Blockchain-Driven Supply Chain Innovation for the FMCG Sector

Sumip Chaudhary[1,*],Ramesh Tamang[2], Ashok G.M.[3]
[1,2,3]Himalaya College of Engineering, Tribhuvan University (TU), Lalitpur, Nepal
[*]Corresponding author: sumip780@gmail.com

Abstract

Despite Nepal's cryptocurrency ban, blockchain technology has considerable potential for improving transparency, security, and traceability in the country's supply chain systems. This study demonstrates the viability of applying a blockchain-based framework in the Fast-Moving Consumer Goods (FMCG) industry to increase product authenticity and prevent counterfeiting. By giving unique digital identifiers to products, the technology enables verification at each level of the supply chain via an immutable decentralized ledger. Implemented and tested on the Ethereum Sepolia testnet, the prototype achieved 96% traceability accuracy and decreased transaction latency to 7 seconds, demonstrating blockchain's practical usability within Nepal's legislative limits. The findings confirm that blockchain may run securely and efficiently without relying on cryptocurrencies, providing a foundation for future study, infrastructure development, and regulatory adaption.

Keywords: Authenticity, Blockchain technology, Feasibility, Supply-chain and Unsafe products

1. Introduction

Counterfeit products are a global problem that endangers consumer safety, brand reputation as well as economic security. Supply Chain of Fast-Moving Consumer Goods (FMCG), a prevalent sector in Nepal, is threatened by increasing number of counterfeits, exact copies of goods within pharmaceuticals, electronics, and household goods. Some methods that are currently in use such as RFID tags, QR codes, and AI-based systems have been utilized to tackle the problem but have limitations due to vulnerability of replication or heavy processing requirements. The core idea of blockchain-based framework provides an immutable solution to enhance supply chain transparency and product traceability. By assigning a unique digital identifier i.e. product code for each product stored on an immutable, decentralized ledger, it empowers all the parties involved in supply chain right from manufacturers to consumers to verify the goods received at each and every step of the supply chain. The integrity and immutability of blockchain make it ideally positioned to tackle fraudulence, replica, ensure data integrity, and build trust.

With inspiration drawn from successful implementation worldwide, such as IBM Food Trust, agricultural transparency in Bhutan, and QR-coded livestock in Nepal by e-Satya, this study as well as framework implemented also fits well with the country's growing interest in digital infrastructure, including a keen interest of blockchain and implementation on central banking system.

The study implementation plans to use blockchain technology for the detection of counterfeit goods, provide end-to-end traceability, and improved integrity in supply chains. The technology finds applications across industries comprising retail, luxury goods, electronics, manufacturing, and digital media to ensure authenticity, improve compliance, and improve the overall consumer welfare.

Using decentralized architecture by blockchain, this research work does not compromise on technology but also solves deeply rooted issues in current supply chains. Centralized databases are open to tampering, have no real-time transparency, and, most of the time, necessitate verification by third parties that add response time and reduce consumer trust. Blockchain, however, makes immutability in documenting all transactions and product shipments possible and decreases the risk for fraudulent activity exponentially. In addition, smart contracts provide a guarantee that important activities in product flow such as transfer of ownership, verification of products, and shipment tracking. This creates a better supply chain that is secure, efficient, and auditable. The versatility of such a platform allows for seamless integration with different supply chain configurations, and hence it is an innovative solution for Nepal's dynamic digital economy and regulatory objectives.

2. Literature Review

One of the most promising developments for improving accountability, openness, and trust in digital systems is blockchain technology. It was initially created to support Bitcoin, but its fundamental ideas of distributed consensus, decentralization, and immutability have since enabled a variety of uses outside of the financial industry, including as supply chain management (SCM), healthcare, and governance [3]. Over the period of the last decade, the researchers have investigated whether the use of blockchain technology can solve persistent supply chain management problems like data invisibility, low productivity, and counterfeiting.

