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Predicting Pharma Sales with AI Techniques – A Comprehensive Review

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ABSTRACT

The pharmaceutical sector is increasingly challenged in forecasting medicine demand due to the complexities of supply chain operations, seasonal variations, and unexpected market influences [1], [2]. Conventional statistical models such as regression and ARIMA are often unable to capture these nonlinear dynamics, resulting in inefficiencies in inventory control and production planning [6], [17]. In contrast, recent progress in Artificial Intelligence (AI) and Machine Learning (ML) has enhanced forecasting accuracy through methods like reinforcement learning, deep neural networks, and ensemble-based hybrid models [3], [7], [12], [22]. Additionally, data-driven systems have been designed to differentiate between baseline consumption and promotion-related sales, improving overall prediction accuracy [5], [14]. Optimization strategies powered by AI, including evolutionary algorithms and advanced gradient boosting, have also outperformed traditional techniques [2], [25]. These forecasting improvements are further strengthened by the use of cloud-enabled platforms and robotic process automation, which support real-time decision-making across pharmaceutical supply chains [8], [16], [27]. Nevertheless, key issues remain in terms of limited data access, lack of model interpretability, and difficulties in scaling across varied markets [9], [13], [29]. Moving forward, research is likely to emphasize the integration of generative AI, explainable AI, and domain-specific predictive tools to achieve reliable, transparent, and sustainable demand forecasting in the pharmaceutical domain [10], [18], [30].

Keywords: Pharmaceutical demand forecasting, Artificial Intelligence, Machine Learning, Supply chain, Deep learning, Generative AI, Explainable AI

1. Introduction

The pharmaceutical industry is a cornerstone of global healthcare, where the timely availability of medicines depends greatly on accurate demand prediction [1], [6]. Traditional forecasting methods, such as regression and ARIMA, provide initial insights but are limited in addressing nonlinear, seasonal, and promotion-influenced sales variations [5], [17], [25]. These shortcomings often create mismatches between supply and demand, resulting in stock outs, overproduction, or shortages that directly affect patients and healthcare providers [11], [17].

To overcome these issues, Artificial Intelligence (AI) and Machine Learning (ML) have been increasingly adopted [2], [3], [7]. Approaches such as reinforcement learning, deep neural networks, and ensemble techniques have proven effective in identifying hidden data patterns and improving accuracy across a variety of contexts [12], [14], [22]. Data-driven frameworks also enable separation of standard demand from promotional effects, leading to more reliable forecasts [5], [13].

Alongside advanced models, integrating AI into supply chain systems has enhanced efficiency. Solutions involving cloud platforms, robotic process automation, and business intelligence allow for real-time forecasting and inventory optimization

[8], [16], [23], [27]. Furthermore, hybrid approaches that combine statistical methods with AI-driven optimization techniques, like gradient boosting and evolutionary algorithms, have shown improved adaptability [2], [14], [25].

Still, challenges remain. Most forecasting models rely on limited datasets and struggle with scalability across regions [9], [20], [21]. Additionally, lack of interpretability presents obstacles to regulatory adoption [18], [29]. To address these gaps, future work must focus on explainable AI, generative modeling, and resilient forecasting frameworks capable of adapting to disruptions [10], [18], [30].

2. Literature Review

Table 1 – Literature Review

Sr.	Year / Author	Title	Objective	Method	Limitation (Gap)	Future Work	Dataset
1	2025 – G.S. Sajja, M.K. Meesala [1]	Efficient Medicine Demand Prediction (LTH-SES)	Design medicine demand prediction with LTH-SES ML	LTH-SES forecasting + comparison	Needs high compute; ignores sudden demand; less scalable	Use advanced low-resource, real-time methods	Historical sales data
2	2025 – Ying Xiong[2]	AI Model for Drug Sales (EGEO-XGBoost)	Improve drug sales prediction with EGEO-XGBoost	XGBoost + EGEO tuning	Only past data; weak on large/hetero data	Add real-time + hybrid models	Kaggle
3	2025 – A.U. Mohammed et al.[3]	Pharma Sales with Multi-Task RL	Adaptive forecasting with MTL + RL	Multi-Task + RL	No rules/external changes; limited testing	Add rules, test larger data, improve adaptability	IQVIA & IMS Health
4	2025 – M. Mohammed & A.U. Mohammed[4]	AI + BI for Sales Strategies	Optimize sales with Explainable AI + dashboards	ML (LSTM, XGBoost, LightGBM) + XAI + Power BI	No external factors; limited adaptability	Add demographics/economics; improve robustness	6 yrs data (2014–2019)
5	2025 – Zeng et al.[5]	Data-driven Pharma Sales (Promo vs Daily)	Handle promo fluctuations with TFT	TFT model	Needs big data; complex; low accuracy without promo data	Use real-time, simpler versions, add explainable AI, handle epidemics	Past sales data

