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A Blockchain-IoT Framework for Preventing Counterfeit Medical Supplies via Ride-Sharing Networks

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ABSTRACT

The increasing prevalence of counterfeit drugs and medical supplies poses significant threats to public health, particularly during last-mile delivery. Therefore, to optimize the delivery of critical medical supplies and enhance the authenticity and security of medical supply chains, a novel solution is proposed to integrate Blockchain technology, the Internet of Things (IoT), and ride-sharing applications. Utilizing a Blockchain-based framework with smart contracts facilitates real-time validation of product authenticity. IoT sensors monitor environmental conditions, such as temperature and humidity, ensuring that medical products comply with regulatory requirements. Ride-sharing services facilitate decentralized, efficient delivery of medical products. Additionally, the Proof of Elapsed Time (PoET) consensus mechanism helps reduce energy consumption and ensures fast, secure transactions. The proposed system is prototyped using the Hyperledger Sawtooth platform, and the Hyperledger Caliper benchmarking tool is used to assess performance. The results demonstrate that Blockchain integration with ride-sharing applications significantly reduces the likelihood of counterfeit products entering the supply chain, ensuring safer delivery of medical supplies. Metrics like delivery efficiency, transaction speed, and counterfeit detection rates are validated.

1. INTRODUCTION

Pharmaceutical production is a multi-billion-dollar global industry where the healthcare sector is constantly striving to deliver high quality drugs as per market needs. As the need for high quality drugs increases, the inflow of counterfeit medicines also increases in the market. Within the pharmaceutical supply chain counterfeit medicines and faulty medical devices can infiltrate the world market in diverse ways. Due to the widespread production of drugs, the supply chain is becoming increasingly intricate. Sometimes, the ingredients for a drug come from one country, but the drug is made and sold in another. Second, the supply chain isn't always very clear, so intruders can tamper with or replace drugs/devices while they are being shipped. These pharma products might cross many borders before they reach the end users.

In this situation, reliable logistics or supply chain management holds significant importance. Logistics is the process of moving goods from producers to authorized customers in an effective manner while maintaining precise amounts and ideal conditions all along the way. With the advancement in technologies the supply chain domain has been greatly improved however some drawbacks still exists in the supply chain flow leading to counterfeits and insecurity. Smart logistics now demands the timely and accurate delivery of genuine product deliveries to authorized individuals at the right time and place, a feat made possible through the establishment of a robust infrastructure [1].

Combining The Internet of Things (IoT) and Blockchain technologies together provide a strong framework that enhances the reliability and convenience of logistics services. While Blockchain ensures the data's security and integrity, IoT uses cutting-edge technologies to manage logistical data. Blockchain, the asset behind the cryptocurrency, uses distributed data storage to prevent tampering, making it an indispensable tool for ensuring the effectiveness and trustworthiness of supply chain management [2].

IoT leverages sensors and actuators in the realm of smart transportation and logistics to connect large vehicles. By monitoring traffic, easing congestion, and enabling prompt decision-making, these sensors are essential to transportation optimization. By enabling data collection from several devices, including sensors, cellphones, and cameras, IoT improves connection with the physical world and raises the standard of real-world activities. It is crucial to protect the integrity of data gathered from Internet of Things (IoT) devices against malicious parties or unethical people impersonating the system. Essentially, the integration of IoT and Blockchain is essential for developing a dependable and highly efficient supply chain management strategy.

Ride-sharing applications bring another layer of innovation to the medical supply chain by offering flexible and decentralized last-mile delivery options. Traditional delivery systems can be rigid and inefficient, often leading to delays, increased carbon emissions, and higher costs. Ride-sharing platforms, on the other hand, utilize a network of decentralized drivers, which can lead to faster and more efficient deliveries. This approach also supports sustainability efforts, as ride-sharing services often optimize routes to reduce emissions, contributing to the development of green supply chains.

1.1 Motivation

Traditional medical supply chains often suffer from inefficiencies, lack of transparency, and vulnerabilities to counterfeit products, particularly during the last-mile delivery phase. The World Health Organization (WHO) has estimated that a significant percentage of medical products in developing regions are counterfeit, posing severe risks to patients and eroding trust in healthcare systems. Addressing these issues requires a multi-faceted approach that combines technological innovation with sustainable practices.

To make the pharmaceutical supply chain safer, better rules are needed starting from suppliers, manufacturers until they reach the customers or end users. The healthcare industry is becoming increasingly interested in Blockchain technology. Many experts believe that decentralized technology can address some of the industry's challenges, including issues like missing data, data tampering, and the security of confidential information. Blockchain introduces a fresh approach to safeguarding data, offering the potential to make medical data consistently accessible to all users instantly within the healthcare system. Using IoT-based Blockchain to track drugs from the ingredient suppliers to the manufacturers and finally to the consumers is crucial for making the pharmaceutical supply chain safer and more efficient.

Our idea is to use Blockchain and IoT with ride sharing applications to fix these issues. Our proposed Blockchain-based framework ensures counterfeit detection through the following mechanisms:

At the manufacturing stage, every batch of medical supply is given a distinct digital identity which will be logged on Blockchain. Also, each transaction in the supply chain process will also be logged on the Blockchain ledger making it impossible to tamper with. Consensus mechanism ensures only legitimate transactions are made on Blockchain. This enables the stakeholders of the system to have a better traceability of the product from the Blockchain history. The smart contract verification can be done at every stage of the supply chain process to verify the genuineness of the product. Integrating IoT enables authentication of products by continuously monitoring the temperature, humidity through sensors and any change or deviation will alert the stakeholders in identifying the counterfeit products.

In this context, integrating Blockchain, IoT, and ride-sharing not only enhances the security and efficiency of medical supply chains but also supports the broader goals of smart city initiatives. Smart cities prioritize sustainability, efficiency, and technological integration to create more livable urban environments. By aligning medical supply chains with these principles, cities can ensure that their healthcare infrastructure is resilient, sustainable, and capable of meeting the needs of their growing populations.

This paper proposes a Blockchain-based system built on Hyperledger Sawtooth, integrated with IoT sensors and ride-sharing applications, to address the challenges of counterfeit prevention, regulatory compliance, and environmental sustainability in medical supply chains. The optimized Proof of Elapsed Time (PoET) consensus mechanism further enhances the system by reducing transaction latency, making it more suitable for real-time applications in urban environments. Through this innovative approach, we aim to contribute to the development of smart, sustainable cities that prioritize public health and safety.

