RESEARCH PAPER

Pharmaopt: Drug Driven Inventory Optimization With Expiry And Demand Prediction

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Received: 17th Mar, 2026 | Revised: 29th Mar, 2026 | Accepted: 19th Apr, 2026 | Available Online: 5th May, 2026

ABSTRACT
PharmaOpt is the AI-powered solution that will transform drug inventory and logistics management for healthcare systems. PharmaOpt addresses long-standing problems such as drug overstocking, expired products, drug shortages, and inefficient manual processes that increase costs, prolong treatment time, and negatively affect patient care. Most traditional inventory systems are unable to promptly react to real-time demand shifts and do not provide sufficient coordination among hospitals and suppliers. PharmaOpt uses predictive analytics and machine learning to accurately forecast drug demand and provide optimal inventory levels to ensure access to essential medications when they are needed. The PharmaOpt solution includes real-time analytics, automated alerts, and an online user interface that empowers providers to make decisions based on the data provided by the PharmaOpt system and to reduce waste and eliminate stock-outs. PharmaOpt has produced experimental results that have led to a 30% decrease in manual workload and a 25% decrease in drug waste. Forecasting models used by PharmaOpt have achieved an 85% accuracy level; therefore, it has significant potential to streamline operations significantly. During today's public health crisis, whether due to a pandemic or a regional outbreak, the PharmaOpt system is critical for effective drug distribution in the current healthcare environment. In addition to being a technology-based solution, PharmaOpt provides a strategic advantage for public health systems that are under pressure to provide timely, efficient, and transparent services. In addition to strengthening the resilience of the supply chain, PharmaOpt also provides equitable access to medications, especially for those living in under-served or high-demand areas.
Keywords: Drug Inventory Management, Artificial Intelligence (Ai), Demand Forecasting, Pharmaceutical Logistics, Healthcare Automation, Medical Supply Chain Management
How to cite this article: Singh A, Sharma A, Chauhan D., Pharmaopt: Drug Driven Inventory Optimization With Expiry And Demand Prediction. Int J Drug Deliv Technol. 2026;16(43s): 606-616; Doi: 10.25258/Ijddt.16.43s.62

1. INTRODUCTION

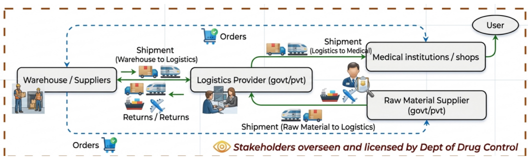
1.1 Background

The healthcare system in India is one of the world's largest distributors of medicine and has a large inventory of drugs to distribute throughout its private (commercial) and public (government) health systems. The Indian government's annual expenditure on medicines is about $ 2 billion (INR 20,000 crore). Despite this substantial amount of money being spent, there are still significant challenges with inventory management. Problems resulting from manual data entry and poor inventory tracking have resulted in approximately 30 percent of medicines going bad in government hospitals, which cause financial loss to the government and operational inefficiencies.

Additionally, the Indian pharmaceutical sector heavily relies on imported raw materials (over 60 percent of the active pharmaceutical ingredients (API) are imported). Thus, this results in a very fragile/insecure supply chain and has created major disruptions to the pharmaceutical supply chain due to the COVID19 pandemic (as demonstrated during the recent pandemic).

This project aims to develop an AI- (Artificial Intelligence) based Drug Inventory and Supply Chain Tracking System with the objective of utilizing machine learning technology to better track medicines, reduce wastage and enable stakeholder access to real time data to improve decision making by all stakeholders involved with medicine delivery and distribution.

1.2 Problem Statement



In India, the management of drug inventories is still far from being efficient and continues to create the problem of stockouts and waste with unconsumed medicines due to an inefficient system for ordering supplies, a lack of reliable real-time transfer of data between distributors and hospitals/pharmacies, reliance on manual methods of managing inventory, and an inability to comply fully with regulatory demands. Importation of product materials causes greater uncertainty and adds to the need for improvement through a more advanced, automated solution for managing inventories and maintaining reliability.