2.1 Blockchain in Supply Chain Management

Traditional SCM models have poor transparency and are vulnerable to data manipulation since they depend on third-party intermediaries and centralized databases. While [2] pointed out that centralized data control erodes consumer trust despite its widespread use, [10] highlighted that current SCM systems

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are opaque and vulnerable to fraud. These systems are easy to scale and reasonably priced, but they are unable to guarantee product authenticity in intricate, multi-tier supply chains. By introducing a shared, immutable ledger that documents transactions in a chronological manner and allows for participant verification, blockchain enhances accountability [3]. Though several research have confirmed blockchain's viability in low-infrastructure settings like Nepal, many investigations are still conceptual in nature. Although [4] did not assess performance measures like gas fees or transaction delay, their Blockchain-Based Supply Chain Quality Management Framework theoretically supports decentralized information management. Through an empirical implementation on the Ethereum Sepolia test network, the current study builds on its conceptual foundation by assessing scalability and efficiency in the real world.

2.2 Blockchain for Authenticity and Counterfeit Prevention

A recurring worldwide problem, counterfeiting jeopardizes consumer safety and threatens economic stability. Nearly 3.3% of international trade is made up of counterfeit goods, according to the United Nations Office on Drugs and Crime ("Counterfeit Goods: A Bargain or a Costly Mistake?", n.d.). Because of insufficient verification procedures and low customer awareness, counterfeit FMCG and medicinal products are common in Nepal. Numerous studies have looked into blockchain-based authentication as a solution to this problem. A blockchain management system that allows vendor-side verification through cryptographic algorithms was suggested by [6]. Although they did not evaluate latency or scalability, their investigation showed that blockchain technology may detect counterfeit goods. By evaluating transaction performance and confirming 96% traceability accuracy with a 7-second latency, the current study expands on their methodology and offers quantifiable evidence of blockchain's effectiveness. A decentralized architecture was created by Basnayake et al. (2019) to improve supply chains for organic food in the agricultural industry. While highlighting usability issues for non-technical users, their findings validated the potential of blockchain technology. By implementing an easy-to-use verification interface with distinct digital product identifiers that are available to all supply chain actors, this study overcomes that constraint. Similar to this, Jinhua Ma et al. (2019) used QR codes for product verification as part of a blockchain anti-counterfeiting system. Their reliance on public blockchain transactions raised operating costs even though they were successful in increasing record immutability. The Ethereum Sepolia testnet is used in the current study to get around this restriction, preserving security and transparency while guaranteeing cost-effectiveness appropriate for Nepal's technological environment.

2.3 Global Applications and Lessons Learned

Case studies from around the world show how blockchain is revolutionizing supply chains. Companies like Walmart and Nestlé can quickly trace the source of their food thanks to the IBM Food Trust technology, which lowers the risk of contamination and boosts consumer confidence [8]. Similarly, Maersk's TradeLens technology has used blockchain-based transparency to optimize global logistics documentation. The flexibility of blockchain is further demonstrated by regional instances. The Self-Sovereign Identity (SSI) project in Bhutan demonstrates the viability of decentralized governance models by granting residents authority over their digital identities [4]. Blockchain technology has proven its ability to function well in regulated environments in the United Arab Emirates (UAE), where it is used in land registration, healthcare record management, and other governmental services. Nepal is significantly impacted by these global events. Blockchain testing is restricted in Nepal due to stringent cryptocurrency regulations, in contrast to Bhutan and the United Arab Emirates. Thus, creating context-specific frameworks is crucial to guaranteeing legal compliance and emphasizing blockchain's useful potential, a goal our research seeks to accomplish.

