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RESEARCH ARTICLE

WALMART FULFILLMENT MANAGEMENT SERVICES ON SUPPLY CHAIN PERFORMANCE OPTIMIZATION USING DEEP LEARNING BASED DECISION MAKING

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Abstract – This research manuscript presents a comprehensive methodology for optimizing supply chain performance at Walmart Fulfillment Management Services (FMS) through deep learning-based decision-making. The study begins with the acquisition of critical supply chain data, encompassing inventory levels, order histories, lead times, and external market trends, which are aggregated from diverse sources to form a robust dataset. Following data acquisition, pre-processing steps, including data normalization, are applied to ensure consistency and comparability across varying scales, thereby enhancing data quality for subsequent analyses. The Parrot Optimization Algorithm (POA) is then utilized to identify and extract optimal features that significantly influence supply chain performance, effectively reducing dimensionality and enhancing the efficiency of the predictive model. Demand forecasting is performed using the Simple Recurrent Unit (SRU) model, a deep learning technique adept at recognizing complex patterns and dependencies within time series data. This approach empowers Walmart FMS to make data-driven decisions that improve supply chain responsiveness and overall operational effectiveness, ultimately leading to increased customer satisfaction. The findings demonstrate the potential of deep learning methodologies in transforming supply chain management practices.

Keywords *– Walmart Fulfillment Management Services, Supply Chain Performance, Deep Learning, Parrot Optimization, Feature Selection, Normalization, Simple Recurrent Unit.*

1. INTRODUCTION

Walmart Fulfillment Management Services (FMS) refers to a set of logistics and supply chain solutions provided by Walmart to streamline order processing, inventory management, and delivery for businesses and customers. It encompasses a network of fulfillment centers, advanced technology, and transportation systems to handle product storage, packing, and shipping efficiently. FMS is designed to enhance Walmart's ability to meet customer demand by optimizing fulfillment operations. Through FMS, Walmart ensures that products are delivered quickly and cost-effectively, leveraging its vast infrastructure and logistics expertise. For businesses using Walmart's online marketplace, FMS provides a way to outsource warehousing and shipping, allowing sellers to focus on growing their operations while Walmart manages the fulfillment process. The service also includes real-time inventory tracking, fast order processing, and various transportation solutions to ensure smooth and timely deliveries.

Walmart FMS leverages advanced automation, predictive analytics, and efficient warehouse management systems to streamline the fulfillment process. Orders placed online or in-store are processed, packed, and shipped quickly, reducing delivery times. By using multiple fulfillment centers across different regions, Walmart minimizes the distance between products and customers, enabling faster last-mile delivery. This rapid processing improves customer satisfaction, making Walmart more competitive in the e-commerce space. Walmart's FMS incorporates real-time inventory tracking, which ensures that stock levels are accurately monitored across all locations. The use of sophisticated demand forecasting tools helps Walmart predict which products are needed where and when. Furthermore, Walmart uses technology like RFID (Radio Frequency Identification) to track products throughout the supply chain, enhancing visibility and allowing for better inventory control. Walmart FMS also impacts transportation management by utilizing data-driven strategies to optimize delivery routes and reduce shipping costs. Through collaborations with various logistics partners and an extensive fleet of trucks, Walmart has created a highly efficient transportation network. The company uses algorithms and AI to plan the best routes, reducing fuel consumption and delivery times. Walmart also invests in eco-friendly logistics solutions, such as electric delivery trucks, to further improve sustainability within its transportation operations.

Walmart’s Fulfillment Management Services focusing on efficiency in order fulfillment, improving inventory management, and optimizing transportation, Walmart has created a highly responsive and agile supply chain. This leads to better customer experiences, lower operational costs, and a stronger competitive position in the retail market. By integrating deep learning into its supply chain operations, Walmart has transformed its ability to fulfill orders rapidly, manage inventory with precision, and optimize transportation logistics. These advanced algorithms help Walmart respond faster to market changes, improve decision-making, and drive down costs while enhancing the customer experience with faster, more reliable deliveries. Deep learning acts as a crucial enabler for Walmart's pursuit of operational excellence and supply chain leadership in the retail industry.