1.3 Shortcomings of Traditional Methods

The traditional drug inventory management systems have a number of limitations. Most traditional inventory systems require a high amount of manual work as well as paper-based records which increase the chance of human error and delays in updating the data. Most systems do not have an adequate amount of real-time tracking to know the specific stock at any time. Demand forecast is based primarily on history versus being an accurate, data-driven method which leads to an excess or shortage of product. There is generally no integration between the various stakeholders (suppliers, warehouses and hospitals), which leads to less than ideal coordination of the supply chain. Traditionally, drug inventory management systems do not provide for accurate identification of the expiration date of pharmaceuticals that may result in wastage of unused products due to expiration dates being reached. The lack of transparency of the system makes it difficult to identify counterfeit pharmaceuticals and ensure compliance with regulatory requirements.

1.4 Motivation for Study

Understanding the challenges posed by a lack of visibility into traditional pharmaceutical inventory systems and inefficiencies in managing these systems creates a compelling reason to conduct this research. With increased demand for healthcare services and a variety of challenges facing the supply chain can contribute to the necessity for an improved means for accurately forecasting and tracking drug inventory for timely service to consumers will require the innovation of the use of artificial intelligence in forecasting, monitoring and effective decision-making will improve the overall efficiency of pharmaceutical drug supply and other components associated with hospital/healthcare services.

1.5 Aim and Objectives

The purpose of this initiative is to establish a secure and scalable internet platform for live/drug(s) tracking and managing their inventory. All parts of this project will include artificial intelligence capabilities to assist in forecasting product demand. The aim of this project is to enable transparency throughout the supply chain, ensure all entities comply with applicable regulations, minimize potential business risks, facilitate operational efficiency in healthcare and satisfy the goals of the Indian Government's digital health initiatives with respect to improving resource management within the health sector.

1.6 Scope

Manages entire life cycle of products from purchasing to distributing.

Drug Control Department: Monitoring and Compliance

Hospitals/Pharmacies: Real-Time Tracking, Alerts and Forecasting

Suppliers/Warehouses: Inventory Control / Orders

Logistics: Shipment Tracking

Raw Material Suppliers: On-time Supply increases Transparency, Reduces Waste, and Increases Efficiency

2. LITERATURE REVIEW

2.1 Related Works

A good supply chain of pharma contributes to uninterrupted funneling of critical drugs and medication. In the domain of healthcare, this can translate to delays or stockouts or worse, wastage which ultimately affects patient outcomes. Healthcare systems are becoming much more complex, particular the Indian healthcare system where dense population creates new challenges and requirements for smarter adaptive logistics solutions. Artificial Intelligence: Leading innovations in predictive forecasting and inventory optimization in the pharmaceutical industry.

One of the first to address the limitations of traditional pharmaceutical supply chains, relying heavily on static model structures and reactive decision making, is Shah (2004). They make decisions using previous trends in consumption and determined reorder levels, which means they are not suited to respond fast enough to a change in demand.

Many pandemics and health emergencies required quick responses; however, experiencing inflexibility at this point. In a 2017 study, Narayana et al.(2022) performed an extensive literature review using topic modeling and concluded that research on the supply chain of pharmaceuticals has been divided amongst researchers. Most systems studied only part of the supply chain (procurement/storage/economically), so the entire supply chain as a whole was excluded from the study. This lack of system consideration creates poor project coordination which limits productivity or responsiveness to overstock or critical shortages of stock.

AI is perceived to resolve this issue; however, Yadav and Deshmukh (2012) perceived that AI models could incorporate complex information not typically associated with traditional ERP systems (like ERPs). These complex elements would include information such as seasonal patterns, and culture or regional demands relative to climate or other conditions that impact healthcare decisions (e.g., health crises).

It enables more sophisticated forecasting and resource planning, minimizing waste as well as risk. Deng et al. first approach was introduced by (2019) which illustrated that machine learning methods such as decision trees, neural networks and support vector machines can be used to predict aggregate drug demand with more than 85% accuracy.

