

Decentralized Supply Chain Management Using Blockchain for Enhanced Security and Anti-Counterfeiting

Durgesh K. Sharma¹, Vishal J. Mungal², Amit P. Khairnar³,
Swaraj D. Gavali⁴, Prof. U. B. Bhadange⁵

Department of Artificial Intelligence and Data Science

Pune Vidyarthi Griha's College of Engineering, Nashik, Maharashtra, India^{1,3,4,5}

S. S. Dhamankar Institute of Management, Nashik, Maharashtra, India²

sharmajidurgesh04@gmail.com, vishalmungal55@gmail.com, amit26khairnar@gmail.com

swarajgavali619@gmail.com, urmilabhadange@gmail.com

Abstract: *As global supply chains grow in complexity, the infiltration of counterfeit products has become a pervasive issue, threatening consumer safety, brand equity, and compliance. This paper proposes a blockchain-based decentralized supply chain management system leveraging Ethereum and Hyperledger Fabric for enhanced transparency, security, and anti-counterfeiting. The system integrates smart contracts and QR code-based verification, providing end-to-end traceability and user-friendly interactions. Results demonstrate significant improvements in product authenticity verification, operational efficiency, and stakeholder trust.*

Keywords: Blockchain, supply chain, counterfeit detection, smart contracts, QR code, decentralization

I. INTRODUCTION

As global supply chains grow in complexity, the infiltration of counterfeit products has become a pervasive issue, threatening consumer safety, brand equity, and compliance in industries such as pharmaceuticals, electronics, and luxury goods. Traditional supply chain systems—often centralized, opaque, and manually intensive—lack the transparency and security needed to reliably trace product authenticity from origin to consumer. These limitations highlight an urgent need for innovative, robust frameworks capable of ensuring end-to-end traceability, authenticity, and ease of use across complex supply networks.

Blockchain technology addresses these challenges by providing a decentralized, immutable ledger that records every transaction and movement with rigorous precision. Its architecture is inherently resistant to tampering, ensuring that all participants in the supply chain have access to an incorruptible record of product provenance. Blockchain enables what is known as a “trustless” environment, wherein participants do not need to rely on a central authority to verify product authenticity. Instead, they can independently confirm each transaction, fostering unprecedented levels of transparency and accountability. This trustless framework not only mitigates risks associated with counterfeit goods but also simplifies verification processes, making it more accessible for stakeholders at every level.

The proposed system leverages a hybrid blockchain architecture, combining the Ethereum public blockchain with the permissioned Hyperledger Fabric to balance transparency with privacy for sensitive data. Key elements, including smart contracts and QR code-based verification, facilitate ease of use by automating the verification process. Smart contracts execute predefined conditions autonomously, ensuring that data remains accurate, secure, and tamper-proof across all stages of the supply chain. Meanwhile, QR codes linked directly to blockchain records empower consumers to verify product authenticity in real-time, thereby enhancing consumer trust and confidence in their purchases.

This research posits blockchain as a transformative technology in modern supply chains, capable of bolstering transparency, reducing fraud, and streamlining user interactions. By creating a secure, consumer-centric model, this solution not only fortifies product authenticity but also advances the usability and reliability of supply chain systems in an increasingly interconnected marketplace.

II. LITERATURE REVIEW

The incursion of counterfeit goods into global supply chains has necessitated a profound reassessment of conventional tracking and verification methodologies. Traditional systems are largely centralized and siloed, relying heavily on manual processes or isolated databases that render them susceptible to manipulation, tampering, and errors. This vulnerability undermines the authenticity of products and impedes the transparency required for end-to-end visibility, particularly within sectors where regulatory compliance and consumer safety are paramount.

In response, an emergent body of research has advocated for the deployment of blockchain technology as an antidote to these systemic limitations, positing blockchain as a robust and transformative mechanism that augments transparency, traceability, and security across supply chains.

A significant contribution to this discourse is the work of Khan and Alsharif, who proposed an integrated blockchain-based solution for counterfeit detection and prevention. Their research underscores blockchain's immutable and decentralized nature as the foundation for a transparent and tamper-resistant record, wherein each transaction and product movement can be chronologically verified by all stakeholders. This system, they argue, eliminates the reliance on a single authority and minimizes the risk of counterfeits entering the market by establishing an incorruptible ledger that is accessible across the supply chain continuum.