Walmart leverages deep learning algorithms to enhance the speed and efficiency of its order fulfillment processes by optimizing demand forecasting, warehouse automation, and real-time order prioritization. First, demand forecasting plays a crucial role in anticipating future needs. This enables Walmart's fulfillment centers to stock products in advance, reducing delays in processing and shipping orders. Second, warehouse automation is another critical aspect. Walmart uses robots and automated systems to handle the picking, packing, and shipping of orders. Deep learning helps optimize the layout of the warehouses, allowing machines to find the fastest routes for retrieving products, further speeding up the fulfillment process. Finally, real-time order prioritization ensures that orders are processed in an optimal sequence. Deep learning models evaluate factors such as proximity to the warehouse, delivery deadlines, and shipping methods to prioritize orders. This guarantees timely processing and helps Walmart meet delivery commitments, minimizing any delays in the overall process.

Efficient inventory management is essential for Walmart to maintain stock levels. Deep learning significantly enhances Walmart's inventory management in several key ways. Firstly, dynamic stock replenishment is driven by deep learning models that continuously analyze past data and external factors such as market trends, competitor pricing, and economic shifts. This predictive approach ensures that products are restocked at the right time, maintaining adequate inventory levels to meet demand while avoiding excess stock. Secondly, real-time inventory tracking is achieved using technologies like RFID tags and IoT sensors, which monitor products throughout the supply chain. Deep learning processes data from these sources to provide accurate, real-time insights into inventory levels, enabling better decision-making for restocking and preventing stock discrepancies. Lastly, inventory placement optimization allows Walmart to strategically store products across its network of fulfillment centers. By analyzing customer purchasing patterns and geographic data, deep learning models determine the best locations to store inventory, placing it closer to regions with higher demand. This not only reduces shipping times but also minimizes costs associated with transporting products to customers.

Walmart's deep learning-powered transportation management system plays a key role in optimizing product delivery, leading to improved efficiency across its supply chain. Firstly, route optimization is achieved by deep learning algorithms that analyze traffic patterns, weather conditions, fuel costs, and delivery constraints to determine the most efficient routes for Walmart's trucks. This reduces delivery times, lowers fuel consumption, and cuts transportation costs, enhancing the overall efficiency of deliveries. Secondly, load optimization helps ensure that products are packed efficiently into trucks. Deep learning models maximize space and weight capacities, reducing the number of trips required for transportation. This not only lowers transportation costs but also minimizes carbon emissions by cutting down on unnecessary trips. Finally, real-time monitoring and predictive maintenance keep Walmart's fleet operational by tracking vehicle performance in real-time. Deep learning predicts potential maintenance issues before they occur, reducing vehicle downtime and ensuring reliable transportation. This leads to fewer delays in product delivery and boosts overall efficiency. The objectives of the research are:

- To acquire the data for optimizing the supply chain management.
- To pre-process the data using data normalization.
- To extract the optimal best features using parrot optimization algorithm.
- To forecast the demand using deep learning method named Simple recurrent unit (SRU) model.

The organization is: Section 2 details the existing methods of supply chain management with its problem statement and the detailed proposed methodology is presented in Section 3. The experimental result is presented in Section 4 and the conclusion in Section 5.

2. RELATED WORKS

Some of the existing supply chain management methods for the Walmart FMS decision making are reviewed in this section. Using machine learning, Yakymchuk and Liashenko's (2023) [6] research aims to create a resource planning system for food retail delivery services. The system seeks to increase overall efficiency, lower transportation costs, and optimise resource allocation. In order to efficiently estimate demand and plan delivery, the authors suggest a system that gathers and examines data from several sources. The process of validating the model encountered obstacles including creating standardised timetables, evaluating performance indicators, and changing work schedules. Notwithstanding these challenges, the model showed encouraging outcomes in resource allocation, shift scheduling, and demand forecasting. The research gives businesses looking to improve their delivery operations a useful answer and emphasises the significance of resource planning in the food retail industry.

Weber and Schütte (2019) [7] investigate the current state of Artificial Intelligence (AI) adoption in retail. They argue that retail's high human labor costs and low profit margins make it a prime candidate for AI applications. Their research analyzes both the potential applications across different retail functions and the current adoption rate among major retailers. They find numerous possibilities for AI use, particularly in areas requiring forecasting, like marketing and inventory management. However, market adoption varies greatly. Leading retailers like Amazon and Walmart are heavily invested in AI, while others show little interest. The authors suggest a link between early AI adoption and financial success might exist, which warrants further investigation.

