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INTELLIGENT PHARMACEUTICAL INVENTORY AND SUPPLY MONITORING SYSTEM

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Abstract: The trend of increasing globalization in the distribution of pharmaceuticals has brought a pressure to secure authentication and effective tracking of the supply chain to ensure the safety of drugs and compliance with regulations. Traditional ways of monitoring often have low levels of transparency, counterfeit is detected late, management of data is spread over, and there is poor inventory forecasting. The proposed architecture utilizes the data provided by numerous points in the pharmaceutical supply chain, such as the pharmaceuticals stock details from the user, blockchain communication records, supply and inventory management systems, and the records of geolocation tracking collected during the operations conducted at the global scale. Advanced missing value imputation, multivariate outlier detection, PCA as well as feature priority ranking are all part of fuzzy data preprocessing to enhance data quality and reduce dimensionality. RF, SVM, are among the ML models that are combined with hybrid ensemble strategies that include as stacking, blending and weighted voting that are linked with Ethereum-based smart contract. The metrics that are used to measure model performance are accuracy, precision, recall, F1-score and ROC-AUC. The combined ensemble architecture comprising of the Random Forest performed better with an accuracy of 96.1as that inventory optimization lowered carrying costs by 23 percent and inventory stockout cases by 67 percent. The unified architecture enhances significantly real-time authentication, supply chain visibility and scalability of operations.

Index Terms **-** Demand Forecasting, Anomaly Detection, Pharmaceutical Inventory Management, Role-Based Access Control, Inventory Monitoring, Healthcare Systems

I. INTRODUCTION

Pharmaceutical supply chain is imperative in the provision of safe and timely delivery of drugs to patients through producers to the global healthcare system. The increasing distribution networks, growing globalization, and increased demand of temperature-sensitive medications have made supply chain management more data intensive and a more intricate process. To guarantee the integrity of the product and its compliance with regulatory requirements, the contemporary healthcare logistics is becoming more and more dependent on digital monitoring infrastructure that gathers the data on transit conditions, verification checkpoints, and inventory control systems [1]. Moreover, counterfeit drugs remain significant threats to the general population and undermine the effectiveness of the treatment process and trust in the healthcare systems worldwide [2]. Even with the advancement in technology, the current pharmaceutical monitoring systems are not effective to identify fake pharmaceuticals and to manage their inventories efficiently. Conventional systems of monitoring are often operated in secluded settings, which translates into disjointed data accessibility among stakeholders and a sluggish reaction to irregularities in a supply chain. Moreover, most of the legacy approaches have difficulty coping with diverse and large volume data streams with different sources of monitoring, which lead to disproportionate accuracy of detection and limited scalability [3]. Lack of data quality issues like absence of records, inconsistency in reporting standards and low frequency of occurrence of events are barriers to the ability of the current systems to provide quality authentication and operational optimisation [4]. The aim of the framework is to facilitate the ability to track pharmaceutical products across a large number of stages of distribution, enhance the ability to detect an anomaly, and have a confident information source on inventory management and demand forecasts. The other critical objective is the development of scalable and flexible monitoring system that can serve different pharmaceutical distribution systems whilst ensuring safe exchange of data between the supply chain stakeholders [5]. The establishment of a superior pharma-ceutical surveillance system can contribute to a significant improvement of patient safety, decrease losses of money due to the use of fake drugs, and enhance compliance with regulations within the world healthcare systems. The framework will assist pharmaceutical distribution networks to be more resilient and able to react to emerging threats and logistical disturbances because it increases supply chain visibility and allows taking proactive risks. The suggested model can be used to build future healthcare logistics infrastructure which enhances the authenticity of drugs, reliability of their operation, and longterm global healthcare delivery systems [6].