The following are the key contributions of this paper:

1) Proposing an effective and efficient decentralized supply chain framework tailored for the healthcare industry. This framework leverages the capabilities of Blockchain-Hyperledger Sawtooth platform along with IoT features. It addresses the needs and requirements of diverse stakeholders, including Manufacturers, Suppliers, Distributors, and end-users such as hospitals, pharmacies, and patients.

2) Presenting algorithms that facilitate various supply chain processes within this framework. These processes encompass activities such as product creation, transfer of product ownership, and product tracking on Blockchain.

3) Presenting the performance metrics such as delivery efficiency, transaction speed, and counterfeit detection.

In conclusion, this paper offers a thorough approach for enhancing the medical supply chain through the use of Blockchain, IoT and ride sharing, enabling improved data security, traceability, transparency, optimized delivery and streamlined operations for all parties concerned.

2. LITERATURE SURVEY

The literature survey explores existing research works based on Blockchain based supply chain, Blockchain application in healthcare, IoT enabled tracking systems and different ride sharing models. The detailed study has been summarized in Table 1 below.

Table 1. Literature survey on existing Blockchain based applications in healthcare domain

Ref No.	Research Contribution
[3]	Blockchain and Supplychain Integration.
[4]	Food Supplychain traceability using IoT and Blockchain.
[5]	Detecting substandard drugs in pharmaceutical distribution.
[6]	Blockchain based system for counterfeit drugs.
[7]	Study on Consensus based on IoT.
[8]	Drug supplychain traceabilty based on Blockchain.
[9]	Blockchain based supplychain in Smart Hospitals.
[10]	The global market for counterfeit, subpar medications is valued at more than $200 billion.
[11]	Trusted and secure consensus for Blockchain based supplychain.
[12]	A light weight Blockchain model using IoT for medical devices.
[13]	Hyperledger Composer for drug supplychain.
[14]	RFID based architecture for food supplychain.
[15]	Applications of Blockchain in supplychain.
[16]	A comparison of the Blockchain platforms Ethereum, Fabric, Sawtooth of the Hyperledger framework, and Fisco-Bcos revealed that both Fisco-Bcos and sawtooth outperformed the others in terms of latency and throughput.
[17]	Consensus based Supplychain traceability.
[18]	PharmaCrypt adapting timestamps in pharmaceutical supply chain with AWS storage.
[19]	RFID based machine learning model for traceability of perishable foods using IoT sensors.

[20]	Challenges and Research directions in Blockchain based supply models.
[21]	Supply chain for the manufacturing and marketing of silk using Blockchain technology.
[22]	Blockchain based food supply chain systems for improved traceability and accountability.
[23]	Traceability model using Blockchain in dairy, agriculture, and seafood supply chains.
[24]	Intelligent supply chain system using Blockchain, IoT and Machine Learning.
[25]	Challenges in Moroccan sustainable supply chain.
[26]	Fog offloading architecture for smart city.
[27]	securing healthcare transactions by using consumer electronics and mobile-edge computing.
[28]	Review on opportunities, challenges and recommendations in Blockchain IoT networks.
[29]	Logistics tracking based on Blockchain and IoT platform.
[30]	Applications and challenges of Blockchain adoption in healthcare industry.

2.1 Background

Blockchain Technology

By using cryptographic techniques, Blockchain, the decentralized and distributed ledger technology, ensures data security and authenticity. It reduces the thirty-party involvement thereby solving the trust issues. Thus, the supply chain as a whole might be elevated to a new level by the technology's transparency and trackability [31]. Such a framework is more suitable for pharmaceutical industry for traceable and transparent supply chain model. In this distributed environment data can be generated by multiple stakeholders like Manufactures, Suppliers, Logistics, distributors and end users yet the integrity of the data can be maintained [32]. The basic structure of Blockchain is given in Figure 1.

The conventional supply chain systems within the healthcare sector primarily operate in a centralized manner, exhibiting limitations in terms of transparency and traceability of products among various stakeholders. Due to data replication, traditional supply chain systems are vulnerable to counterfeiting. However, Blockchain resolves this problem by storing the data in immutable ledgers [33].

Figure 2 shows how Blockchain takes a prominent role in the healthcare domain. The application areas are wide with varied benefits like immutability, data provenance, integrity, etc.

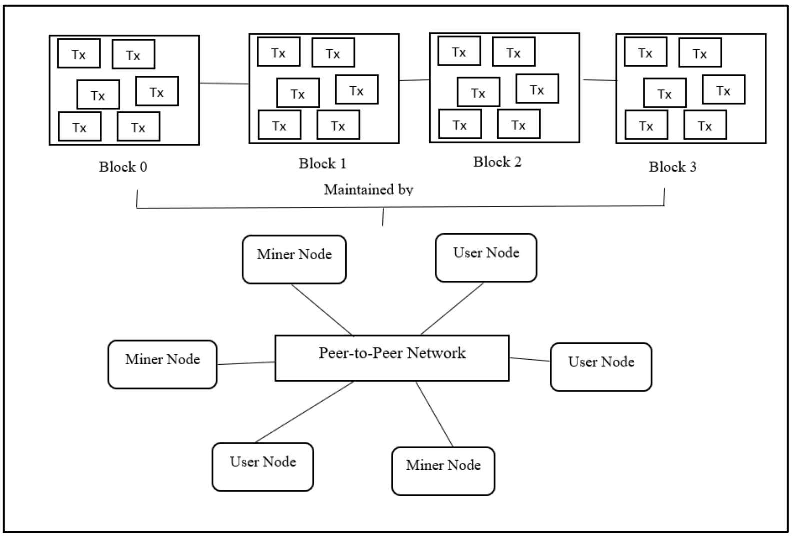

Figure 1. A generic Blockchain structure maintained by user and miner nodes of a peer-to-peer network

