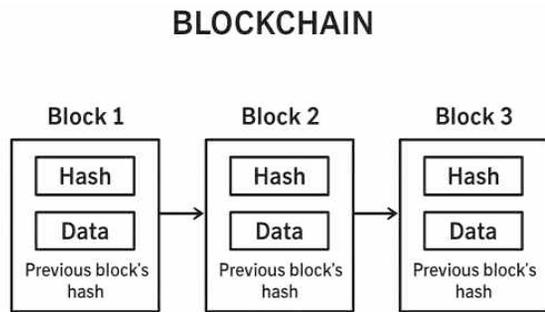

Fig.1 A Typical blockchain representation

A fundamental benefit of blockchain-based traceability in the T&C industry is its ability to increase sustainability initiatives. By having a transparent system in place, organizations can simply track the carbon footprint of each component in their product, monitor resource utilization, and guarantee that suppliers conform to environmental requirements. This is becoming more and more significant as governments impose tighter laws on environmental effect and customers want more sustainable products. Furthermore, since the legitimacy of the goods can be checked at every point in the supply chain, it aids in the detection and removal of counterfeit goods.

Blockchain technology can promote ethical behaviors in the T&C supply chain by guaranteeing compliance with fair-trade rules and labor norms. Both customers and brands can confirm that resources are sourced sustainably, that workers are paid fairly, and that they are working in safe settings. This degree of exposure can help a company gain more credibility and trust from consumers, who are becoming more and more tolerant of businesses that uphold moral standards. Furthermore, because blockchain is decentralized and does not rely on a single centralized institution for data storage, the entire system is immune to manipulation or hacking. This lowers the possibility of data breaches and improves the security of supply chain information
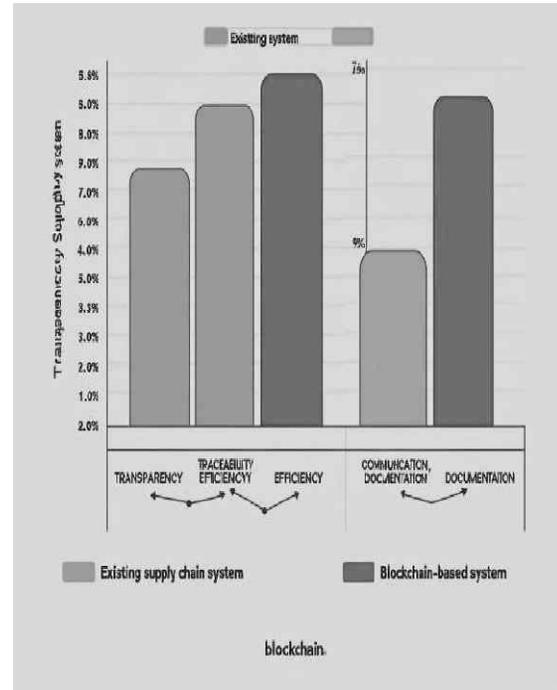

Fig.2 Blockchain Existing & Proposed Comparison Graph

To sum up, supply chain traceability for the T&C sector based on blockchain technology is a strong option for raising sustainability, efficiency, and transparency. A safe and unchangeable record of the process from raw materials to final goods is made possible, which tackles numerous contemporary issues confronting the business, including ethical sourcing, regulatory compliance, and counterfeiting. This technology has the potential to completely change how businesses manage and interact with stakeholders and customers regarding their supply chains, especially as the demand for ethical fashion continues to rise.

VII. SECURITY ANALYSIS

Supply Chain Blockchain Understanding Transparency: All parties involved can check data since each transaction is documented on a public ledger.

Immutability: A transaction cannot be changed after it has been recorded, preventing fraud and illegal modifications. Possible Hazards to Security

Data Breaches: Despite blockchain's security, assaults may still be possible at the endpoints, such as user interfaces and APIs. Vulnerabilities in Smart Contracts: Malicious actors may take advantage of bugs or exploits in smart contracts to manipulate data or cause financial loss.

