



A Blockchain-Based Framework for Transparent and Accountable Management of Medical Supply Chains Using Smart Contracts

¹Pooja Singh*, ²Vipin Kr. Kushwaha, ³Shiva Gupta, ⁴B. Sharan, ⁵Murari Kumar Singh

^{1,2,3,4}Department of CSE, IEC College of Engineering & Technology, Greater Noida, India

⁵Department of CSE, GNIOT, Greater Noida, India

¹singhpooja6289@gmail.com

²ithead@ieccollege.com

³shivagupta.cs@ieccollege.com

⁴hodcs@ieccollege.com

⁵mksinghjamia@gmail.com

Abstract. The global medical supply chain, particularly for critical items such as vaccines and pharmaceuticals, faces challenges including low transparency, counterfeit products, slow recall processes, and inadequate tracking of usage and waste. Centralised systems struggle to give an immutable, auditable trail from manufacturer to end consumer. This paper proposes a decentralised framework using blockchain to automate and secure the medical supply chain lifecycle. In this paper, we created and deployed a decentralised platform with four main smart contracts on an EVM-compatible blockchain: (1) registration.sol, for permissioned onboarding of entities with a regulatory authority: manufacturers, distributors, and hospitals; (2) LotProductionCommitment.sol, which allows for a demand-driven production model by permitting manufacturers to commit to producing a lot after obtaining sufficient pre-committed interest from distributors and hospitals, thus minimising excess production and waste; (3) DeliveryAndConsumption.sol, which tracks delivery, receipt, and consumption of medical packages to ensure chain of custody; and (4) WasteAssessment.sol, which records usage and disposal on a transparent ledger, supporting regulatory compliance and environmental impact assessment. We used the Truffle suite and tested our deployed system on the local Ganache blockchain. Overall, our work demonstrates how blockchain's characteristics of immutability, transparency and decentralisation can provide a trustless environment in which to conduct business. Our framework will help reduce both the risk of fraud and the risk of counterfeit products while helping improve operational efficiency through automated process checks and a verifiable audit trail of all transactions and changes to product states from the time that an order is committed until the time that it is finally disposed of as waste. This research can be considered a first step toward the development of more resilient, accountable, and efficient medical supply chains in the future.

Keywords: Blockchain, Smart Contract, Supply Chain, Healthcare, Truffle.

1 Introduction

Nowadays, the global medical supply chain is a complex and unsafe network that provides the essential healthcare items, such as vaccines, medicines, and other medical devices. It is also critical for public health. Additionally, it is open to substantial issues, such as counterfeiting, very poor logistics, and slow recalls. The medical supply chain faces severe transparency issues as highlighted by Boppanaa [1], while the lack of secure digital tracking in healthcare systems leads to operational inefficiencies [2]. Furthermore, the pharmaceutical industry's struggle with drug traceability has created an urgent need for technological revolution [3]. Most of the time, in traditional systems, which are centralised and managed by third-party intermediaries. Organisations sometimes function within data silos that restrict the creation of a unified, authoritative source of truth concerning a product's trajectory from maker to end-user. This lack of transparency makes it easier for fraud to occur. And makes it harder to be efficient and follow the rules, especially when it comes to tracking and reporting medical waste. Blockchain technology is foundationally rooted on the core principles of distributed ledger, tamper-proof, decentralization, and transparency that offer a paradigm-shifting solution to these long-standing problems. It can eliminate the need for trusted third-party intermediaries by providing a distributed and tamper-proof ledger. It can generate a trusted and immutable record of all the transactions and state changes that occur in the supply chain [4]. A smart contract, written in a high-level language like Solidity or Vyper, is a self-executing contract with the agreement's obligations directly written into code; take this potential even further by eliminating the controlling authority that enforces the rules and automating business logic [5].

This research paper proposes a decentralized framework designed to automate and secure the entire lifecycle of the medical supply chain. The paper focuses on a comprehensive, decentralised, and distributed framework that has been built on an Ethereum Virtual Machine (EVM) and is compatible with blockchain. This framework has four core smart contracts that manage the participant's registration, demand-driven production commitment, physical delivery and consumption, and final waste assessment. Our work also illustrates the practical feasibility of leveraging a permissioned blockchain to create a flawless ecosystem where accountability is inherent and transparency is achieved through an immutable audit trail from production initiation to final disposal, thereby addressing key vulnerabilities in the current medical supply chain model.

