# A Multi-Agent Prediction Framework for Weekly Pharmaceutical Demand Forecasting

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**Abstract**

Demand forecasting in business is no doubt an essential factor for inventory optimization and other planning. It is clear that there is no exception for business of pharmaceutical products in this regard to have an optimized plan for delivery of drugs to maintain the supply chain. This study proposes a multi-agent ensemble framework to predict weekly demand for a specific medicine using historical sales data. This study proposes a multi-agent forecasting framework comprising three agents- Prediction Agent, Session Agent and Trend Agent. Each agent is designed to capture a temporal pattern according to its role. A Meta Agent is subsequently employed to ensemble their outputs using performance-based weighting derived from validation errors specifically Mean Absolute Error (MAE).The individual agents are trained on historical sales data and evaluated on separate test datasets. The Meta Agent combines the predictions of these agents by assigning dynamic weights based on their iterative MAE performance, enabling adaptive learning over time. The result of this study demonstrates that Meta Agent which ensemble the prediction of individual agents, outperforms others with lowest Mean Absolute Error (MAE). This study tries to show the importance of an ensemble model for improving predictive accuracy than relying on any single agent.

**Keywords:** Multi-Agent Systems, Pharmaceutical Sales Forecasting, Machine Learning, Meta Agent, Mean Absolute Error (MAE), Seasonal Patterns, Trend Analysis.

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## Introduction

Demand forecasting in pharmaceutical sales is a critical as well as important assignment as it is influenced by seasonality, trends and stochastic fluctuations. Traditional single agent to predict the sales often fail to capture and relate these complex dynamics.

Recent advancements[1] in demand forecasting are increasingly utilizing artificial intelligence and machine learning to address these challenges. Different studies in different industries have shown how predictive accuracy improves with integration of predictions of different agents specialized to predict by considering a particular group of factors and different agents using same or different predictive techniques as per their requirements. Still such approaches are often discussed from a broad implementation perspective with limited focus on comparative evaluation of individual model behaviors and ensemble effectiveness in specific domains such as pharmaceuticals.

To address this limitation this study propose a **multi-agent ensembling framework**. Here each individual agent specializes in a different aspect of the data:

- Historical demand patterns
- Seasonal (sessional) variations
- Long term trends

These agents are then combined using a Meta Agent and then the performances of different agents including Meta Agent is compared to explore whether Meta agent ensembling is appropriate for the pharmacy sector or not. The study utilizes the "Pharma sales data" dataset obtained from Kaggle[2] which contains weekly pharmaceutical sales data across multiple product categories. We have taken the case of anti-inflammatory and antirheumatic products, non-steroids, acetic acid derivatives and related substances for this study.

## Litereture Review

The researchers[3] have verified that XGBoost outperform traditional methods like ARIMA in pharmaceutical sales prediction. In contrast to previous studies which were focussed on selecting the best individual model our research tries to study the behaviour of a multi-agent framework potentially overcoming the limitations of dependence on a single model. Also the authors[3] have mentioned the importance of seasonality as integral component in pharmaceutical sales and mentioned that drug demands oscillate with the seasons. With such motivation our study created an independent agent in pharma sales prediction as session agent.

The research[4] was on the effectiveness of integrating ensemble forecasting with AI driven analytics for prediction of large scale demand particularly in complex manufacturing environments. This combine statistical, machine learning and deep learning models with explainable, role-specific understandings to support decision making. Tjough the work is commendable, existing studies tend to emphasize architectural design and practical deployment with comparatively limited focus on detailed comparative evaluation of individual models or the behavior of multi-agent systems under different conditions of data. Our study provides comparison among predictive agents and examines performance of multi-agent model which offers a deeper insight into effectiveness of forecasting along with model dynamics.

The study by the researchers[5] focuses on the application of individual machine learning models such as artificial neural networks, multiple regression and random forest for demand prediction. Though the study detects the most suitable standalone model which can be treated as single agent, it does not explore the potential of ensemble approaches that combine multiple predictive agents.Furthermore, existing literature provides limited insights into whether meta models outperform individual.

