Proc. of the International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)
16-18 November 2022, Maldives

2022 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME) | 978-1-6654-7095-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICECCME55909.2022.9987875

Blockchain-based Pharmaceutical Drug Supply Chain Management System

Kaushal Shah
Computer Engineering
Pandit Deendayal Energy University
Gandhinagar, India
shah.kaushal.a@gmail.com

Shivrajsinh Rana
Information and Communication Technology
Pandit Deendayal Energy University
Gandhinagar, India
rana.shiv68@gmail.com

Neel Solanki
Information and Communication Technology
Pandit Deendayal Energy University
Gandhinagar, India
neelsolanki2910@gmail.com

Vomini Desai
Information and Communication Technology
Pandit Deendayal Energy University
Gandhinagar, India
vominid20@gmail.com

Dhyani Prajapati
Information and Communication Technology
Pandit Deendayal Energy University
Gandhinagar, India
dhyanioct@gmail.com

Urvashi Vasita
Information and Communication Technology
Pandit Deendayal Energy University
Gandhinagar, India
urvashi.vasita23@gmail.com

***Abstract*—Blockchain technology was recently invented in financial technology to provide an irreversible, consensus-based, and secure environment. There are areas where trust and transparency are crucial, and that is when blockchain comes to the rescue. It is essential to transmit pharmaceutical data to several parties reliably. Similar to prescription drugs, blockchain technology enables traceability and visibility to supply chains, offering complete information from producers to buyers. Large manufacturers now gather and manage data, and drugstore stores abuse their centralized systems. Many existing approaches and methods enable pharmaceutical data to be kept and centralized between the tending supplier and other stakeholders. This article introduces blockchain technology, reviews and analyses the most recent and significant research using blockchain technology in pharmaceutical supply chains, identifies the challenges connected with blockchain technology, and suggests some future research. Here, we propose an enhanced supply chain management system where the medicine data is available on blockchain to verify all stakeholders and consumers.**

Keywords—Blockchain Technology, Consensus Mechanism, Pharmaceutical Supply Chain, Decentralized Systems

I. Introduction

A. *Supply Chain Management*

The supply chain is a system that connects a company and its suppliers in order to produce and distribute a product to the end user. It applies to a variety of businesses, including manufacturers, suppliers, warehouses, transport companies, distribution facilities, and retailers. The supply chain comprises the entire procedure of developing a product or service and delivering it to customers. Companies create supply networks in order to decrease costs and boost efficiency. The administration of a product's or service's entire product lifecycle in achieving the highest standards, delivery, customer satisfaction, and profitability is referred to as supply chain management. The word supply chain management refers to the following situation "when the market is global, the only way to guarantee and sustain market share is to have an efficient value chain, as well as a flexible structure and production tailored towards the requirements of the client" [1]. Increasing product safety and security, improving quality management, reducing illegal counterfeiting, advancing inventory management and replenishment, eliminating the need for intermediaries, influencing new product design and development, and decreasing the cost of supply chain transactions are just a few ways blockchain could morph OSCM practice (Operations and Supply Chain Management). Because blockchain researchers and practitioners are still in their infancy, OSCM researchers have the opportunity to examine the technology early on and help define its acceptability [2].

B. *Blockchain*

Blockchain technology is said to have a high potential for disruption and the capacity to function without the use of a middleman. Several articles examine the implications for logistics and supply networks, as well as the possibility for disruption [3]–[8]. The privacy of the data is preserved through [9], [10]. Blockchain, as a technology, combines the advantages of peer-to-peer networks with cryptographic techniques to verify the legality of conducted agreements [11]. Blockchain is a decentralized and distributed ledger that chronicles the provenance of digital assets. The data on a blockchain cannot be changed by design, making it a genuine disruptor in domains such as commerce, cybersecurity and healthcare. Blockchain is a powerful and revolutionary technology because it reduces risk, eliminates fraud and allows scalable transparency across a wide range of applications. Blockchain in its core essence consists of three main concepts via a viz Blocks, Miners, and Nodes. Blockchain has the potential to make the supply chain more efficient, reliable, secure, and traceable due to characteristics such as decentralization, transparency, trust-free environment, anonymity, and immutability.