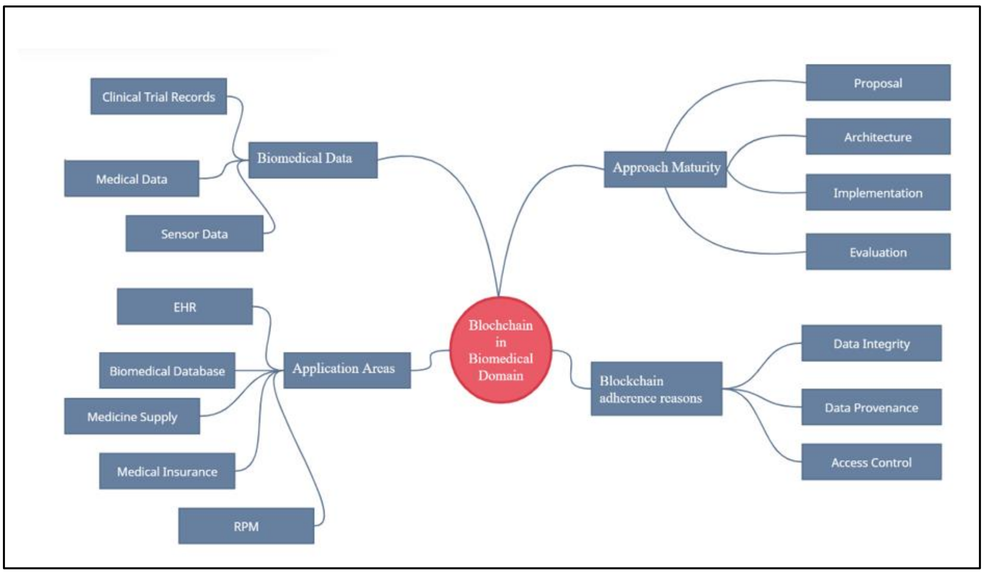

Figure 2. A mind map depicting the reasons of Blockchain integration and its application areas in healthcare domain [34]

Internet of Things (IoT) in Logistics

IoT's integration with transportation and logistics systems not only improves efficiency but also enhances safety, reduces costs, and contributes to a more sustainable and eco-friendly approach to managing the movement of goods and people [35].

Smart logistics and transportation rely on the intellectual interconnection of IoT devices to form a coherent system. Real-time tracking and constant monitoring are applied to these devices. Integrated sensors, actuators, and other devices that gather and send real-time data across the network infrastructure are used by the IoT system to accomplish this connectivity. In the transportation and logistics industry, real-time data transmission and the integration of IoT components are critical to improving productivity, security, and decision-making.

IoT has made transportation and logistics smarter, but it also brings problems like keeping data safe, protecting privacy, and making sure systems work reliably. To address these issues, a number of crucial elements and solutions are required, such as robust cryptographic techniques to ensure the confidentiality and safety of data transported and stored within IoT systems. Encryption, authentication, and secure key management play critical roles in safeguarding sensitive information from unauthorized access and tampering.

In addition, IoT devices usually have low processing and storage capacities, which leaves them vulnerable to several kinds of cyberattacks. Building a safe system is therefore crucial. This requires strong access controls, frequent software updates, and secure communication protocols. Furthermore, using security monitoring and intrusion detection systems can assist in quickly identifying and addressing possible threats. It is essential to put systems in place to ensure data integrity. Digital signatures and hash functions can be used to verify that data has not been altered during storage or transmission.

In summary, IoT in smart transportation and logistics systems requires a multifaceted approach to address security and privacy concerns. To secure data integrity, availability, and confidentiality while unleashing the full potential of IoT technology in various areas, this comprises resilient infrastructure, resource-efficient security mechanisms, and cryptographic algorithms.

Therefore, a safe, open, and effective logistics and transportation system can be created by combining Blockchain technology with IoT. It enhances data integrity, supply chain visibility, and automation while reducing the risks associated with fraud, errors, and cyberattacks. This combination has the ability to completely reshape the industry and improve its dependability and credibility.

Blockchain for Sustainability

Due to its potential to fill in a number of environmental, social, and economic research gaps, Blockchain technology adoption in the creation of sustainable supply chains is gaining momentum [36]. The following are some ways that sustainable supply chains might use Blockchain:

Transparency and Traceability: Blockchain provides a transparent and immutable ledger that records every transaction and movement of products in the supply chain. This transparency enables stakeholders to trace the origin of products, ensuring that they are ethically sourced, environmentally friendly, and adhere to sustainability standards.

Supply Chain Visibility: IoT enabled Blockchain enhances supply chain visibility by providing real-time updates on product locations, conditions, and status. This enables better decision-making, reduces waste, and minimizes the environmental impact associated with inefficient supply chain practices.

Smart Contracts: Smart contracts, self-executing agreements coded on the Blockchain, can automatically enforce sustainability criteria and agreements between supply chain partners. For instance, a smart contract can ensure that a shipment of sustainable materials meets specific environmental standards before payment is released.

Reduction of Counterfeits: Blockchain's immutability and traceability make it difficult for counterfeit products to enter the supply chain. This ensures that consumers receive genuine, sustainable products and reduces the environmental and economic impact of counterfeit goods.

Efficiency and Cost Reduction: Blockchain streamlines supply chain processes by automating tasks such as verification, authentication, and payment. This reduces operational costs and the environmental impact associated with resource-intensive paperwork and manual processes.

Carbon Footprint Tracking: Some Blockchain platforms offer tools to calculate and record the carbon footprint of products as they move through the supply chain. This data can help companies make informed decisions to reduce emissions and adopt more sustainable practices.

Compliance and Reporting: Blockchain simplifies compliance reporting for sustainability standards and regulations. Companies can easily access and share accurate, auditable data, demonstrating their commitment to sustainability.

Consumer Engagement: Blockchain-powered platforms can engage consumers in sustainability efforts. Consumers can use apps to track the environmental impact of their purchases, encouraging responsible buying decisions.

Collaboration: Blockchain encourages collaboration among supply chain partners. It creates trust through transparent and verifiable data, fostering cooperation on sustainability initiatives.

To effectively adopt Blockchain for sustainable supply chains, organizations should carefully plan their implementation, collaborate with partners, and ensure data accuracy and integrity. As sustainability becomes a paramount concern for businesses and consumers, Blockchain technology offers a potent tool to align supply chains with sustainable practices and goals [37]. Figure 3 shows what an ideal supply chain requires.