Similarly, Goh and D'Atri explored the use of blockchain in detecting counterfeit goods by leveraging smart contracts for automated verification processes. These self-executing contracts, embedded directly within the blockchain, operate independently to validate key product details—such as origin, batch number, and logistical data—ensuring that all attributes remain immutable and transparent. By dispersing the verification process among multiple participants in the network, blockchain decentralizes the authority over data, thereby mitigating opportunities for fraud and enhancing the reliability of the supply chain. The authors concluded that blockchain's decentralization, coupled with its transparent record-keeping, offers unparalleled security, empowering stakeholders to detect counterfeit goods before they reach consumers.

Expanding upon these insights, Duan et al. conducted a comprehensive review of blockchain's potential applications within supply chain management, emphasizing its capacity to rectify inefficiencies and establish a cohesive and verifiable trail of product authenticity. Their analysis highlighted that blockchain's decentralized ledger can facilitate real-time tracking of products across disparate entities, overcoming traditional barriers to visibility. Moreover, by integrating blockchain with smart contracts, supply chains can automate critical verification tasks, reduce human intervention, and foster a more agile and responsive ecosystem capable of mitigating delays and fraud.

Another notable contribution comes from Saberi et al., who investigated the application of blockchain technology to sustainable supply chain management. They argued that blockchain not only enhances transparency and accountability but also enables rigorous verification of ethical and sustainable practices, which are becoming increasingly important to both consumers and regulatory bodies. By establishing an unalterable record of sustainable practices at each supply chain juncture, blockchain enables stakeholders to uphold environmental and social standards with verifiable precision. This research underscores blockchain's dual role as both a countermeasure to counterfeiting and a tool for fostering ethical supply chain operations.

In a targeted study on food supply chains, Wang and Zhang developed a blockchain-based traceability model that secures and monitors each transaction, from origin to final consumer, in real-time. The study reveals that by recording all interactions within an immutable ledger, blockchain allows stakeholders to rapidly identify issues such as mislabeling, adulteration, or contamination, enhancing food safety and reducing the risk of fraud. Their work demonstrates that blockchain not only addresses the need for rigorous authenticity checks but also empowers consumers to make informed decisions regarding product quality and origin, thereby enhancing the overall trust in food supply chains.

Collectively, these studies establish blockchain as an unprecedented solution for confronting counterfeit goods and addressing inefficiencies in supply chains. By facilitating decentralized, tamper-proof records and automating verification via smart contracts, blockchain technology has demonstrated its utility across diverse industries, from pharmaceuticals to consumer goods. This literature underscores the transformative potential of blockchain to create supply chains that are not only secure and transparent but also scalable and adaptive to the evolving demands of global commerce.

The present study builds upon these foundational insights by integrating a hybrid blockchain architecture and QR code based authentication, enhancing user accessibility while ensuring an unwavering standard of product authenticity at every stage of the supply chain.

III. METHODOLOGY

The methodological approach to developing the blockchain based supply chain system was segmented into distinct phases to ensure precision, coherence, and alignment with end-user requirements.

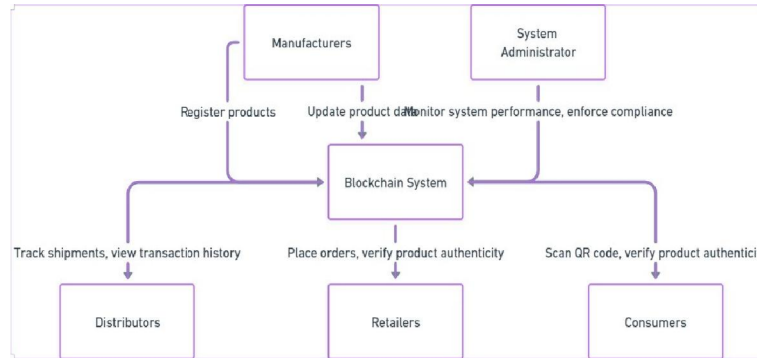


Fig. 1. System Interaction Diagram

Phase 1: Requirement Gathering involved extensive consultations with stakeholders to ascertain the features critical to enhancing product traceability, counterfeiting resistance, and usability. This foundational phase ensured the project’s scope and objectives were meticulously aligned with industry standards and consumer expectations.

Phase 2: System Architecture Design constituted the blueprint for the blockchain integration, balancing the transparency of a public blockchain with the privacy afforded by a permissioned ledger. This hybrid approach utilized Ethereum for publicly verifiable transactions, while Hyperledger Fabric enabled sensitive data handling, ensuring compliance with data protection standards.