C. *Integration of Blockchain and Supply Chain Management*

The pharma business confronts various challenges that demand answers in the near future, as the worldwide pandemic has demonstrated how disruptive these issues are for the smooth functioning of the concerned organizations involved in the process. Numerous blockchain studies have been undertaken in the pharmaceutical business (Bushra Mukri, 2018; Vineet Paliwal, Shalini Chandra & Suneel Sharmai, 2020). These researchers have observed that the decentralized network offered by blockchain provides a variety of benefits for a supply chain network: Blockchain will connect all supply chain components, making data secure, verifiable, and structured, benefiting everyone involved, including customers, manufacturers, and delivery providers. A blockchain supply chain network has the potential to significantly improve' Supply Chain Management (SCM)'. Blockchain is the technology that establishes the platform for the implementation of blockchain and the management of the supply chain networks in the manufacturing business. These Blockchain technologies, which create the framework for the development of blockchain for managing the supply chains of firms in the manufacturing and SCM sectors, have the potential to produce enormous value through a blockchain supply chain network. The traditional methods of supply chain management are riddled with flaws and inefficiencies. The primary issues with the conventional supply chain were product tampering, excessive delays at every stage, corruption among middlemen, transparency, inefficiency, and so on. These flaws have a negative impact on the healthcare industry, leading to public distrust and mistrust of healthcare professionals. Aside from those already stated, other critical areas where the conventional supply chain lacks are sufficient authentication procedures among participants, as well as uncontrolled data handling. While efforts are being made to solve the issues associated with current supply chain management systems, the scope of the issue is substantial. The solution described here uses Blockchain technology, which has the ability to make the supply chain more effective, trustworthy, secure, and traceable owing to characteristics such as decentralization, accountability, trust-free environment, privacy, and data integrity. This article walks through a proposed system's architecture, detailing the relationships shared by the primary modules (Manufacturer, Distributors, User, IPFS, and smart contracts), as well as the general flow of the system implementation. Toward the end, results and conclusions are drawn from the study that has been conducted and the system that has been established.

II. LITERATURE REVIEW

The global supply chain is significantly being impacted by recent technological developments and the fast expansion of manufacturing. Enhancing the effectiveness and openness of a company's supply chain is essential as the pace of change quickens. Fortunately, blockchain technology can facilitate the process' simplification. Blockchain technology offers the principles of efficiency and transparency in supply networks, which are reliability and integrity. Blockchain in pharmaceutical supply chain management has been a topic of research today. They design a model for detecting falsified drugs which consists of five main nodes: for FDA, manufacturer, wholesaler, retailer, and the consumer portal [12]. The customer portal can scan codes that come with the receipt of their purchases to view the drug distribution history. The drug distribution history that contains a listing of the participants who possessed the drug at some point during the distribution, as well as information on shipments. This model is good to work at United States and a similar model we would to propose to function in India. The article describes the investigation that should be done while implementing blockchain in Pharmaceutical Supply chain management [13]. It suggests that the blockchain technology suits well for the protection of integrity of data in health supply chain. The following are the questions must be posed initially, while considering the blockchain for securing the supply chain of pharmaceutical products: 1. What are the improvements through the adoption of blockchain-based database over the existing one? 2. What is it that blockchain technology offeres that is not available with centralized and existing systems? 3. How existing supply chain can be extended to incorporate the advantages of blockchain technology? These are some of the questions that needs to be answered while implementing blockchain in pharmaceutical supply chain management. The use of blockchain in supply chain management has been extensively investigated [14]. It mentions the problems associated with the current supply chain management and how blockchain resolves those issues. Significant company value may be achieved by raising transparency, decreasing risk, and improving efficiency and overall supply chain management via blockchain. conducted a thorough analysis of the literature and prospective blockchain uses in the supply chain [15]. Because they relied on a centralized structure, traditional organizations are frequently the subject of hostile assaults, threats, and malfunctions. Through a series of research and implementations of several pilot projects in various domains, blockchain technology has demonstrated useful applications from both academic and practical perspectives. The qualities of blockchain significantly minimize the requirement for trusted centralized authority, allowing for irreversible transactions and increased supply chain efficiency [16]. Blockchain has already shown to be an excellent Supply Chain traceability technology and its use will undoubtedly increase in order to improve the transparency, traceability and auditability of materials movement as well as Supply Chain participants. The supply chain meets all of the decision criteria for implementing blockchain technology [17].