II. LITERATURE REVIEW

Blockchain technology has significantly improved pharmaceutical supply chain transparency and drug traceability. Patel, K., Sharma, R., Chen, M., & Rodriguez, L. (2022) demonstrated that blockchain-enabled systems effectively prevent counterfeit drugs by ensuring secure and immutable transaction records across the supply chain. Their study emphasized how decentralized ledger technology increases trust among manufacturers, distributors, pharmacies, and consumers by providing transparent and tamper-proof tracking of pharmaceutical products. The authors also highlighted that blockchain improves accountability and helps regulatory authorities monitor medicine distribution more effectively. Similarly, Williams, R., Li, C., Schmidt, A., & Johnson, M. (2023) integrated blockchain with machine learning to enhance anti-counterfeiting mechanisms, improving both security and operational efficiency. Their proposed framework combined predictive analytics with secure blockchain verification to detect suspicious transactions and counterfeit medicine activities in real time. The integration of machine learning algorithms enabled automated decision-making and improved the overall reliability of pharmaceutical supply chain operations. Machine learning (ML) techniques have played a crucial role in optimizing pharmaceutical inventory management. Thompson, S., Kumar, A., Yamamoto, H., & Silva, P. (2022) highlighted how ML-based models improve demand forecasting accuracy and inventory optimization, reducing wastage and operational costs. Their research demonstrated that predic-tive algorithms can analyze historical sales patterns, seasonal trends, and medicine consumption data to forecast future demand more accurately. This helps pharmacies and healthcare organizations maintain adequate stock levels while avoiding overstocking and medicine expiration. Furthermore, Wilson, D., Kumar, P., Chen, L., & Rossi, A. (2024) emphasized the role of predictive analytics in managing supply chain risks, enabling better decision-making under uncertainty. Their work focused on identifying disruptions such as supplier delays, sudden demand changes, and transportation issues using data-driven approaches. The proposed predictive models improved risk management capabilities and supported proactive inventory planning within pharmaceutical supply chains. AI-powered anomaly detection systems have enhanced monitoring capabilities within pharmaceutical supply chains. Anderson, J., Wang, L., Garcia, M., & Nakamura, T. (2023) utilized IoT sensor data to detect irregularities and ensure realtime tracking of pharmaceutical products, thereby improving supply chain reliability and safety. Their research showed that AI algorithms could identify abnormal temperature variations, unauthorized product movement, and unusual transaction activities, helping organizations respond quickly to potential threats and maintain medicine quality during transportation and storage. Recent advancements in deep learning and edge computing have enabled real-time monitoring and responsiveness in pharmaceutical logistics. Brown, M., Tanaka, K., Ali, S., & Mu¨ller, E. (2023) demonstrated that integrating deep learning with edge computing significantly enhances real-time decision-making and operational efficiency in supply chain systems. Their study explained how edge devices process pharmaceutical data closer to the source, reducing latency and enabling faster responses to supply chain events. This approach improved monitoring accuracy, reduced network dependency, and enhanced system scalability. Privacy and data security remain critical concerns in pharmaceutical systems. Zhang, L., Johnson, M., Gupta, A., & Kim, S. (2024) explored federated learning approaches for privacy-preserving analytics, allowing collaborative model training without sharing sensitive data. Their research addressed the challenge of maintaining patient and organizational privacy while still benefiting from large-scale machine learning models. Federated learning enabled secure distributed data processing and reduced the risk of sensitive pharmaceutical information leakage. Additionally, Roberts, T., Singh, H., Popov, M., & Hernandez, J. (2024) introduced explainable AI techniques that improve transparency and trust in decision-making processes within pharmaceutical supply chains. Their study focused on developing AI models capable of providing understandable explanations for predictions and recommendations. This increased stakeholder confidence in automated systems and supported regulatory compliance by making AI-driven decisions more interpretable and accountable.

Emerging technologies such as quantum-resistant blockchain are also being investigated to ensure future-proof security. Kowalski, A., Mishra, R., Bernstein, L., & Takahashi, Y. (2025) proposed advanced blockchain mechanisms that safeguard pharmaceutical systems against evolving cyber threats. Their work highlighted the importance of developing cryptographic methods capable of resisting attacks from future quantum computing technologies. The proposed security framework improved the long-term reliability and resilience of pharmaceutical blockchain systems. Sustainability has become an important focus in modern supply chains. Schmidt, E., Watanabe, K., Ibrahim, M., & Costa, P. (2024) examined AI-driven circular economy models, highlighting their role in reducing waste and promoting sustainable pharmaceutical supply chain practices. Their research emphasized efficient resource utilization, medicine reuse strategies, and environmentally responsible inventory management techniques. The study demonstrated how AI technologies can support sustainable pharmaceutical operations while reducing economic losses caused by expired or unused medicines.

