Drug Inventory and Supply Chain Tracking System

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ABSTRACT

This research paper introduces a novel Drug Inventory and Supply Chain Tracking System to address persistent challenges in pharmaceutical management, such as drug shortages, inventory inaccuracies, and supply chain traceability issues. Built on Python-based technologies—Flask for the backend, Streamlit for the frontend, and SQLAlchemy for database management—the system offers a scalable, modular, and user-friendly platform. Key features include real-time inventory visibility across multiple locations, end-to-end supply chain tracking, role-based access control, supplier management, audit trails for regulatory compliance, and advanced data analytics. By analyzing the limitations of existing systems, this paper underscores the need for such a solution and details its two-tier architecture with interactive dashboards. The methodology, security measures, and potential for future enhancements are explored, highlighting the system's potential to enhance patient care, reduce operational costs, and improve efficiency in healthcare settings.

Keyword: *Drug Inventory, Supply Chain Tracking, Pharmaceutical Management, Real-Time Visibility, Flask, Streamlit, SQLAlchemy, Automation, Role-Based Access Control, Audit Trails, Data Analytics, Regulatory Compliance, Scalability, User-Friendly Interface, Drug Shortages, Inventory Accuracy, Supplier Management, Healthcare Efficiency.*

1. INTRODUCTION

1.1. Motivation

The pharmaceutical supply chain is a critical component of healthcare, ensuring that drugs reach patients when needed. However, it faces significant challenges, including frequent drug shortages, inventory miscalculations, and difficulties in tracking supply chains. According to the University of Utah Drug Information Service, there were 323 active drug shortages in the first quarter of 2024 (Drug Shortages Statistics). These shortages can lead to delayed treatments, increased medical errors, and higher costs due to the need for alternative therapies. For instance, a 2019 survey estimated that drug shortages cost the U.S. healthcare system approximately $360 million annually in labor costs alone (PBS News). Traditional inventory management systems, such as manual record-keeping or outdated software, often lack real-time visibility and automation, exacerbating these issues. The complexity of the pharmaceutical supply chain, involving multiple stakeholders and stringent regulatory requirements, further underscores the need for a modern, unified digital platform to streamline operations and ensure drug availability.

1.2. Objectives

- Provides real-time inventory visibility across multiple healthcare facilities.
- Enables efficient tracking of the supply chain from order placement to delivery.
- Implements role-based access control to enhance security and compliance.
- Offers comprehensive supplier management, including performance tracking and contract management.
- Maintains detailed audit trails to meet regulatory standards.

- Integrates robust data analytics for informed decision-making.
- Ensures scalability and modularity for integration with existing healthcare IT systems.
- Delivers a user-friendly interface to improve adoption and operational efficiency.

1.3. Scope of the System

The proposed system covers the entire pharmaceutical supply chain, from procurement to distribution, across various healthcare settings such as hospitals, pharmacies, and clinics. It includes modules for user management, drug tracking, supplier management, inventory control, procurement, reporting, auditing, and notifications. Designed to be flexible, the system can adapt to different organizational needs while maintaining consistency and compliance with regulations like the Drug Supply Chain Security Act (DSCSA).

2. LITERATURE SURVEY

2.1. Overview of Existing Systems

Current approaches to drug inventory and supply chain management include a range of systems, each with distinct advantages and limitations:

- **Manual Record-Keeping and Spreadsheets**: Widely used in smaller facilities, these methods are prone to human error and lack real-time updates, making it difficult to respond to supply chain disruptions.
- **Enterprise Resource Planning (ERP) Systems**: Comprehensive but often complex and costly, requiring extensive customization to meet pharmaceutical needs.
- **Legacy Software Solutions**: These older systems may not support modern requirements like real-time tracking or integration with other platforms.
- **Off-the-Shelf Inventory Systems**: Not tailored to the unique demands of pharmaceutical supply chains, such as regulatory compliance or specialized drug handling.
- **Barcoding and RFID Systems**: Effective for tracking individual items but lack comprehensive supply chain visibility or automated reporting.
- **Manual Stakeholder Coordination**: Inefficient and error-prone, especially in large-scale operations involving multiple locations.
- **Cloud-Based Solutions**: Offer scalability but raise concerns about data security and compliance with healthcare regulations.

These systems often fail to provide the integrated, real-time solutions needed to address the complexities of pharmaceutical supply chains.

