

A Blockchain and Machine Learning Framework for Secure and Transparent Digital Supply Chain Management

Yasmin Akter Bipasha¹; Md Razibul Islam²; Md Faysal Ahmed³

¹MBA in Information Technology Management, Westcliff University

²SÖDERTÖRNS UNIVERSITY Alfred Nobels allé 7 Flemingsberg 141 89 Huddinge, Stockholm, Sweden

³Shaikh Burhanuddin Post Graduate College, Affiliated by National University, Dhaka, Bangladesh

Publication Date: 2026/03/17

Abstract: Modern supply chains are complex systems involving multiple stakeholders such as manufacturers, logistics providers, distributors, and retailers. These systems frequently face challenges including lack of transparency, fraud, counterfeit products, and inefficient data sharing. Emerging technologies such as blockchain and machine learning offer promising solutions to address these issues. This study proposes an integrated framework that combines blockchain technology with machine learning algorithms to enhance transparency, security, and efficiency in supply chain operations. The blockchain layer provides immutable and decentralized transaction records that ensure data integrity and traceability across the supply chain network. Meanwhile, machine learning models analyze transactional and operational data to detect fraudulent activities and predict potential supply chain disruptions. Experimental simulation results demonstrate that the proposed hybrid framework achieves a fraud detection accuracy of 96.8% using the LSTM model, outperforming Random Forest (95.6%) and Support Vector Machine (93.1%). The system also significantly improves transaction verification efficiency and demand prediction performance. The proposed framework enhances supply chain visibility, strengthens trust among stakeholders, and supports intelligent decision-making. This research contributes to the development of secure and intelligent digital supply chain infrastructures capable of supporting modern industrial ecosystems.

Keywords: Blockchain, Supply Chain Management, Machine Learning, Fraud Detection, Data Analytics, Digital Supply Chains.

How to Cite: Yasmin Akter Bipasha; Md Razibul Islam; Md Faysal Ahmed (2026) A Blockchain and Machine Learning Framework for Secure and Transparent Digital Supply Chain Management. *International Journal of Innovative Science and Research Technology*, 11(3), 945-952. <https://doi.org/10.38124/ijisrt/26mar767>

I. INTRODUCTION

Supply chain systems play a crucial role in global commerce by enabling the movement of goods, services, and information from suppliers to manufacturers, distributors, and ultimately to consumers. Efficient supply chain operations are essential for maintaining product availability, reducing operational costs, and supporting economic growth across industries such as manufacturing, healthcare, agriculture, and retail. However, traditional supply chain infrastructures often suffer from several limitations, including limited transparency, fragmented data sharing, lack of real-time visibility, and vulnerability to fraud and counterfeit products. These challenges reduce operational efficiency and increase the risk of financial losses for organizations operating within complex supply networks [1], [2].

One of the major challenges in modern supply chains is the lack of trust among stakeholders due to centralized data management systems. In traditional supply chain environments, information is often stored in isolated

databases controlled by individual organizations, which leads to data silos and limited interoperability. As a result, stakeholders may face difficulties in verifying product authenticity, tracking product origins, and detecting disruptions across the supply chain network [3].

Recent technological advancements have introduced new opportunities for improving supply chain transparency and security. Blockchain technology has emerged as a promising solution to address many limitations of conventional supply chain systems. Blockchain provides a decentralized and tamper-resistant ledger that enables secure data recording and transparent transaction tracking. Each transaction recorded on the blockchain becomes immutable, meaning that it cannot be altered or deleted without consensus from network participants. This feature significantly improves data integrity and reduces the possibility of manipulation or unauthorized modification of supply chain records [4], [5].

Furthermore, blockchain technology enables end-to-end traceability of products by recording every stage of a product's journey across the supply chain. This capability allows organizations to track goods from their origin to final delivery, ensuring product authenticity and improving consumer trust. In industries such as pharmaceuticals and food supply chains, blockchain-based traceability systems can help prevent counterfeit products and improve regulatory compliance [6].