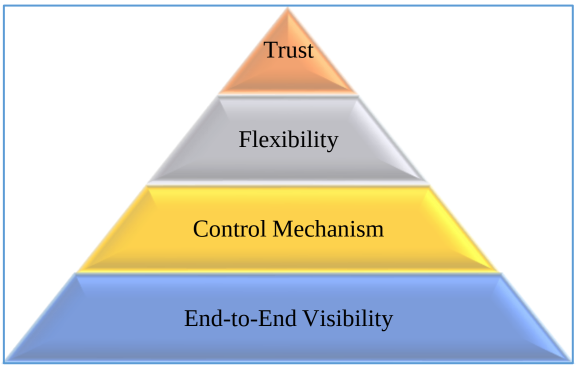

Figure 3. Ideal supply chain system hyperledger sawtooth

Hyperledger is an open-source community dedicated to providing solutions for permissioned Blockchains, including projects like Fabric, Sawtooth, and Iroha. Among these, Hyperledger Sawtooth stands out as an enterprise-grade permissioned Blockchain platform designed for the development of Blockchain-based applications and networks.

One of the distinctive features of Sawtooth is its use of the Proof of Elapsed Time (PoET) consensus mechanism. PoET efficiently handles large distributed node groups while minimizing resource usage. PoET is designed for permissioned Blockchain networks where only verified nodes can take part in the transactions thereby avoiding the sybil attacks. PoET does not require complex computational mining process like PoW consensus mechanisms. Hence the chances of 51% attack to occur is impossible. This makes Sawtooth suitable for enterprise-level applications that require scalability and efficiency. It offers specific templates and guidelines tailored for Supply Chain and Logistics applications, making it well-suited for these industries.

A key advantage of Hyperledger Sawtooth is its modularity. This flexibility allows corporations to customize transaction rules, consensus algorithms, and authorization schemes to align precisely with their unique requirements. Another vital requirement in logistics and supply chain systems is the ability to integrate seamlessly with Internet of Things (IoT) devices. Hyperledger Sawtooth meets this requirement by providing APIs that facilitate integration with IoT devices, enhancing the efficiency and functionality of these systems [38]. Figure 4 shows the main elements of the sawtooth framework.

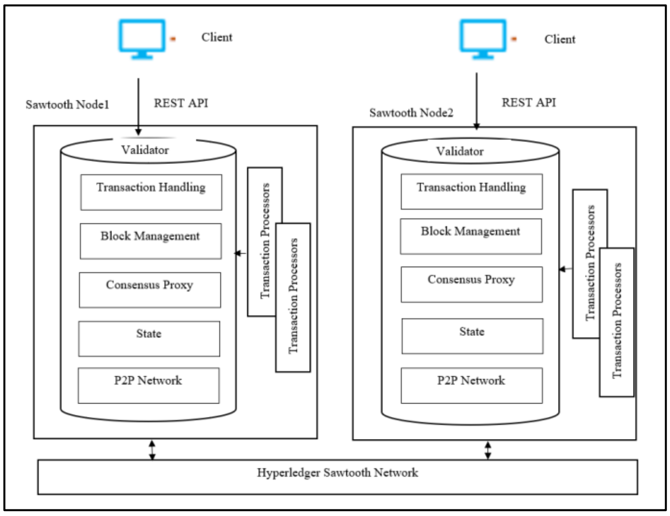

Figure 4. Detailed architecture of sawtooth nodes and its interaction with the sawtooth network

2.2 Proposed system

The system architecture of the Hyperledger saw tooth framework-based healthcare supply chain system is given in Figure 5. The major components of a business network are stakeholders or participants, assets, and then the transactions. The supplier, manufacturer, distributors, and end users like a hospital, pharmacies, and patients are the stakeholders or actors of the proposed system. The asset includes the order invoice, device details, lot details, repositories, etc. The transaction includes the updated order status, update raw materials details, update logistics details, etc. Every user will have a replica of the ledger.

Data leakage is a serious problem in the traditional healthcare supply chain and is prevented by the immutability of the data placed into the Blockchain. According to the Blockchain structure described above, an asset is any record that has the owner, the location, and a unique identifier. An actor is an entity who can own, update and transfer a record. And every actor has a private and public key to sign the transactions. The transactions can be creating records, updating records, and making transactions. The proposed system uses the transaction processor to validate the transactions. Sawtooth Python 3 SDK is used to design and develop the transaction processor.

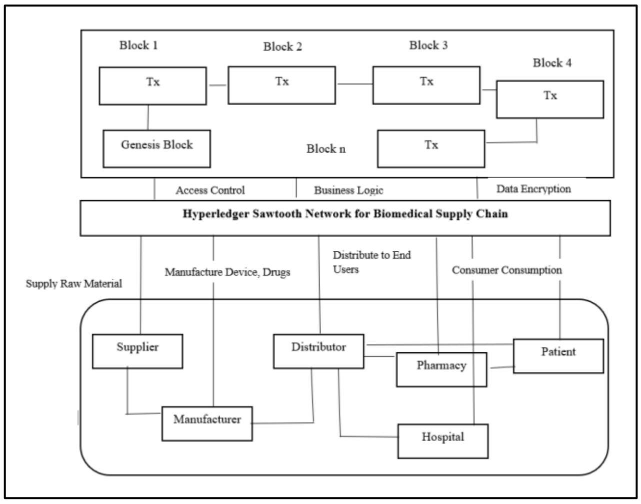

Figure 5. Architecture of proposed healthcare supply chain using Sawtooth with different stake holders of the system

Client: A lightweight web app is developed using JavaScript to add new stakeholders and assets and change the rights of the assets to different owners and change its location. These client requests are submitted to the REST API as HTTP requests.

REST API: Written in python this takes care of a few of the clients like handling the transaction requests, talking to the validator, etc. In the off-chain database, it also maintains the user data and private/public key pair.

A Python event subscriber handles all the sawtooth events and stores the data in an off-chain database. Figure 6 shows the suggested architecture of the medical supply chain model.