2.2. RESEARCH GAPS

The limitations of existing systems highlight several research gaps:

- **Lack of Real-Time Visibility**: Most systems rely on periodic updates, which are inadequate for dynamic healthcare environments.
- **Fragmented Supply Chain Tracking**: There is no end-to-end visibility from order to delivery, complicating issue identification and resolution.
- **Manual Processes**: Procurement and restocking often involve manual steps, leading to delays and errors.
- **Inadequate Supplier Management**: Few systems offer tools for evaluating supplier performance or managing contracts.
- **Regulatory Compliance Challenges**: Audit trails and reporting capabilities are often insufficient for meeting stringent regulations.
- **Limited Analytics**: Predictive insights and data-driven decision-making are rarely supported.
- **User Experience Issues**: Many systems are cumbersome, requiring extensive training and reducing adoption rates.

2.3. Key Contributions of Proposed System

The proposed system addresses these gaps by:

- Offering centralized, real-time inventory visibility across multiple locations.
- Providing end-to-end supply chain tracking with automated updates.
- Implementing role-based access control for enhanced security and compliance.
- Enabling comprehensive supplier management with performance metrics.
- Ensuring regulatory compliance through detailed audit trails.
- Integrating advanced data analytics for predictive insights.
- Designing a modular, scalable architecture for seamless integration.
- Creating an intuitive interface to enhance usability and adoption.

2.4. Related Work

Recent research underscores the need for innovative solutions in pharmaceutical supply chain management:

- Shen et al. (2024) explored the use of artificial intelligence and vendor-managed inventory (AI+VMI) to optimize drug supply chain management in hospitals, achieving significant cost and efficiency improvements (AI+VMI Study).
- Saha and Ray (2019) used qualitative system dynamics to identify supply chain challenges, such as forecasting inaccuracies and long lead times (Supply Chain Challenges).
- Gao (2014) modeled pharmaceutical supply chain reliability, highlighting how disruptions at manufacturing plants contribute to shortages (Supply Chain Reliability).
- Alkahtani et al. (2023) proposed digitalization using big data analytics and blockchain to mitigate supply chain risks (Digitalization Study).
- Islam et al. (2021) developed a deep reinforcement learning model for hospital inventory optimization to prevent shortages (Inventory Optimization).

These studies emphasize the importance of advanced technologies and systematic approaches to enhance supply chain efficiency and resilience.

3. PROPOSED WORK

3.1. System Architecture

The proposed system adopts a two-tier architecture for simplicity and scalability:

- **Backend**: Developed using Flask, a lightweight Python web framework, the backend handles data logic, business rules, and API endpoints. It ensures efficient request processing and database integration.

- **Frontend**: Built with Streamlit, a Python library for creating interactive web applications, the frontend provides a user-friendly interface with dashboards, reports, and real-time updates.

- **Database**: Managed using SQLAlchemy, an Object-Relational Mapping (ORM) tool, the database stores data on users, drugs, suppliers, and transactions, ensuring efficient storage and retrieval.

The system is modular, allowing easy integration with existing healthcare IT systems and scalability to handle growing data volumes and user bases. Security measures, such as encryption and role-based access control, protect sensitive data and ensure compliance with regulations.

3.2. Data Flow Diagram

Level-0 DFD (Context Diagram)

```
[Users] --> (Login Credentials, Drug Details, Shipment Updates) --> [Drug Inventory System]
[Users] <-- (Dashboards, Reports, Alerts) <-- [Drug Inventory System]
[Suppliers] --> (Supplier Details, Shipment Statuses) --> [Drug Inventory System]
[Suppliers] <-- (Purchase Orders) <-- [Drug Inventory System]
```

Level-1 DFD

```
[Users]
  | (Login Credentials)
  v
[1. Authenticate User] --> [Central Database (Users)] (Store/Retrieve Credentials, Roles)
  | (Session Token)
  v
[Users]

[Users]
  | (Drug Details: Name, Quantity, Expiration)
  v
[2. Manage Drugs] --> [Central Database (Drugs)] (Store/Retrieve Drug Records)

[Users]
  | (Supplier Details: Contact, Contract)
  v
[3. Manage Suppliers] --> [Central Database (Suppliers)] (Store/Retrieve Supplier Records)
  ^ (Shipment Confirmations)
  |
[Suppliers] <-- (Purchase Orders) <-- [3. Manage Suppliers]

[Users]
  | (Inventory Updates: Stock Adjustments)
  v
[4. Track Inventory] --> [Central Database (Transactions)] (Store/Retrieve Transaction Records)

[Users]
  | (Shipment Details: Order Quantities, Delivery Dates)
  v
[5. Track Shipments] --> [Central Database (Shipments)] (Store/Retrieve Shipment Records)
  ^ (Shipment Status Updates)
  |
[Suppliers] <-- (Purchase Orders, Delivery Requests) <-- [5. Track Shipments]

[Users]
  | (Report Requests: Stock Levels, Supplier Performance)
  v
[6. Generate Reports & Analytics] --> [Central Database (All Data)] (Retrieve Data for Reports)
  | (Dashboards, Reports, Alerts)
  v
[Users]

[1-6. All Processes] --> [7. Log Audits] --> [Central Database (Audit Logs)] (Store Audit Records)
```

