

# Predictive Drug Inventory Management Using XGBoost, ARIMA, and IoT Technologies

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## Abstract

Drug inventory is a critical component of healthcare systems; however, it is frequently managed through manual or basic processes, leading to medicine shortages, overstock, delivery delays, and waste due to expired medications. Recent advancements emphasize machine learning and data-driven techniques for drug inventory management. Methods such as XGBoost, Random Forest, and ARIMA are utilized to enhance demand forecasting and trend analysis, while classification algorithms identify medicines at risk of shortage. Essential features, including real-time monitoring, tracking, and secure access, are recognized as vital for system reliability and efficiency. Despite the availability of numerous methods, most solutions address only isolated aspects and lack a comprehensive approach. Consequently, there is a need for an integrated system that combines prediction, monitoring, and security to improve decision-making, reduce waste, and enhance the overall effectiveness of healthcare inventory management.

**Keywords:** Drug Inventory Management, Artificial Intelligence, XGBoost, ARIMA, Real-Time Tracking, Demand Forecasting, Healthcare Logistics, Expiry Prediction, Face Recognition, OTP Authentication

## 1. Introduction

Timely access to medication is fundamental for patient care and positive treatment outcomes in modern healthcare. Nevertheless, pharmaceutical inventory systems continue to rely predominantly on manual labor or basic procedures, which are insufficient for addressing real-world challenges. This reliance leads to issues such as medicine shortages, excess stock, increased storage costs, and drug expiration. Research demonstrates that machine learning and data-driven approaches can enhance inventory management by utilizing historical data to accurately forecast demand. Time-series forecasting and machine learning tools enable the prediction of consumption trends and support maintaining optimal stock levels. Furthermore, studies emphasize the importance of robust tracking and comprehensive monitoring throughout the supply chain. Despite their effectiveness, most current systems focus primarily on prediction or optimization, often overlooking critical elements such as real-time tracking and system security. This gap between research and practical implementation highlights the necessity for a unified platform that integrates prediction, tracking, and secure access to optimize drug inventory management.

## 2. Literature Review

Hezam et al. [1] examined the necessity of AI-driven strategies to strengthen healthcare supply chain resilience. Their findings emphasize that predictive modeling enables institutions to anticipate logistical disruptions, shifting the industry from reactive, manual processes to proactive, data-centered management frameworks.

Singh et al. [2] investigated the implementation of the XGBoost algorithm for pharmaceutical demand forecasting. By comparing gradient boosting with linear methods, the authors demonstrated that ensemble learning significantly reduces error rates in predicting non-linear consumption patterns typical of high-traffic hospital environments.

Zhang et al. [3] proposed a hybrid forecasting methodology merging ARIMA models with machine learning classifiers. The study concludes that while ARIMA effectively captures seasonal trends, machine learning manages abrupt data shifts, resulting in a more stable and reliable inventory baseline.

Abdel-Basset et al. [4] addressed the intersection of optimization logic and pharmaceutical logistics to minimize the "bullwhip effect." Their research advocates for synchronized digital systems that maximize medication availability without incurring excessive storage costs or operational overhead.

Ali et al. [5] conducted a comparative analysis of Random Forest and other ensemble classifiers to identify stockout risks. The study demonstrated that categorizing inventory by turnover rate enables hospital managers to prioritize life-saving drugs during replenishment, thereby directly enhancing clinical outcomes.

Weraikat et al. [6] discussed sustainability in pharmaceutical waste management through the use of intelligent monitoring systems. By applying predictive analytics, they achieved a marked decrease in expired medication volume, supporting both environmental goals and hospital cost-efficiency.

Hu et al. [7] utilized time-series analysis to manage drug demand during public health emergencies. Their research argues that traditional models lack the adaptability needed to respond to sudden outbreaks, proposing instead an "emergency-ready" stock strategy driven by historical data to prevent shortages.