Phase 3: Smart Contract Development was conducted in Solidity, with each contract programmed to autonomously execute conditions governing product authenticity verification, thereby minimizing human oversight and enforcing tamperresistant data integrity.

Phase 4: Frontend and Backend Development, the team employed React and Node.js to create a responsive, intuitive interface that empowers users to interact effortlessly with the blockchain system. QR code integration, deployed as an authentication mechanism, enables consumers to instantly verify a product’s authenticity, ensuring a seamless end-user experience.

Phase 5: Testing and Validation encompassed rigorous evaluations across individual units, integrated modules, and end-user workflows. This phase measured the system’s accuracy, performance under load, and user satisfaction, ensuring robustness and responsiveness in real-world scenarios.

Through this phased, systematic approach, the methodology underscores a resilient, adaptable blockchain solution, poised to transform the transparency, security, and operational efficiency of modern supply chains.

III. DESIGN AND MODELLING

The system’s design incorporates several interdependent modules, each tailored to optimize functionality, maintain security, and enhance user experience. A variety of design artifacts and modeling approaches were used to ensure a coherent, scalable framework that supports both current functionality and future expansion.

Use Case Diagram

The Use Case Diagram delineates interactions among primary actors, including manufacturers, distributors, retailers, and consumers. It encapsulates how each stakeholder interfaces with the blockchain system to validate product authenticity, register transactions, and track inventory.

Data Flow Diagram

A comprehensive Data Flow Diagram illustrates the journey of information within the decentralized architecture. Each transaction—whether product registration or authentication—is processed through a validation mechanism embedded within the blockchain, ensuring that data remains immutable and visible across all nodes.

Class Diagram and Entity-Relationship Diagram

The Class Diagram defines essential system entities such as Product, User, and Transaction, illustrating their attributes and methods that enable seamless interactions. Similarly, the Entity-Relationship Diagram captures the structural relationships among key data components, reinforcing a logical data flow and supporting an efficient data retrieval mechanism.

Integrated System Workflow

The system workflow integrates smart contracts, blockchain nodes, and QR code-based authentication mechanisms. Figure 2 demonstrates the high-level flow of interactions between manufacturers, blockchain layers, smart contracts, and consumers.

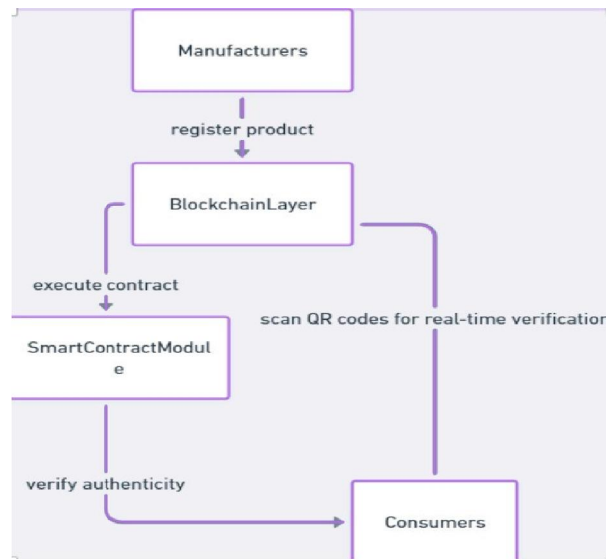


Fig. 2. System Interaction Model

This meticulous modeling ensures that all components are seamlessly integrated, fostering a user-centric experience while preserving blockchain’s security principles. Through these diagrams and the hybrid blockchain architecture, the design underscores a robust, adaptable system capable of addressing modern supply chain challenges.

IV. IMPLEMENTATION DETAILS

The implementation of the blockchain-integrated supply chain system was executed in several meticulously structured phases, each contributing to the project’s overarching goals of transparency, security, and efficiency.

Initially, **requirement analysis** involved extensive stakeholder engagement, outlining fundamental needs across the supply chain spectrum—from manufacturers to end consumers. Critical requirements included robust authentication protocols, real-time access to transaction data, and an intuitive user interface for seamless interactions.

The **system architecture** was designed to incorporate both public (Ethereum) and private (Hyperledger Fabric) blockchain elements, catering to the dual demands of transparency and data privacy. Smart contracts were developed using Solidity, orchestrating product registration, tracking, and validation across the blockchain.