Kumari and Kumar's (2024) [8] article explore supply chain optimization strategies to enhance efficiency and performance. They highlight the challenges faced by supply chains, including inventory management, market volatility, shipping costs, and collaboration. The article proposes various strategies such as inventory management, demand forecasting, transportation optimization, and buyer relationship management to address these issues. These tactics can boost a company's ability to compete, save expenses, raise customer happiness, and achieve long-term success. The writers' goal is to provide readers a thorough understanding of supply chain optimisation strategies and how they affect company performance. Businesses may gain a competitive edge in the market, save costs, increase customer happiness, and streamline their supply chain procedures by putting these tactics into practice. To traverse the intricate and quickly evolving business world, practitioners and researchers alike must remain current on the newest trends and technology in supply chain optimisation.

Taghiyeh et al. (2023) [9] suggest a brand-new machine learning-based multi-phase hierarchical forecasting method for supply chain management. They support the use of child-level predictions in hierarchical supply chains to enhance parent-level forecasts. The authors' method entails employing machine learning models to anticipate each series in the hierarchy separately, then merging these estimates at the parent level. Their strategy significantly improves forecast accuracy compared to conventional top-down and bottom-up methods. The approach's potential applications across several sectors are highlighted by the authors, who also stress how harnessing multivariate data might revolutionise supply chain forecasting.

In their 2024 study, Hassan et al. [10] investigate how supply chain management techniques may be integrated with artificial intelligence and predictive analytics to achieve sustainable corporate development. The Random Forest technique is used to construct predictive models that anticipate emissions with high accuracy and a tolerable R-square value. SCM Shows how AI-driven insights may be utilised to help decision-making by using data in -The model's ability to lower carbon footprints while boosting operational effectiveness and competitiveness in the market is demonstrated by case studies from the food processing and electronics manufacturing industries. The research tackles issues including inadequate data quality and intricate modelling and offers suggestions for businesses to use comparable tactics. The study establishes a framework for businesses to apply AI and predictive analytics for environmental and financial goals, adding to the expanding body of knowledge on sustainable supply chain management. Prospective avenues for investigation encompass merging real-time data, investigating blockchain technology, employing deep learning methodologies, forecasting various sustainability metrics, and evaluating the enduring financial consequences for enterprises that use analogous approaches.

2.1. Problem Statement

Walmart Fulfillment Management Services (FMS) aims to optimize supply chain performance across various processes, including order fulfillment speed, inventory management, and transportation management. However, the current system faces challenges in handling the complexity and scale of Walmart’s global operations. These challenges include inaccurate demand forecasting, inefficient warehouse operations, stockouts, overstocking, increased transportation costs, and delays in product delivery. Given the scale and data volume of Walmart’s supply chain, traditional methods of decision-making are proving inadequate to achieve optimal performance. The need arises for a more efficient, data-driven approach to improve decision-making, reduce costs, and increase overall efficiency. To address these issues, Walmart seeks to leverage deep learning models that can analyze vast datasets in real-time, predict future demand, optimize resource allocation, and improve the responsiveness of the entire supply chain. The objective is to develop a deep learning-based decision-making framework for Walmart’s FMS that optimizes supply chain performance by improving order fulfillment speed, inventory management, and transportation efficiency. This solution must enable real-time data processing and decision-making to ensure accurate demand prediction, efficient stock management, and cost-effective transportation routes.

3. PROPOSED METHODOLOGY

Management Services (FMS) using deep learning-based decision-making begins with data acquisition, where relevant supply chain data including inventory levels, order histories, lead times, and external factors such as market trends is gathered from various sources to create a comprehensive dataset. Following data acquisition, the next step involves pre-processing, which includes data normalization to ensure consistency and comparability across different scales and units, enhancing the quality of the data for subsequent analysis. Once the data is pre-processed, the Parrot Optimization Algorithm is employed to extract optimal features that contribute significantly to supply chain performance, thus reducing dimensionality and improving the model's efficiency. Finally, demand forecasting is conducted using the Simple Recurrent Unit (SRU) model, a deep learning technique well-suited for time series predictions. This model captures complex patterns and dependencies in the data, allowing Walmart FMS to make informed decisions that enhance supply chain responsiveness and effectiveness, ultimately leading to improved operational performance and customer satisfaction. The workflow is presented in Figure 1.