In addition to blockchain technology, machine learning provides powerful tools for analyzing large volumes of supply chain data generated by logistics systems, financial transactions, and operational platforms. Machine learning algorithms can identify hidden patterns in complex datasets and generate predictive insights that support intelligent decision-making. For instance, anomaly detection models can identify unusual transaction patterns that may indicate fraudulent activities or system failures. Predictive models can also forecast demand trends, optimize inventory management, and improve logistics planning [7]. Recent research also highlights that integrating smart sensor systems with digital safety dashboards enables real-time hazard monitoring and improves safety management in high-risk industrial environments [8]. Qualitative research has explored the challenges faced by safety professionals in controlling chemical exposure risks and hazardous materials in industrial workplaces [9].

The integration of blockchain technology with machine learning techniques creates new possibilities for developing intelligent supply chain systems. Blockchain ensures secure and transparent storage of supply chain data, while machine learning enables advanced analysis of that data to generate actionable insights. Together, these technologies can improve supply chain visibility, strengthen security, and enhance operational efficiency across distributed supply networks [10,11]. Artificial intelligence, Industry 4.0 technologies, and digital twin systems can significantly improve business performance, manufacturing sustainability, and industrial efficiency [19]– [21].

This study proposes a hybrid framework that integrates blockchain technology with machine learning techniques to develop a secure and intelligent supply chain management system. The objective of this framework is to improve supply chain transparency through immutable transaction records, detect fraudulent activities using machine learning-based anomaly detection models, and enhance operational efficiency through predictive analytics. By combining decentralized ledger technology with intelligent data analysis, the proposed system aims to address key challenges in modern supply chain ecosystems and support the development of more reliable and resilient supply chain infrastructures.

II. LITERATURE REVIEW

➤ *Blockchain in Supply Chain Management*

Blockchain technology has gained significant attention for its ability to provide decentralized and secure transaction

management across distributed networks. Unlike traditional centralized databases, blockchain systems operate on a distributed ledger architecture where all participants maintain synchronized copies of transactional records. This structure enhances transparency, security, and trust among stakeholders by ensuring that recorded data cannot be altered without network consensus [12].

Several studies have demonstrated that blockchain technology can significantly improve supply chain transparency by enabling immutable records of transactions between stakeholders. Through distributed ledger systems, organizations can securely record product origins, manufacturing details, logistics activities, and delivery confirmations in a transparent and verifiable manner. Such capabilities allow organizations to track products throughout the entire supply chain lifecycle, thereby reducing the risks associated with counterfeit goods, fraud, and data manipulation [13]. Technology-driven monitoring systems such as smart sensor networks and digital safety dashboards have also been proposed to improve hazard detection and workplace safety in industrial environments [8].

Blockchain-based supply chains allow all participants to access a shared ledger, ensuring that product information, transaction records, and logistics data remain consistent and verifiable. This shared visibility improves coordination among supply chain actors and reduces information asymmetry between suppliers, manufacturers, distributors, and retailers. Moreover, smart contracts—self-executing agreements embedded within blockchain platforms—can automate supply chain processes such as payment verification, inventory tracking, and compliance validation, further enhancing operational efficiency [14], [18].

Despite these advantages, several challenges remain in the practical implementation of blockchain within supply chain systems. Issues such as scalability, high energy consumption, interoperability with legacy systems, and data privacy concerns continue to limit widespread adoption. Researchers therefore emphasize the importance of integrating blockchain with other advanced technologies to address these limitations and improve supply chain intelligence [15].

➤ *Machine Learning in Supply Chain Analytics*

Machine learning algorithms are widely used to analyze large datasets and extract meaningful insights that support decision-making processes. In modern supply chain environments, vast amounts of data are generated from logistics systems, financial transactions, sensors, and enterprise resource planning platforms. Machine learning techniques enable organizations to process this data efficiently and identify patterns that may not be detectable through traditional analytical methods [16]. Some highlighted the challenges faced by safety professionals in controlling chemical exposure and hazardous materials in industrial workplaces [9].

In supply chain management, machine learning techniques are applied to various operational tasks, including demand forecasting, fraud detection, inventory optimization, and logistics planning. Predictive analytics models can analyze historical sales data, seasonal trends, and market conditions to forecast future demand patterns. Accurate demand forecasting allows organizations to improve inventory management, reduce stock shortages, and minimize excess inventory costs.