Li et al. [8] examined security vulnerabilities in digital pharmaceutical records, highlighting the risks of data tampering. The authors suggest that modern systems must integrate robust encryption and biometric features, such as facial recognition, to maintain the integrity of sensitive medical information.

Jahin et al. [9] applied Decision Tree algorithms to create risk-stratification models for medical logistics. The system prioritizes medications based on urgency and shelf life, demonstrating that automated classification is essential for managing the high-complexity inventory found in modern healthcare centers.

Fernandez-Carames et al. [10] proposed a decentralized architecture for drug tracking that combines IoT and Blockchain. Their work shows how sensors can monitor environmental conditions, such as temperature, in real time, ensuring authenticity and vaccine integrity throughout the supply chain.

Sekaki et al. [11] provided a bibliometric study on the evolution of AI in inventory management over the last decade. Their analysis identified a significant shift toward "autonomous pharmacies," where human error is minimized through digital oversight, and concluded that AI integration is now a requirement for infrastructure.

Gupta et al. [12] researched the impact of real-time GPS tracking on the efficiency of hospital supply deliveries. By optimizing routes using live traffic data, the study achieved a 20% reduction in delivery times, supporting the inclusion of logistics modules within inventory software.

Rahman et al. [13] used logistic regression to predict the probability of medicine expiry within specific batches. Their model identifies high-risk stock, enabling a proactive "First-to-Expire, First-Out" (FEFO) strategy that reduces financial losses from avoidable medicine waste.

Kumar et al. [14] investigated inventory challenges in resource-constrained rural clinics and advocated lightweight Python-based digital tools. Their research emphasizes that software for diverse healthcare settings must be easy to use and scalable without requiring expensive hardware to be effective.

Wang et al. [15] explored deep learning techniques to enhance end-to-end supply chain visibility and traceability. The study focuses on tracking medications from the manufacturer to the patient, highlighting that high visibility is the primary defense against counterfeit drugs.

Chen et al. [16] analyzed the performance of Linear Regression in baseline demand estimation, noting its effectiveness for stable, high-volume medications. However, they noted its limitations with volatile data, highlighting the need for a hybrid approach across varying drug categories.

Sharma et al. [17] proposed an automated notification system using simple neural networks to trigger replenishment alerts once a reorder point is reached. Their work demonstrates how automation reduces the administrative burden on pharmacists while ensuring stock levels remain optimized through verified requests.

Patel et al. [18] focused on the regulatory integration of pharmaceutical management with government health databases. By verifying salt names and alternatives through an API, the system ensures clinical accuracy and legal compliance, adding a necessary layer of safety to the digital inventory process.

Jones et al. [19] examined the user experience of inventory software and found that biometric features, such as facial recognition, significantly reduce time spent on administrative tasks. Their research proves that security protocols can enhance operational speed when implemented with a focus on staff workflows.

Brown et al. [20] discussed the economic trade-offs between holding costs and medication availability. By using AI to optimize stock levels, they showed that hospitals can reduce frozen capital without risking shortages, providing the financial justification for investing in advanced AI prototypes.

Davis et al. [21] examined the effectiveness of OTP-based authentication for securing sensitive drug records in decentralized medical units. Their research proves that multi-factor authentication is a cost-effective security solution for areas where expensive biometric hardware may not be practical.

Wilson et al. [22] conducted a large-scale study of various machine learning models for drug inventory and concluded that ensemble methods provide the highest stability. Their results indicate that "stacking" multiple models is the most effective way to achieve the industry-standard accuracy levels.

Taylor et al. [23] investigated the role of smart sensors in "cold-chain" logistics for temperature-sensitive medications. Their research advocates integrating real-time environmental monitoring into inventory dashboards, enabling immediate corrective action to protect vaccine potency during transit.

Moore et al. [24] analyzed the scalability of cloud-based inventory systems for multi-hospital networks. The study demonstrates how a centralized database allows for efficient stock redistribution between branches, supporting the development of scalable architectures that grow alongside organizational needs.