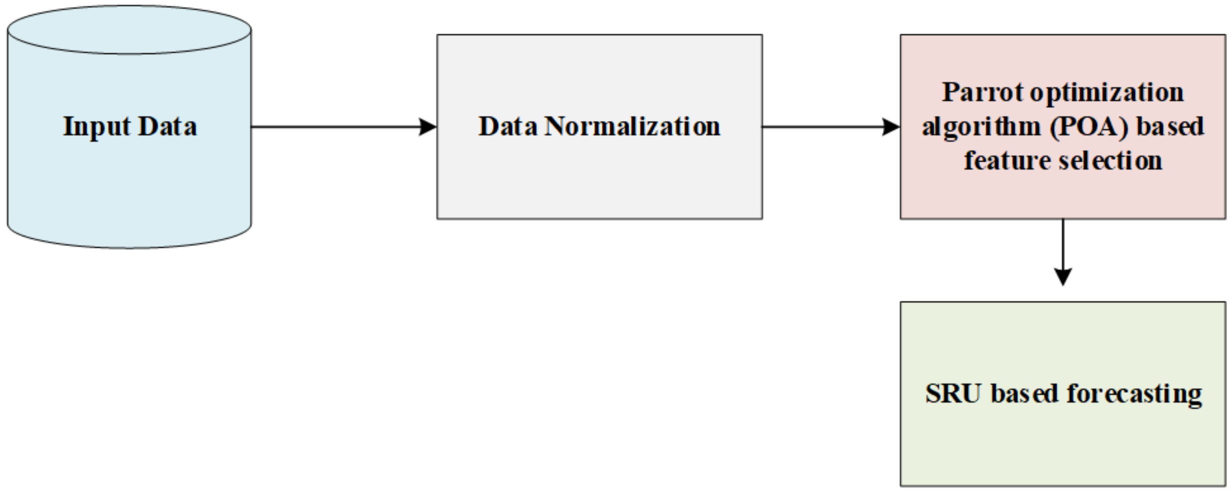

Figure.1. Deep Learning based Supply chain Management

3.1. Data Gathering

The data like historical sales data, customer demand patterns, warehouse operations, and real-time supply chain activities are utilized for efficient supply chain management.

3.2. Data Pre-Processing

By adjusting the size of the data to make sure that various characteristics have a comparable range, data pre-processing employing normalisation can enhance the accuracy and performance of machine learning models. When the dataset's characteristics have different sizes or units, which might adversely affect algorithms, normalisation becomes very helpful. Usually, normalisation entails converting the values of numerical columns to fall inside a predetermined range, which is frequently between 0 and 1 or -1 and 1. To calculate the range (the difference between the maximum and minimum values), remove the feature's minimum value and divide the result. For min-max normalisation, the formula is:

$$D_{norm} = \frac{D-D_{min}}{Dmin_{max}} \qquad (1)$$

where,

D is the original value of the feature.

Dmin is the minimum value of the feature in the dataset.

Dmax is the maximum value of the feature in the dataset.

D$norm$ is the normalized value of the feature.

3.3. Feature Selection

The Parrot Optimization Algorithm (POA) is a nature-inspired metaheuristic optimization algorithm, relatively new in the field of feature selection. It mimics the foraging behavior and social interaction of parrots, focusing on the balance between exploration (searching for new solutions) and exploitation (refining the best-found solutions). The algorithm is designed to select the most relevant features from a dataset while discarding redundant or irrelevant ones, which can improve the performance of machine learning models by reducing the dimensionality of the data.

Initialization: The algorithm begins by randomly generating a population of "parrots" (candidate solutions), where each parrot represents a potential subset of features from the dataset. The formula for initializing the position of the parrot is defined as:

$$P_r^0 = D + u(0,1) \cdot (X - D) \qquad (2)$$

where, $u(0,1)$signifies the random number generated between 0 and 1, ensuring randomness in the initialization and $P_r^0$is the initial position of the r^{th}parrot.

Fitness Evaluation: The fitness of each parrot (or feature subset) is evaluated using an objective function, often based on the accuracy of a classifier trained on that feature subset. The goal is to find the subset that maximizes the performance of the model while minimizing the number of features selected.

Exploration and Communication: In nature, parrots communicate with each other to share information about food sources. Similarly, in POA, parrots communicate or exchange information about good solutions. This allows the algorithm to explore different areas of the search space.