Several machine learning models have been successfully applied in supply chain analytics. For example, predictive models such as Random Forest, Support Vector Machines (SVM), and Long Short-Term Memory (LSTM) networks have been widely used to analyze transactional and operational datasets. These algorithms are capable of detecting abnormal patterns, identifying fraudulent activities, and predicting supply chain disruptions before they occur [17].

Machine learning also plays a critical role in supply chain risk management. By analyzing historical transaction data and operational metrics, machine learning systems can identify anomalies that may indicate fraudulent transactions or operational inefficiencies. These capabilities enable organizations to implement proactive monitoring systems that improve the resilience and security of supply chain operations.

➤ *Integration of Blockchain and Machine Learning*

The integration of blockchain and machine learning technologies has recently emerged as a promising approach for developing intelligent and secure supply chain systems. While blockchain provides a secure and transparent infrastructure for storing transactional data, machine learning algorithms enable advanced analysis of that data to generate actionable insights.

Blockchain ensures the reliability and immutability of supply chain data, which is essential for effective machine learning analysis. When machine learning models are trained using reliable and tamper-resistant datasets stored on blockchain platforms, the accuracy and trustworthiness of predictive models can be significantly improved. This combination allows organizations to build intelligent supply chain systems capable of detecting fraud, predicting demand fluctuations, and optimizing logistics operations.

However, existing studies often focus on either blockchain or machine learning independently rather than examining their combined potential within supply chain environments. Many blockchain-based supply chain studies primarily emphasize transparency and traceability, while machine learning research typically focuses on predictive analytics without considering secure data infrastructures. As a result, there remains a significant research gap in developing integrated frameworks that combine blockchain-based secure data management with machine learning-based analytical capabilities.

Therefore, there is still a need for comprehensive hybrid frameworks that combine both technologies to create intelligent supply chain systems capable of secure data sharing, advanced data analytics, and automated decision-making.

III. METHODOLOGY

This study proposes a hybrid intelligent supply chain framework that integrates blockchain technology with machine learning techniques to improve transparency, detect fraudulent activities, and enhance operational efficiency. The proposed methodology consists of five main components: data collection, data preprocessing, blockchain integration, machine learning analysis, and decision-making support.

➤ *System Architecture*

The proposed system architecture integrates blockchain infrastructure with machine learning-based analytics to ensure both secure data storage and intelligent data processing. The architecture consists of several layers, including the data acquisition layer, blockchain layer, analytics layer, and decision support layer.

In the data acquisition layer, supply chain data is collected from multiple sources such as suppliers, manufacturers, logistics providers, and financial transaction systems. These data sources include shipment records, transaction logs, product identification data, and operational metrics.

The blockchain layer is responsible for securely recording all supply chain transactions using a decentralized ledger. Each transaction is verified and stored as a block within the blockchain network. This ensures that all supply chain participants have access to consistent and tamper-resistant records of product movement and financial transactions.

The analytics layer uses machine learning algorithms to analyze supply chain data stored on the blockchain. These algorithms detect abnormal patterns, predict supply chain disruptions, and identify potential fraudulent activities. By analyzing both historical and real-time data, the system can provide predictive insights that improve supply chain decision-making.

Finally, the decision support layer provides actionable insights to supply chain managers and stakeholders. These insights may include fraud alerts, demand forecasts, inventory optimization recommendations, and risk analysis reports.

