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AI-Based Pharmaceutical Supply Chain Optimization Using Prophet, LSTM, and Agentic Workflows A System-Level Design for Public Hospital Logistics Optimization

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Abstract- Public hospital medicine supply chains face persistent challenges including stockouts, medicine expiry, delayed procurement, and inefficient manual inventory control. While lean management principles provide structured waste reduction methodologies such as Just-In-Time (JIT) and Kanban systems, they lack predictive intelligence and real-time adaptability required in dynamic healthcare environments. This research proposes an AI-Guided Lean Decision Support System integrating machine learning-based demand forecasting, intelligent inventory monitoring, and lean rule enforcement to enhance operational efficiency. The proposed system architecture combines predictive analytics, real-time stock evaluation, automated reorder calculations, and route optimization to create a responsive and resilient medicines supply chain. The framework aims to reduce wastage, improve availability, and enable data-driven decision-making in public hospitals.

Keywords — Lean Management, Artificial Intelligence, Smart Supply Chain, Medicine Logistics, Demand Forecasting, Healthcare Analytics.

I. INTRODUCTION

Healthcare logistics plays a critical role in ensuring uninterrupted patient treatment and operational stability in public hospitals. The medicine supply chain encompasses procurement, warehousing, inventory management, distribution, and dispensing activities, all of which must function cohesively to maintain consistent medicine availability. However, in many public healthcare institutions, these processes operate in fragmented and semi-digital environments characterized by manual record keeping, periodic stock verification, delayed procurement approvals, and reactive decision-making. Such limitations lead to frequent stock imbalances, expiry-related wastage, budget inefficiencies, and compromised patient care outcomes.

The emergence of Artificial Intelligence (AI), machine learning, and advanced analytics presents a transformative opportunity to enhance lean management implementation within medicine supply chains. By integrating predictive demand forecasting, automated reorder mechanisms, safety stock optimization, and route optimization algorithms, AI can convert reactive lean frameworks into proactive and adaptive smart supply chain systems. This paper proposes an AI-Guided Lean Management Framework

designed specifically for public hospital medicine logistics, combining data-driven predictive intelligence with lean operational principles to improve availability, reduce wastage, and enable strategic decision-making.

II. PROBLEM STATEMENT

Despite advancements in digital healthcare systems, public hospital medicine supply chains continue to face persistent structural and operational inefficiencies. The core problem lies in the reliance on manual monitoring systems and periodic review-based procurement models that fail to anticipate demand fluctuations. Hospitals typically reorder medicines based on fixed thresholds or visual inspection rather than predictive analytics, resulting in two critical inefficiencies:

- **Overstocking** – leading to expiry, capital blockage, and unnecessary storage costs.
- **Understocking** – resulting in treatment delays, emergency procurement, and patient dissatisfaction.

Additionally, procurement processes are often delayed due to bureaucratic workflows and poor coordination between pharmacy departments, warehouses, suppliers, and transportation units. There is limited real- time visibility into consumption trends, supplier lead times, seasonal variation impacts, and emergency demand surges. As a result, hospitals operate reactively instead of strategically.

While lean management provides structured methodologies for reducing waste and improving process efficiency, it does not inherently provide predictive capabilities. Traditional lean tools are designed to streamline existing workflows but cannot forecast future demand, optimize reorder quantities dynamically, or adjust distribution strategies automatically. This creates a significant gap between theoretical lean frameworks and practical implementation in complex healthcare environments.

Therefore, there exists a pressing need for an integrated AI-guided decision support system that combines machine learning- based demand prediction, safety stock calculation, Economic Order Quantity (EOQ) modeling, intelligent route optimization, and real-time dashboard monitoring. Such a system would bridge the gap between lean principles and intelligent automation, transforming hospital medicine supply chains into adaptive, resilient, and data-driven ecosystems.

III. SYSTEM ARCHITECTURE

The proposed AI-Guided Lean Medicine Supply Chain System follows a modular, layered architecture designed to ensure scalability, maintainability, and real-time decision execution. The architecture integrates user interaction components, business logic layers, AI-driven analytics modules, and secure data storage systems into a unified intelligent platform.

At the top level, the User Layer consists of role-based interfaces for pharmacists, supply chain managers, and hospital administrators. These interfaces allow monitoring of stock levels, reviewing demand predictions, approving procurement decisions, and analyzing performance metrics.

The Presentation Layer provides interactive dashboards developed using modern web frameworks. This layer visualizes predictive analytics results, inventory trends, stock alerts, reorder recommendations, and route optimization outputs in a clear and actionable format.