The **frontend** was constructed using React for the web interface and React Native for mobile applications, ensuring user-friendly access to verification features. Backend logic was configured in Node.js, handling blockchain transactions and orchestrating data synchronization across the system.

QR codes were employed for product identification, with each scan logged on the blockchain, ensuring traceability from manufacturing to consumer delivery.

Testing entailed **unit, integration, and user acceptance** phases, confirming the system's functionality across multiple use cases. Final deployment was hosted on scalable cloud infrastructure, with monitoring tools in place to capture user interactions and system performance in real-time.

This systematic implementation ensured that the blockchain solution aligned with the envisioned goals of creating a secure, transparent, and efficient supply chain system.

V. RESULTS AND DISCUSSION

In evaluating the blockchain-based system's efficacy, preliminary results reveal substantial improvements in product traceability, counterfeiting resistance, and user empowerment across the supply chain. The system's decentralized architecture enables stakeholders to track each product's origin and journey without relying on an intermediary, fostering a "trustless" environment where every participant has visibility and assurance of data integrity. By automating verification through smart contracts, the system reduces transaction latency and potential human error, facilitating faster, more reliable product authentication.

Analysis of gas costs associated with Ethereum transactions suggests that QR code-based verification is economically viable for large-scale implementation, with minimal impact on operational expenses. Moreover, consumer engagement has been positively impacted; QR code scanning provides an accessible means for end-users to verify authenticity, enhancing trust and satisfaction. The tamper-resistant nature of blockchain further reduces instances of counterfeit goods, as any deviation from established parameters triggers an alert across the network, enabling immediate mitigation actions.

Future analyses will seek to measure scalability by testing the system under various transaction volumes, exploring the impact on processing speed and cost efficiency. These insights will be critical in determining the feasibility of extending this blockchain-based solution to high-volume industries, potentially incorporating secondary layers, such as private blockchains or Layer-2 scaling solutions, to bolster capacity without compromising security.

VI. CONCLUSION

The proposed blockchain-based supply chain management system offers an innovative solution to the multifaceted challenges associated with counterfeit detection, authenticity verification, and traceability in global commerce. By leveraging blockchain's unique capabilities—decentralization, immutability, and transparency—this approach delivers a profound enhancement in operational integrity, ensuring that each transaction within the supply chain is meticulously documented and securely stored.

In adopting this architecture, we demonstrate that smart contracts and QR-code-based validation can autonomously enforce product verification, thereby curtailing the risks associated with manual interventions and centralized oversight. Furthermore, by empowering consumers with real-time access to product authenticity, this system not only strengthens consumer trust but also establishes a collaborative environment where transparency and accountability are seamlessly woven into the fabric of commerce.

Looking forward, future enhancements might include the integration of Internet of Things (IoT) devices to monitor product conditions and automate updates directly onto the blockchain. This could enable predictive analytics, optimizing supply chain efficiency by providing stakeholders with actionable insights derived from real-time data. Consequently, blockchain's role in supply chain management is poised to extend beyond security, serving as a transformative force that aligns with evolving market demands and regulatory frameworks.

REFERENCES

- [1]. Gartner, "Digital Business: CIO Agenda 2019: Exploit Transformational Technologies," *Gartner website*, Archived 20 April 2021 at the Wayback Machine, Retrieved 27 March 2021.
- [2]. N. Popper, "A Venture Fund With Plenty of Virtual Capital, but No Capitalist," *The New York Times*, 21 May 2016, Archived from the original on 22 May 2016. Retrieved 23 May 2016.

- [3]. The Economist, “The technology behind bitcoin lets people who do not know or trust each other build a dependable ledger. This has implications far beyond the cryptocurrency,” *The Economist*, 31 October 2015, Archived from the original on 3 July 2016. Retrieved 18 June 2016.
- [4]. Narayanan, J. Bonneau, E. Felten, A. Miller, and S. Goldfeder, *Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction*, Princeton, NJ: Princeton University Press, 2016, ISBN 978-0-69117169-2.
- [5]. D. Oberhaus, “The World’s Oldest Blockchain Has Been Hiding in the New York Times Since 1995,” *Vice*, 27 August 2018, Retrieved 9 October 2021.
- [6]. Lunn, “Blockchain may finally disrupt payments from Micropayments to credit cards to SWIFT,” *dailyfintech.com*, 10 February 2018, Archived from the original on 27 September 2018. Retrieved 18 November 2018