2. Literature Review

[1], [2], [3] Today's application of blockchain technology in supply chain management has been a subject of growing academic and industrial interest. Early foundational work by [6] highlighted blockchain's potential to enhance traceability and provenance in manufacturing, arguing that it could significantly reduce fraud and improve compliance. Further, the applications of blockchain have been explored by [7]. In the various sectors, such as luxury goods, proving authenticity is crucial. In the view of the pharmaceutical and medical supply chains, the applications of blockchain technology have

also been recognized by various researchers as a potential approach to address counterfeiting. Authors in [8] and [9] showed a summary of the global impact of falsified medicines, presenting the blockchain-based serialisation solution as a means of deterrence. Similarly, authors in [10] also examined how blockchain could be integrated into supply chain scenarios and the Internet of Things (IoT) to facilitate overall integration of systems. Furthermore, researchers in [11] illustrated the applications of the blockchain in healthcare and the utilization of IoT and machine learning integration for the optimisation of waste management in residential societies through automated scheduling and real-time monitoring. Authors in [12] turn their attention from intelligent systems towards the health sector and propose a lean blockchain architecture for the purposes of secure medical information exchange, without compromising on performance. Further, they extend this work to propose a decentralised storage blockchain-IPFS architecture, which facilitates the management of health data through enhanced security, scalability, and interoperability [13]. Besides this, authors in [14] also suggest a better healthcare infrastructure that implements a new HEO-PRAFT consensus mechanism with SPS-based EPRSS encryption, prioritising robust patient data protection and proper data encryption management.

The concept of using smart contracts for specific supply chain functions, such as payment upon delivery confirmation, has also been previously discussed in a general context. However, an in-depth analysis of the existing literature has shown that all the existing contributions are based on the concept of tracking and tracing the product as the major value proposition, with the implementation of a simplistic asset transfer concept. Although all the existing contributions are useful in their own way, the gap lies in the development of an end-to-end framework that incorporates demand-driven operational models and post-consumption accountability. The existing proposed systems are based on tracking the location of the product but do not incorporate the production decision based on the actual demand. Furthermore, the explicit and automated tracking of product consumption and disposal for regulatory waste assessment remains an under-explored area. This study attempts to fill these gaps through the development of an all-encompassing framework. This framework promotes both traceability and a new mechanism for calculating demand/commitment in order to optimise production and contains a dedicated waste assessment module to close the accountability loop. This project goes beyond theoretical models to develop a workable prototype that shows real operational efficiency and regulatory compliance for the medical supply chain, in addition to designing and developing four interoperable smart contracts that oversee each stage of the workflow within the supply chain.

3. Proposed Methodology

This research follows a design-science development approach. It focuses on the creation and evaluation of a blockchain-based artefact, a smart contract system, to address the identified problems in the medical supply chain. The methodology was executed in three primary phases, such as (1) System Architecture and Workflow Design, (2) Smart

Contract Development and Implementation, and (3) System Deployment and Functional Validation.

3.1 System Architecture and Workflow Design

The proposed framework has been developed as a permissioned system on a blockchain network, wherein participants are pre-registered by a regulatory authority (RA). An architecture, as shown in Fig. 1, is also embedded that consists of four interrelated smart contracts (SCs). SCs handle the entire life cycle of a medical product lot, including waste disposal. It also illustrates the layered architecture of the proposed medical supply chain system. Ethereum blockchain technology is at the base layer. At the next layer, smart contracts are shown along with their interdependencies as indicated by arrows. At the next layer, participants are shown to interact with each other through four main contracts, as indicated at the participant layer. At the centre, a step-by-step workflow is shown, indicating how each participant is registered, how a product is committed to being produced, how it is delivered and consumed, and how it is eventually disposed of as waste, indicating a seamless integration of each step into the next.