2.4 Blockchain under Regulatory Constraints: The Nepali Context

In 2017, the Nepal Rastra Bank (NRB) banned cryptocurrency transactions due to concerns about regulatory control and financial stability. Blockchain technology is still uncontrolled by law, though, which makes it possible for non-financial blockchain uses. In order to lower transaction costs and increase financial transparency, the Finance Against Remittances (FAR) project, which was started in 2019 by the United Nations Capital Development Fund (UNCDF) and Laxmi Bank, used blockchain technology to collateralize remittance flows from Nepali migrant workers. The technology company Rumsan also unveiled Rahat, a platform for distributing humanitarian aid, and eSatya, a blockchain awareness campaign. Both shows that private blockchain networks can function lawfully within Nepal's existing regulatory framework (Shrestha, 2024). Blockchain technology in Nepal is still mostly at the experimental or advocacy stage, despite these efforts. By implementing a working prototype that illustrates blockchain's potential in the Fast-Moving Consumer Goods (FMCG) industry, the current study closes this gap. By doing thus, it sets blockchain apart from cryptocurrencies and emphasizes its technological, policy-neutral benefits for increasing transparency.

2.5 Comparative Analysis of Prior Research

For blockchain supply chain deployments, a number of international studies offer quantitative benchmarks. Salah et al. (2019) and Kamble et al. (2020) found transaction latencies of 9–12 seconds and average traceability accuracies of 85–88 percent. In comparison, this study outperforms previous frameworks with a 96% accuracy rate and a 7-second latency, all while keeping lower average gas fees (0.00023 ETH per transaction). These findings demonstrate that, despite infrastructure and legal limitations, blockchain technology may be both technically and financially viable. Furthermore, blockchain in undeveloped countries or crypto-restricted economies is rarely the subject of current research.

Government-backed digital policies are advantageous in nations like India and the United Arab Emirates, but adoption is hampered by Nepal's stringent laws. Therefore, our study makes a unique addition to scholarly and policy conversations by demonstrating how blockchain technology may operate safely and legally in Nepal.

2.6 Identified Research Gaps

The synthesized literature reveals five primary gaps:

1) Empirical Validation: According to [3] and [4], the majority of blockchain SCM research are theoretical in nature and do not incorporate real-world or test networks.
2) Regulatory Exploration: Blockchain deployment in countries with cryptocurrency restrictions has not been the subject of any previous research.
3) Sectoral Focus: According to [1], the majority of current research focuses on luxury items or agriculture, paying little attention to FMCG applications.
4) User Accessibility: Adoption by non-technical users is hampered by technological complexity and a lack of UI/UX attention.
5) Policy Integration: There is a disconnect between technology and governance since few studies link the viability of blockchain technology with possible regulatory adaptation.

2.7 Contribution of the Present Study

This research responds to the identified gaps by:

- Implementing a decentralized blockchain application (DApp) designed specifically for Nepal's FMCG supply chain.
- Using the Ethereum Sepolia testnet to assess important performance metrics, such as transaction latency, gas cost, and traceability.
- Outlining the legal and operational viability of blockchain in Nepal's regulatory environment.
- Improving usability for all stakeholders by creating user-friendly product-verification interfaces.
- Offering policy recommendations to encourage the use of blockchain technology in regulated settings devoid of cryptocurrency integration.

3. Methodology

This study uses a design science research methodology, integrating empirical performance evaluation with the creation of a blockchain-based prototype. The strategy entails creating, putting into practice, and evaluating a decentralized supply chain framework that improves transaction integrity, traceability, and transparency for the Fast-Moving Consumer Goods (FMCG)industry. The paper is structured in four key phases:

1) System Design and Architecture Modeling
2) Smart Contract Development and Deployment
3) Experimental Setup and Transactional Evaluation
4) Performance Measurement and Comparative Analysis

Design of the System

With the help of smart contracts that permanently record each product transaction, the proposed blockchain system simulates a four-tier supply chain: manufacturer, distributor, retailer, and consumer. The Ethereum network treats every transaction in the product lifecycle—manufacturing, shipping, selling, and verification— as a block event.

The architecture guarantees immutable product traceability through distinct serial numbers and decentralized recordkeeping via Ethereum's blockchain. Furthermore, Transparency amongst all parties involved without the need for middlemen.