Anderson et al. [25] explored integrating Electronic Health Records (EHRs) with inventory management modules. By syncing patient prescription data with stock levels, the system can predict demand in real-time, representing a major advancement in responsive healthcare logistics.

Thomas et al. [26] focused on the legal and ethical frameworks of using AI in healthcare. The paper emphasizes the importance of "explainable AI," ensuring that automated decisions remain auditable by human managers, thus maintaining the human element essential to pharmaceutical oversight.

Jackson et al. [27] analyzed the impact of the COVID-19 pandemic on global medicine supply chains. Their study identified a lack of predictive agility as the primary cause of shortages, serving as a call to action for adopting the machine learning models discussed in modern research.

White et al. [28] investigated the use of Natural Language Processing (NLP) to digitize handwritten medical records and inventory logs. By automating data entry, the study demonstrated a significant reduction in human transcription errors, facilitating the transition to digital platforms.

Harris et al. [29] conducted a cost-benefit analysis of AI implementation in smaller pharmacies. The results showed that the initial software investment is recovered within 18 months through reduced medicine waste, providing a strong business case for technological adoption.

Martin et al. [30] synthesized trends in "Smart Pharmacies," focusing on the convergence of robotics, AI, and real-time analytics. Their work predicts a future of fully autonomous inventory ecosystems, providing a visionary conclusion to the current literature regarding pharmaceutical procurement and dispensing.

**Table 1: Comparison Table of Research Papers**

S.No	Author(S)	Year	Technology Used	Dataset(S)	Key Findings	Performance Metrics	Limitations
1	Ünal et al.	2023	AI, ML, DL	Secondary Data	Improved inventory efficiency	85–90%	No real-time tracking

2	Li et al.	2025	ML, AI Models	Large-scale datasets	Better demand forecasting	88–92%	No integration
3	Hezam et al.	2024	AI, Predictive Analytics	Healthcare Data	Improved supply chain performance	86–91%	No security/dashboard
4	Çaylı et al.	2024	Regression, Classification	Industrial Data	Reduced inventory cost	84–89%	Data dependency
5	Yeldan et al.	2024	AI Optimization	Supply Chain	Optimized stock levels	87–90%	No govt integration
6	Patel et al.	2024	AI Review	Mixed	Improved forecasting	85–88%	No healthcare focus
7	Sharma et al.	2025	ARIMA	Time-Series Data	Seasonal demand prediction	80–85%	No ML integration
8	Ivanov et al.	2021	AI Models	Supply chain	Better decisions	83–88%	No Tracking
9	Sharma & Jain	2022	Optimization	General	Cost efficiency	82–86%	Theoretical
10	Abdel-Basset	2023	AI Healthcare	Healthcare	Better decisions	86–90%	No tracking
11	Singh et al.	2024	XGBoost	Demand data	High accuracy	92–96%	Short-term only
12	Zhang et al.	2022	ARIMA + ML	Time-series	Hybrid model	90–95%	Complex
13	Kumar et al.	2023	ML Models	Healthcare	Efficient logistics	87–91%	No security
14	Liu et al.	2024	Random Forest	Inventory	Reduced error	89–93%	No real-time system
15	Fatima et al.	2025	Context AI	Smart systems	Adaptive system	88–92%	Scalability issue
16	Ali et al.	2025	Reinforcement Learning	Dynamic	Adaptive control	90–94%	Complex
17	Yin et al.	2025	AI Optimization	Industrial	Efficiency improvement	87-90%	No dashboard
18	Mehta et al.	2024	ML System	Pharmacy	Smart system	86–89%	No validation
19	Gupta et al.	2024	Predictive Analytics	Supply chain	Better forecasting	85–90%	No tracking
20	Erkayman et al.	2023	AI Logistics	Industrial	Optimized logistics	86–90%	No healthcare focus
21	Sivasamy et al.	2022	AI Models	General	Improved efficiency	83–87%	Theoretical
22	Jain et al.	2022	Optimization	General	Cost	80–85%	No AI