III. RESEARCH GAPS

A. *Current issues in Supply Chain*

Although the technology is novel in its own right, there are various limits and impediments to its use in applications. The integration of blockchain with supply chain management is still in its early stages. Scholars and practitioners alike underestimate the blockchain's power to upend traditional business models [18]. There are many studies on supply chain coordination under risk aversion at the moment, but no researchers have looked at supply chain risk aversion and coordination under the effect of blockchain technology. The application of blockchain technology in supply chain management has mostly focused on traceability and credit problems [19]. Despite the fact that Radio Frequency Identification (RFID) chips and scanners are now widely available in terms of convenience, the availability of technology does not guarantee its acceptance where many warehouses continue to rely on paper in critical areas [20]. Lack of understanding of Blockchain, the belief that it is a passing fad and the desire to wait for broader acceptance before executing are all factors working against the technology's adoption. Even executives in corporations who observe Blockchain's potential are hesitant to invest money and effort in it due to a lack of industrialized standards and processes. To be successful and productive in a traditional supply chain industry, everyone must be convinced of its benefits such as key stakeholders must be on board and perceived their interests or profits. The issue of accuracy of entered data lies at the intersection of technological and non-technical difficulties. As the blockchain technology is immutable and transparent, data entered into a blockchain must be accurate and correct because the user cannot easily change or modify the record. If a supply chain partner's information is recorded in an unreliable system, the adoption of Blockchain technology may be more harmful to the user than beneficial. The Blockchain's immutability does not ensure the data's quality.

IV. Research Contributions

A. *Why Blockchain is needed in Supplychain?*

The distinguishability, security, and transparency of web infrastructure are improved by the unique collection of qualities that make up the blockchain technology. A concurrent algorithm, smart contracts, on-chain resources, a varied range of specifics, a decentralized system, and storage methods are a few of these aspects. Thanks to blockchain, there is a lot of opportunity for change in supply chain (SC) operations, including SC inclusion, business process transformation, and security enhancement. Blockchain technology makes it simpler to detect problematic items more quickly and remove them from the supply chain, such as those that are defective, mishandled during storage, or fake.

B. *Solving Scalability issue with Polygon Network*

Supply Chain's Smart Contract, when deployed on the Polygon Network, greatly aids in the transaction process and the handling of several transactions at once. Polygon has a range of protocols, including the zero-knowledge (zk) proof variety. In cryptography, zk proofs are a cryptographic primitive for proving the validity of a statement to a third party (the verifier). At the same time, other than the fact that the assertion is true, the prover is not needed to supply any other information.

C. *Use of Chainlink Oracle (RFID Tracking)*

Chainlink oracles integrate supply chain smart contracts to online APIs, cloud networks and a variety of real-world sensors such as GPS, temperature, velocity, acceleration, humidity, light and so on. This information may be utilized to automatically trigger payments and data transfers between partners in ways that no one supply chain player can control.

V. Methodology

A. *Tools*

1) Smart Contracts: A smart contract is a self-executing contract in which the terms of the buyer-seller agreement are written directly into lines of code. The code and the agreements it contains are distributed and decentralized over a blockchain network. Transactions are trackable, irreversible and the implementation is managed by the code. The Smart Contract's role is to record and validate information from all entities engaged in the supply chain, including the medicines itself, on the Ethereum Blockchain. The Smart Contract features an IPFS-based mechanism for preserving batch documents on-chain. IPFS is a distributed file storage system that keeps a file by splitting it into smaller bits, cryptographically hashing it, and assigning it a unique fingerprint known as a content identifier. As a result, medical doc files stored on IPFS are resistant to manipulation and censorship, and modifications to the file do not overwrite the original, and common chunks across files may be reused to minimize storage costs.

2) Solidity: Ethereum supports a wide range of script languages for writing smart contract code. The most well known among them is Solidity, a contract-oriented high level language with a static type system that has a syntax basically the same as JavaScript. Solidity is a high-level programming language that is object-oriented and used to create smart contracts, statically typed and supports inheritance, libraries and advanced user-defined types among other features. Smart Contracts are programs that govern how records behave in the Ethereum state. It is influenced by C++, JavaScript, Python and it is designed to work with the Ethereum Virtual Machine (EVM).