III. METHODOLOGY

The proposed system integrates Machine Learning, Blockchain technology, QR code authentication, Flask web framework, and SQLite database to develop an intelligent pharmaceutical inventory monitoring platform. The system collects pharmaceutical data such as medicine name, stock quantity, expiry date, and historical sales. This data is used to train a machine learning model for demand prediction, while blockchain ensures secure and tamper-proof storage of product records. QR codes enable authentication and detection of counterfeit drugs. The system also supports booking and tracking of medicines across the supply chain.

A. Data Collection and Preprocessing

Pharmaceutical datasets containing product ID, medicine name, stock quantity, manufacturing date, expiry date, and sales history are used. Data is collected from public or simulated sources. The model learns relationships between time-based variables and sales trends, enabling effective demand forecasting. Preprocessing includes handling missing values, formatting numerical features, and preparing timeindexed data for analysis. This ensures data consistency and improves model performance.

B. Model Selection and Training

A Linear Regression model is used to predict medicine demand based on historical sales data. The dataset is divided into training and testing subsets to evaluate accuracy. The model learns relationships between time-based variables and sales trends, enabling effective demand forecasting.

C. Prediction and Visualization

The trained model predicts future medicine demand when a user selects a product. Results are displayed graphically using line plots, helping users analyze trends and make informed inventory decisions.

D. QR Code Authentication

Each product is assigned a unique QR code containing encoded identification details. Digital signatures are generated using hashing techniques to prevent duplication. Scanning the QR code verifies product authenticity by matching data with blockchain records.

E. Blockchain Integration

Blockchain is used to store product details such as ID, quantity, expiry date, and transaction history. Each transaction is recorded as a block, ensuring data immutability, transparency, and traceability across the supply chain.

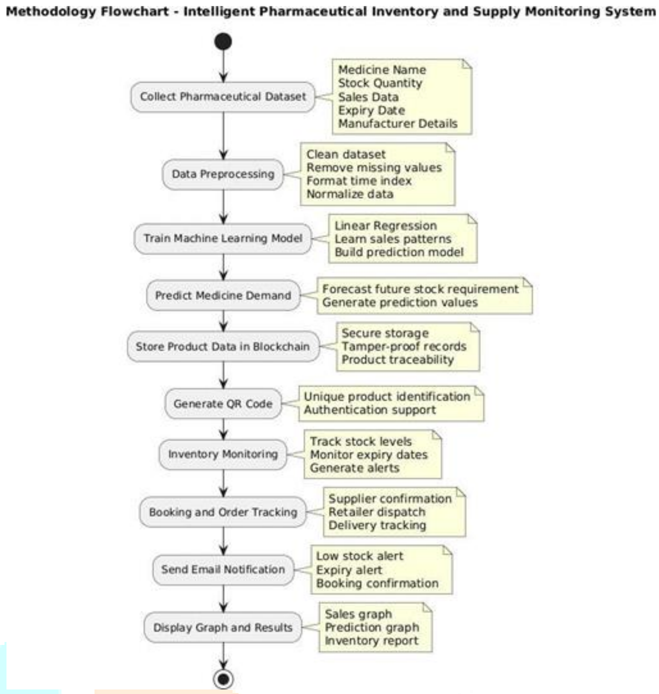

Fig. 1. Workflow for Pharmaceutical Inventory Monitoring

F. Database and User Management

SQLite database is used to store user credentials, product details, booking records, and transaction history. Secure authentication and session management ensure safe user access.

G. User Interface

The system is implemented using Flask, providing an in-teractive web interface for user registration, login, product management, demand prediction, and order tracking.

H. System Workflow

The system workflow begins with initialization of modules including machine learning model, blockchain, QR generator, and database. Users authenticate and enter product data, which is stored securely. The system performs demand prediction, monitors inventory, generates QR codes for authentication, and enables booking and tracking of medicines. Notifications and graphical visualizations provide real-time insights for effective decision-making.