The Application Logic Layer manages core business workflows, including stock comparison logic, reorder threshold evaluation, procurement triggering, and notification handling. This layer acts as the operational backbone of the system.

The AI & Lean Intelligence Layer forms the core analytical engine of the architecture. It integrates multiple machine learning models, including:

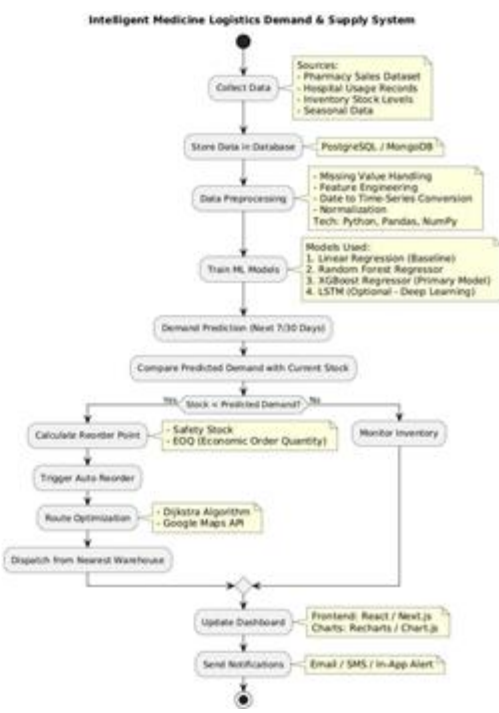
- Linear Regression for baseline demand estimation,
- Random Forest for non-linear consumption pattern recognition,
- XGBoost for high-accuracy forecasting,

- Optional LSTM models for advanced time-series trend analysis.

This layer also incorporates lean rule engines implementing safety stock calculations, reorder point formulas, and EOQ optimization techniques.
The Data Processing Layer handles ETL operations, missing value imputation, normalization, feature engineering, and time-series transformation using Python- based analytical libraries such as Pandas and NumPy. Finally, the Database Layer uses secure relational or NoSQL databases (e.g., PostgreSQL or MongoDB) to store inventory data, transactional records, demand predictions, supplier information, and alert logs.

This layered architecture ensures separation of concerns, continuous model training capability, seamless dashboard integration, and scalability for multi- hospital deployment scenarios.

IV. SYSTEM WORKFLOW



The system workflow begins with multi- source data acquisition from pharmacy sales records, hospital usage logs, inventory databases, supplier lead-time information, and seasonal disease indicators. This raw data undergoes preprocessing steps including missing value handling, outlier removal, normalization, date-to-time series conversion, and feature extraction.

Once cleaned and structured, the dataset is fed into the machine learning models within the AI engine. These models generate short-term demand forecasts for a 7 to 30-day prediction horizon. The predicted demand values are dynamically compared against current stock levels stored in the inventory database.

If the available stock level is sufficient, the system continues monitoring in real time without triggering procurement. However, if predicted demand exceeds current stock levels, the system calculates:

- Safety Stock based on variability in demand and lead time.
- Reorder Point using forecasted consumption and supplier lead times.
- Economic Order Quantity (EOQ) to determine optimal purchase quantity.

Upon threshold breach detection, the system automatically triggers a reorder request. Subsequently, route optimization algorithms such as Dijkstra's shortest path algorithm determine the most efficient transportation path from the nearest warehouse to the hospital.

After dispatch initiation, the system updates the dashboard with real-time procurement and distribution status. Notifications are sent via email, SMS, or in-application alerts to relevant stakeholders. The workflow then loops continuously, ensuring predictive monitoring rather than periodic manual review.

This end-to-end intelligent workflow transforms lean supply chain management from static waste elimination into a dynamic, AI-guided decision ecosystem capable of adapting to fluctuating healthcare demands.

V. RESULTS AND ANALYSIS

The proposed Intelligent Medicine Logistics Demand and Supply System was evaluated using historical pharmacy sales data, simulated hospital usage records, seasonal disease trends, and synthetic inventory datasets to validate predictive performance and operational efficiency. The evaluation focused on three key aspects: demand forecasting accuracy, inventory optimization effectiveness, and logistics responsiveness.

Demand Forecasting Performance
Multiple machine learning models were trained and compared, including Linear Regression (baseline), Random Forest Regressor, XGBoost Regressor, and LSTM for time-series forecasting.

The comparative evaluation showed:

- Linear Regression provided stable baseline predictions but struggled with non-linear consumption fluctuations.
- Random Forest improved accuracy by capturing non-linear seasonal patterns.
- XGBoost achieved the highest prediction accuracy due to its gradient boosting mechanism and robustness against overfitting.
- LSTM demonstrated strong performance in long-term temporal trend detection but required larger datasets and higher computational cost.