B. *Use-Case Diagram*

Figure 1 illustrates the functions performed by each entities such as the manufacturer of the medical supplies can create a batch doc/ record of the supplies over the blockchain, view the votes and verify data on the application and the only entity that can add distributors and retailers to the chain whereas supplier can validate a batch by scanning the RFID code on each batch and also see the history of verifiers, while consumers of the medicine can see the list of verifiers and their remarks regarding the medical supply batch.

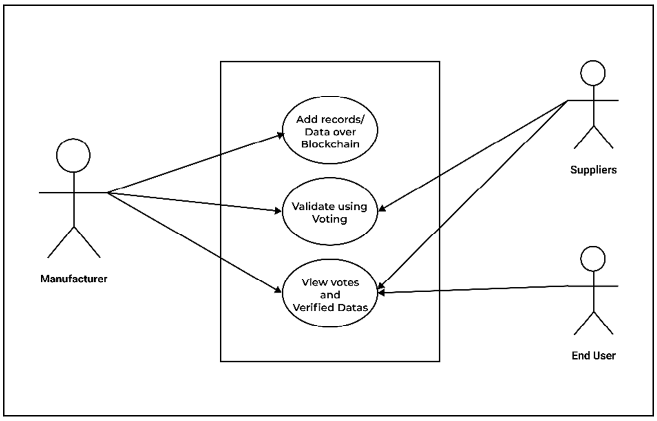

Fig. 1. Use Case diagram illustrating the functions performed by each entity

C. *Supply Chain Entities*

1) Manufacturer: The job of the manufacturer is to upload a verified batch doc on Blockchain which must include the important information about the medicine and that doc can be accessed by both Distributors/Retailers and Consumers.

Only the manufacturer can add new Distributors or Retailers to the chain by adding their addresses and other relevant information like position and job description on the Blockchain as seen in Figure 2.

Algorithm 1 Add Distributor Or Retailer:

```
ADD-DISTRIBUTOR-OR-RETAILER(address, type, position)
if type = 1 then
    distributors[address] ← Distributors(position, true)
    Else:
    retailer[address] ← Retailer(position, true)
End_if
```

Fig. 2. Algorithm of adding Distributor or Retailer

2) Distributors, Retailers, etc.: Figure 3 shows the structure of Distributors and Retailers (all suppliers) stores their Ethereum Addresses and other relevant information for their verification. Their information can be fetched when required with the help of mappings and getter functions. The information of a new Distributor or a Retailer can be only added by the deployer of the Smart Contract, i.e. the Manufacturer.

Algorithm 2 Verify The Data

VERIFY-THE-DATA (batchcode,vote)
if $distributors[msg.sender].verified = TRUE$ **then**
    $verifydata[batchcode]$
    $[batch[batchcode].verifycount++] \leftarrow Distributors(position, true)$
End_if
elseif: $retailer[msg.sender].verified = TRUE$
$verifydata[batchcode]$
    $[batch[batchcode].verifycount{+}{+}] \leftarrow VerifyData(retailer[msg.sender].position, msg.sender, block.timestamp, vote)$
End_if

Fig. 3. Algorithm of verifying the data

The medicine batch is verified on chain with help of the "verifythedata" function of the contract. This function can be accessed by only the authorized entities, i.e. the distributors and retailers. They will first verify the batch received with the untamperable medical doc (which is stored on blockchain). Once they verify the batch, the distributor or the retailer will sign a transaction by their vote. If the medicine has no-fault then they'll sign a transaction with a vote "yes", if a counterfeit is detected then they can sign a transaction with a "no" vote and can report the issue immediately. The RFID tag is scanned either by the retailer or the distributor in order to trigger smart contract that is available at Chainlink oracle. i.e. The requestData method of the contract makes a Chainlink request to the RFID, and after completion, puts the UID (batch number) in the variable called last_uid. The value of last_uid is sent to the Supply chain smart contract and then the verification function verifythedata() is called. Moreover, the retailers and the distributors are provided with the medical doc of that batch on their Dashboard.

3) Consumer: As shown in Figure 4, the transparency is achieved through a publicly available portal for the consumers. Through this portal, the consumers can see all the details regarding the medicines like the distributor's and retailer's address, who verified it and at what time, how many verification has taken place (number of suppliers).