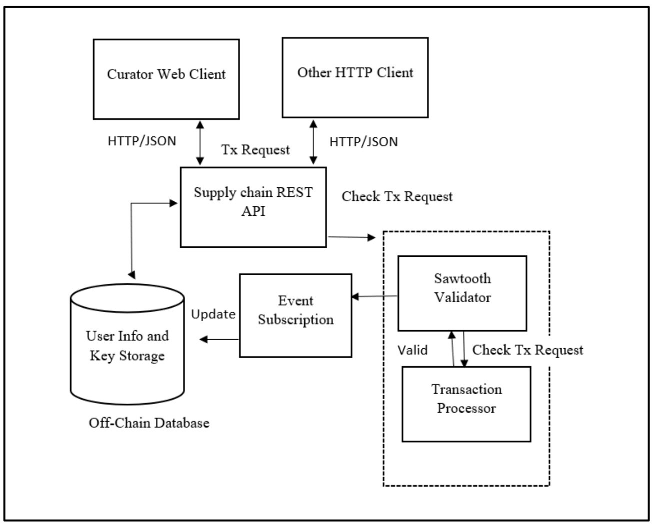

Figure 6. Data flow of registering a supply chain event transaction into the Blockchain platform

Blockchain energy consumption is too high in case of PoW consensus mechanism, where complex computational problems to be solved as a part of their mining work. However, the proposed approach uses PoET which adapts Trusted Execution Environments (TEEs) where the energy consumption is greatly reduced. In order to make it more sustainable the system reduces more on-chain transactions and integrate off chain storage systems.

2.3 System architecture

The workflow architecture of the proposed system is given below in Figure 7. the integration of Blockchain and RFID technology creates a powerful combination that offers numerous benefits in asset management within the supply chain. It enhances efficiency, traceability, security, and innovation while enabling differentiation and providing a foundation for more transparent and reliable supply chain operations. The data flow of the supply chain process shown in Figure 8 is as follows.

- All the stakeholders must resister and are part of the network. Initially, the hospitals or pharmacists will check for the stocks and can place an order request for the medical devices from the manufacturer.
- The request will be sent to the manufacturer who will authenticate and verify the request made and will send a request to the suppliers to send the necessary raw materials needed for the manufacturing process.
- Once the procedure is completed, the manufacturer starts the transaction to create the product on the Blockchain. This information includes the product's name, ID, expiration date, manufacturer details, batch number, and RFID tags, which enable users to identify and track inventory throughout the supply chain lifecycle.
- The transaction number then can be shared with the distributors to verify the validity of the transaction.
- The distributor then can add his signature and send the product to the wholesaler.
- When the product reaches the last-mile delivery phase (e.g., a ride-sharing driver picks up the medical supply), the Blockchain ensures that the product’s integrity has been maintained up to that point. The final delivery to the healthcare provider or patient can be confirmed and recorded.

Sometimes the hospitals and pharmacies can purchase the products directly from the manufacturer or a wholesaler. In each phase when the product is transmitted to another level, the corresponding user should transfer the ownership by adding their signature for authenticity. Once the process gets completed the manufacturer again sends a request to the distributor associated and will update the orders status and the ownership details. The distributor then delivers the product to the consumer who will verify the transaction history and will start consuming the products.

RFID (Radio Frequency Identification) is a contactless automatic identification and communication technology that excels in simultaneously identifying multiple high-speed moving objects, even in challenging environments, without the need for human intervention. Furthermore, it can label, store, and oversee information related to objects via radio-frequency signals [39]. In comparison to barcodes, RFID tagging technology offers numerous advantages, including convenience, resistance to pollution, the ability to handle vast amounts of information, and recyclability. Within the realm of logistics, RFID has found widespread applications in tasks such as production processes, warehouse management, logistics tracking, and combating counterfeit products. As a result of its extensive use, RFID technology has significantly enhanced the efficiency of supply chain management. The sequence flow of the supply chain process is shown in Figure 9 below. The IoT sensors are attached to the medical supplies for seamless monitoring. Using HTTP REST APIs the real time data is transmitted to the edge nodes for pre-processing. The Smart contracts validate the real time data with predefined conditions and alerts if counterfeits are detected. Once the validation the data is encrypted and critical data are stored on the distributed ledger while large datasets are maintained in off-chain databases with Blockchain hashes. This assures the data integrity. The trusted stakeholders can access real-time shipment data via Hyperledger APIs ensuring secure and tamper-proof tracking of medical supplies.

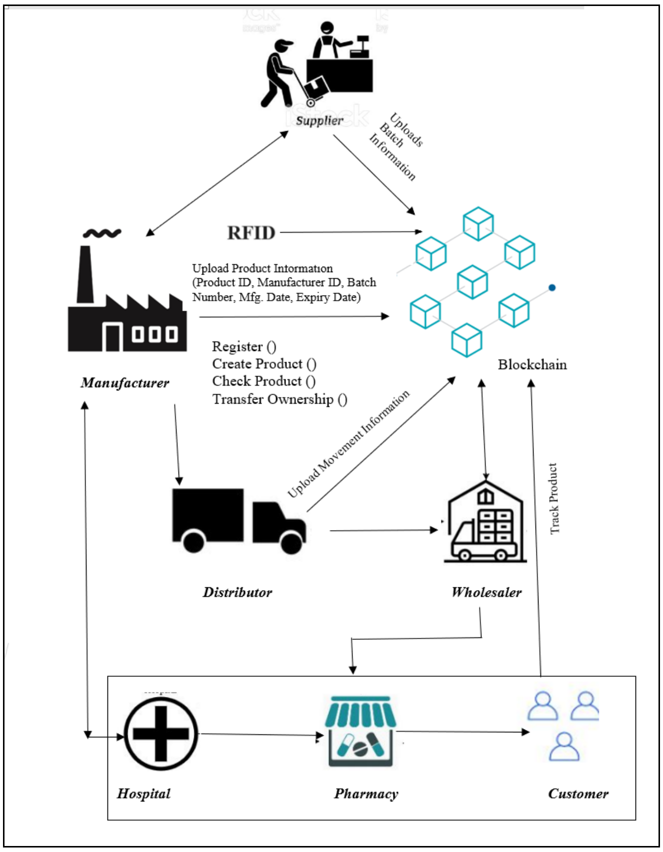

Figure 7. Workflow of different users of the medical supply chain and their interaction within the process and the role of Blockchain in the proposed system

Real-time data exchange between the proposed approach and existing supply chain system can be done using the REST API. The IoT sensor data are processed through edge nodes transmitted via HTTP Protocols to the smart contracts for seamless data exchange.

2.4 Experimental setup

In this section the experiment setup, tools, and methods used on the Hyperledger framework.

Test Environment: A four-node BC network is virtualized for the experiments using the Docker platform on a single machine. The client application and the smart contracts (transaction processors) of the Sawtooth network are written in Python.