Explanation of Components

- **External Entities**:
    - **Users**: Pharmacists, Administrators, Warehouse Managers, Distributors interact via the Streamlit frontend to input data and view outputs.
    - **Suppliers**: Provide shipment updates and receive orders, interacting indirectly through the system.
- **Processes**:
    - **Authenticate User**: Validates credentials using Flask's authentication module, retrieving user roles from the database.
    - **Manage Drugs**: Handles CRUD operations for drug records, ensuring accurate stock levels.
    - **Manage Suppliers**: Maintains supplier data and tracks performance metrics.
    - **Track Inventory**: Logs all inventory changes, updating stock levels in real time.
    - **Track Shipments**: Manages the procurement of lifecycle, from order to delivery.
    - **Generate Reports & Analytics**: Produces visualizations and reports using Streamlit's data visualization features.
    - **Log Audits**: Automatically records all transactions for compliance, storing logs in the database.
- **Data Store**:
    - **Central Database**: A relational database (e.g., PostgreSQL via SQLAlchemy) storing all system data, with tables for Users, Drugs, Suppliers, Shipments, Transactions, and Audit Logs.
- **Data Flows**:
    - Data flows represent inputs (e.g., user-entered drug details) and outputs (e.g., generated reports), facilitated by HTTP requests between the Streamlit frontend and Flask backend.

This DFD aligns with the system's architecture (Flask backend, Streamlit frontend, SQLAlchemy database) and supports its objectives of real-time tracking, security, and compliance, as described in the research paper.

4. CONCLUSIONS

The proposed Drug Inventory and Supply Chain Tracking System offers a transformative solution for pharmaceutical management. By addressing the limitations of existing systems, it enhances inventory accuracy, supply chain visibility, and regulatory compliance. Its modular design and intuitive interface make it adaptable to various healthcare settings, while its real-time capabilities empower stakeholders to make informed decisions. The system's potential to reduce drug shortages and operational costs underscores its significance in improving patient care and healthcare efficiency.

5. RESULT AND DISCUSSION

5.1. System Performance

As a proposed system, performance is based on expected outcomes. The lightweight architecture, leveraging Flask and Streamlit, ensures fast response times and scalability. SQLAlchemy's efficient database queries minimize latency, even with large datasets. Regular monitoring and optimization will be essential to maintain performance as the system scales.

5.2. User Experience

The Streamlit-based frontend offers an intuitive interface, reducing the learning curve for users. Role-based access control ensures that users only see relevant information, enhancing usability and security. Feedback mechanisms, such as user surveys, can further refine the interface post-implementation.

5.3. Comparison with Existing Systems

The proposed system outperforms existing solutions in several areas:

Feature	Proposed System	Manual Systems	ERP Systems	Legacy Software
Real-Time Visibility	Yes	No	Partial	No
Supply Chain Tracking	End-to-End	Fragmented	Partial	Limited
Automation	High	Low	Moderate	Low
Analytics	Advanced	None	Basic	None
Scalability	High	Low	Moderate	Low

5.4. Challenges and Limitations

Implementation may face challenges, including:

- **Data Security**: Protecting sensitive patient and drug information requires robust encryption and compliance with regulations like HIPAA.
- **Integration**: Connecting with diverse existing systems across healthcare providers may require custom APIs.
- **User Training**: Staff may need training to adopt the new system effectively.
- **Maintenance**: Keeping the system updated with evolving regulations and technologies will be ongoing.

5.5. Future Scope

Future enhancements could include:

- **AI and Machine Learning**: For demand forecasting and inventory optimization.
- **Blockchain Technology**: To enhance supply chain transparency and traceability.
- **EHR Integration**: For seamless data exchange with electronic health records.
- **Mobile Applications**: For on-the-go access and real-time updates.

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