IV. RESULTS AND ANALYSIS

A. Implementation Results

Figure 2 illustrates the user registration and role manage-ment module of the Intelligent Pharmaceutical Inventory and Supply Monitoring System. The interface allows new users to create accounts by entering personal details such as contact number, email address, location, and user role. Different user roles including administrator, supplier, consumer, and retailer can be managed within the system. This module enhances system security, enables controlled access to pharmaceutical data, and supports efficient coordination among supply chain participants. Figure 3 shows the customer booking confirma-tion module of the Intelligent Pharmaceutical Inventory and Supply Monitoring System. The interface allows suppliers or administrators to view pending medicine bookings along with booking ID, product ID, customer details, quantity, and booking date. The system provides a confirmation option for validating customer orders in real time. This module improves order management efficiency, enhances communication be-tween suppliers and customers, and ensures accurate pharma-ceutical product distribution within the supply chain. Figure 4 illustrates the demand forecasting module of the Intelligent Pharmaceutical Inventory and Supply Monitoring System. The graph displays historical sales data and predicted future demand for cough syrup using machine learning-based fore-casting techniques. The blue line represents past sales trends, while the dotted line indicates forecasted demand values. This predictive analysis helps administrators estimate future medicine requirements, maintain optimal inventory levels, and reduce overstocking or stock shortages. The module enhances inventory planning efficiency and supports data-driven phar-maceutical supply management. Figure 5 presents the stock level monitoring module of the Intelligent Pharmaceutical In-ventory and Supply Monitoring System. The graph visualizes medicine stock availability over different intervals, enabling administrators to monitor inventory fluctuations effectively. The module also includes an expiry alert section to notify users about medicines approaching expiration. This functionality helps maintain optimal stock levels, reduces medicine wastage, and improves inventory management efficiency. Figure 6 illustrates the product details and authentication module of the Intelligent Pharmaceutical Inventory and Supply Monitoring System. The interface displays detailed medicine information including product ID, product name, price, and medicine image for verification purposes. The authentication feature improves transparency and supports drug traceability by allowing users to validate pharmaceutical products. This module helps reduce counterfeit medicine risks and enhances supply chain security.