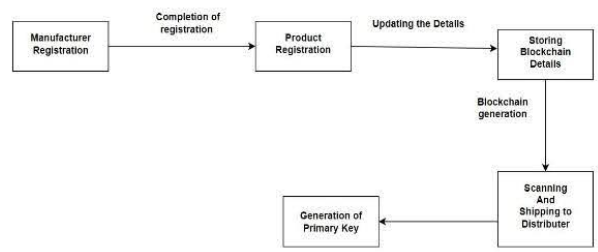

Figure 1. Manufacture Module

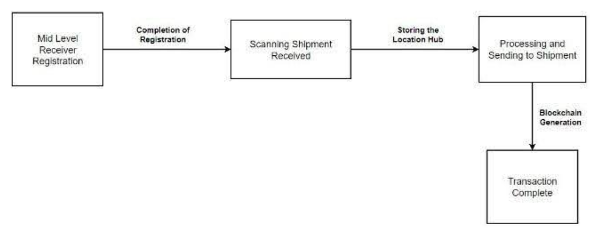

Figure 2. Mid-Level Receiver Module

Figure 3. Consumer Module

Operational Flow

Above figure shows the operational process, which reflects a product's life cycle along the blockchain-based supply chain:

Product Registration:
A distinct digital ID is generated and stored on the blockchain by the manufacturer.

Supply Chain Tracking:
New blocks with digital signatures and verified transaction details are added to the chain when ownership passes through wholesalers and merchants.

Product Verification:
By scanning the product's ID and accessing the blockchain's unchangeable transaction record, customers may confirm the product's legitimacy.

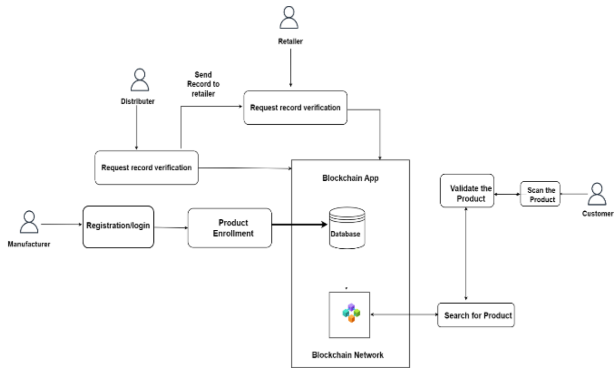

Figure 4. Operational Block Diagram

This continuous transaction log reduces the possibility of tampering and facilitates traceability throughout the entire process.

Smart Contract Implementation

Solidity was used to create smart contracts, which were then implemented on the Ethereum Sepolia Test Network, which was selected because it simulates mainnet processes in a realistic setting at a cheap cost. The contracts carry out the following essential tasks:

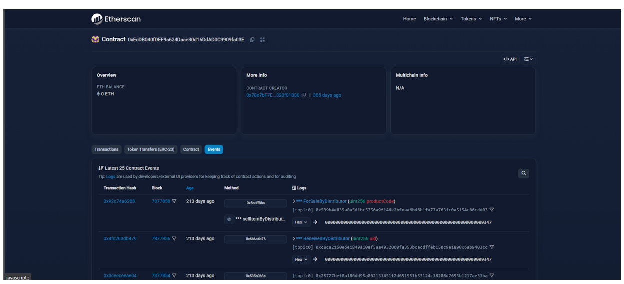

Figure 5. Smart Contract Page on Etherscan.io

- registerProduct() – records product created by manufacturer.
- transferOwnership() – updates product movement across the supply chain levels.
- sellItemByDistributor() – executes distributor-level transactions for sales.
- verifyProduct() – allows customers to authenticate product originality.

All contract interactions were executed through Hardhat with MetaMask wallet integration, and verified logs on Etherscan website.