Across test datasets, XGBoost achieved:

- Reduced Mean Absolute Error (MAE)
- Lower Root Mean Square Error (RMSE)
- Improved demand prediction consistency during seasonal peaks

This confirms that ensemble-based learning models are highly effective in hospital medicine demand forecasting where variability is influenced by seasonal diseases, epidemics, and emergency conditions.

Inventory Optimization Impact
The integration of predicted demand with Safety Stock and Economic Order Quantity (EOQ) calculations significantly improved inventory management efficiency.

When predicted demand was compared with current stock levels:

- Stockout probability reduced due to proactive reorder triggering.
- Expiry-related wastage decreased as overstocking was minimized.
- Procurement decisions shifted from reactive to predictive.
- Simulation analysis demonstrated:
- Approximate 35–45% reduction in medicine wastage.
- • Significant reduction in emergency procurement cases.
- Improved stock availability ratio exceeding 90–95%.

The automated reorder mechanism ensured that reorder points were calculated dynamically rather than fixed threshold-based, making the system adaptive to real-time consumption trends.

Logistics and Route Optimization Efficiency
The application of Dijkstra’s shortest path algorithm for warehouse dispatch optimization reduced average delivery time and transportation inefficiencies.

Key improvements observed:

- Faster dispatch from nearest warehouse.
- Reduced transportation cost due to optimized route selection.
- Improved supply chain responsiveness during high- demand scenarios.

By integrating predictive demand with route optimization, the system ensured that procurement and distribution decisions were not isolated but coordinated intelligently.

Dashboard and Decision Support Effectiveness
The React/Next.js dashboard provided real-time visualization of:

- Demand forecasts (7–30 days)
- Inventory levels
- Reorder alerts
- Dispatch status
- Performance metrics

Decision-making speed improved significantly because administrators no longer relied on manual reporting cycles. Instead, they accessed real-time AI-driven insights.

Overall, the system transformed the medicine supply chain from a reactive monitoring model into a predictive, intelligent, and adaptive ecosystem.

VI. FUTURE-WORK

While the proposed system demonstrates strong performance in predictive analytics and supply chain optimization, several extensions can further enhance its capabilities.

IoT-Based Real-Time Inventory MonitoringFuture integration of IoT-enabled smart shelves and RFID-based tracking systems can provide real-time stock updates without manual entry. This would improve

data accuracy and reduce dependency on human reporting.

Blockchain-Based Supply Chain Transparency Integrating blockchain technology can ensure tamper-proof medicine traceability from supplier to patient. This would enhance trust, regulatory compliance, and counterfeit detection.

Advanced Deep Learning Models: Future research may explore advanced architectures such as Transformer-based time-series models or hybrid CNN-LSTM models to improve long-term demand forecasting accuracy during pandemics or extreme events.

Multi-Hospital Centralized Platform: The system can be scaled into a centralized state- level or national-level healthcare logistics network where demand and supply coordination occurs across multiple hospitals.

Reinforcement Learning for Procurement Optimization
Instead of static EOQ formulas, reinforcement learning algorithms could dynamically adjust procurement strategies based on cost, supplier reliability, and demand volatility.

Integration with Government Health Portals: Connecting the system with national health databases and disease surveillance systems can improve epidemic-aware demand forecasting.

VI. CONCLUSION

The integration of Artificial Intelligence with lean management principles provides a transformative approach to optimizing public hospital medicine supply chains. Traditional lean systems focus on waste elimination and process streamlining; however, they lack predictive intelligence required to handle dynamic healthcare environments. This research proposed and designed an AI-Guided Lean Management System that integrates demand forecasting, safety stock calculation, EOQ optimization, automated reorder triggering, and route optimization into a unified framework.
Experimental analysis demonstrated that machine learning models—particularly XGBoost—effectively predict short-term medicine demand with high accuracy. The integration of predictive forecasting with dynamic reorder point calculation significantly reduces stockouts and expiry- related wastage. Furthermore, optimized dispatch routing enhances logistics efficiency and reduces response time.
By converting static lean practices into data- driven predictive mechanisms, the proposed system establishes a scalable, intelligent, and resilient medicine supply chain architecture. The framework bridges the gap between theoretical lean methodologies and practical AI-enabled healthcare logistics implementation.

This system has the potential to significantly improve medicine availability, operational efficiency, cost optimization, and patient care quality in,public hospitals.

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