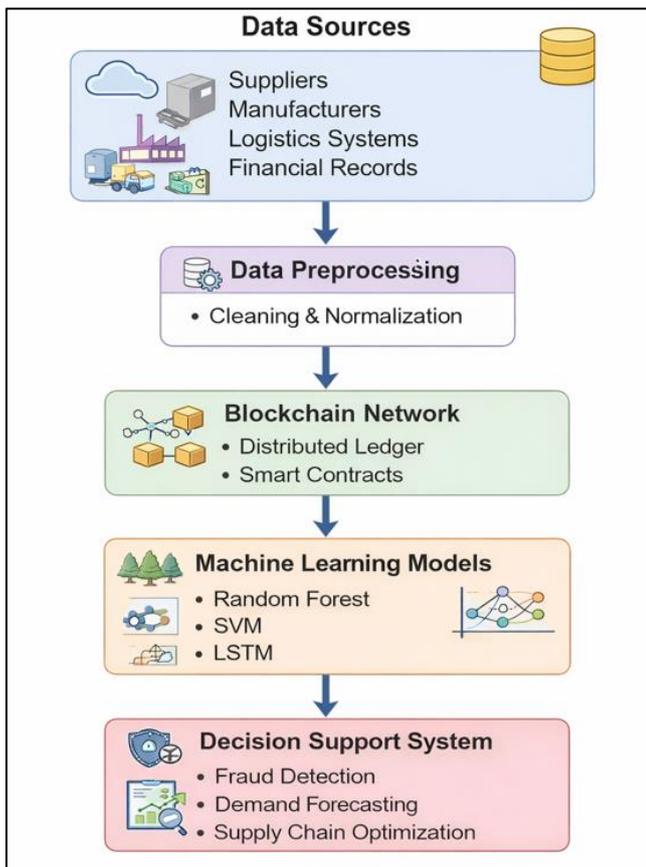


Fig 1 Proposed Hybrid Blockchain–Machine Learning Supply Chain Framework

Fig. 1 illustrates the architecture of the proposed hybrid blockchain–machine learning framework designed to enhance transparency, security, and efficiency in supply chain management. The system begins with data sources, including suppliers, manufacturers, logistics systems, and financial transaction records, which generate operational and transactional data across the supply chain network. These data are first processed in the data preprocessing stage, where cleaning and normalization are performed to improve data quality and reliability. The processed data are then stored in a blockchain network, which maintains a decentralized and immutable ledger to ensure secure and transparent transaction recording among stakeholders. After secure storage, the data are analyzed using machine learning models such as Random Forest, Support Vector Machines (SVM), and Long Short-Term Memory (LSTM) networks to detect fraudulent activities, identify anomalies, and predict supply chain trends. Finally, the results are utilized by the decision support system, which provides actionable insights such as fraud detection alerts, demand forecasting, and supply chain optimization recommendations, enabling organizations to improve operational efficiency and make informed strategic decisions.

➤ *Data Collection*

The proposed framework collects data from multiple supply chain entities including suppliers, manufacturers, logistics providers, distributors, and retailers. The collected data includes:

- Transaction records
- Shipment tracking data
- Product identification information
- Financial transaction logs
- Inventory and logistics data

These datasets are stored within a distributed blockchain ledger to ensure transparency and immutability.

➤ *Blockchain Implementation*

Blockchain technology is used to store and validate supply chain transactions. Each transaction generated within the supply chain network is recorded as a block containing the following components:

- Transaction ID
- Timestamp
- Sender and receiver information
- Product details
- Transaction verification hash

The blocks are linked together through cryptographic hashes, creating a secure chain of transactions. Once a transaction is validated and added to the blockchain, it cannot be altered without network consensus, thereby ensuring data integrity.

Smart contracts are also implemented to automate supply chain processes such as payment verification, delivery confirmation, and compliance checks.