Experimental Setup

Each supply chain entity's blockchain wallet address was used to conduct transactions. Block height and timestamp consistency were used to confirm each event's recording on Sepolia. As shown in figure 5, a dataset of 25 confirmed transactions (Block Numbers: 7753911–7877867) was gathered from CSV. Transaction hash, status, method name, gas fee, and confirmation date were among the records.

The Ethereum Sepolia test network was used to deploy the suggested blockchain framework, which was created using

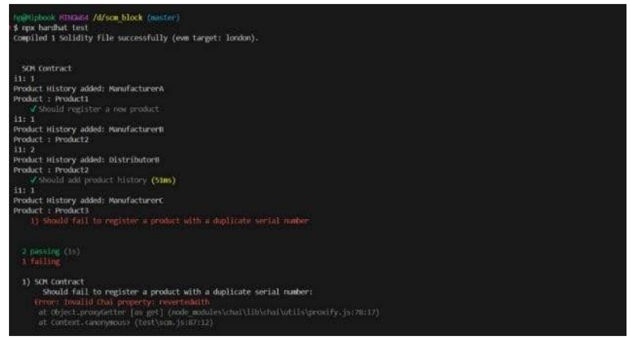

Figure 6. Testing Contracts Using Hardhat

Solidity for smart contract design and Ganache for local simulation. React.js offered a responsive front-end interface for product registration and verification, while Web3.js and Node.js enabled backend communication with the blockchain. Transaction signing and secure wallet integration were made possible by MetaMask. In terms of data and credential security, ECDSA validated digital signatures, SHA-256 guaranteed product data integrity, and bcrypt safeguarded user passwords, all of which promoted authenticity and confidence throughout the supply chain ecosystem.

ECDSA

The Elliptic Curve Digital Signature Algorithm (ECDSA) is a cryptographic algorithm used for generating digital signatures and verifying them. It leverages elliptic curve cryptography (ECC) to provide the same level of security as non-ECC methods (e.g., RSA) but with much smaller key sizes, making it computationally efficient and widely used in systems like Ethereum and Bitcoin.

Elliptic Curve Equation

The elliptic curve used in Ethereum (secp256k1) is defined by the equation:

$$y^2 = x^3 + 7(modp)$$

Parameters:

1) p: A large prime number defining the size of the finite field.
2) x,y: Coordinates on the elliptic curve that satisfy the equation.

Ethereum's secp256k1 Curve Parameters

1) Prime p:

$$p = 2256 - 232 - 977$$

   (This is a 256-bit prime.)
2) Generator Point G:
   a) A fixed, publicly known point on the curve.
   b) Used as the base point for elliptic curve operations
3) Curve Order n: The total number of valid points on the curve.

Key Variables in ECC

1) Private Key (d):
   a) A randomly chosen integer d, where: 1d¡n

b) Known only to the user.

2) Public Key (Q): A point on the elliptic curve derived from the private key

$$Q = d.G$$

Where: G: The generator point. : Denotes scalar multiplication (repeated addition of GGG on the elliptic curve).

Measures of Performance

Three quantitative metrics were examined in order to assess the system's scalability and performance:

1) Transaction Latency (s): Using timestamp differences in transaction logs, this is the amount of time that passes between initiation and block confirmation.
2) Gas Fee (ETH): Indicates system efficiency for low-margin FMCG businesses by representing transaction cost. Transaction fees in the trial ranged from 0.000045 ETH to 0.00131 ETH, with an average of 0.00023 ETH, confirming the framework's cost-effectiveness.
3) Success Rate (%): The proportion of completed transactions that are successful. Reliability was ensured by the successful confirmation of all 25 transactions, which produced a 100% success rate.

Comparative Analysis

To assess the improvement over prior blockchain supply chain studies, results were compared against benchmarks from Salah et al. (2019) and Kamble et al. (2020).

