RESEARCH PAPER

A Hybrid Model To Integrate Permissioned Blockchain And Machine Learning Framework To Deliver A Secure Drug Delivery Systems

Shivanshu Katoch[1], Sandeep Kumar Rawat[2] and Neha Tuli[3]

[1] Research Scholar, Sri Sai University, Palampur, Himachal Pradesh, India,
[2] Research Scholar, Sri Sai University, Palampur, Himachal Pradesh, India,
[3] Department of CSE, Sri Sai University, Palampur, Himachal Pradesh, India

[1] katochshiva@gmail.com, [2]er.rawat07@gmail.com, [3]neha.tuli@srisaigroup.in

Corresponding author : Shivanshu Katoch
katochshiva@gmail.com

Abstract

Supply chains are the backbone of most of the industries out their and plays a crucial role in ensuring the safe, timely, and reliable delivery. Drug delivery is one of the fields that entirely depends on supply chains. However, when we talk about the contemporary drug delivery system there are certain and significant challenges to drug delivery chains which include counterfeit drugs, limited traceability, data manipulation, poor inventory management and delivery delays.

Blockchain technology has emerged as a new age technology in the field of supply chain management which tends improve transparency, security, traceability amongst the supply chains dealing with healthcare. Blockchains mostly focus on securing data, managing storage and transaction management but the real lacking lies in an intelligent decision making capabilities.

Also, some of the machine learning techniques have showed an impressive performance in demand forecasting, logistics optimization, and detection of anomaly but they are heavily reliant on centralized data repositories which are prone to security and integrity concerns.

This paper proposes a new Blockchain based machine learning enabled intelligent drug delivery system, what it does is it actually the integration of specialized machine learning techniques with the modern day blockchain networks which will ensure secure, transparent and intelligent supply chain related to pharmaceutical. In the given framework, each drug will be given a unique digital identification and further it will be stored on a permissioned blockchain which will then use smart contract which in turn will enable a secure tracking by the distributors, hospitals, pharmacies and the end users – patient. Blockchain infrastructure allows data integrity, authenticity, and traceability, then smart contracts automate validation of transaction and transfer of ownership. ML layer will then be incorporated which will analyze trusted blockchain data for various tasks such as demand predictions, counterfeit detections, delivery predictions and inventory forecasting and route optimization, which has all the potential to support operational decisions and managing supply chain efficiency.

Integration of blockchain and machine learning the proposed framework enhances transparency, reduces the chances of counterfeit medicines which will improve inventory utilization and minimize delays. It provides a scalable model for the upcoming digital revolution in healthcare ecosystem further it can be integrated with Internet of things and NFC (Near Field Communication) technology, federated learning, explainable artificial intelligence for smart future applications.

Keywords: - Blockchain, Drug Delivery System, Supply Chain, Machine Learning, Smart Contracts, Drug Traceability, Counterfeit Drug Detection, Demand Prediction, Healthcare Security.

How to cite this article: Katoch S, Rawat SK, Tuli N. A Hybrid Model To Integrate Permissioned Blockchain And Machine Learning Framework To Deliver A Secure Drug Delivery Systems. Int J Drug Deliv Technol. 2026;16(66s):1440-1445. DOI: 10.25258/ijddt.16.66s.154

Introduction

Pharmaceutical Supply chains be termed as the backbone of global healthcare system. When we specifically talk about this industry it has manly stakeholders namely manufacturers, wholesalers, distributors, logistic providers, hospitals, pharmacies, regulatory authorities and ultimately patients. However, the rapid growth in this field has also led to increased complexities of drug supply networks, which makes them more vulnerable to operational inefficiencies and counterfeit medicines, inventory shortages and other security breaches.

The biggest problem in these days are counterfeit drugs which not only reduce the effectiveness of the medicines but also have a major share in other medical complicacies. Other big problem which rise is poor product traceability and lack of real time monitoring.

Recent advances in digital technologies have opened new avenue for supply chain management, there are many technologies which are contributing to this cause with one of the prominent being Blockchain as it is transparent, tamper proof and decentralized.