Algorithm 3 View the Verified Data

VIEW-VERIFIED-DATA(batchcode,verifierID)
return: $verifydata[batchcode][verifierID].position,$
    $verifydata[batchcode][verifierID].verifier,$
    $verifydata[batchcode][verifierID].date,$
    $verifydata[batchcode][verifierID].vote$

Fig. 4. Algorithm of viewing the verified data

The consumers can also view the batch to verify whether they have received the correct medicine strip or not. Consumers can view all these details by scanning the QR code on the medicine strip. If the consumers cannot find any data of a particular medicine then they can immediately report a counterfeit and it can save someone's life.

D. RFID Data Provider Smart Contract

1) Job/Oracle Specifications: A Chainlink external adapter will interface with a MiFare RC522 RFID scanner (or simulate the scanner when no hardware is connected). A server will return the UID of an RFID card(here in this case,the UID will be the batch code of a medicine batch) on a POST request.

2) Contract (Only the Integral functions are mentioned) : Our RFID integration is a proof of concept that we can run a real-time hardware device on a smart contract as seen in Figure 2. Hence an item(or batch) containing an RFID chip can be scanned at numerous checkpoints to securely trace its position. This approach is useful for supply chain management.

VI. Results

A. Contract Deployment

We deployed our smart contract successfully on Mumbai Polygon Testnet using Remix IDE and solidity programming language as seen in Figure 5. The execution cost analysis are as follows :

Contract address : 0x63a3c44bb...0c70dcb

Transaction Hash : 0xdd87a29a23959eb...7cab

Transaction fees : 0.001743823015694407 Ether

Gas Price: 0.000000001000000009 Ether (1.000000009 Gwei)

Solidity Version: 0.8.0

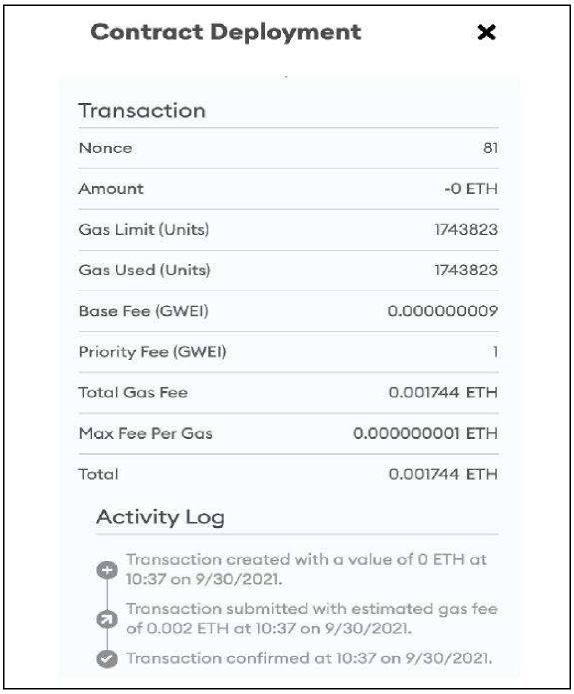

Fig. 5. Contract Deployment through Remix IDE

B. Smart Contract Output

When the consumers scan the QR code of the medicine strip on the dashboard, they can view all the details of that medicine's supply chain history including by whom the medicine was verified (through their Ethereum Wallet Address), at what time it was verified and the position of the verifier. The patient can also view the batch doc (from IPFS), the link will be provided on the portal itself. The consumers now can have the full transparency of the medicine they are consuming and if they find any counterfeit, they can immediately report it to the concerned authorities and can be saved from taking a fake medicine.

C. Transaction Output

A successful transaction takes place when the authenticated supply chain entity verifies the medicine and adds itself to the list of people who authenticated the medicine. The authenticated supply chain entities are those that are originally added by the manufacturer when smart contracts are deployed. This functionality builds a secure, reliable and transparent system in supply chain management. It will have the following attributes in the description:

Status: It suggests whether the transaction was a success or failure.
Transaction hash and hash: For each transaction, a unique transaction hash is present to identify each transaction that has taken place. This maintains security of the transaction because any change in the smart contract will produce new transaction hash which can help identify any tamper during the transaction.
From: It contains the Sender's Ethereum address.
To: It contains the receiver's Ethereum address.
Gas and transaction cost: The fees paid by the sender for the particular transaction in gas.
Input: This contains the encoded input.
Val: The amount in Gwei to transfer from the sender to the receiver