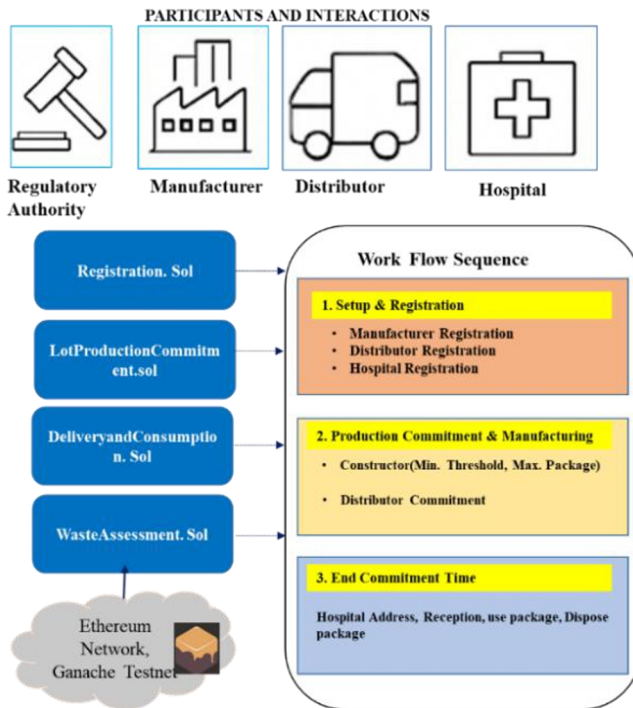


Fig. 1: System Architecture and Workflow

Core Participants:

Regulatory Authority: The trusted entity that deploys the initial 'registration contract' and onboards other participants.

Manufacturer: The entity that initiates production lots and manufactures the medical supplies.

Distributor: The logistics entity responsible for committing to distribute a lot and executing its delivery.

Hospital: The end-user that places demand bids for medical supplies and consumes them.

High-Level Workflow: The operational workflow of the system is designed as a sequential, state-dependent process, ensuring that each step is validated before progressing to the next. The workflow is broken down into the following stages, managed by the respective smart contracts:

1. **Registration & onboarding:** All entities register their Ethereum addresses via the registration contract.
2. **Demand Aggregation & Production Commitment:** A manufacturer proposes a new lot, and distributors/hospitals place commitments, creating a demand-driven production trigger.
3. **Delivery & Consumption:** The distributor delivers the produced lot, and hospitals confirm reception and record usage.
4. **Waste Assessment & Accountability:** Hospitals log the disposal of expired or unused products, providing a final, auditable record.

Fig. 2 contains a technical summary outlining a modular smart contract process for a regulated medical supply chain beginning with the 'Registration Contract', which acts as a central whitelist to manage access to the network by the governing authority. The 'Lot Production Commitment Contract' establishes a model where lots are produced based on demands placed on that lot after an agreement to supply logistics as part of the bidding process of all the hospital locations, which will meet a minimum threshold of orders; if the minimum order is met, the system will automatically authorise production of the lot. The 'Delivery and Consumption Contract' manages the physical logistics of the lot from the point of origin through delivery by utilising a state machine that will track that lot at all times during transit and delivery, while also providing all participating hospitals an opportunity to log all consumptions and disposals made with the supplies associated with that lot. Finally, the 'Waste Assessment Contract' generates an audit trail through aggregation of disposable data recorded in the consumption phase that provides regulators with a permanent record of compliance and efficiency. Table 1 provides a functional summary of each of the primary smart contracts used in this process.

phase to provide an unalterable audit trail to show compliance and help with operational performance measurement. The functionalities of these four core smart contracts will also be summarized in Table 1.

Table 1: Summary of Core Smart Contracts and Their Functions

Contract	Deployer	Key Functions	Primary Purpose
Registration	Regulatory Authority	Manufacturer Registration	Create a permissioned network of participants.
LotProductionCommitment	Manufacturer	Distributor Commitment, Place Bid, Lot Production	Demand aggregation & production authorization
Delivery and Consumption	Regulatory Authority	Start Delivery, Confirmation of Reception, Use Packages	Track logistics, reception, and consumption.
Waste Assessment	Regulatory Authority	(Inferred) Record waste data	Provides a dedicated audit trail by aggregating disposal data from the consumption phase.

3.3 System Architecture and Workflow Design

The successful initialisation of the Registration Contract by the Regular Authority (RA) contract (0x6bA96...) and the successful deployment of the LotProductionCommitment contract by the Manufacturer contract (0x57E9A...) indicate that from day one, the role-based permissions were able to be effectively enforced. Both the frontend application and the smart contracts were able to interact with one another and provided the participants, i.e., regulatory authorities (only Regulatory_authority), manufacturers (only Manufacturer), etc., to carry out their respective role functions without role violation, i.e., as defined in the smart contracts by the “onlyRegulatory_authority” modifier or the “onlyManufacturer” modifier. This illustrates the ability to implement a transparent, automated and accountable medical supply chain using a system of interconnected smart contracts on a blockchain platform.