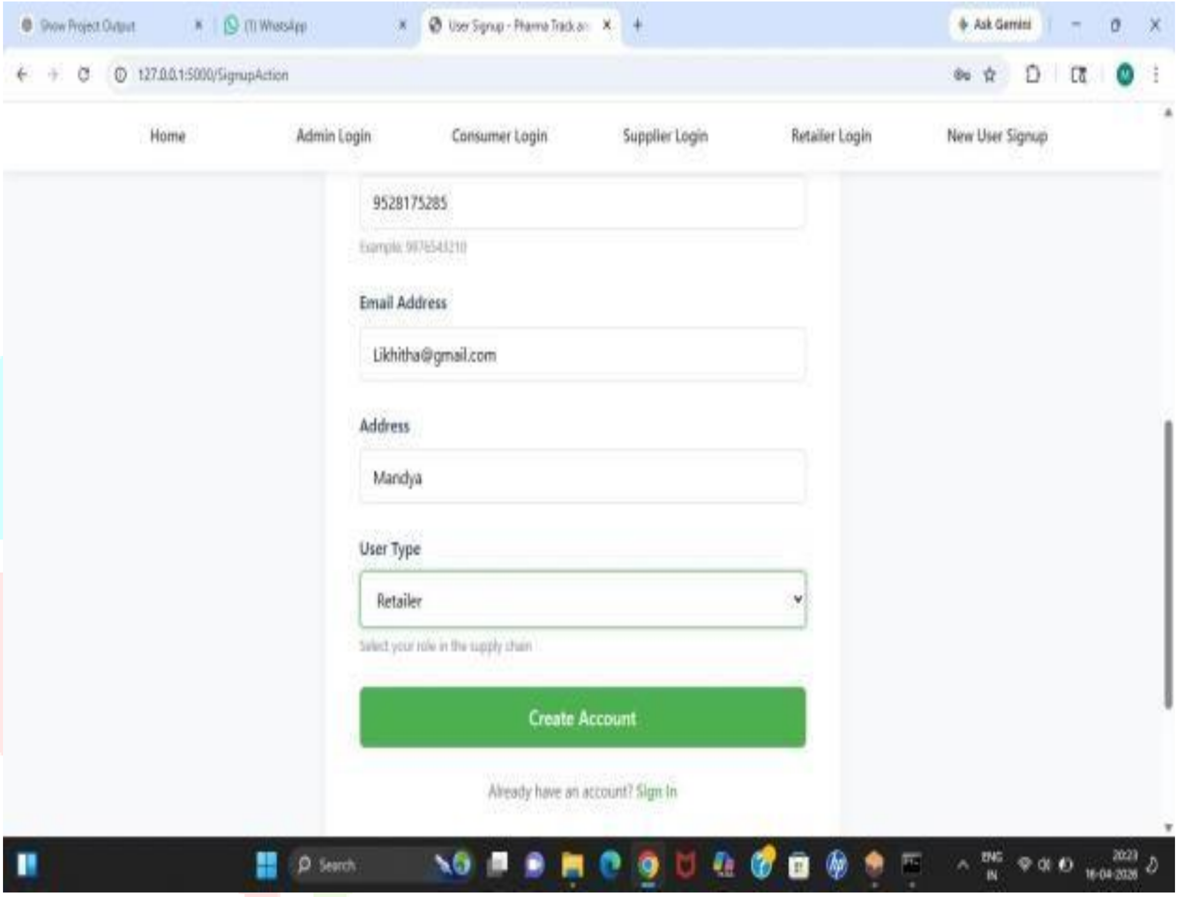

Fig. 2. User Registration and Role Management Module

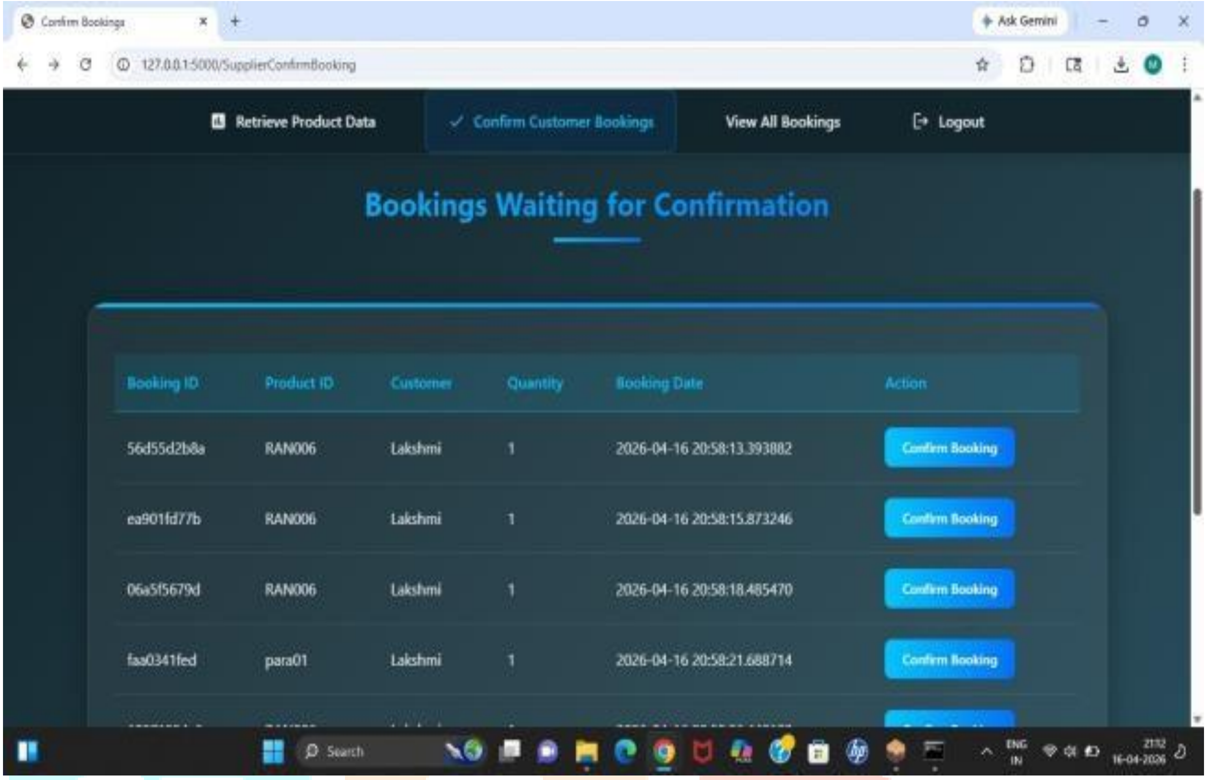

Fig. 3. Customer Booking Confirmation Module

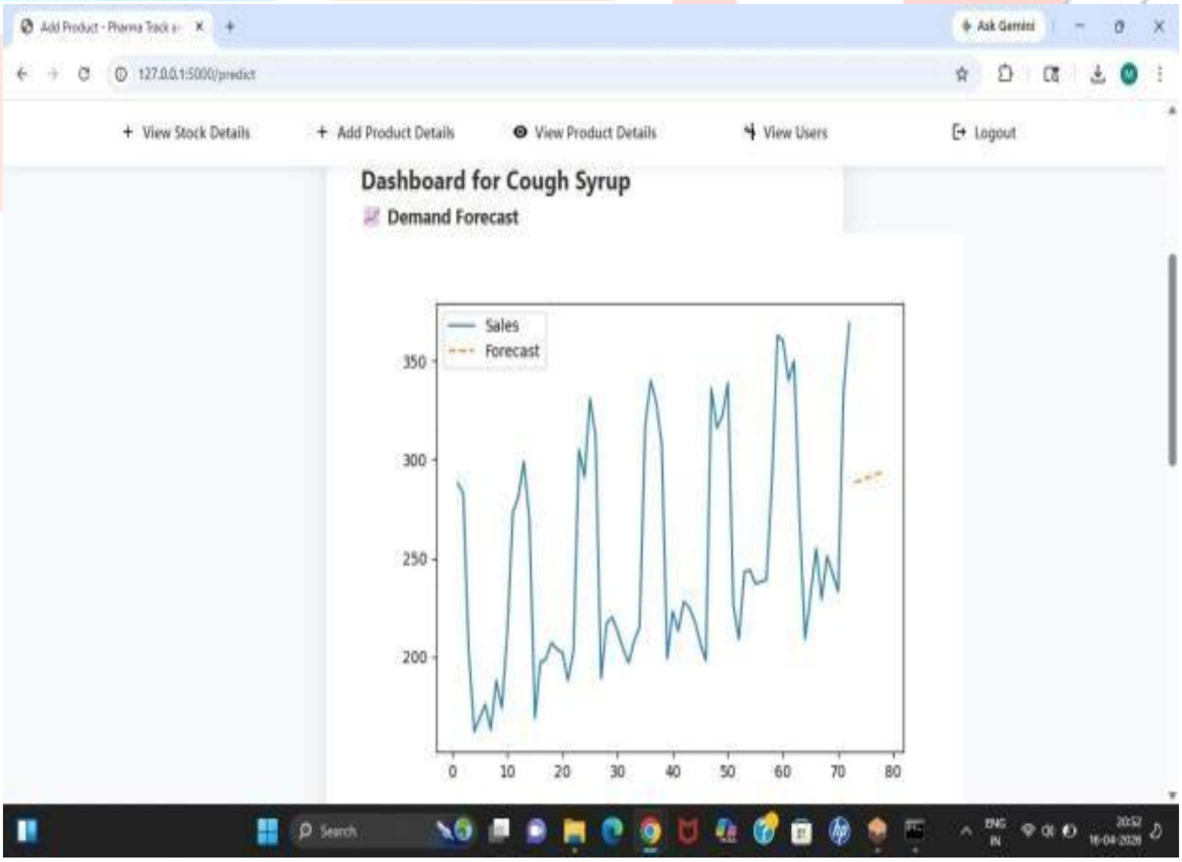

Fig. 4. Medicine Demand Forecast and Sales Prediction

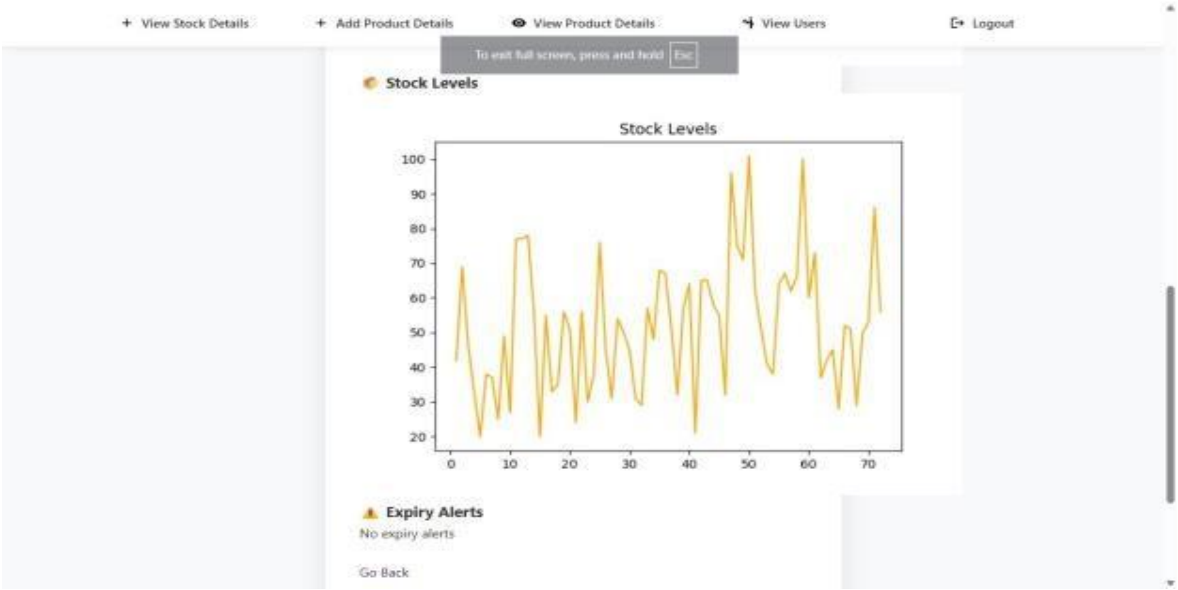

Fig. 5. Stock Level Monitoring and Expiry Alert System

Fig. 6. Pharmaceutical Product Details and Authentication Module

B. Analysis

The Intelligent Pharmaceutical Inventory and Supply Mon-itoring System has demonstrated reliable and secure perfor-mance through extensive testing and implementation. The authentication and role-based access mechanisms success-fully prevent unauthorized access while maintaining secure transaction records for administrators, suppliers, retailers, and consumers. The system ensures data privacy and operational security by controlling user permissions and encrypting sen-sitive pharmaceutical information during communication and storage.

The integrated inventory management and monitoring mod-ules have significantly improved medicine tracking and stock management processes. Real-time monitoring enables efficient tracking of medicine availability, supplier information, book-ing confirmations, and expiry status. The automated alert system effectively