Learning and Adaptation: Parrots "learn" from their own experience (individual exploration) and the experiences of other parrots (social interaction). This helps them refine their solutions over time by selecting better feature subsets and discarding poorer ones. It is formulated as:

$$Ad_w = P_r^{Y+1} + F\left((P_r^Y)_{good} - (P_r^Y)\right) \qquad (3)$$

where, the adaptive weighting strategy is signified asAw, the solution arrived in the current iteration is denoted as $P_r^{Y+1}$and the solution obtained by the parrot search agent in the past iteration is denoted asP_r^Y. $(P_r^Y)_{good}$ indicates the best solution in past iteration and the controlling parameter is symbolized as$F$.

Exploitation (Local Search): As the algorithm progresses, the parrots focus on exploiting the best-found solutions by refining the search around promising feature subsets. This ensures that the algorithm converges to an optimal or near-optimal solution.

Termination: The algorithm stops either when a predetermined number of iterations are completed or when the fitness of the solutions no longer improves significantly. The final output is the optimal subset of features.

By selecting the most relevant features, the POA can help models generalize better, reducing the risk of over-fitting to the training data.

3.4. Deep Learning based Decision Making

The supply chain management through the optimal decision making is devised through the simple recurrent unit (SRU) model. The SRU is a variant of the recurrent neural network (RNN) architecture, designed to handle sequential data more efficiently. Unlike traditional RNNs, which can struggle with long-range dependencies and are computationally expensive, SRUs are faster and more scalable, making them suitable for real-time decision-making in complex systems like supply chain management. Using SRUs for decision-making in optimal supply chain management involves leveraging their ability to process temporal data and make predictions based on historical patterns. In the context of order fulfillment speed, inventory management, and transportation management, SRUs can be employed to improve decision-making across these three key areas by analyzing historical trends, identifying patterns, and predicting future behavior.

SRUs can analyze past order data, customer demand patterns, and seasonal variations to predict when certain products will experience spikes in demand. By using this temporal data, SRUs can help Walmart optimize its fulfillment processes. The SRU model could predict Peak order times for Anticipating high-demand periods, enabling fulfillment centers to prepare and allocate resources in advance.

Inventory management involves maintaining optimal stock levels and predicting when replenishment is necessary. SRUs can process sequential inventory data and external factors (like market trends, weather, and competitor pricing) to optimize stock management. The SRU model could assist with Stock level forecasting by analyzing historical sales and demand fluctuations, the SRU can predict when stock will run low, triggering timely replenishment to avoid stockouts or overstocking. Also, demand prediction using SRUs can identify patterns in customer purchasing behavior and external factors, enabling Walmart to adjust inventory levels dynamically, ensuring that high-demand products are readily available.

Transportation management involves optimizing delivery routes, reducing fuel costs, and ensuring timely deliveries. SRUs can process sequential data, such as delivery times, fuel costs, and traffic conditions, to optimize transportation logistics. The SRU model could support Route optimization by analyzing historical traffic patterns, weather conditions, and fuel consumption data, SRUs can predict the most efficient delivery routes for Walmart’s fleet of trucks. This reduces travel time, fuel costs, and shipping delays. SRUs can predict how best to load trucks based on the volume and weight of products, ensuring that each truck is utilized efficiently, reducing the number of trips and lowering overall transportation costs through load optimization. The structure of SRU for supply chain forecasting is presented in Figure 2.

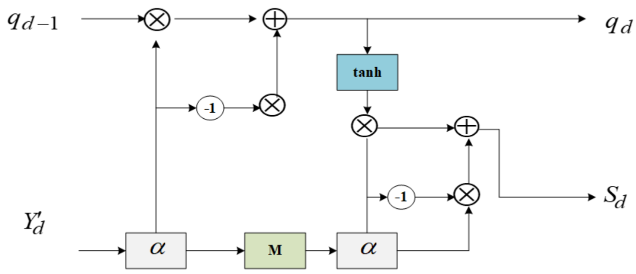

Figure. 2. Structure of SRU

where, the candidate state is defined asM_d, the final hidden state is defined as q_d, the input is signified as Y', the previous hidden state is defined as q_{d-1}, new state is defined asS_d.

By integrating SRUs into Walmart’s decision-making processes for supply chain management, the company can significantly enhance its ability to make real-time, data-driven decisions. SRUs can optimize order fulfillment speed by predicting demand spikes and processing times, improve inventory management through better stock forecasting and replenishment scheduling, and streamline transportation by optimizing routes and maintaining fleet efficiency. With SRUs, Walmart can create a more responsive, cost-effective, and reliable supply chain system.