4. Results and Analysis

This section describes the findings for implementation and operational testing of the proposed blockchain-based medical supply chain system. The system was evaluated using gas consumption, transaction execution cost, role-based access control validation, and audit trail completeness to assess its functional performance and operational efficiency. To demonstrate this, a functioning prototype of a blockchain-based medical supply chain system was built and assessed with respect to the operational activities, technical feasibility, economic viability, and qualitative benefits derived from the data collected through the use of the system. A local blockchain network (Ganache) was created to run and test the prototype. Components of the prototype were created and

migrated using Truffle and, due to their unique addresses, can be identified. The deployment process was performed by generating the migrations of four separate smart contract components and providing them with unique and unalterable addresses, as detailed in Table 2.

4.1 Gas Cost Analysis

The gas costs for deploying and executing a smart contract will give you an idea of how economically feasible the system is. Although the costs on a private testnet differ from those on the Ethereum mainnet, they are proportional to one another, thus allowing for comparison and analysis to be made.

Observation: the LotProductionCommitment contract has the greatest cost of deployment (0.0437 ETH). This is expected, as it is built with very complex business logic, including mapping for bidders and bidder amounts and time constraints for committing to bidders.

User Function Costs: Transactions like the PlaceBid and UsePackages functions were relatively low-cost, making frequent interactions by hospitals feasible. LotProduction was the most costly user-facing feature since it writes a lot of data (delivery and expiration) to storage.

Implication: The cost structure makes sense and is appropriate for a supply chain model in which frequent status updates (such as usage and disposal) are inexpensive but high-value, infrequent transactions (such as production and final delivery) are more expensive.

Table 2: Smart Contract Deployment Results

Contract	Contract Address	Deployer Account	Deployment Cost (ETH)
Registration	0x492B782...83fb1	Regulatory Authority (0x6bA96...F284)	0.01116962
Lot Production Commitment	0x14CF93b...3403A	Manufacturer (0x57E9A...2826)	0.04373294
Delivery and Consumption	0xF945483...309d	Regulatory Authority	0.04255298
Waste Assessment	0x738E312...ea66	Regulatory Authority	0.03167162
Total			0.129127

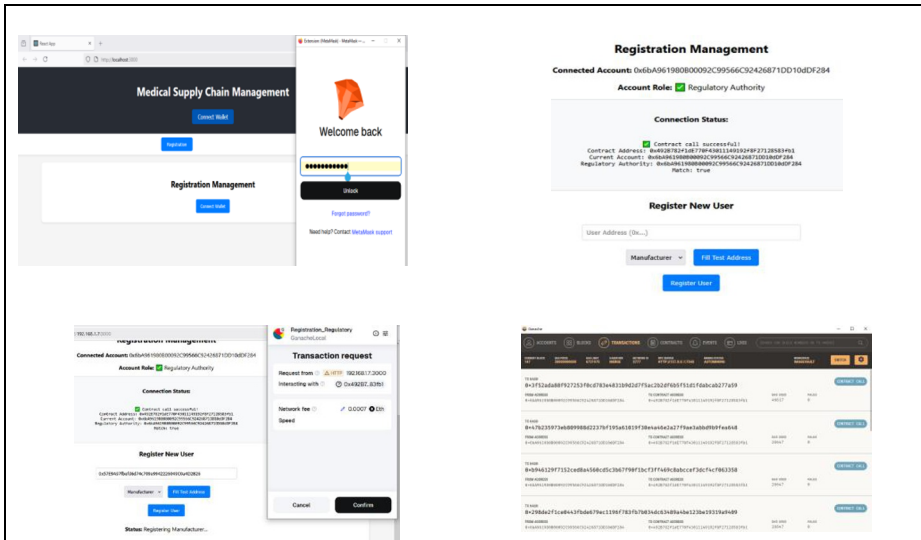


Fig. 3: The frontend application successfully interfaced with smart contracts and Ganache accounts.

4.2 Analysis of Security and Transparency

Access Control: Role-Based Access Control (RBAC) was successfully implemented by the system. For instance, depending on how the require statements and modifiers are written, attempts to call DistributorCommitment() from a hospital or any function from an unregistered address will fail. **Data Integrity & Audit Trails:** From registration to disposal, every state change will cause a transaction and produce events. A tamper-proof audit trail for the complete transaction is produced by this procedure. With a straightforward blockchain query for Lot 0x14CF93b...3403A's event history, any participant or regulator could follow its entire history, providing the highest level of assurance and transparency.