It also solves the purpose of traceability and real time tracking. Smart contracts can further automate predefined rules of the business which enables security verification of the drug ownership and automated payment settlement, inventory updates, compliance verification and regulatory reporting without requiring manual intervention.

Also, machine learning and artificial intelligence has proved to be a key contributor in solving the complexities in prediction and classification challenges across the healthcare sector in general. Supervised learning platforms such as Random Forest, SVM's, Extreme Gradient Boost, Logistic Regression, and Artificial neural network have achieved a high success rate.

ML models can have a major role to play in pharmaceutics for counterfeit drug detection, demand prediction, warehouse optimization, inventory forecasting, transportation scheduling and risk assessment, thereby improving operational efficiency.

This paper proposes a novel permissioned blockchain-enabled ML framework which ensures a safe and intelligent drug delivery system. In proposed architecture every batch will have a unique identity which will ensure complete traceability. Whereas smart contracts with automate validations, ownership transfer, inventory updates and compliance verification while maintaining the record. Further the proposed model can be scaled through future integration of IoT, Devices and Near Field Communication, federated learning and explainable AI.

Literature Review

Ghadge et al. [1] has studied the implementation of blockchain in supply chains pertaining to pharmaceutics and has proposed a framework using which the technology can be adopted. This review has its main focus on improving the transparency and security of the supply chain.

Uddin et al. [2] has presented an architecture which is blockchain based. The has its main focus on how decentralized ledgers can prevent counterfeits and enhance supply chains and transparency also it can help a lot in improving regulatory compliances. It also highlights the challenges related to scalability, interoperability and privacy.

Fiore et al. [3] have conducted a deep literature review on the applications of blockchains in healthcare. It has highlighted the potential of blockchain to improve traceability and data integrity. It has also discussed the research gaps, scalability limitations and future directions.

Tseng et al. [4] has talked about Gcoin blockchain which is aimed at improving accountability in pharmaceutical supply chains. The study has shown its potential to reduce counterfeit medicines and stakeholder's trust.

Casino et al. [5] has presented a brief literature review of blockchain-based application in multiple domains, which has supply chain management. The authors have clearly classified existing blockchain solutions and they have very categorically identified key challenges and have also outlined the future scope.

Mackey and Nayyar [6] reviewed the emerging digital technologies. The study has highlighted examined technology such as RFID, Blockchain and serialization.

Mackey er al. [7] examined opportunities for blockchain technology in healthcare which also includes pharmaceutical supply chains and electronic healthcare records.

Katuwal et al. [8] has showed a different perspective in blockchain healthcare which focused on electronic health record, pharmaceutical supply chains medical research and insurance system. This study has shown a improvement in data security, transparency, traceability and al so discussed the challenges.

Ullah and Aslam [9] have emphasized on the fact that there is a n urgent need for securing medical records to integrate with blockchains.

Shinde et al. [10] conducted a systematic study on integrating blockchain with AI in healthcare systems. They have very efficiently highlighted the fact that how blockchain enhances the security and treatability of the drugs.

Gomasta et al. [11] has proposed a Pharma chain, which is a blockchain-based verification system for pharmaceutical supply chain this system ensures end to end traceability and tamperproof record management.

Bapatla et al. [12] has proposed a system that integrated smart contract to a decentralized ledger technology which provide secure product tracking and authentication and transaction.

Bali et al. [13] presented blockchain-based application designs and traceability algorithms for pharmaceutical supply chains. Their approach enables secure recording of drug movement.

Niesya and Sayeed [14] reviewed the adoption of blockchain technology in healthcare supply chain management.

Saad et al. [15] reviewed blockchain-enabled healthcare supply chain solution and presented a case study demonstrating their practical implementation. The study high practical implementation.

Methodology

The proposed research introduces a Hybrid Machine Learning model coupled with Blockchain to design a secure, transparent and intelligent drug delivery system. The primary aim of this framework is overcoming the shortcomings of the traditional drug delivery system such as fake medicine, lack of transparency, data manipulation, and inefficient management.

The new framework is the combination of security and immutability of permissioned blockchain technology along with the prediction capability of machine learning algorithms. What blockchain does is it creates a trust between various supply chain entries and a hybrid ML model that performs intelligent analysis on the verified data.