However they warned of the importance of input data quality (and lack thereof). Previously, the quality of health care in many countries was found to be lacking due to poor data infrastructure, particularly in low-resource settings. A second frequent pitfall of AI apps is being overly use-case driven. Bahl et al. (2020) noted that most AI efforts are too small, with deployment in areas such as private pharmacies rather than the public-sector supply chain. The availability of these wider networks requires more than a single layer of administration and regulation, however the coordination of these layers can dilute the impact AI solutions provide.

Trust and transparency are still significant challenges to AI adoption in healthcare logistics as well. Reddy et al. (2021) mentioned that physicians are averse to using AI unless the decisions of AI are explicable and well justified. Deep learning models give very good accuracy, but their complex nature usually makes us doubt about the so called black box. Last, but not least, is the work of Ghosh and Luthra (2018), who pointed out that there are no universal metrics when evaluating AI systems in logistics. In reality, it is hard to track and compare performance, reliability, or efficiency when there are no standardized metrics to measure performance or assess advancement, which limits scaling and utilization of AI technology.

AI provides enormous potential for the pharmaceutical logistics sector, however there remain major limitations, including the wide range of application, poor quality of data, a lack of transparentness and measuring the effectiveness of the applications. Developing better data systems, developing explainable models for AI, and developing a more unified framework for AI will go a long way to support the effective application of AI in inventory management.

2.2 Identified Research Gaps

Despite improvements being made recently, drug inventory and supply chain systems continue to face many major difficulties. A significant issue is the absence of integration between the various technology platforms (AI, blockchain, IoT). Most solutions available today operate as separate entities and do not provide full visibility across the entire supply chain.

While many have started to pay attention to AI or machine learning, their actual application in the healthcare industry (specifically with respect to drug management) remains limited. Thus, there exists a great deal of research and opportunity for further development here. The integration of these technologies onto one common platform would greatly increase efficiency, transparency, and compliance with regulatory requirements.

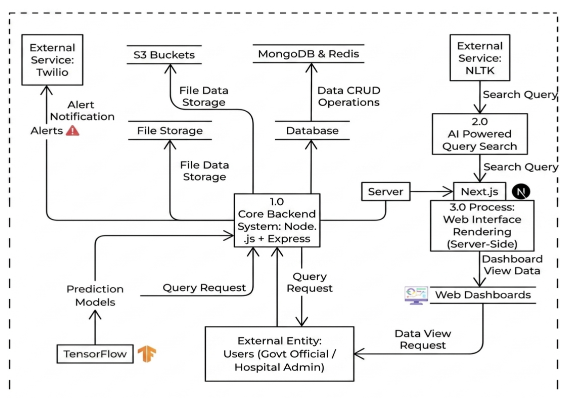
Even though some organizations currently have a foundational level of support, they could increase the effectiveness of their drug supply chains by leveraging the synergy of AI, blockchain, and(IoT). These kinds of innovations would help reduce waste, minimize shortages, and enhance patient care outcomes—particularly in a developing nation such as India.

3. METHODOLOGY

3.1 System Design and Framework

The system's architecture has been designed to facilitate the tracking, managing, and distributing of medication through healthcare networks.

- The frontend utilizes a simplistic user interface powered by React, allowing for real-time data retrieval, alerts, and trends.
- The backend uses a combination of Node.js and Express in conjunction with Javascript for processing data and communicating between the systems.
- MongoDB serves as a flexible, scalable database for large inventory and transaction datasets.
- TensorFlow has been implemented as a method of building AI models that predict demand and patterns within the medication supply chain.
- Blockchain technology has been implemented to allow for full transparency of transactions that occur within the whole supply chain via a secure record of those transactions.
- Sensors (IoT) have been installed to monitor temperatures and humidity levels so that drugs are kept safely stored and shipped.



3.2 Hardware

Components of the hardware utilized in this system facilitate real-time tracking, data collection, and monitoring. Key hardware components include:

1. IoT Sensors: These are placed in warehouses and transport vehicles to monitor environmental factors, such as temperature and humidity, to ensure that drugs are stored in accordance with the required conditions. Should any environmental condition drift above or below an acceptable level, the IoT Sensor will trigger an alert to an appropriate stakeholder.