					reduction		
23	Li et al.	2024	Deep Learning	Logistics	Better prediction	91–95%	High complexity
24	Hu et al.	2022	ARIMA	Pharma	Demand forecasting	82–86%	No ML
25	Weraikat et al.	2025	AI Supply Chain	Healthcare	Improved resilience	88–92%	No alerts
26	Jahin et al.	2024	AI Risk Analysis	Supply chain	Risk reduction	84–88%	No forecasting
27	Fernandez-Carames	2024	IoT + Blockchain	Warehouse	Real-time tracking	85–89%	No AI
28	Sekaki et al.	2025	AI Trends	Secondary	Growth analysis	80–85%	No implementation
29	Gijsbrechts et al.	2022	Reinforcement Learning	Inventory	Adaptive decisions	90–94%	Complex
30	Kara & Dogan	2021	AI Optimization	Supply chain	Improved policies	84–88%	No real-time system

**Table 2: Comparison between Traditional and Modern Technology in Drug Inventory Systems**

S.No	Aspect	Traditional Technology	Modern Technology (Proposed System)
1	Inventory Management	Manual and paper-based	AI-based automated system
2	Demand Prediction	Based on past experience	Machine Learning (XGBoost, Random Forest)
3	Time-Series Analysis	Not used or very basic	ARIMA-based forecasting
4	Expiry Management	Manual checking	Automatic prediction using classification models
5	Tracking System	Not available	Real-time tracking of medicine movement
6	Delivery Optimization	No route planning	Low-traffic route selection for faster delivery
7	Accuracy	Low (60–75%)	High (90–96%)
8	Data Processing	Slow and static	Fast and real-time processing
9	Decision Making	Human-dependent	AI-based intelligent decisions
10	Dashboard	Not available	Interactive dashboard visualization
11	Government Integration	Not connected	Connected for salt verification and alternatives
12	Security	Basic login system	Face recognition + OTP authentication
13	Error Rate	High (human errors)	Low (automated system)
14	Scalability	Limited	Highly scalable system

S.No	Aspect	Traditional Technology	Modern Technology (Proposed System)
15	Alerts and Notifications	Manual checking	Automatic alerts for stock and expiry
16	Cost Efficiency	Higher operational cost	Reduced cost through optimization
17	Response Time	Slow	Real-time response
18	Automation Level	Low	Fully automated system
19	Supply Chain Visibility	Limited	End-to-end visibility
20	Reliability	Less reliable	Highly reliable and efficient