4. RESULT AND DISCUSSION

The implementation of the proposed POA+SRU is implemented in PYTHON and is analysed based on various measures.

MAPE (Mean Absolute Percentage Error): MAPE measures the accuracy of a model's predictions as a percentage of the actual data. A lower MAPE value indicates better performance because the model is making predictions that are closer to the actual values. In this case, the proposed model (4.02%) has the lowest MAPE, meaning it performs better than GRU (12.6%), RNN (9.4%), LSTM (6.9%), and SRU (5.2%) in terms of predictive accuracy.

RMSE (Root Mean Square Error): RMSE represents the square root of the average squared differences between predicted and actual values. It gives an idea of how much error exists between the predicted and observed values, with a lower RMSE indicating better model performance. Here, the proposed model (0.55) shows the lowest RMSE, meaning it has the smallest error variance among the compared models, outperforming SRU (0.7), LSTM (1.1), RNN (2.4), and GRU (2.6).

MAE (Mean Absolute Error): MAE is the average of the absolute differences between predicted and actual values. It gives an indication of the magnitude of errors. A lower MAE value means the predictions are closer to the true values. The Proposed model (0.43) has the lowest MAE compared to GRU (2.2), RNN (1.12), LSTM (0.92), and SRU (0.67), meaning it makes the most precise predictions on average.

The experimental outcome is portrayed in Figure 3 and its detailed outcome is presented in table 1. The provided table compares the performance of different machine learning models like GRU (Gated Recurrent Unit), RNN (Recurrent Neural Network), LSTM (Long Short-Term Memory), SRU (Simple Recurrent Unit), and the proposed model based on POA (Parrot Optimization Algorithm) for feature selection combined with SRU across three evaluation metrics: MAPE, RMSE, and MAE.

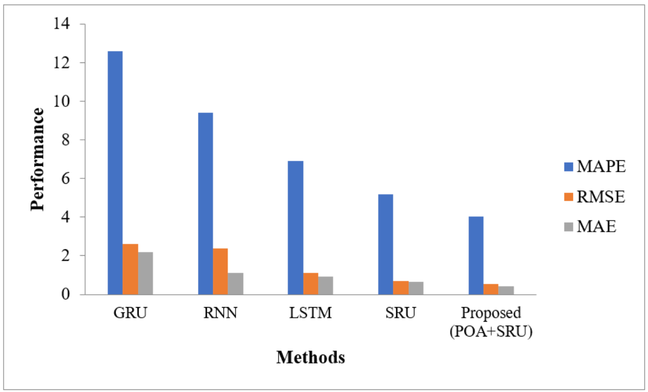

Figure. 3. Experimental Outcome

Table 1. Comparative Analysis

Metrics/ Methods	GR U	RN N	LS TM	SR U	Proposed (POA+SRU)
MAPE	12.6	9.4	6.9	5.2	4.02
RMSE	2.6	2.4	1.1	0.7	0.55
MAE	2.2	1.12	0.92	0.67	0.43

The proposed model outperforms all other models across all metrics—MAPE, RMSE, and MAE. By combining Parrot Optimization Algorithm (POA) for feature selection with the decision-making power of SRU, the model significantly reduces prediction errors, as seen in the lowest MAPE (4.02%), RMSE (0.55), and MAE (0.43) values. The success of the proposed model suggests that POA effectively selects the most relevant features, while SRU provides efficient and accurate sequential data processing for supply chain decision-making. GRU and RNN perform less effectively across all metrics, with the highest MAPE, RMSE, and MAE values. This indicates that these models struggle with optimizing supply chain decision-making compared to more advanced architectures like LSTM, SRU, and the proposed model. LSTM performs better than RNN and GRU but is outperformed by SRU and the proposed model, showing that while LSTMs are effective for sequential data, SRUs and the optimized feature selection process further enhance performance.

5. CONCLUSION

The Proposed model, which integrates POA-based feature selection and SRU-based decision-making, shows superior performance in predicting supply chain metrics (order fulfillment speed, inventory management, and transportation management) with the highest level of accuracy and efficiency among the models analyzed. This makes it an optimal choice for improving supply chain management decisions at Walmart. The proposed model has been implemented using a Python simulator. The proposed model is assessed metrics like MAPE, RMSE, MAE, and MSE. The Proposed model achieves the lowest MAE of 2.2%, 1.12%, 0.92%, and 0.67% than GRU, RNN, LSTM, and SRU respectively, it makes the most precise predictions on average.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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