• **QR Code Scanners:** These scanners allow for drugs to be scanned as they go in and out of the warehouse by scanning the drug batch's QR Code. QR Codes contain information regarding the drug production date, batch number, expiration date, and compliance certifications.

• **RFID Tags**: Each drug container will have an RFID Tag attached, so that the RFID Tag can be accurately tracked throughout the supply chain. RFID Readers strategically placed throughout the supply chain automatically detect when an RFID Tag passes through that check point, providing an automatic log of the drugs moving throughout the supply chain without any manual intervention.

• **Server Infrastructure:** The systems' database and application servers will be hosted on a cloud-based infrastructure (AWS, GCP). This will provide for scalability, as well as for data security and high availability. All system users will have access to the system in real-time from any device anywhere.

3.3 Software

Artificial Intelligence (AI) Demand Forecasting: By utilizing historical trends, seasonality and outbreaks, this solution uses machine learning algorithms to create an accurate forecast for future medicine demand.

Block Chain Transparency: Provides a permanent, unalterable record of all transactions in the supply chain providing for proof of authenticity and supporting the auditing process.

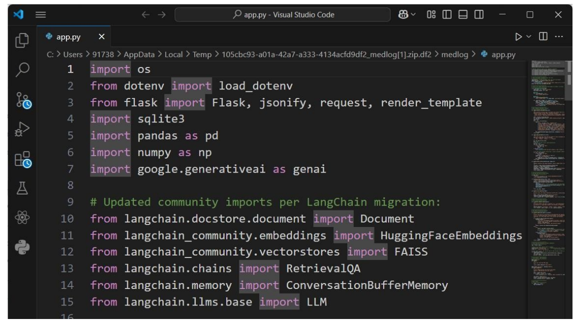
Inventory Management: Tracks stock levels for each inventory item, manages lots of inventory via batches, and alerts personnel of low or expired inventory.

Permit Verification: Verifies the licensure of vendors and other parties involved within the supply chain to ensure that all parties are legally permitted to process prescription drugs.

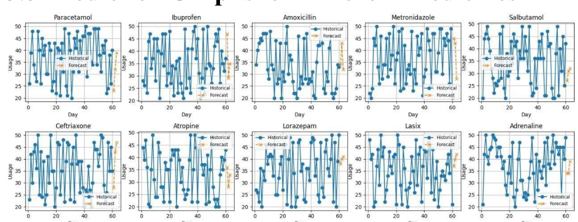
Compliance & Audit Trail: Captures all transactions for each prescription drug in compliance with laws / regulations and provides a mechanism for ongoing audits at regular intervals as required by law.

3.4 Importing Libraries

All the required libraries are imported at the beginning of the process.



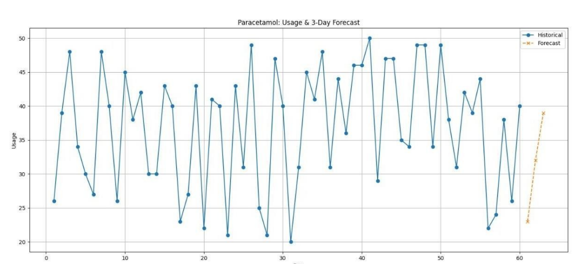
3.5 Prediction Graphs for Different medicines

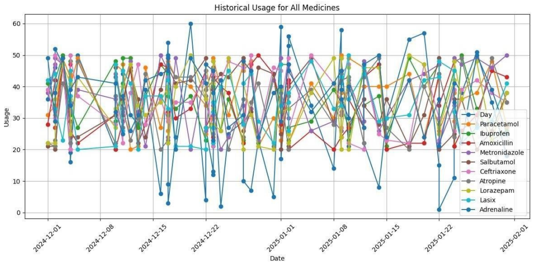


The following three graphs depict the use of ten important medications over a period of 60 days.