The proposed methodology has six major phases first one being data preprocessing followed by drug identity generation and verification based on blockchain which is then followed by smart contract validations of the transactions. Then the next step development of hybrid Machine Learning model which is then followed by predication and decision mechanism based on blockchain with the last one being performance assessment and comparative analysis.

System Architecture has four major parts. First one being the Data layer, which is solely made for collection of data from the supply chain which will represent the complete life cycle of a drug.

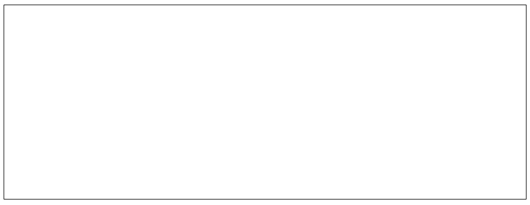
The major parameter considered are:-

- DIN (drug identification number)
- Batch Number
- Manufacturing Date
- Expiry Date
- Manufacturing Details
- Supplier Information
- Storage Temperature
- Transportation Duration
- Delivery Route
- Inventory Level
- Transaction History

This data parameters are designed in such a way the it represents the operational behavior of supply chains.

The next part of the architecture in Blockchain Trust Layer which helps in induction of a permissioned blockchain network which maintains proper records. The traditional systems had a down side that all the data was managed at a central database where single authority was in control, whereas what permissioned blockchain does is it distributes the transaction records amongst all the concerned parties. (Manufacturer, Distributor, Hospital, Pharmacy and the Regulatory Authorities).

Then the next step is data pre processing which includes data cleaning :- cleaning of the data, removing missing and inconsistent data which will help to improve model reliability.



Example

Incorrect - Storage temperature = -49°C
Corrected – Storage temperature = 4-9°C

Incorrect - Mfg. Date – 2602/26
Corrected -Mfg. Date – 26/02/26

Now the next step is Data Transformation, where in the data is converted into a much categorical information such as supplier category drug type or should be stored in cold store or not. All such information is encoded using various encoding schemes.

Example

Delivery Partner Status
Authorized = 1
Unauthorized = 0

Now as we have done data cleaning and data transformation, we can clearly deduce that all of our preprocessing is done so now we have to move to the next step which is feature selection where in we have to select the features from the collected dataset which actually influence the decision making this step is very much similar to stop word removal process in lexical analysis.

The features that can be crucial in detection of counterfeit drugs will be selected in this process.

The final vector is

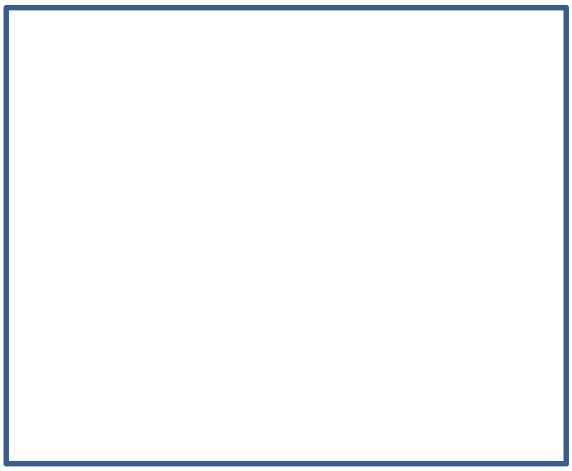
$F = [x_1, x_2, x_3 \ldots x_n]$
where

x_1 : Supplier reliability
x_2 :Temperature Variation
x_3: Delivery Delay
x_4 : Transaction Frequency
x_5: Trust Score

The feature selection process is made to reduce the unnecessary computations and it also helps to improve the prediction accuracy of the models.

The next step in Blockchain based Drug Authentication Mechanism whose main function is to help the whole system give every newly manufactured drug batch a unique identity so that every batch is unique and difficult to make copy or counterfeit. This is ensured by giving a digital identity to every drug batch by using cryptographic hashing using special hashing function specifically designed for this purpose.

D = {
ID – 1563



Bno – B2612
Expiry – 2029
}

Here D , stand for the batch identity for the drug batch, now this data is the fed to hash function which will generate a hash.