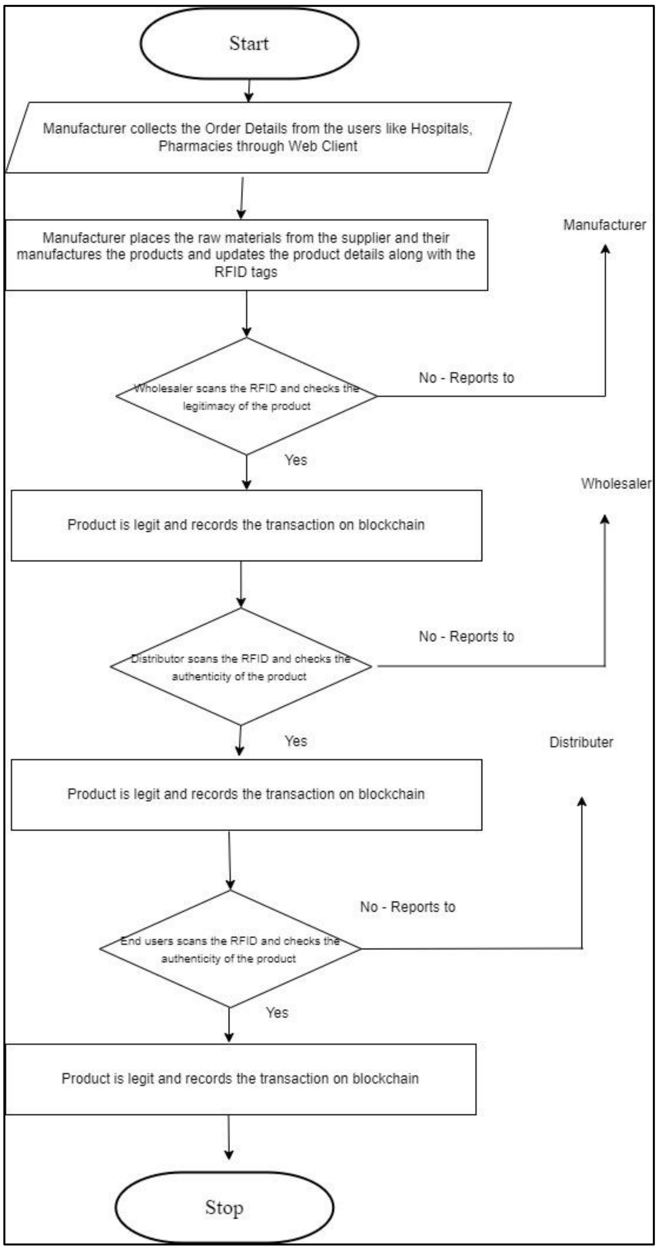

Figure 8. IoT enabled Blockchain based healthcare supply chain system process flow

Hardware Requirements

- Model: ASUS N56JK-CN051H
- CPU: Intel Core i7-4710HQ, 2.50GHz
- RAM: 7,7 GiB DDR3, 1600 MT/s
- Disk: 1 TB WDC PC SN530 SDBPNPZ-1T00-1014

Software Requirements

- OS: 18.04.3 LTS
- Docker Version: Docker Community Edition, version 17.05.0-ce
- Docker-compose: Docker Compose, version 1.13.0
- Sawtooth Version: 1.2.3
- Node: v10.24
- No. of nodes involved in test transaction: Four including a validator, a REST API, to process the smart contracts a transaction processor, and a consensus engine for every node
- Consensus: PoET
- Maximum batches per block: 1000
- Maximum Block transaction:1000
- Block Publishing time: 100ms

Test Tool:

Hyperledger caliper the benchmarking tool is used to perform tests locally. Caliper helps in tracking metrics like latency, throughput, resource consumption etc. The Blockchain benchmarking tool Hyperledger caliper is used to evaluate metrics such as transaction throughput, latency, success rate, and CPU / Memory resource consumption. This can be done based on the timestamps of the transaction and calculating the metrics based on the study [40]. It supports multiple Blockchain platforms and is presented in Table 2.

Table 2. Hyperledger caliper compatibility with Blockchain platforms

Blockchain Platform	Domain	Caliper Support	Caliper Version support
Hyperledger Sawtooth	HealthCare	Yes	2.4
Hyperledger Fabric	HealthCare	Yes	1.4,2.2,2.4
Ethereum	Internet of Medical Things (IOMT)	Yes	1.2.1,1.3
Corda	NA	No	NA
Bitcoin	NA	No	NA
Fisco-bcos	Finance	Yes	2.0.0

Workload: The workload is both CRUD operations and asset flow from producer to consumer.

Measure Type: The metric throughput is used to assess Blockchain performance. Throughput can be measured by dividing the total committed transactions by the total duration in seconds. Throughput shows how quick the transactions get committed to the ledger successfully. The latency is measured in seconds as the time between a transaction being sent and a response.

Observation Points: The performance of the Blockchain network is measured from the client's perspective.

Chain code: A program where business logic for sawtooth is written. The number of transactions, the transaction speed can be preset using this chaincode test. It is then run by the caliper and outputs the results.

Transaction characteristics: Simple and small transactions are used for testing.

The various assets, stakeholders, and transactions are shown in Figure 10. The primary operational requirements of the proposed system are as follows.

- A manufacturer can create a product on Blockchain.
- A manufacturer can transfer a product to a distributor and so on.
- The owner can start the transfer request
- Any consumer/end-user can track the product.

The algorithms for various functionalities of the proposed system are given below. Algorithm1 shows the sample code of how a product is created on a Blockchain. The manufacturer enters the product details such as the ProductID, Batch and Lot number, and Expiry date along with the manufacturer ID. The timestamp of the transaction is then generated which is then later combined with the product key for more authentication and traceability. As a result of this transaction, a transaction ID will be generated which can be further used to ensure traceability.