5. Conclusion and Future Scope

This work addresses major shortcomings of current medical supply chain systems by presenting an end-to-end blockchain-based framework that combines secure logistical monitoring, waste responsibility, and demand-driven production. Future research should investigate integration with Layer-2 solutions or other high-throughput blockchain systems to facilitate wider adoption. Furthermore, important procedures like consumption tracking and delivery confirmation still rely on human input, which could result in errors and inefficiencies. Accuracy and operational efficiency would be improved by using IoT-enabled oracles to automatically collect data like inventory levels and transit temperature. Lastly, as lower transaction costs are necessary to enable wider

adoption, improving the smart contract design to reduce gas usage is still a significant area for improvement.

References

1. Boppanaa, V.R.: Blockchain Applications in Pharmaceutical Supply Chain Management. *MZ Journals* 1, 1–18 (2023)
2. Kunchur, P.N., Pujar, P., Hiremath, K., Budnimath, A., Bangarashetti, S., Pandurangi, V.: Blockchain Technology in Healthcare. *JNNCE J. Eng. Manag.* 5, 15 (2021)
3. Islam, M.A., Chuity, S.M., Sultan, T., Baul, S., Ahamed, J., Mobin, D.M.I.: Blockchain technology is revolutionizing the pharmaceutical industry's drug supply chain management. pp. 1081–1088 (2024)
4. Singh, M.K., Pippal, S., Sharma, V.: Secure and Decentralized Patient Medical Record Management System Powered by Ethereum Blockchain and IPFS. In: *Pro c. ICISCT 2024*, pp. 258–263. IEEE (2024)
5. Wang, S., Ouyang, L., Yuan, Y., Ni, X., Han, X., Wang, F.Y.: Blockchain-Enabled Smart Contracts: Architecture, Applications, and Future Trends. *IEEE Trans. Syst. Man, Cybern. Syst.* 49, 2266–2277 (2019)
6. S.A.A.: Blockchain-Ready Manufacturing Supply Chain Using Distributed Ledger. *Int. J. Res. Eng. Technol.* 05, 1–10 (2016)
7. Francisco, K., Swanson, D.: The Supply Chain Has No Clothes: Technology Adoption of Blockchain for Supply Chain Transparency. *Logistics* 2, 2 (2018)
8. Vora, J., Nayyar, A., Tanwar, S., Tyagi, S., Kumar, N., Obaidat, M.S., Rodrigues, J.J.P.C.: BHEEM: A Blockchain-Based Framework for Securing Electronic Health Records. In: *2018 IEEE Globecom Work. (GC Wkshps)*, pp. 1–6. IEEE (2018).
9. Kumar, A., Krishnamurthi, R., Nayyar, A., Sharma, K., Grover, V., Hossain, E.: A Novel Smart Healthcare Design, Simulation, and Implementation Using Healthcare 4.0 Processes. *IEEE Access* 8, 118433–118471 (2020)
10. Agrawal, K., Aggarwal, M., Tanwar, S., Sharma, G., Bokoro, P.N., Sharma, R.: An Extensive Blockchain Based Applications Survey: Tools, Frameworks, Opportunities, Challenges and Solutions. *IEEE Access* (2022)
11. Dubey, S., Singh, M.K., Singh, P., Aggarwal, S.: Waste Management of Residential Society using Machine Learning and IoT Approach. In: *2020 Int. Con f. Emerg. Smart Comput. Informatics (ESCI)*, pp. 293–297. IEEE (2020)
12. Singh, M.K., Pippal, S., Sharma, V., Chakraverti, A.K., Saini, K., Raj, G., Sharad, S.: Lightweight blockchain mechanism for secure data transmission in healthcare system. *Biomed. Signal Process. Control* 102, 107411 (2025)
13. Singh, M.K., Pippal, S., Sharma, V.: A Blockchain-IPFS Framework for Secure, Scalable, and Interoperable Healthcare Data Management. *SN Comput. Sci.* 6 (2025)
14. Chakraverti, A.K., Saini, K., Raj, G., Sharad, S., Singh, M.K.: Enhancing healthcare system for patient data with HEO-PRAFT consensus mechanism using SPS authentication based EPRSS encryption. *Biomed. Signal Process. Control* 109 (2025)

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