{
Generated Hash = Hash function (D)
}

The generated hash is then stored in the permissioned blockchain. Any manipulation / modification in the drug information will change the hash value making the unauthorized manipulation of the drug detectable.
After that the next step is blockchain transaction process where in one have to record the movement of the drug into the blockchain network. Once this step is done the next step is smart contract-based validation of the data smart contracts are automated programs stored on the blockchains that execute predefined task which usually contains rule which are likely in the form of if-else and act as conditional statements which ensures authentications validations and checks on the predefined rules and conditions.
The proposed hybrid algorithm integrates blockchain technology with the machine learning model which ensures security and a spot on counterfeit drug detection In the supply chains. At first each transaction is authenticated by a permissioned blockchain wherein a unique hash code and smart contract. These techniques are then used to generate a trust score to ensure data integrity.
These records are then converted into feature vectors which hold drug batch information, supplier reliability, storage condition, delivery duration, transaction history and blockchain score. The authenticated data is then processed with Random Forest, XGBoost and a Anomaly detection. The output of these models are combined through a weighted fusion mechanism (0.6 RF, 0.6 XGBoost, 0.3 AD) which generates a hybrid predict score. The score is then adjusted using blockchain trust value which ensures that unreliable or tampered transactions will eventually get lower confidence regardless of the machine learning predication.
And at last the threshold based classification is used to categorize each drug as Genuine, Suspicious or Counterfeit which enables security, transparency and automated supply chain monitoring which improves detection and accuracy which ultimately reduces false classification.

Evaluation Metrics
The performance of the algorithm was evaluated using the standard ML classification metrics and blockchain performance parameters. The evaluation was performed keeping in view two aspects (i) predictive performance of the hybrid ML model and (ii) reliability of the blockchain based authentication mechanism.
The classification performance is evaluated using confusion matrix which consist of four major parameters:

- True Positive (TP): correct identification of counterfeit.
- True Negative (TN): Correct rejection of incorrect drug
- False Positive (FP): Incorrect classification of genuine dugs as counterfeit.
- False Negative (FN): Incorrect classification of counterfeit drugs as genuine.

		Actual Values	
		Positive	Negative
Predicted Values	Positive	**TP**	**FP**
	Negative	**FN**	**TN**

Accuracy
{TP + TN}/ {TP + TN +FP + FN}

Precision
{TP}/{TP+FP}

Recall
{TP}/{TP + FN}

F1-Score
2 x Precision x Recall / Precision + Recall

Specificity
{TN}/{TN+FP}

Result and Discussion

The hybrid model was evaluated for secure drug authentication and counterfeit detection in pharmaceutical supply chain management. In this analysis, evaluation was performed which compared the hybrid model with each algorithm involved and then the performance was measured by using the above-mentioned machine learning confusion matrix parameters (accuracy, precision and F1- Score.

The evaluation included drug batch information, supplier reliability, storage condition, delivery history, transaction behavior, and blockchain trust score. The first layer which was evaluated was blockchain layer which generated a score which was later provided to hybrid machine learning algorithm.

	Authentic	Counterfeit
Authentic	488 (TP)	15 (FN)
Counterfeit	13 (FP)	495 (TN)

The model was able to correctly identify 488 authentic drug transactions 495 counterfeit transactions. Only a few numbers (15) of transactions were reported false.

Accuracy	97.5%
Precision	97.9%
Recall	96.9%
F1 Score	97.4%

The obtained results demonstrated a balanced performance in identifying both genuine and counterfeit drugs.

Model	Accuracy (%)	Precision (%)	Recall (%)	F1score (%)
Random Forest	92 %	91.6 %	90.8 %	91.74 %
XGBoost	94.6 %	93.1 %	94.3 %	95 %
Anomaly Detection	88.7 %	87.9 %	88.2 %	88 %
Hybrid Algorithm	97.5 %	97.9 %	96.9 %	97.4 %

Parameter	Traditional System	Proposed Hybrid algorithm
Data Modification Detection	Low	High
Drug Traceability	Partial	Complete
Transaction Verification	Manual	Automated
Data Integrity	Medium	High
Authentication Capability	Limited	Improved

The permissioned blockchain was able to maintain immutable record of drug transaction, whereas the generated hash value of each drug batch enabled verification. Smart contracts reduced manual verification by validating ownership.