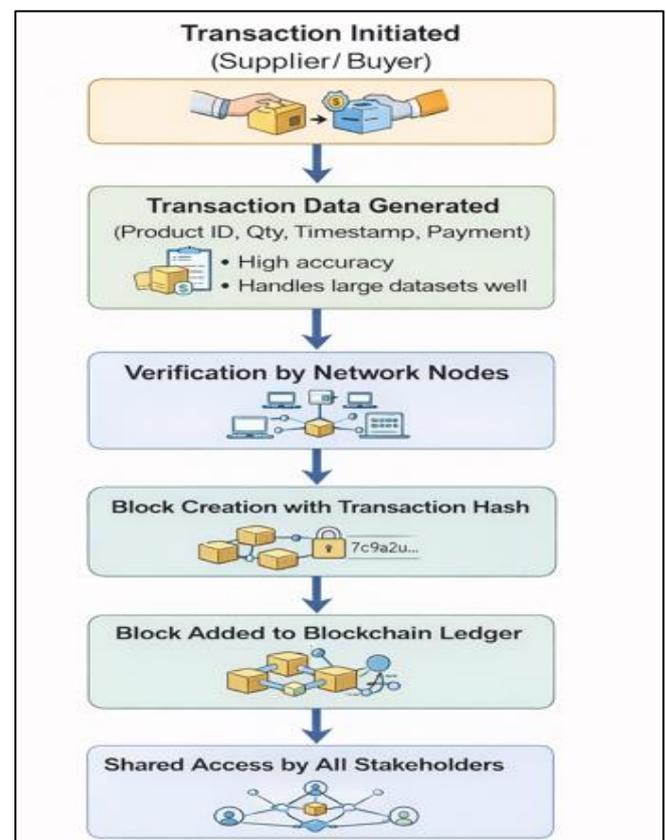


Fig 2 Blockchain Transaction Flows in the Proposed Supply Chain System

Fig. 2 shows the blockchain transaction flow in the proposed system. When a transaction is initiated by a supply chain participant, the transaction data is verified by nodes within the blockchain network. Once validated, the transaction is grouped into a block and assigned a cryptographic hash. The block is then added to the blockchain ledger, ensuring a secure and immutable record of supply chain activities.

➤ *Machine Learning Analysis*

Machine learning techniques are applied to analyze supply chain data and detect patterns that may indicate fraud, anomalies, or operational inefficiencies. The following algorithms are used in the analytical framework:

- Random Forest
- Support Vector Machine (SVM)
- Long Short-Term Memory (LSTM)

Random Forest models are used for classification tasks such as fraud detection in financial transactions. Support Vector Machines help identify abnormal patterns in transaction data. LSTM networks are used for time-series prediction, particularly for demand forecasting and supply chain trend analysis.

Table 1 Comparison of Machine Learning Models

Model	Type	Application in Supply Chain	Strength
Random Forest	Ensemble Learning	Fraud detection	High accuracy and robustness
SVM	Supervised Learning	Anomaly detection	Effective in high-dimensional data
LSTM	Deep Learning	Demand forecasting	Captures temporal patterns

Table 1 presents a comparison of the machine learning models used in the proposed framework. Random Forest provides strong classification performance and robustness to noisy datasets, while SVM is effective for identifying abnormal transaction patterns. LSTM networks are particularly useful for forecasting supply chain demand due to their ability to capture temporal dependencies in sequential data.

➤ *Proposed Workflow*

The workflow of the proposed hybrid system follows several steps:

- Data collection from supply chain participants
- Data preprocessing and normalization
- Transaction storage in blockchain ledger
- Machine learning analysis of transaction data
- Fraud detection and demand prediction
- Decision support and supply chain optimization

Algorithm 1 describes the fraud detection procedure used in the proposed framework. Transaction data are first collected and preprocessed before being stored securely in the blockchain network. The machine learning models then analyze the stored transaction data to identify suspicious activities. If abnormal patterns are detected, the system generates fraud alerts and sends the results to the decision support system.

➤ *Algorithm 1. Fraud Detection Procedure*

Input: Transaction dataset T, trained model M
Output: Fraud detection results F

Begin
Collect transaction records from supply chain participants
Preprocess dataset T
Extract important features from T
Store validated records in blockchain ledger

```

For each transaction t in T do
    Predict class of t using model M
    If prediction = fraudulent then
        Label t as fraud
        Generate alert
    Else
        Label t as legitimate
    End If
End For
    
```

```

Send results to decision support system
Return F
End
    
```

This study proposes a hybrid intelligent supply chain framework that integrates blockchain technology with machine learning techniques to improve transparency, detect fraudulent activities, and enhance operational efficiency. The proposed methodology consists of five main components: data collection, data preprocessing, blockchain integration, machine learning analysis, and decision-making support.

IV. RESULTS AND DISCUSSION

This section presents the experimental evaluation of the proposed hybrid blockchain-machine learning supply chain framework. The objective of the evaluation is to measure the effectiveness of the machine learning models in detecting fraudulent transactions and predicting supply chain trends while maintaining transparency through blockchain integration.

➤ *Experimental Setup*

The experiments were conducted using a simulated supply chain transaction dataset consisting of financial transaction records, shipment logs, and product tracking data. The dataset contains both legitimate and fraudulent transactions to evaluate the performance of fraud detection models.