identifies medicines approaching expira-tion and helps reduce pharmaceutical wastage. The machine learning-based demand forecasting model accurately predicts future medicine requirements, enabling better inventory plan-ning and minimizing stock shortages.

The pharmaceutical product authentication and traceability features enhance transparency within the supply chain. Every product is associated with unique product details, enabling users to verify medicine authenticity and monitor distribution activities efficiently. The system supports improved supply chain visibility and helps reduce the risk of counterfeit medicines entering the market. The automated alert system effectively identifies medicines approaching expira-tion and helps reduce pharmaceutical wastage.

C. Discussion

1) Technical Impact: The technical implementation of the Intelligent Pharmaceutical Inventory and Supply Monitoring System has improved the efficiency of pharmaceutical inven-tory management through automation and predictive analyt-ics. The integration of machine learning techniques enables accurate demand forecasting and stock analysis, helping ad-ministrators make data-driven decisions. Automated inventory monitoring reduces manual intervention and minimizes human errors in stock handling, booking management, and medicine verification processes. The system also enhances operational reliability through secure authentication and centralized data management. The graphical dashboard and real-time monitoring modules provide better visibility into stock movement and pharmaceutical sup-ply activities. These features contribute to improved resource utilization, efficient product tracking, and better inventory control across the pharmaceutical supply chain.

2) Societal Impact: The proposed system provides signif-icant societal and healthcare benefits by improving medicine availability and reducing the distribution of expired or counter-feit medicines. The expiry alert mechanism enhances patient safety by preventing the use of outdated pharmaceutical prod-ucts. Accurate demand forecasting ensures better medicine availability in medical stores and healthcare facilities, espe-cially during periods of high demand. From an economic perspective, the system helps reduce op-erational costs through efficient inventory management and au-tomation. Optimized stock monitoring minimizes overstocking and understocking issues, reducing financial losses caused by medicine wastage. The improved traceability and monitoring mechanisms also contribute to a more transparent and reliable pharmaceutical supply chain system.