D. Dashboard

1) *Manufacturer Dashboard:* The manufacturer dashboard has two functions. Figure 6 shows the page where manufacturer adds a new supplier to the supply management chain, the Ethereum address of that supplier is stored on the blockchain through supply chain smart contract with additional information of the supplier such as his/her position or designation on chain. The details of suppliers, for example a distributor and a retailer are stored within the Smart Contract with the use of mappings, which is a reference type. Storing supplier's details directly on chain using mappings is beneficial because it will help in easy fetching of data to track suppliers in case of an identified counterfeit, another advantage would be that this data would be immutable and hence nobody can alter it by any means which enhances security. Mappings are also advantageous in terms of making data redundancy zero; same supplier cannot be re-added. Additionally, this function can only be accessed by the manufacturer who will add only the verified suppliers on chain.

Fig. 6. Adding a new supplier to the supply chain

Also, the manufacturer can add a new batch to the supply chain and the batch doc is stored on IPFS as seen in Figure 7.

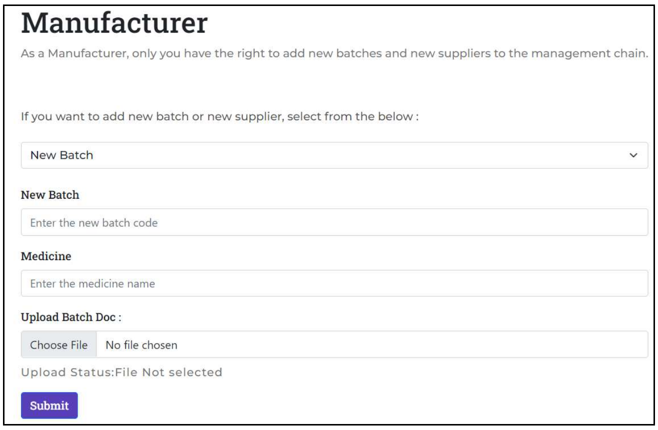

Fig. 7. Adding a new batch to the supply management chain

2) *Supplier Dashboard:* Figure 8 depicts how a verified supplier may validate a batch after fetching its batch code through scanning the batch's RFID, the remarks (vote) and the time stamp of the verification can be viewed by a consumer through the consumer's dashboard. If a supplier is not verified on the chain by the manufacturer, then the transaction will be reverted, which will be notified by a toast (Reactjs).

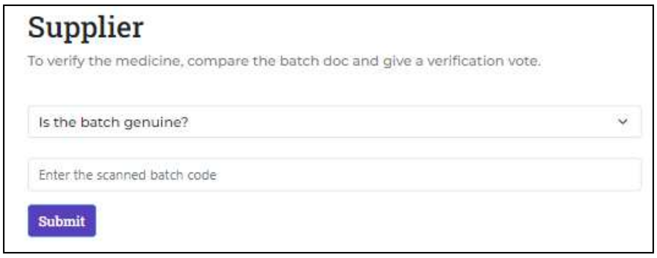

Fig. 8. Represents the page where supplier can add its vote in the batch

3) *Consumer Dashboard:* Figure 9 represents how a consumer may check if the received medicine strip is legit or counterfeited. The consumer may scan the QR code given the medicine strip on the dashboard to view the validation history of that medicine, it promotes transparency to a patient.

Note: Here on a medicine strip, QR codes are kept instead of an RFID because it is practically not possible for all the consumers to have an RFID scanner at their homes, so just to view a validation history, QR codes are more preferable.

Fig. 9. Showing a successful QR code scan along with the details of the medicine

VII. Conclusion

Various organizations, from manufacturers to suppliers, distributors, and consumers, desire or require information from those in the supply chain network. However, nobody is in authority to enable all of that information exchange. Therefore, there is no significant figure who facilitates trust. Because of its decentralized nature, blockchain solves this quandary and helps address challenges related to manual processes. It provides efficient and accurate end-to-end supply chain monitoring and tracking and a verified and fully transparent information account. Our security analysis proves that the proposed solution is secured against security threats. Our platform does not take high computation overheads as suggested by the smart contract's transaction and execution costs analysis. Ultimately, our study provides several benefits to improving the pharmaceutical supply chain management system compared to the existing framework. With the advent of technology and blockchain, we can manage the pharmaceutical supply chain entirely without any need of human involvement. Therefore will aid us in completely eliminating drug counterfeiting issues, improving drug traceability, and enhancing the drug verification process.