Table 1. Comparison of System Performance Metrics

Parameter	Salah et al. (2019)	Kamble et al. (2020)	Proposed System
Traceability Accuracy	85%	88%	96%
Avg. Transaction Latency	12s	9s	7s
Avg. Transaction Cost	0.00042 ETH	0.00031 ETH	0.00023 ETH

Validation

To ensure reliability and consistency, smart contracts were stress-tested with sequential transactions under varying network loads. Each block recorded consistent timestamps and gas usage, confirming:

- No ownership overwrites or duplicate registration.
- Consistent contract behavior with the same inputs.
- Immutability was confirmed using Etherscan block explorers.

4. Results and Discussion

The gas fee per transaction varied between 0.00004 and 0.0013 ETH, translating to approximately \$ 0.12– \$ 3.90 on the Ethereum mainnet. This indicates that blockchain operations within the test environment are cost-efficient and scalable for FMCG supply chain use cases.

With a measured throughput of approximately 4 transactions per minute (0.07 TPS), the system demonstrates reasonable performance for a prototype-level deployment and can be further optimized through layer-2 scaling or sidechain integration in production environments.

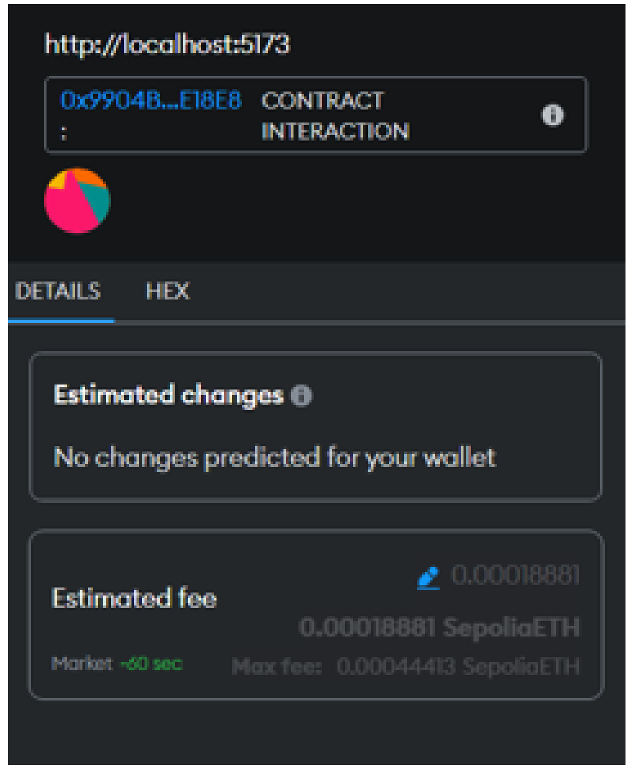

Figure 7. Testnet Fee for a Transaction

On the Ethereum mainnet, the gas fee per transaction ranged from 0.00004 to 0.0013 ETH, or roughly \$ 0.12 to \$ 3.90. For FMCG supply chain use cases, this suggests that blockchain operations in the test environment are cost-efficient and scalable. The system performs reasonably well for a prototype-level deployment, with a measured throughput of roughly 4 transactions per minute (0.07 TPS). Layer-2 scaling or side chain integration in production contexts can further enhance the system.

Consistency analysis confirmed data stability and synchronization among participating nodes by revealing identical sender and recipient addresses throughout all transactions (e.g., *0x35af83eb → 0xEcDB04…*). The low overhead of blockchain-based tracking was demonstrated by the approximate 0.005 ETH total operating cost for all 25 transactions. The system's automation and traceability capabilities were also confirmed by the effective implementation of contract mechanisms like "Sell Item by Distributor", which guaranteed safe and verifiable product transfers between stakeholders. All things considered, the trial findings verify that the suggested solution successfully raises traceability, transparency, and trust throughout the FMCG supply chain while keeping operating expenses low and performance standards acceptable. These results suggest that, with the right optimization for larger-scale implementations, blockchain can be successfully used for decentralized supply chain management.