Discussion

The results clearly show that the proposed model provide an highly improved performance of secure drug delivery management. Though each machine learning is capable of its own but they were highly dependent on input data. The hybrid model was able to achieve higher accuracy. The weighted fusion strategy combined the strengths of all models and reduced the possibility of incorrect classification.

Then the integration of smart contract enabled automatic decision making by approving genuine transactions which generated alerts for suspicious activities, and prevented duplicate drug movement. Therefore, the model is scalable and is a solution for improving transparency, security and intelligence in pharmaceutical supply chain system.

References

[1] A. Ghadge, M Bourlakis, S.Kamble and S. Securing "Blockchain implementation in pharmaceutical supply chains: A review and conceptual framework" International Journal of Production Research vol 61, no 19 PP6633–6651, 2023, doi: 10.1080/00207543.2022.2125595

[2] M Uddin K Salah, R Jayaraman, Y Al-Hammadi and I Yaqoob, Blockchain for drug traceability: architectures and open challenges, Health Informatics Journal, 2021.

[3] M. Fiore, M. Casola, and M. Rak, "Blockchain for the Healthcare Supply Chain: A Systematic Literature Review," Applied Sciences, 13(2), 686 (2023).

[4] J.-H. Tseng, Y.-C. Liao, B. Chong and S.-W. Liao, "Governance on the Drug Supply Chain via Gcoin Blockchain," International Journal of Environmental Research and Public Health, vol. 15, no. 6, Art. no. 1055, 2018.

[5] F. Casino, T.A. Dasaklis, C. Patsakis, A systematic literature review of blockchain-based applications: Current status, classification and open issues, Telematics and Informatics 36 (2019) 55-81. [6] T. K.

Mackey and G. Nayyar, "A review of existing and emerging digital technologies to combat the global trade in fake medicines," Expert Opinion on Drug Safety, vol. 16, no. 5, pp. 587–602, 2017.

[7] T. K. Mackey, T. Kuo, B. Gummadi, et al., "Is it fit for purpose? Challenges and opportunities for blockchain technology applications in the future of healthcare, BMC Medicine, vol. 17, no. 1, 2019.

[8] G. J. Katuwal, S. Pandey, M. Hennessey, and B. Lamichhane, "Applications of Blockchain in Healthcare: Current Landscape and Challenges," arXiv:1812.02776, 2018.

[9] H. S. Ullah, and S. Aslam, "Blockchain in Healthcare and Medicine: Applications, Challenges and Future Perspectives", arXiv : 2004.06795, 2020.

[10] R. Shinde, S. M. Choudhari, A. D. Dureha and P. Bedi, "Securing AI-Based Healthcare Systems Using Blockchain Technology: A Systematic Literature Review", arXiv:2206.04793, 2022.

[11] S. S. Gomasta, A. Dhali, T. Tahlil, M. M. Anwar and A. B. M. S. Ali, "PharmaChain: Blockchain-based Drug Supply Chain Provenance Verification System", Heliyon.

[12] A. K. Bapatla, S. P. Mohanty, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A blockchain to ensure counterfeit-free pharmaceutical supply chain," IET Networks, vol. 12, no. 2, pp. 53–76, 2023, doi:10.1049/ntw2.1204

[13] V. Bali, A. K. Yadav, and S. Sharma, "Design and Algorithms for Blockchain Application for Traceability in Pharmaceutical Supply Chain," International Journal of Healthcare Information Systems and Informatics, vol. 16, no. 4, 2021.

[14] N. Niesya and M. S. Sayeed, "Review on Adoption of Blockchain Technology in Healthcare Supply Chain Management," HighTech and Innovation Journal, vol. 5, no. 4, pp. 1-10, 2024.

[15] M. Saad, M. A. Khan, S. Ahmed, et al., "Blockchain enabled healthcare supply chain: review, case study and future opportunities," International Journal of Advanced Computer Science Applications, vol. 16, no. 8, 2025.