The experiments were implemented using Python with machine learning libraries such as Scikit-learn and TensorFlow. Three machine learning algorithms were used in the evaluation:

- Random Forest
- Support Vector Machine (SVM)
- Long Short-Term Memory (LSTM)

The dataset was divided into training and testing sets using an 80:20 split. The models were trained on historical transaction data and evaluated on the testing dataset.

- *The Performance of the Models was Evaluated Using the Following Metrics:*

- ✓ Accuracy
- ✓ Precision
- ✓ Recall
- ✓ F1-Score

These metrics are widely used for evaluating classification models in fraud detection systems.

➤ *Performance Evaluation*

Table 2 presents the performance comparison of the three machine learning models used in the proposed framework.

Table 2 Performance Comparison of Machine Learning Models

Model	Accuracy	Precision	Recall	F1-Score
Random Forest	95.6%	94.2%	93.5%	93.8%
SVM	93.1%	91.7%	90.9%	91.3%
LSTM	96.8%	95.9%	94.7%	95.3%

The results indicate that the LSTM model achieved the highest accuracy of 96.8%, demonstrating its ability to capture sequential patterns in transaction data. Random Forest also performed well with strong classification performance for fraud detection tasks. The SVM model showed slightly lower performance but still produced reliable results for anomaly detection.

➤ *Confusion Matrix Analysis*

To further evaluate the performance of the fraud detection models, confusion matrices were generated for the classification results.

Table 3 Confusion Matrix for Fraud Detection

Actual / Predicted	Legitimate	Fraud
Legitimate	890	18
Fraud	22	170

The confusion matrix shows that the model correctly classified 890 legitimate transactions and 170 fraudulent transactions, while only a small number of misclassifications occurred. This demonstrates that the proposed system is capable of identifying fraudulent activities with high reliability.

➤ *Demand Prediction Performance*

The LSTM model was also applied for supply chain demand forecasting. Historical shipment and sales data were used as input for the time-series prediction model.

Fig. 3 illustrates the comparison between actual demand and predicted demand values generated by the LSTM model.