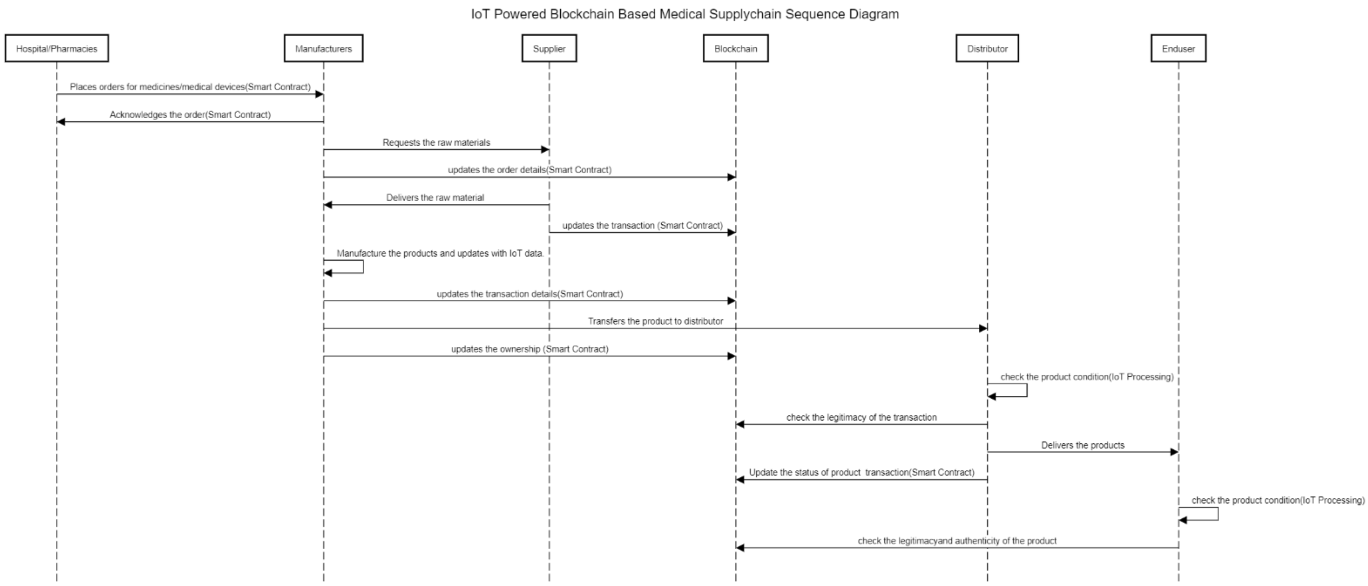

Figure 9. Sequence diagram for medical supply chain workflow

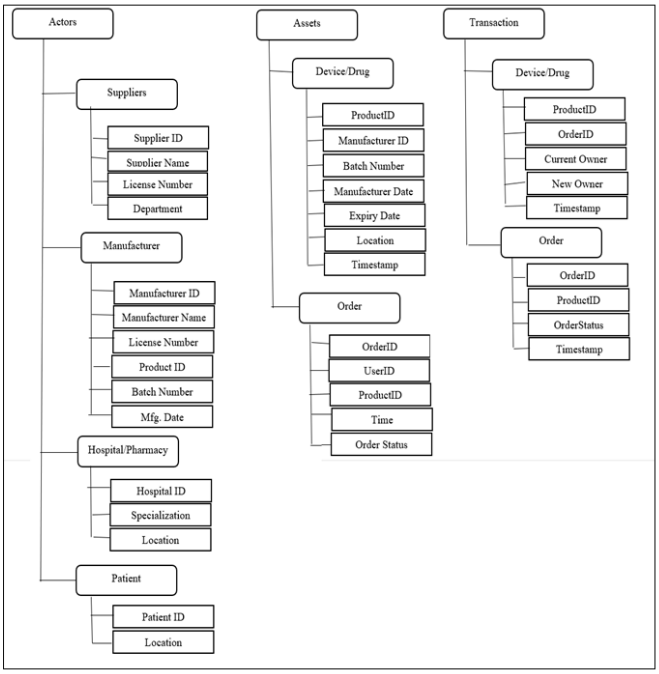

Figure 10. Different users, assets and the transactions of the Sawtooth network with their attributes

Algorithm 2 is to validate the product creation transaction which will be done by the validators of the Blockchain network. This can be done using the manufacturer's public key. If he is a registered user then the transaction can be accepted else rejected by the nodes of the system.

Algorithm 1 to create a product on Blockchain

1. Input: ProductID(PID) and Manufacturer Public Key(MPK)
2. Output: Transaction Data(TID)
3. Generate the timestamp Ti
4. Concatenate ProductID and the Timestamp forming Secret Key (SecKey)
5. Generate actual data, Data: combine the current owner public Key (CO_PK) and new owner public key(NO_PK)
6. Transaction data(TID): SecKey+Data
7. Action=Create
8. End

Algorithm 2 to check product creation

1. Input: Manufacturer1 public key
2. Output: valid owner or not; True or False
3. Check: if action is "Create" and input is "M_1PK" then
4. Return True
5. else
6. Return False
7. End

Algorithm 3 shows the logic for transferring the ownership from one user to another. The transaction includes the previous owner's private key and the new owner's private key along with the product ID, which will create new transaction data with the new timestamp and new owner details.

Algorithm 3 to transfer the product ownership

1. Input: Co_PK and NO_PK, Product ID(PID)
2. Output: Transaction Data: PID, Timestamp
3. Retrieve SecKey by REST API using the PID
4. Data: CO_PK+NO_PK
5. Generate Timestamp
6. TID: SecKey+ Data+ New Timestamp
7. Action="Transfer"
8. End

Algorithm 4 explains the traceability feature of the product. Any user of the network can trace the product by inputting the product ID. IT will show the timeline of details with the current and previous owners.

Algorithm 4 to trace the product

1. Input: PID
2. Output: Manufacturer ID and Current Owner
3. Select all transactions having the Product ID
4. Retrieve SecKey by REST API using the PID
5. For all selected transactions
8. Extract the data
9. Retrieve owner1, owner2, owner n data
10. End

The delivery status of a Batch is shown in Algorithm 5. First the verification of BatchID happens. If a BatchID doesn't exist, "Invalid BatchID" notice will be given to the user. If the BatchID is valid, it stores the delivery Status (status, location, timestamp) on Blockchain. If the status is "Delivered", it verifies the recipient and releases the driver's payment. Finally, a notification confirming the delivery status will be sent.

Algorithm 5 to updateDeliveryStatus

```
1. Input: BatchID, status, location
2. Output: Delivery Status
3. If not Blockchain.contains(batchID) then
   return "Invalid BatchID"
   Endif
4.deliveryStatus ← {BatchID, status, location, timestamp}
5. Blockchain.store(BatchID, deliveryStatus)
6. If status == "Delivered" then
   verifyRecipient(BatchID)
    releasePayment(driverID)
    Endif
7. Notify "Delivery status updated"
8. End
```

3. RESULTS AND DISCUSSION

The application of the Sawtooth framework to a supply chain system not only highlights the system's capacity to support sustainability initiatives but also gives vital information regarding system performance. While the specific configurations of software, hardware, and network components exert influence over the attainable Transactions Per Second (TPS) figures, there are overarching observations to consider. In Sawtooth the transactions enable to modify the shared status. In contrast to other Blockchain platforms in Sawtooth the transactions are included in batches. A list of batches will be included in each block, and each batch will be regarded as a single Blockchain modification.