Sybil Attacks: To take over most of the network, malevolent actors can assume several identities.

51% Attacks: The blockchain can be manipulated if one party obtains a disproportionate amount of the network's processing power.

Supply Chain Attacks: The advantages of traceability can be compromised if any aspect of the supply chain is compromised (for example, by altering data before it is published on the blockchain). Important Security Steps

Techniques in Cryptography: Use strong encryption techniques to safeguard data both at rest and in transit.

Monitoring and Auditing: Regular examinations of the blockchain's smart contracts can help identify and address problems. Decentralized Identity Management Systems: Install decentralized identification systems to ensure data integrity and reduce the risk of unauthorized access.

Multi-Signature Transactions: By demanding multiple permissions for some transactions, you can reduce the risk of fraud.

Adherence to Regulations Make that all applicable laws (such as HIPAA and GDPR) are followed in order to preserve user privacy and secure data. Establish precise guidelines for parties in the supply chain regarding data exchange, access, and retention. Optimal Techniques for Execution

Instruction and Practice: All parties involved receive regular training on security procedures and possible dangers. Frequent Patching and Updates: To reduce vulnerabilities, keep all software, including blockchain platforms and smart contracts, up to date.

Initiatives for Collaborative Security: Collaborate with other supply chain participants to exchange security best practices and expertise. Plan for Responding to Incidents Develop a comprehensive incident response plan to manage possible security breaches effectively and reduce damage.

IX. RESULTS AND DISCUSSION

The numerous problems with conventional supply chain management have been addressed by the innovative approach of supply chain traceability based on blockchain technology. The study's findings show that by offering a decentralized, unchangeable ledger for transaction recording, blockchain can greatly increase supply chains' efficiency, trust, and transparency. This ensures increased accountability and lowers the possibility of fraud, counterfeiting, and errors by allowing all stakeholders to access and verify the same data in real-time. The results also highlight a number of issues that still need to be resolved, including the requirement for broad adoption, scalability, and technological obstacles.

Enhanced Transparency and Trust: Transparency has dramatically improved as a result of supply networks incorporating blockchain technology. All authorized players in the supply chain have access to a common ledger where every transaction is documented. It is simpler to follow a product's path from point of origin to point of destination when an audit trail is provided by this unchangeable record.

Blockchain, for instance, can trace ingredients in the food sector from farm to table, giving customers important details about the origin and sustainability of the food products they buy.

The study also emphasizes how blockchain builds stakeholder trust, especially in intricate supply chains with multiple tiers and middlemen. Businesses no longer need to rely on perhaps biased or erroneous records from third parties because all data is time-stamped and tamper-proof. For businesses that deal with expensive commodities, including pharmaceuticals, electronics, and luxury goods, where tampering and counterfeiting are frequent problems, this trust is essential.
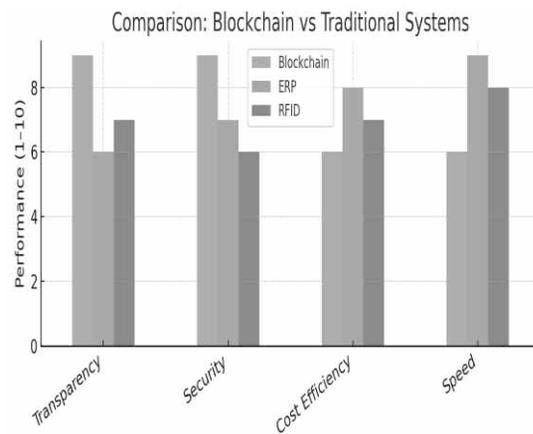

Fig.3 Comparison of Blockchain vs Traditional Systems (ERP, RFID)

Fig.3 illustrates a comparison of Blockchain, ERP, and RFID systems based on four performance parameters like Transparency, Security, Cost Efficiency, and Speed. Blockchain achieves the highest ratings in Transparency and Security, reflecting its strong reliability and data integrity. Overall, the chart emphasizes Blockchain's dominance in security and transparency, while ERP stands out for its speed and cost efficiency.