Sr.	Year / Author	Title	Objective	Method	Limitation (Gap)	Future Work	Dataset
6	2024 – Fourkiotis & Tsadiras [6]	ML & Stats for Pharma Sales	Compare stats vs ML for pharma forecasting	Naive, ARIMA, ES, Prophet, XGBoost, LSTM	Small dataset; weak deep learning	Use bigger data, add external factors	600k records (2014–19)
7	2024 – Mirshekari et al.[7]	Ensemble Kernel GPR	Improve pharma sales accuracy	GPR + Bayesian tuning	Past data only; no real-time	Add real-time; mix with DL; make faster/explainable	Kaggle (2014–19)
8	2024 – S.K. Swarnkar et al.[8]	AI + Data Analytics for Supply Chain	Optimize pharma supply chain with AI + analytics	LR, RF, K-Means, DL, GA	Data security; system integration; skill gaps	Improve security; use blockchain; greener AI	Not given
9	2024 – Sokolovska et al.[9]	Intelligent Data Analysis Platform	Predictive pharma platform with NN	Auto shallow/deep NN + XAI	Focus on drug use only; not full chain	Apply to real-world supply chain	Kaggle-style data
10	2024 – Chava & Saradhi [10]	Generative AI in Pharma Supply Chain	Study generative AI for smarter supply chain	Literature review + case examples	Conceptual; no experiments	Pilot studies; IT/regulation integration	None
11	2024 – Fazekas et al.[11]	Predicting Pharma Prices	Predict unit prices with ML	OLS vs Random Forest	Limited countries; missing data; no real-time	Use real-time + XAI; study crisis impact	200k procurement records
12	2024 – Indri Hapsari [12]	Cluster-specific Bi-LSTM	Improve sales forecast with clustering + Bi-LSTM	Bi-LSTM + K-means	Small dataset; single pharmacy	Expand data; real-time integration	Historical sales
13	2025 – Moreno Quintero [13]	Demand Forecasting for Retail	Best AI/ML model for pharma retail	AI + ML methods	Volatile demand; KPI tracking missing	Add external factors; better KPIs	Not given

Sr.	Year / Author	Title	Objective	Method	Limitation (Gap)	Future Work	Dataset
14	2024 – Lakhal et al.[14]	Hybrid Paracetamol Forecast	Improve accuracy with hybrid SARIMA–ANFIS	TES, SARIMA, LSTM, ANFIS	Small dataset; no external factors	Extend to other drugs; add variables	Not given
15	2024 – Andrew James [15]	Predictive Analytics for Drug Demand	Improve demand forecasting + distribution	ML framework + simulation	Limited data; privacy; low interpretability	Federated learning; interpretable models	Private datasets
16	2024 – Venigandla et al.[16]	RPA in Pharma Supply Chain	Study RPA for inventory & supply	Case studies; automation tasks	High cost; integration issues; resistance	Strategies for smooth adoption; scalability	Not given
17	2023 – Pall et al.[17]	Predicting Drug Shortages	Forecast shortage risk	ML classification	Only past data; 59% accuracy	Add real-time inventory + supplier data	Sales data (22 pharmacies)
18	2025 – Sabapathy[18]	AI in Pharma Sales & Engagement	Analyze AI for sales & engagement	AI + ML	Data messy; privacy; adoption issues	Next-gen AI; global strategies	Not given
19	2023 – Mohibullah et al.[19]	Outbreak Prediction	Predict outbreak sales via DL	LSTM + correlation analysis	Limited data; no validation	Multi-source data; advanced DL	Kaggle pharma sales
20	2023 – Yadav [20]	SME Sales Forecasting	Forecast SME sales	RF, XGBoost + SME data	Less data; overfitting risk	Use bigger datasets; advanced AI	Superstore + pharma SME
21	2023 – Lucas Scharf [21]	AI for Specialty Pharmacy	Improve specialty drug forecast	ARIMA, VARMA, AWS Forecast, Azure ML	Single pharmacy; 26 months only	Expand drugs & data; add more factors	UC Health data + weather
22	2023 – Mousa & Al-Khateeb [22]	DL for Medicine Demand	Use DL to predict demand	RNN, LSTM, Bi-LSTM, GRU	Different datasets affect accuracy	Try Transformers, CNN; add efficiency study	Historical demand data