References

[1] G. C. et al., "Efficient Supply Chain Management: traceability and transparency," 12th International Conference on Signal-Image Technology Internet-Based Systems.

[2] R. Cole, M. Stevenson, and J. Aitken, "Blockchain technology: Implications for operations and supply chain management," Supply Chain Manag., vol. 24, no. 4, pp. 469–483, 2019.

[3] S. Tonnissen and F. Teuteberg, "Analysing the impact of ¨ blockchaintechnology for operations and supply chain management: An explanatory model drawn from multiple case studies," Int. J. Inf. Manage, vol. 52, 2020.

[4] C. Lepore, M. Ceria, A. Visconti, U. P. Rao, K. A. Shah, and L. Zanolini, "A survey on blockchain consensus with a performance comparison of pow, pos and pure pos," Mathematics, vol. 8, no. 10, p. 1782, 2020.

[5] V. Patel, F. Khatiwala, K. Shah, and Y. Choksi, "A review on blockchain technology: Components, issues and challenges," in ICDSMLA 2019. Springer, 2020, pp. 1257–1262.

[6] K. Shah, "An efficient implementation of a blockchain-based smart grid," in Handbook of Research of Internet of Things and CyberPhysical Systems. Apple Academic Press, 2022, pp. 169–186.

[7] K. Shah, N. Patel, J. Thakkar, and C. Patel, "Exploring applications of blockchain technology for industry 4.0," Materials Today: Proceedings, 2022.

[8] J. Thakkar, N. Patel, C. Patel, and K. Shah, "Privacy-preserving e-voting system through blockchain technology," in 2021 IEEE International Conference on Technology, Research, and Innovation for Betterment of Society (TRIBES). IEEE, 2021, pp. 1–6.

[9] K. A. Shah and D. C. Jinwala, "Privacy preserving, verifiable and resilient data aggregation in grid-based networks," The Computer Journal, vol. 61, no. 4, pp. 614–628, 2018.

[10] K. Shah and D. Jinwala, "Privacy preserving secure expansive aggregation with malicious node identification in linear wireless sensor networks," Frontiers of Computer Science, vol. 15, no. 6, pp. 1–9, 2021.

[11] J. Al-Jaroodi and N. Mohamed, "Blockchain in industries: A survey," IEEE Access, vol. 7, p. 36500–36515, 2019.

[12] Sylim P, Liu F, Marcelo A, Fontelo P, "Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention", JMIR Res Protoc 2018.

[13] Leveraging Blockchain Technology to Enhance Supply Chain Management in Healthcare: An Exploration of Challenges and Opportunities in the Health Supply ChainKevin A. Clauson,1 Elizabeth A. Breeden,2 Cameron Davidson,3 Timothy K. Mackey4

[14] B. Mukri, "Blockchain technology in supply chain management: A review," in International Research Journal of Engineering and Technology, vol. 05, no. 06, 2018.

[15] S. E. Chang and Y. Chen, "When blockchain meets supply chain:a systematic literature review on current development and potential applications," in IEEE Access, vol. 08, 2020.

[16] J. M. Song, J. Sung, and T. Park, "Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry," Computers Industrial Engineering, vol. 154, 2021.

[17] L. Robison, "The Next Evolution of Blockchain and Distributed Ledger Technology," Gartner Catalyst Conference, 2018.

[18] M. M. Queiroz, R. Telles, and S. H. Bonilla, "Blockchain and supply chain management integration: A systematic review of the literature," Supply Chain Manage., vol. 25, no. 2, pp. 241–254, 2019.

[19] L. Liu, F. Li, and E. Qi, "Research on risk avoidance and coordination of supply chain subject based on blockchain technology," Sustainability, vol. 11, no. 7, p. 2182, 2019.

[20] Shah, K., & Jinwala, D. C. (2018). Performance analysis of symmetric key ciphers in linear and grid based sensor networks. arXiv preprint arXiv:1809.