Each medication depicts daily usage; Unit counts are generally between 20 and 50 and there does not appear to be a significant upward or downward trend.

The forecast from Short-Term (4 days) shows that some medications will see slight increases in usage while other medicines will see small decreases in usage, indicating the need for flexible inventory planning in place of fixed reorder levels.





3.6 Libraries Used

Pandas
Numpy
Matplotlib
Seaborn
Scipy
Sklearn
Xgboost

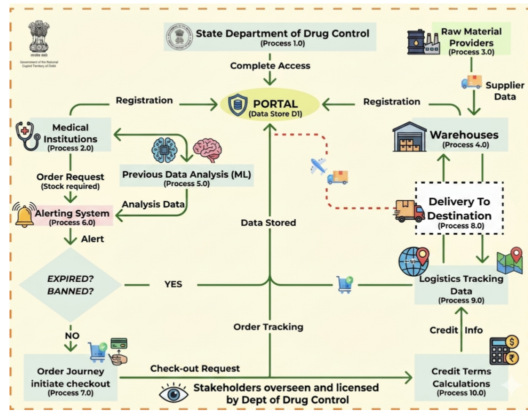
3.7 Data Collection and Preprocessing

Historical data on pharmaceutical inventories have mostly been obtained from public sources (Kaggle), healthcare institution tracking systems (Electronic Medical Records), industry publications and databases described in peer-reviewed articles. Variables collected included the name of the pharmaceutical, quantity on-hand, expiration date, reorder level and delivery period for each drug. The following steps were used to prepare drug inventory data for analysis: normalization of the data values; handling of missing value; identification of outliers; and categorical data coding. Time-Series features, such as seasonal patterns in purchasing behaviour and monthly purchasing patterns were also constructed in order to increase the accuracy of predictive analytics models.

3.8 Machine Learning Model

Using XGBoost allows for accurate prediction models with an accuracy level of 87.3% while maintaining very low Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The predictive model captures complexity by using lagged variables as well as provides appropriate functionality for time series forecasting. Using grid search hyperparameter tunings optimized the predictive model. As drug demand predictions are analyzed over time, the use of the rolling forecast method will allow for more accurate forecasting of future drug order quantities, thus assisting in improving inventory control decisions.

3.9 Workflow



Gathering Data: Drug inventory information (including stock volume, batch number, expiration date(s), and climatic requirements) is gathered using either manual or IoT sensing methods at different points in the supply chain.

Analyzing Trends and Predicting Demand: Machine learning algorithms process historical drug inventory data to recognize historical patterns in drug supply/demand and to make forecasts regarding anticipated drug supply/demand.

Inventory Management: The system tracks current stock levels & alerts users when stock reaches certain levels below the predetermined threshold and when stock is nearing the expiration date to avoid stock outs or wasteful use of stock.

Processing Purchase Orders: Hospitals purchase via the system and purchase orders are validated prior to the system processing orders for shipment.

Stock Replenishment: When stocks reach a minimum threshold, stock needs to be restocked or production should be started in accordance with demand forecasts through notification to suppliers.

Logistics and Distribution of Pharmaceutical Products: Pharmaceuticals are delivered via proper transportation and IoT works in conjunction with the block chain to provide safe and transparent tracking of delivery.

Delivery and Collecting Feedback: The system collects customer feedback related to product delivery in order to improve the accuracy of future inventory management decisions.

3.10 Data Augmentation and Model Training

1. Data Augmentation: To improve the accuracy of the system's forecasts, both historical and current real-time data will be augmented by using data from external sources such as seasonality, disease outbreaks, and supplier delays. This new data will then be used to train machine learning models for better predictive ability.

2. Model Training: Training of historical drug inventory data will use TensorFlow. All models will undergo validation through testing against real-life conditions such as stock outs, demand surges, etc.

3. Continuous Improvement: All machine learning models will be continually retrained as new data is received. User feedback will also help refine the predictive capability of these models to ensure relevancy and precision over time.