The findings also demonstrate how blockchain might enhance inventory control by lowering the possibility of shortages or overstocking by giving real-time stock level updates. Moreover, with automated tracking, organizations may streamline their logistics and distribution processes, avoiding delays and guaranteeing that products are delivered in a timely manner.

Table 1. Comparative analysis of existing non-blockchain-based solutions.

Features	[6]	[23]	[24]	[26]	[27]	Our Solution
Prototype	Yes	No	Yes	No	Yes	Yes
Transperancy	No	No	No	No	No	Yes
Decentralized	No	No	No	No	No	Yes
Traceability	Yes	No	Yes	Yes	Yes	Yes
Integrated	No	No	No	No	No	Yes

Challenges of Adoption: Notwithstanding these benefits, the findings point to a number of obstacles preventing blockchain technology from being widely used in supply chains. A significant obstacle is scalability. Blockchain networks frequently have trouble effectively managing high transaction volumes, especially open ones like Ethereum or Bitcoin.

With thousands of transactions taking place every day in a worldwide supply chain, this constraint may make the technology less effective. Furthermore, there is the question of interoperability across different blockchain platforms. It can be challenging to ensure interoperability and easy data sharing across systems because businesses utilize a variety of platforms and software. Without a uniform standard, blockchain networks risk becoming fragmented, decreasing the potential for full supply chain integration.

Technological and Regulatory Hurdles: Added hurdles include the intricacy of blockchain technology and the technical know-how needed to apply it. Many businesses, particularly smaller ones, do not have the funding or technological know-how to completely implement blockchain technology. The substantial upfront costs associated with infrastructure, cybersecurity, and training may put off some organizations.

Table2. Comparison between our and the existing non-blockchain-based solutions.

Features	[10]	[11]	[12]	Our Solution
Prototype	Yes	No	Yes	Yes
Platform	Public	Public	Public	Private
Decentralized	Yes	Yes	Yes	Yes
Traceability	Yes	Yes	Yes	Yes
Integrated	No	No	No	Yes
Security Analysis	No	No	No	Yes

The findings also draw attention to the issue of regulation. Regulating blockchain technology remains a challenge for governments and international organizations, especially in relation to data privacy and international trade. To guarantee blockchain's responsible use, protect sensitive data, and uphold legal requirements, clear laws are required.

Despite its potential, blockchain in supply chain management faces several challenges. Scalability remains a major issue as public blockchains often cannot handle the high transaction volumes typical in global supply chains. Implementation costs, including infrastructure, energy consumption, and specialized expertise, may deter small and medium-sized enterprises. Interoperability across different blockchain platforms and legacy systems is another unresolved concern, often leading to fragmented solutions. Regulatory uncertainty, especially regarding data privacy (GDPR, HIPAA) and cross-border trade compliance, further complicates adoption. Moreover, blockchain cannot guarantee data accuracy at entry points, making IoT integration both necessary and challenging. Acknowledging these limitations is crucial for balanced adoption strategies.

X. CONCLUSION

Transparency, security, and efficiency can all be significantly increased in a variety of businesses with blockchain-based supply chain tracking. Blockchain technology makes sure that every step in the supply chain is recorded and verifiable by offering a decentralized and tamper-proof ledger, which lowers the risk of fraud and increases stakeholder trust. It promotes increased accountability and transparency by enabling real-time product tracing from raw ingredients to the end user. By automating data collection and validation procedures, this system also enhances operational efficiency. Furthermore, by confirming the ethical procurement of materials, it supports sustainability initiatives. Blockchain technology has the potential to completely transform supply chain management as its use develops, improving its resilience, transparency, and dependability.

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