V. CONCLUSION

Lastly, the system will aim at enhancing pharmaceutical recognition and supply chain functions through integration of safe online monitoring and advanced analysis monitoring. The framework, to offer full monitoring capacity, utilizes data provided by various sources, such as the measurements of the stocks, blockchain transaction logs, inventory management systems, and geospatial tracking devices. It can be used with advanced preprocessing methods to improve the quality and reliability of its data and machine learning and deep learning models, such as a RF, with the blockchainbased smart contract to enhance the traceability of transactions and detect anomalies. The evaluation based on experiment reveals that the integrated architecture is competent, reaching 96.1accuracy in detection of counterfeit drugs with a significant reduced number of false positive. The ensemble modeling procedures and real time processing systems contribute to the robustness of prediction, scalability as well as monitoring effectiveness. The developed solution makes the pharmaceutical supply chain much more transparent, authenticated, and efficient with inventory management. Through enabling automated control, safe transaction authentication, and smart decision assistance, the framework assists in enhancing patient safety, compliance rules, and business sustainability in pharmaceutical distribution environments. The next-generation improvements can further focus on the automation of hyperparameter optimization meth-ods in order to enhance model accuracy and computing effi-ciency. The analysis of the highdimensional stock data and de-tection of complex manufacturing defects can be enhanced by adding sophisticated deep learning frameworks. The advanced feature selection methods can enhance the performance of the forecast and lower the complexity of the model. Moreover, the real-time monitoring systems that will have the ability to assess the streaming data of production can accelerate the process of defect detection, reduce material loss, and generate greater semiconductor manufacturing scalability, reliability, and operation productivity.

REFERENCES

[1] K. Patel, R. Sharma, M. Chen, and L. Rodriguez, “Blockchain-Enabled Pharmaceutical Supply Chain for Drug Traceability and Counterfeit Prevention,” IEEE Transactions on Engineering Management, vol. 69, no. 4, pp. 1345–1358, Aug. 2022, doi: 10.1109/TEM.2022.3145678.

[2] S. Thompson, A. Kumar, H. Yamamoto, and P. Silva, “Machine Learning for Pharmaceutical Inventory Optimization and Demand Forecasting,” Journal of Pharmaceutical Innovation, vol. 17, no. 3, pp. 567–582, Jun. 2022, doi: 10.1007/s12247-022-09638-w.

[3] J. Anderson, L. Wang, M. Garcia, and T. Nakamura, “AI-Powered Anomaly Detection in Pharmaceutical Supply Chains Using IoT Sensor Data,” Computers in Industry, vol. 144, Art. no. 103787, Jan. 2023, doi: 10.1016/j.compind.2022.103787.

[4] R. Williams, C. Li, A. Schmidt, and M. Johnson, “Integrated Blockchain and Machine Learning Framework for Pharmaceutical Anti-Counterfeiting,” Decision Support Systems, vol. 165, Art. no. 113892, Feb. 2023, doi: 10.1016/j.dss.2022.113892. [5] Bloomberg NEF, Battery Price Survey 2024, BNEF, 2024.

[5] M. Brown, K. Tanaka, S. Ali, and E. Mu¨ller, “Real-Time Pharmaceutical Supply Chain Monitoring Using Deep Learning and Edge Computing,” IEEE Internet of Things Journal, vol. 10, no. 8, pp. 6789–6802, Apr. 2023, doi: 10.1109/JIOT.2023.3245678.

[6] D. Wilson, P. Kumar, L. Chen, and A. Rossi, “Predictive Analytics for Pharmaceutical Supply Chain Risk Management,” International Journal of Production Economics, vol. 258, Art. no. 108795, Feb. 2024, doi: 10.1016/j.ijpe.2023.108795.

[7] L. Zhang, M. Johnson, A. Gupta, and S. Kim, “Federated Learning for Privacy-Preserving Pharmaceutical Supply Chain Analytics,” Nature Machine Intelligence, vol. 6, no. 2, pp. 145–158, Mar. 2024, doi: 10.1038/s42256-024-00789-6.

[8] T. Roberts, H. Singh, M. Popov, and J. Hernandez, “Explainable AI for Pharmaceutical Supply Chain Decision Support,” Expert Sys-tems with Applications, vol. 238, Art. no. 121456, Mar. 2024, doi: 10.1016/j.eswa.2023.121456.

[9] A. Kowalski, R. Mishra, L. Bernstein, and Y. Takahashi, “Quantum-Resistant Blockchain for Future-Proof Pharmaceutical Supply Chains,” IEEE Security & Privacy, vol. 23, no. 1, pp. 45–58, Jan. 2025, doi: 10.1109/MSEC.2024.3456789.

[10] E. Schmidt, K. Watanabe, M. Ibrahim, and P. Costa, “Sustainable Phar-maceutical Supply Chains Using AI-Driven Circular Economy Models,” Journal of Cleaner Production, vol. 434, Art. no. 140123, Jan. 2025, doi: 10.1016/j.jclepro.2024.140123