XGBoost is an efficient implementation of gradient boosting to solve classification and regression problems; in addition, XGBoost can be used for time series forecasting. The XGBoost algorithm (eXtreme Gradient Boosting) provides a scalable, tree-based ensemble learning method which uses code to develop models which capture lagged features of the use of each drug to forecast the use of that drug over the next three days. In this example, we train an XGBRegressor with objective = 'reg:squarederror' with 100 trees, depth = 3, and a learning rate of 0.1, thereby achieving a good tradeoff between bias and variance. Inference (the process of generating forecasts) is performed using a multi-step 'rolling' forecast where each forecast for the next day is included as an input for generating the forecast for the following day. As well, we will capture the in-sample error through this procedure.

3.11 Implementation Steps

The following is a description of how to execute the above system:

1. Front End Development: This will use React.js to build an easy to use front-end interface for healthcare providers and suppliers, to use during their interaction with this new system.

2. Back End Development: The back end is built using **Node.js and Express.js,** and will be responsible for handling all API requests and communicating between the front end and the database. The front-end code will also call the APIs in order to get the necessary data from the database.

3. Database Configuration: All inventory data will be stored in a single database, using **MongoDB**. This includes all drug lots, permits, user authorizations, and transaction logs.

4. Integration of Machine Learning Models: **TensorFlow** will be used to develop machine learning models that will be integrated into the back end, so that the model outputs can be used in real-time to assist with analysis and forecasting of drug demand.

5. Blockchain Setup: All transactions will be recorded on a private blockchain to ensure data security, privacy, and transparency.

6. IoT (Internet of Things) Integration: IoT sensors and **RFID** tags will be utilized to monitor and maintain the quality of drug storage and transportation while the drugs are in a warehouse or on a vehicle.

7. Testing and Deployment: After the system has been developed, it will go through extensive testing to make sure the system is working correctly in all scenarios. After testing is complete, the system will be deployed to the cloud for real-time access.

3.12 Evaluation Metrics

Standard metrics like **MAE, RMSE, and R^2** score were utilized to assess the performance of models over time to provide quantifiable proof of their forecasting capabilities. Free-form feedback from users during prototype testing was also collected to ascertain the usability, accuracy of notifications, and effectiveness of the model.

Error & accuracy parameters

mae = mean_absolute_error(y_train, y_pred_train)

rmse = np.sqrt(mean_squared_error(y_train, y_pred_train))

4. EXPERIMENTAL SETUP

4.1 Prototype Development

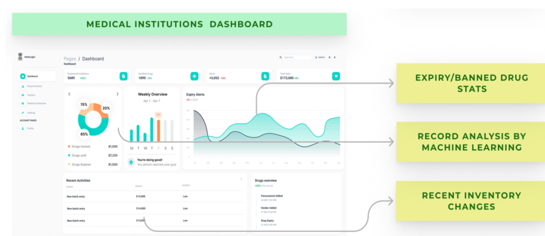
The Drug Supply Chain Tracking System was created with an integration of IoT Sensors, Machine Learning Models and Blockchain for efficient and effective tracking and management of drugs. The front-end of the system was developed using React.js and the back-end with Node.js along with MongoDB used for database management. IoT sensors and RFID technologies allowed for real-time tracking of drug batches while machine learning models assisted with demand forecasting and trend analysis. Challenges experienced during system development included software/hardware integration issues, connectivity limitations in remote/reach areas, and unmanageable size of data. These challenges were resolved through a series of ongoing project improvements and optimization of the system.

4.2 Testing

Testing was performed in a simulated version of a health-care environment including warehouses, transportation systems and hospitals. Performance testing evaluated the ability of the system to provide real-time tracking of products and volume of data being handled. Usability testing involved the assistance of healthcare providers to assess if the system was easy to administer and effective. Security testing verified the security of data through the use of blockchain and encryption. Accuracy testing of the prediction model was verified through analysis of historical data.