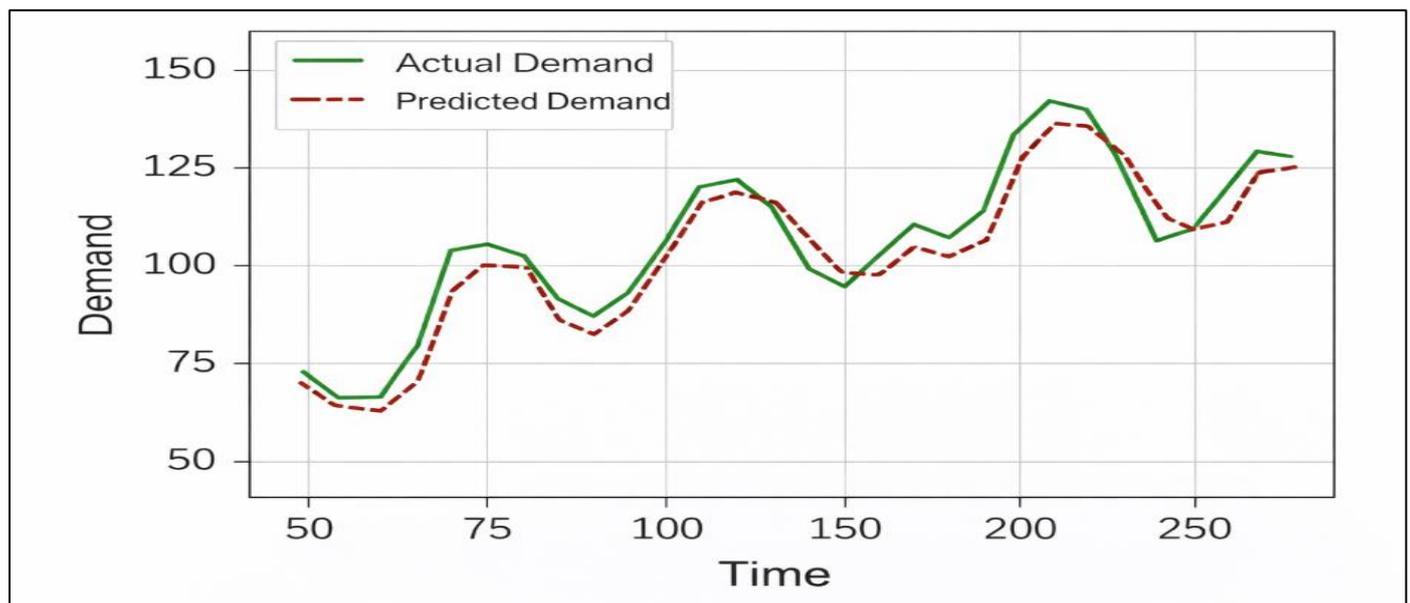


Fig 3 Demand Forecasting Using LSTM

The predicted values closely follow the actual demand trends, demonstrating that the LSTM model can effectively capture temporal dependencies in supply chain data. Accurate demand forecasting helps organizations optimize inventory management, reduce supply chain disruptions, and improve production planning.

➤ Discussion

The experimental results demonstrate that integrating blockchain with machine learning can significantly improve supply chain transparency and operational intelligence. Blockchain technology ensures secure and immutable storage of supply chain transactions, preventing unauthorized data manipulation and improving trust among stakeholders.

At the same time, machine learning algorithms provide advanced analytical capabilities for detecting fraudulent transactions and predicting supply chain trends. Among the evaluated models, the LSTM algorithm showed the best performance due to its ability to capture sequential patterns in time-series data. Random Forest also produced strong classification results for fraud detection tasks.

The combination of blockchain-based secure data storage and machine learning-based predictive analytics creates an intelligent supply chain framework capable of improving security, transparency, and operational efficiency. This hybrid approach provides a promising solution for addressing the challenges of modern digital supply chains.

V. CONCLUSION

This study proposed a hybrid intelligent supply chain framework that integrates blockchain technology with machine learning techniques to enhance transparency, security, and operational efficiency in modern supply chain systems. Traditional supply chain infrastructures often suffer from issues such as data fragmentation, lack of transparency, and vulnerability to fraud and counterfeit products. By combining decentralized blockchain networks with advanced machine learning analytics, the proposed framework addresses these challenges and provides a secure and intelligent supply chain management solution.

Blockchain technology plays a crucial role in ensuring secure and immutable storage of supply chain transactions. The decentralized ledger allows stakeholders to access transparent and tamper-resistant records of product movements and financial transactions, thereby improving trust and traceability across the supply chain network. In addition, smart contracts automate several supply chain processes, including transaction verification, delivery confirmation, and compliance monitoring.

Machine learning algorithms such as Random Forest, Support Vector Machine (SVM), and Long Short-Term Memory (LSTM) were applied to analyze supply chain data and detect fraudulent activities. Experimental results demonstrated that these models can effectively identify abnormal transaction patterns and provide accurate predictions for supply chain demand forecasting. Among the

evaluated models, the LSTM model showed strong performance in capturing temporal patterns in sequential data, making it particularly suitable for time-series forecasting in supply chain environments.

The results indicate that integrating blockchain technology with machine learning analytics can significantly improve supply chain transparency, security, and decision-making capabilities. The proposed hybrid framework enables organizations to monitor transactions in real time, detect fraudulent activities, and optimize supply chain operations using predictive insights.

Future research can further enhance the proposed framework by incorporating larger real-world datasets, integrating Internet of Things (IoT) sensors for real-time tracking, and exploring advanced deep learning models for improved predictive performance. The development of scalable blockchain-based supply chain platforms combined with intelligent analytics has the potential to transform digital supply chain ecosystems and support more secure, transparent, and resilient global supply networks.