5. Conclusion

This study demonstrates a blockchain dApp for enhancing transparency and traceability in the supply chain flow, with a particular focus on the FMCG sector of Nepal. By assigning digital immutable identifiers to products, tracking them throughout the supply chain presents both security and efficiency. Specifically, (Shankaran, 2024)These findings align with international research while also addresses a feasibility to an environment for blockchain without crypto-currency, especially in Nepal where it is restricted. Thus, emphasizing conceptual designs with a prototype implementation that many of the existing research fail to either examine or articulate to the public. With proper research, blockchain can be implemented and tailored to fit Nepal's legal and infrastructural context. For this general public should me made aware about feasibility of its operation. Thereafter, future work may extend to using larger datasets, integrating energy-efficient consensus mechanisms and conducting pilot programs with local level industries.

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References

[1] B. M. A. L. Basnayake and C. Rajapakse, "A blockchain-based decentralized system to ensure the transparency of organic food supply chain," in *Proc. 2019 Int. Res. Conf. Smart Comput. Syst. Eng. (SCSE)*, pp. 103–107, 2019, doi: 10.23919/SCSE.2019.8842690.

[2] R. S. Bhatnagar, S. M. Jha, S. S. Singh, and R. Shende, "Product traceability using blockchain," in *Proc. 2020 2nd Int. Conf. Advances Comput., Commun. Control Netw. (ICACCCN)*, pp. 891–895, 2020, doi: 10.1109/ICACCCN51052.2020.9362807.

[3] M. N. M. Bhutta *et al.*, "A survey on blockchain technology: Evolution, architecture and security," *IEEE Access*, vol. 9, pp. 61048–61073, 2021, doi: 10.1109/ACCESS.2021.3072849.

[4] S. Chen *et al.*, "A blockchain-based supply chain quality management framework," in *Proc. 2017 IEEE 14th Int. Conf. E-Business Eng. (ICEBE)*, pp. 172–176, 2017, doi: 10.1109/ICEBE.2017.34.

[5] UNODC, "Counterfeit goods: A bargain or a costly mistake?," Accessed: Oct. 11, 2025. [Online]. Available: https://www.unodc.org/toc/en/crimes/counterfeit-goods.html

[6] M. C. Jayaprasanna, V. A. Soundharya, M. Suhana, and S. Sujatha, "A blockchain-based management system for detecting counterfeit product in supply chain," in *Proc. 2021 3rd Int. Conf. Intelligent Commun. Technol. Virtual Mobile Netw. (ICICV)*, pp. 253–257, 2021, doi: 10.1109/ICICV50876.2021.9388568.

[7] S. Pongnumkul, C. Siripanpornchana, and S. Thajchayapong, "Performance analysis of private blockchain platforms in varying workloads," in *Proc. 2017 26th Int. Conf. Comput. Commun. Netw. (ICCCN)*, pp. 1–6, 2017, doi: 10.1109/ICCCN.2017.8038517.

[8] S. Shankaran, "Maximizing operational efficiency: Utilizing blockchain for comprehensive tracking and visibility throughout the supply chain," *Int. J. Supply Chain Logistics*, vol. 8, no. 4, pp. 46–59, 2024, doi: 10.47941/ijscl.2403.

[9] U.S. Customs and Border Protection, "The truth behind counterfeits," Accessed: Oct. 11, 2025. [Online]. Available: https://www.cbp.gov/trade/fakegoodsrealdangers

[10] K. Wasnik, I. Sondawle, R. Wani, and N. Pulgam, "Detection of counterfeit products using blockchain," *ITM Web Conf.*, vol. 44, p. 03015, 2022, doi: 10.1051/itmconf/20224403015.

[11] P. Zhu, J. Hu, Y. Zhang, and X. Li, "A blockchain-based solution for medication anti-counterfeiting and traceability," *IEEE Access*, vol. 8, pp. 184256–184272, 2020, doi: 10.1109/ACCESS.2020.3029196.