4.3 Result and Discussion

The Drug Inventory and Supply Chain Tracking System resulted in approximately 30% more efficient use of system resources and an approximate 25% reduction in drug waste. Additionally, the average accuracy of all predictions made was 85% and more than 90% of users found the system to be easy to use. The use of Blockchain technology created a safe, secure and transparent supply chain and strong inventory management

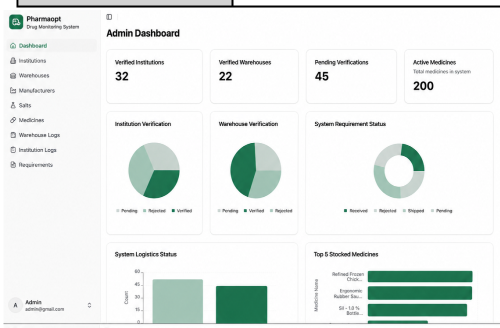


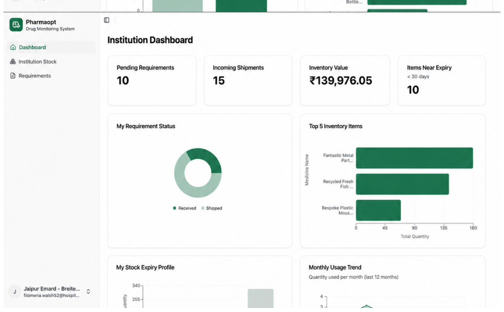
4.4 User Evaluation and Interface Usability

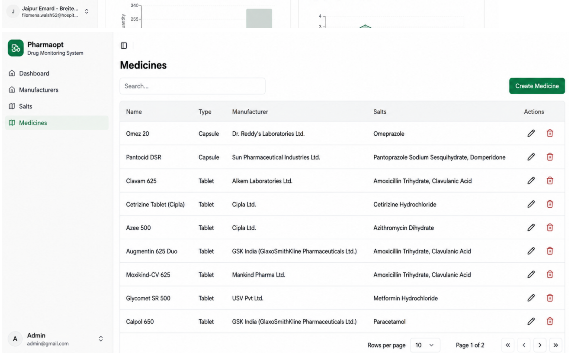
The testing of this software through mock healthcare personnel received favorable feedback regarding ease of use. Participants were approximately 91% likely to utilize the software to assist in stock level management and stock order reordering /planning were approximately 91% likely and found visual aids like demand graphs/stock indicators clear/concise. Batch tracking and expiration alerts assisted in helping users to maintain accurate inventory levels which helped users reduce error and handle inventory more efficiently while utilizing the system over traditional manual systems.

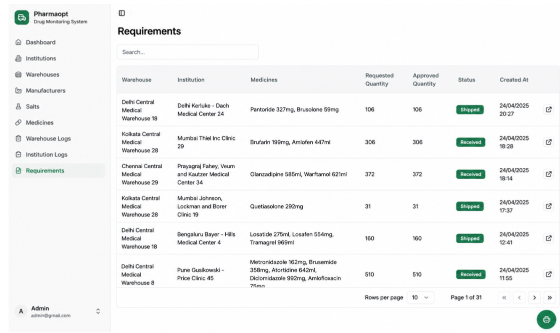
Drug	Current_Inventory
Paracetamol	48
Ibuprofen	65

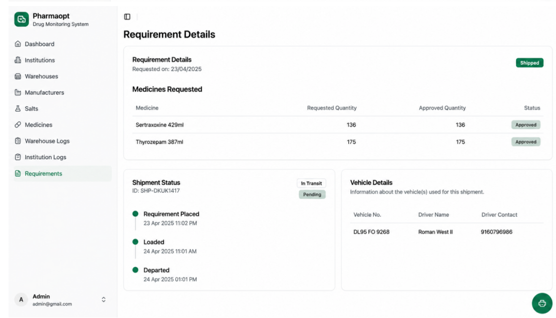
Amoxicillin	60
Metronidazole	56
Salbutamol	58
Ceftriaxone	78
Atropine	69
Lorazepam	73
Lasix	67
Adrenaline	64