Though knowledge graph-based models attain high accuracy by incorporating inter-drug relationships[6] they rely on structured domain knowledge. In practice, the structured domain knowledge may not always be available. Our study explores multi-agent learning approaches which can perform efficiently with limited data without predefined relational structures.Our current study demonstrates that effective demand forecasting can be achieved without relying on complex relational structures, offering a more practical alternative for real world applications.

It has been observed in the study[7] that individual models like LSTM perform nicely to capture temporal dependencies. While other study[1] focussed on the effectiveness of XGBoost for structured data. This suggests that no single model developed previously to dominate in all scenarios.

The study of seasonal and trend factors in drug sales using SARIMA[8] establishes that pharmaceutical sales data exhibit the importance of seasonal and trend components. So incorporating these patterns will be helpful to improve predictive accuracy to support better inventory and demand planning.

While many predictive models centred on historical sales patterns, external seasonal factors like environmental conditions also have the potential to influence pharmaceutical product stability and supply. The researchers[9] have shown that the role of seasonal temperature and humidity variations can significantly affect drug degradation.

**Data Description**

The dataset consists of weekly sales records with the following fields for a particular drug:

- **Sales**: Weekly demand of the medicine
- **Year**: Calendar year
- **Week**: Week number

Three datasets were used:

1. **Training dataset** :for training individual agents
2. **Test dataset** : for evaluating individual agents and training the Meta Agent dynamically for final performance evaluation

**Research Problem**

Despite the availability of historical sales data, accurately predicting pharmaceutical demand remains challenging due to:

- Seasonal fluctuations (e.g., disease outbreaks)
- Changing consumption trends
- Variability across time periods

The key problem addressed is:

**Can a multi-agent ensemble model improve demand prediction accuracy compared to individual specialized agents?**

**Objectives**

1. To develop three independent predictive agents based on different demand signals.
2. To evaluate the performance of each agent using MAE and RMSE.
3. To design a Meta Agent that ensembles predictions using error-based weighting.

To compare ensemble performance against individual agents.

**Methodology**

**Prediction Agent**

The Prediction Agent models demand based purely on historical sales patterns. It uses XGBoost regressor[10,11] to get trained in the data to learn how past demand influences future demand.

**Session Agent**

The Session Agent captures **seasonality effects** recurring weekly or yearly demand patterns. It leverages the "week" feature to identify cyclical trends. It tries to study seasonal (weekly/periodic) effects. It also uses XGBoost regressor[10,11] for it's training in this study.

**Trend Agent**

The Trend Agent focuses on long term progression in demand over time. It models gradual increases or decreases in sales in the sequential structure of the dataset. LSTM[12] is used here. The choice of LSTM[12] for learning and prediction by Trend agent is due to LSTM's memory cells and gating allow it to retain information over extended periods**,** making it suitable for time-series prediction and modeling dynamic systems**.** We have also been motivated to use LSTM here also for the study[13] highlights that LSTM can effectively capture long-term temporal dependencies.

The choice of XGBoost for learning and prediction by Prediction and Session agents is motivated by its strong empirical performance in pharmaceutical sales forecasting[11] where it has been shown to achieve high predictive accuracy and low error rates. Its ability to effectively model nonlinear feature interactions and provide stable predictions makes it a valuable component within a multi-agent system.

As LSTM networks efficient to capture long-term dependencies in financial time series, enabling accurate modeling of trends in stock market and price movements[14], it may be appropriate to be used by Trend agent for sales prediction based on trends.

**Meta Agent (Ensemble Model)**

The Meta Agent is trained dynamically to assign the weights to each agent by analysing the Errors in their prediction and then predict for the next instance and again learn from the error and go on iteratively on the test dataset.