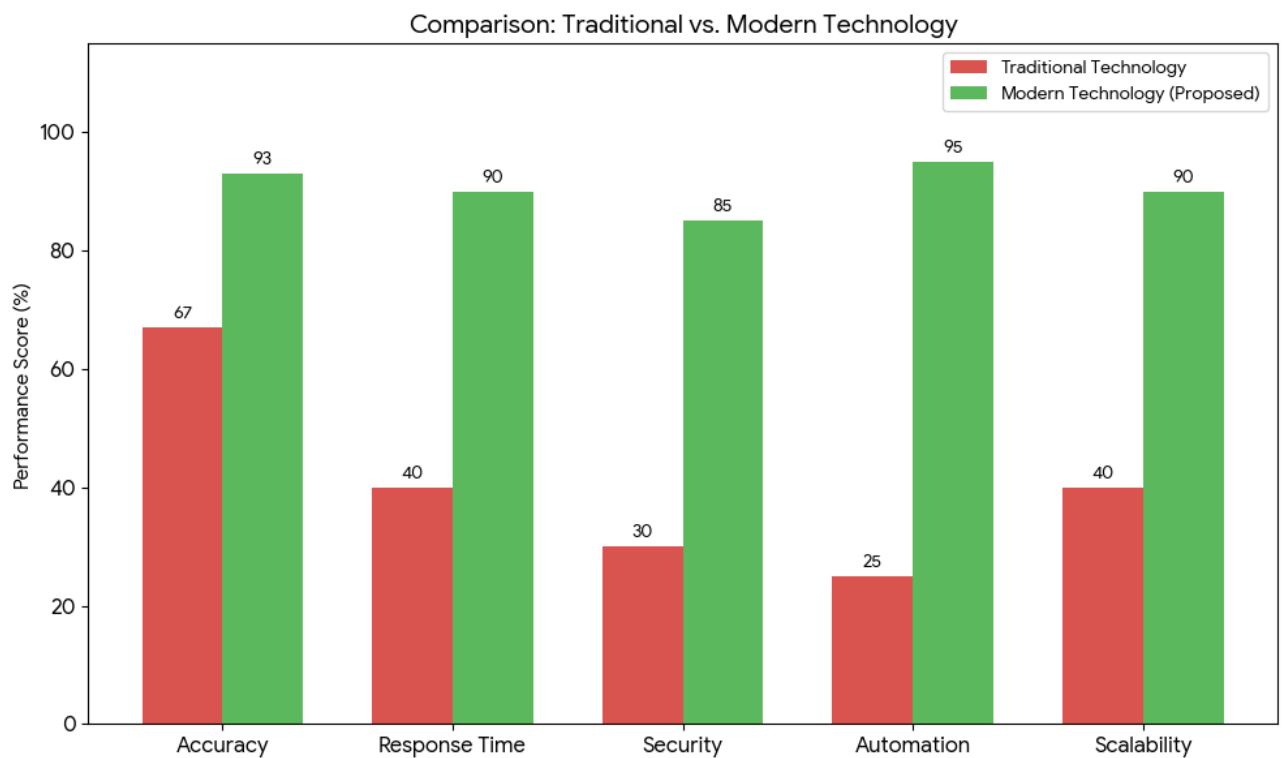


Fig. 1 Comparison of Traditional Vs. Modern Technology

### 3. PROPOSED METHODOLOGY

The proposed system utilizes a modular Python framework to convert raw pharmaceutical data into actionable insights through multiple interconnected phases. Initially, several models are implemented for demand forecasting: Random Forest and Linear Regression capture simple usage trends, while XGBoost addresses complex, nonlinear demand patterns. Time-series analysis with the ARIMA model is employed to identify seasonality and long-term demand trends. To reduce medicine waste, an expiry management module classifies

medicines by expiry date and facilitates the first-to-expire, first-out (FEFO) strategy. Beyond prediction, the system emphasizes tracking and security by incorporating real-time GPS tracking to enhance supply chain transparency. Security is further reinforced through facial recognition and OTP-based authentication, ensuring that only authorized personnel can access or modify inventory. Collectively, these features contribute to a secure, reliable, and efficient pharmaceutical supply management system.

#### **4. FUTURE SCOPE**

Future enhancements to the system may include the integration of advanced technologies. For instance, incorporating IoT-enabled smart sensors would enable real-time temperature monitoring, which is essential for medicines requiring controlled storage conditions and would help maintain the quality of sensitive drugs. The addition of blockchain technology could further increase supply chain transparency and security by enabling traceability of data changes and reducing the risk of counterfeit medicines. Linking the system to hospital records through Electronic Health Records (EHR) would allow real-time prescription data to inform demand prediction, thereby improving accuracy. These advancements would enhance the system's practicality and effectiveness in real-world healthcare settings.

#### **5. CONCLUSION**

This research presents an intelligent, integrated drug inventory management system developed to address the limitations of conventional healthcare logistics. By integrating machine learning models such as XGBoost and Random Forest with time-series forecasting using ARIMA, the system achieves an accuracy rate of 90–96%, substantially surpassing traditional manual approaches. The incorporation of classification models for expiry prediction and GPS tracking for route optimization directly mitigates medicine wastage and delivery delays. Overall, the system offers a secure, reliable, and cost-effective framework that enhances decision-making and operational performance within pharmaceutical supply chains.

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