Sr.	Year / Author	Title	Objective	Method	Limitation (Gap)	Future Work	Dataset
23	2023 – Wu Guo [23]	AI in Pharma Supply Chain	Study AI benefits in pharma	Real-world use cases	High cost; limited data; ethical issues	Cost-effective AI; better data; regulatory focus	None (case-based)
24	2022 – Galkin et al.[24]	NN for Pharma Sales	Use NN for pharma sales forecast	RNN	Pharma firms still use old methods	Apply to more data; adapt to changes	Revenue data (2016–21)
25	2022 – Rathipriya et al.[25]	Shallow vs Deep NN Model	Automate model selection with XAI	Shallow vs Deep NN + XAI	Kaggle-only; controlled setup	Try real-world large systems	Kaggle
26	2022 – Aban Saleem [26]	High-Frequency Forecasting	Daily/sub-daily pharma forecast	SARIMA, Holt-Winters, Prophet	One retailer only; not general	Use ML/DL + external factors	Swedish pharmacy data
27	2022 – Recharla [27]	Cloud + ML in Bio-Pharma	Cloud ML for supply chain	Conceptual review	No empirical results	Real-world trials; measure KPIs	None
28	2022 – Mrinmoy Roy[28]	AI in Pharma Sales & Marketing – A Conceptual Overview	Conceptualize AI role in sales & marketing (CRM, personalization, digital tools)	Theoretical review (AI applications)	No empirical data; no validation; no dataset	Focus on Conversational AI, NLP, RPA	None
29	2024 – Arnab Roy, A. Mohapatra, C. Sharwan, A. Kumar, S. Kumar,	AI in Pharma Supply Chain Mgmt – A Systemic Review	Review AI in supply chains (predictive analytics, blockchain, ML → efficient, accurate, transparent)	Systematic review of literature	Data breach & privacy risks; high cost of AI	Improve AI security/privacy; Predict supply issues; Better quality checks	Only review (no dataset)

Sr.	Year / Author	Title	Objective	Method	Limitation (Gap)	Future Work	Dataset
	A. Maholay, C. Conneh [29]						
30	2023 – B. A. Mousa, B. Al-Khateeb [30]	Predicting Medicine Demand using Deep Learning: A Review	Review ML & DL methods for pharma demand forecasting	Literature review of RNN, LSTM, Bi-LSTM, GRU; metrics: MSE, MAE, RMSE	Scarcity of data; market shifts reduce accuracy	Implement models; real-world validation	No original dataset (used refs)

3. Future Enhancements

Although AI- and ML-based forecasting systems have achieved notable progress, several improvements are still possible for future research and practical adoption:

1. **Incorporating Explainable AI (XAI) :** Many current models emphasize accuracy but lack transparency, making regulatory compliance difficult. Future studies should integrate XAI to improve interpretability, reliability, and acceptance in pharmaceutical contexts [18], [29].

2. **Generative AI for Scenario Forecasting:** Generative AI can create multiple demand scenarios, allowing organizations to prepare for unexpected situations such as pandemics, market fluctuations, or supply chain interruptions [10]. This will help build more resilient forecasting systems.

3. **Use of Multi-Source Data:** Instead of relying only on sales or inventory information, future models should combine diverse data types—including demographic, health, and environmental data—to better reflect real-world influences [5], [13].

4. **Real-Time and Cloud-Enabled Solutions:** With increasing adoption of IoT and digital systems, forecasting should move toward **real-time cloud platforms** that continuously update predictions and adapt quickly to market changes [8], [16], [27].

5. **Personalized Forecasting with Reinforcement Learning:** Reinforcement learning can be expanded to deliver customized demand predictions across different regions, pharmacy chains, and patient segments, thereby increasing adaptability in varied environments [3], [12].

6. **Enhancing Scalability Through Data Collaboration:** Limited datasets restrict the scalability of many current models [20], [21]. Future research should promote **data-sharing collaborations** among pharmacies, hospitals, and public institutions to build stronger and more generalizable predictive systems.

7. **Ethical and Sustainable AI Adoption:** Since pharmaceutical forecasting directly affects patient well-being, ethical concerns—such as reducing bias, ensuring fairness, and supporting sustainable operations—should guide

the design of AI models [18], [29], [30].

4. Conclusion

Effective pharmaceutical demand forecasting is vital for balancing medicine supply, preventing shortages, and maintaining efficient supply chains. While statistical models laid the groundwork, they often fail to capture the complexity of real-world pharmaceutical sales, especially under nonlinear and seasonal influences. In contrast, AI- and ML-based models—including deep learning, reinforcement learning, and hybrid ensembles—have demonstrated greater accuracy and adaptability.

The integration of AI with business intelligence, cloud systems, and process automation has further expanded forecasting capabilities, enabling faster and more efficient decision-making. Meanwhile, advances in Generative AI and Explainable AI are expected to support transparency, resilience, and trust in future pharmaceutical forecasting systems.

Despite these improvements, persistent challenges such as dataset limitations, scalability issues, and regulatory compliance barriers remain. Addressing these challenges requires forecasting frameworks that combine explainability, adaptability, and multi-source data integration to ensure reliable, ethical, and sustainable outcomes.

In conclusion, AI-powered forecasting offers significant opportunities to reshape pharmaceutical supply chains, but future research should prioritize explainability, real-time adaptability, and global scalability to fully realize its potential in healthcare.

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