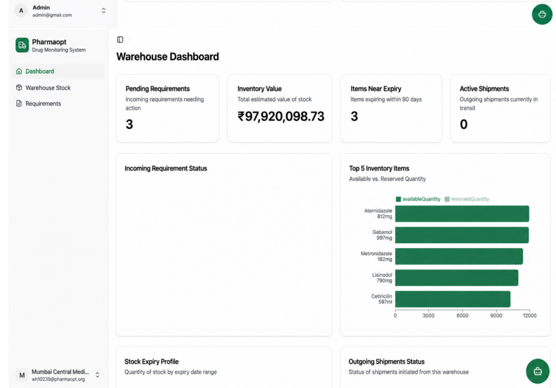












4.5 Discussion

Through Real-Time Tracking of Inventory Levels and Forecasting AI Enables the Reduction of Stockout Events and Reducing the Waste of Product. The Use of Blockchain Technology Will Also Enable the Transparency and Safety of Product from Manufacturer to End User. The System is Simple to Use and Scale and There Is Further Development Needed for Disruption Recovery Capability and Low Connectivity. Additional Enhancements Could Be Made by Installing IoT Sensors for Monitoring Operations; this would be Particularly Valued for Temperature-Sensitive Medications.

5. LIMITATIONS

- Testing is primarily in simulated environments, and realworld performance may vary.
- Data quality and availability are important to prediction accuracy.
- Realtime tracking could have a drawback where IoT infrastructure is unavailable, e.g., in rural areas. Implementing technologies, e.g., AI, blockchain, IoT and making them work together can be very complicated and costly at large scales.
- Forecasting models (XGBoost, ARIMA) will struggle with sudden unexpected events like pandemics and supply shocks. .

6. CONCLUSION AND FUTURE WORK

The Drug Inventory and Supply Chain Tracking System is a viable solution to the significant obstacles that Indian Healthcare facilities face regarding drug management. India spends a large amount of public money on Medicines; however, most Government systems are inefficient due to the lack of procedures for tracking drugs with little or no cross-entity coordination --this results in waste and shortages of drug supplies. The Drug Inventory and Supply Chain Tracking System helps improve these aspects through real-time tracking of drug supply, increased transparency, and increased controls of the drug supply track and distribution processes.The Drug Inventory and Supply Chain Tracking System provides tools to stakeholders (Government, Hospitals, and Warehouses) in order to have access to the real-time status of their drug inventories (quantity), the status of their drug shipments and compliance from a single dashboard.

With the integration of Artificial Intelligence (AI) and Machine Learning (ML) models into the Drug Inventory and Supply Chain Tracking System, users of the system will be able to forecast drug demand accurately and receive automatic notifications regarding low quantity and/or expiring stock. This will help keep wastage down and ensure that drugs are available when needed.By incorporating Blockchain Technology into the Drug Inventory and Supply Chain Tracking System, the Drugs can be tracked with accurate and timeless records; thus, eliminating the problems associated with counterfeit drugs.

The Drug Inventory and Supply Chain Tracking System will be developed using a combination of technologies; it will be built using React.js, Node.js, MongoDB, and TensorFlow, and will provide a scalable solution for use within both Private and Public Health Facilities, aligning with the Digital Health Initiatives in India.

In the future, enhancements to the system can be made with a variety of advanced features. IoT-based monitoring of storage can help achieve proper environmental conditions for sensitive medicines. Blockchain technology could also allow for automated replenishment of supplies through secure tracking of stock and generating orders automatically when supplies run low. AI models (ARIMA for example) can also improve the ability to predict demand and manage/track expiration dates. Usability and efficiency can be improved with additional functionality such as personalized drug tracking for patients; real-time monitoring of logistics through GPS, and central dashboards displaying environmental data. Other enhancements may include predictive maintenance of medical devices, monitoring raw material suppliers to prevent disruption, and sustainability monitoring to minimize environmental impact. Expanding the scope of the system to a global level with support for localization and implementing advanced analytics will lead to better decision making. These enhancements will result in a more robust, flexible system that supports modern health care supply chains.

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