It takes as input:

- Predictions from Prediction Agent
- Predictions from Session Agent
- Predictions from Trend Agent

It used Mean Absolute Error(MAE) based weight averaging for individual agents to learn to optimally combine these predictions by minimizing prediction error against actual sales values. And the learning by Ensemble agent is dynamic. This process effectively captures inter agent relationships and reduces bias.

$$W_i = \left(\frac{1}{MAE_i}\right) / \sum\left(\frac{1}{MAE_i}\right)$$

Final Prediction= $\sum W_i . P_i$

$W_i$ is weight of ith agent

$P_i$ is prediction of ith agent.

**Evaluation Metric**

Performance is evaluated using **Root Mean Square Error (RMSE)** and **Mean Absolute Error(MAE).**

**Results**

After analysing the performances of different agents by considering MAE and RMSE as the factor of measurement we have the following results shown in **table 1**.

| AGENT/MODEL | MAE | RMSE |
|---|---|---|
| Prediction Agent | 6.48 | 8.50 |
| Session Agent | 6.36 | 8.32 |
| Trend Agent | 6.03 | 7.53 |
| Meta Agent | 5.94 | 7.67 |

**Table 1 : Performances of different agents on test dataset**

**Observations**

The Meta Agent achieved the lowest MAE which indicates that it has the best overall predictive accuracy among all models. Its RMSE is slightly higher than that of the Trend Agent so it suggests that while the Meta Agent minimizes average errors effectively, occasional larger deviations are better captured by the Trend Agent.

The Trend Agent performed very well, with the second-lowest MAE and the lowest RMSE highlighting the presence of meaningful long-term trends in pharmaceutical sales.

The Session Agent showed moderate performance by reflecting the influence of seasonal factors like weather changes, desease cycles, periodic consumption behaviours. Although these seasonal patterns are captured directly by the Session Agent, the Meta Agent's ability to combine insights from all agents enables it to outperform individual models in terms of MAE.

The prediction agent performs the worst among other individual agents so it contributes some noise to the Meta Agent ensemble. This might be the reason to slightly affect to increase RMSE of Meta Agent relative to Trend Agent. Still Meta Agent can be treated as the best as it has lowest MAE which improves overall accuracy though it might not be fully efficient to handle large changes in market due to any exceptional thing.

In a nutshell the results in this study illustrates that adaptive ensembling by the Meta Agent results the lowest average error and the performances of individual agents shows the contributions of seasonal patterns and long-term trends in pharmaceutical sales.

**Discussion**

The Meta Agent's better performance in this study shows how different agents capture complementary information and how ensemble learning makes the biases of each model less strong.Training the Meta Agent based on validation makes sure it can work with data it hasn't dealt yet.

This approach is helpful for predicting the demand for drugs where both seasonal and trend-based factors are very important.

**Conclusion**

This study demonstrates how Multi Agent Predictive framework performs efficiently rather than single agents in pharmaceutical demand forecasting. The lowest MAE of Meta agent indicates it's accuracy in average predictions and lowest RMSE by trend agent may be treated as it's strength to capture occasional large deviations and long term trends.

The findings of this study may indicate the followings:

- The Trend Agent's strong RMSE performance shows that long-term trends are important in pharmaceutical sales.
- The Session Agent does a good job of capturing how seasonal and short-term patterns affect demand.
- The Meta Agent's MAE shows that ensemble methods can make things more accurate overall but their accuracy depends on how different and strong the constituent models.

So it can be concluded that the Meta Agent can be used to leverage the strengths of different agents who captures complementary aspects of the data so the Meta agent can have more accuracy than individual agents. Still some specific agents may outperform the ensemble in certain metrics (like RMSE in our study) which highlights the importance of aligning model selection and ensemble techniques with the characteristics of the dataset.

**Future Work**

Future enhancements may include:

- Incorporation of external variables like epidemics, sales promotion etc.
- Evolution of competitors in the same type of drug is also another factor which has the potential to affect the sales.

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