During the testing process, we got a maximum throughput of 2300 transactions per second the highest of any permissionless Blockchain. It is observed that keeping the batch size constant and varying the input transaction rate resulted in a linear increase in throughput up to 1000 transactions per second. However, after that the performance has been degraded and timed out. Additionally, the throughput is examined and evaluated to see if it stays linear when batch size and input transaction rate are altered. As shown in Figure 11 the batch size and throughput were almost linear up to 2300 tx/s but after which it declined. So having a batch size greater than the input rate will greatly affect the throughput.

At the same time, as there is an increase in input transaction rate there had been greater increase in the memory usage as shown in Figure 12. This could affect the transaction speed and create latency issues.

The effectiveness of the Blockchain model in detecting counterfeit products, maintaining compliance through smart contracts, and its impact on delivery efficiency is shown in Table 3 and graphically shown in Figure 13.

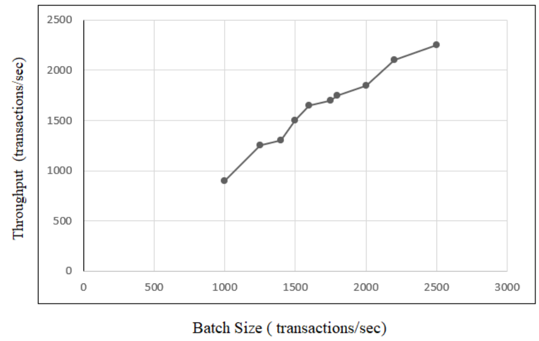

Figure 11. Throughput vs Batch size

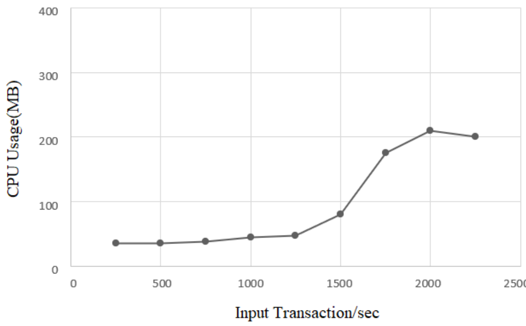

Figure 12. Input transactions vs CPU utilizations

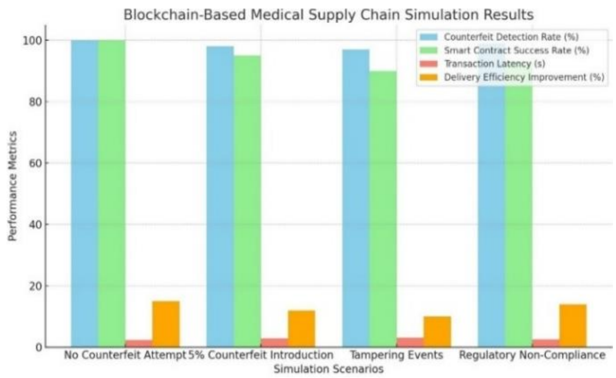

Figure 13. Simulation results for various metrics

Table 3. Blockchain model in detecting counterfeit product

Scenario	Counterfeit Detection Rate (%)	Smart Contract Execution Success Rate (%)	Average Transaction Latency (s)	Delivery Efficiency Improvement (%)
No Counterfeit Attempt	100	100	2.3	15
5% Counterfeit Introduction	98	95	2.8	12
Tampering Events	97	90	3.1	10
Regulatory Non-Compliance	99	93	2.5	14

3.1 Limitations and future directions

In preceding sections, we delved into the diverse benefits of Blockchain technology, ranging from heightened asset integrity and reduced transaction fees to enhanced transparency, effective fraud detection, and the nurturing of trust among partners. However, it's important to recognize that Blockchain also introduces sustainability challenges and implementation complexities. Among these challenges, the prominent ones include issues of interoperability, scalability, and regulatory compliance within the context of sustainability. Within a Blockchain network, each node actively engages in transaction validation, demanding considerable computing power and significantly increased bandwidth. Furthermore, given the array of Blockchain platforms available, determining the ideal combinations of interoperable and compatible systems can be a formidable task. Moreover, the imposition of various sustainability-focused rules and regulatory constraints by government bodies or authorities can have a transformative impact on Blockchain technology. These regulations have the potential to both hinder and enhance the utility of Blockchain, particularly with regard to its role in promoting sustainable practices, safeguarding transaction integrity, preserving privacy, and facilitating environmentally responsible asset transfers.

In summary, Blockchain technology not only offers substantial benefits but also presents a compelling opportunity to drive sustainability within complex supply chain ecosystems. By addressing the associated challenges and harnessing the technology's capabilities, we can realize a more sustainable and eco-conscious future for supply chains.

This research demonstrates the effectiveness of integrating Blockchain, IoT, and ride-sharing applications to enhance security, efficiency, and sustainability in medical supply chains for smart cities. To expand our study, the future directions can focus on the scalability and optimization to improve the transaction speed for supply chains on a larger scale. The proposed work can be extended by integrating privacy preserving techniques like Zero Knowledge Proof to maintain the data privacy of the patients.

4. CONCLUSIONS

This research demonstrates the effectiveness of integrating Blockchain, IoT, and ride-sharing applications to enhance security, efficiency, and sustainability in medical supply chains for smart cities. The system uses Hyperledger Sawtooth to ensure secure data sharing, with the energy-efficient Proof of Elapsed Time (PoET) consensus mechanism reducing transaction latency. IoT sensors monitor environmental conditions, ensuring compliance, while ride-sharing enables decentralized, eco-friendly deliveries. The system's performance, measured through simulations, shows improvements in delivery efficiency, transaction speed, and counterfeit detection rates. This solution aligns with green supply chain principles, reducing carbon emissions and supporting sustainability. By addressing counterfeit prevention and regulatory challenges, this approach enhances the reliability of medical supply chains, contributing to safer and more sustainable healthcare infrastructure in smart cities.

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