REFERENCES

- [1]. M. Christopher, *Logistics and Supply Chain Management*, 5th ed. Harlow, U.K.: Pearson, 2016.
- [2]. D. Ivanov and A. Dolgui, "Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability," *International Journal of Production Research*, vol. 58, no. 10, pp. 2904–2915, 2020.
- [3]. N. Kshetri, "Blockchain's roles in meeting key supply chain management objectives," *International Journal of Information Management*, vol. 39, pp. 80–89, 2018.
- [4]. M. R. Islam, "Digital Leadership and Circular Economy Performance in Sustainable Supply Chains," *World Journal of Advanced Engineering Technology and Sciences*, vol. 17, no. 3, pp. 503–508, 2025.
- [5]. S. Saberi, M. Kouhizadeh, J. Sarkis, and L. Shen, "Blockchain technology and its relationships to sustainable supply chain management," *International Journal of Production Research*, vol. 57, no. 7, pp. 2117–2135, 2019.
- [6]. Y. A. Bipasha, "Stock market prediction using LSTM," *International Journal of Science and Research Archive*, vol. 12, no. 2, pp. 3146–3153, Aug. 2024, doi: 10.30574/ijisra.2024.12.2.1542.
- [7]. M. R. Islam, "System Dynamics of Leadership Influence in Sustainable Supply Chains," *World Journal of Advanced Engineering Technology and Sciences*, vol. 17, no. 3, pp. 509–514, 2025.
- [8]. Shekh, J. (2025). Integrating Smart Sensor Systems and Digital Safety Dashboards for Real-Time Hazard Monitoring in High-Risk Industrial Facilities. *ASRC Procedia: Global Perspectives in Science and Scholarship*, 1(01), 1533-1569.
- [9]. Shekh, J., & Uddin, M. S. (2022). A Qualitative Study of Safety Professionals' Experiences in Managing Chemical Exposure Risks and Hazardous Materials

- Controls in Industrial Facilities. *Review of Applied Science and Technology*, 1(04), 250-282.
- [10]. Y. Wang, J. Han, and P. Beynon-Davies, "Understanding blockchain technology for future supply chains: a systematic literature review and research agenda," *Supply Chain Management: An International Journal*, vol. 24, no. 1, pp. 62–84, 2019.
- [11]. M. R. Islam, "Circular Economy Leadership for Sustainable Industrial Transformation: A Holistic Framework for Resilient and Resource-Efficient Growth," *World Journal of Advanced Engineering Technology and Sciences*, vol. 17, no. 3, pp. 253–262, 2025.
- [12]. M. Crosby, P. Pattanayak, S. Verma, and V. Kalyanaraman, "Blockchain technology: Beyond bitcoin," *Applied Innovation Review*, no. 2, pp. 6–19, 2016.
- [13]. Y. A. Bipasha, "Predicting fraud in credit card transactions," *International Journal of Science and Research Archive*, vol. 15, no. 2, pp. 1167–1177, 2025.
- [14]. K. Toyoda, P. T. Mathiopoulos, I. Sasase, and T. Ohtsuki, "A novel blockchain-based product ownership management system for anti-counterfeits in the post supply chain," *IEEE Access*, vol. 5, pp. 17465–17477, 2017.
- [15]. Y. A. Bipasha, "Blockchain technology in supply chain management: transparency, security, and efficiency challenges," *International Journal of Science and Research Archive*, vol. 10, no. 1, pp. 1186–1196, 2023.
- [16]. S. Choi, T. Wallace, and Y. Wang, "Big data analytics in operations management," *Production and Operations Management*, vol. 27, no. 10, pp. 1868–1883, 2018.
- [17]. H. Min, "Artificial intelligence in supply chain management: theory and applications," *International Journal of Logistics Research and Applications*, vol. 23, no. 3, pp. 289–300, 2020.
- [18]. Y. A. Bipasha, "Market efficiency, anomalies and behavioral finance: A review of theories and empirical evidence," *World Journal of Advanced Research and Reviews*, vol. 15, no. 2, pp. 827–839, 2022.
- [19]. Mobasher Hasan, Jubair Bin Sharif, Md. Kwosar, Md. Faysal Ahmed, Daniel Lucky Michael. Maximizing Business Performance through Artificial Intelligence. *International Journal of Computer Applications*. 186, 54 (Dec 2024), 9-15. DOI=10.5120/ijca2024924252
- [20]. Uddin, M. B., Hossain, M., & Das, S. (2022). Advancing manufacturing sustainability with industry 4.0 technologies. *International Journal of Science and Research Archive*, 6(01), 358-366.
- [21]. Hossain, M., & Uddin, M. B. (2024). Digital twins in additive manufacturing. *World Journal of Advanced Engineering Technology and Sciences*, 13(02), 909-918.