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Machine Learning to Predict Food Prices in Aceh Province Using the Fuzzy Time Series Method Based on Average

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Abstract: This study aims to develop a food commodity price prediction system based on Fuzzy Time Series (FTS) using average-based methods, with a case study of price data from 2018 to 2023. The system is designed to predict the prices of five main commodities: Super Quality Rice, Fresh Chicken Meat, Fresh Chicken Eggs, Bulk Cooking Oil, and Premium Quality Sugar. The prediction process involves constructing the Universe of Discourse, intervals, and fuzzy logic relations (FLR and FLRG) to model historical price patterns. The results show that this model provides accurate predictions, with the best Mean Absolute Percentage Error (MAPE) value of 0.49% for Super Quality Rice, while MAPE for other commodities ranges from 0.69% to 1.44%. The comparison graph between actual data and prediction results demonstrates consistent pattern alignment, suitable for commodities with both high price fluctuations and stable trends. This system proves effective in projecting future food prices with low error rates, making it a reliable tool to support strategic decision-making in managing food commodity prices during the five-year analysis period.

Keywords: Food Commodities, Fuzzy Time Series Based Average, Machine Learning, Prediction, Time Series

INTRODUCTION

Agriculture is a vital sector in the economy of many countries, not only supplying food for the population but also influencing social and political stability. One of the most important aspects of the agricultural sector is the price of food commodities. Fluctuations in food commodity prices can have a significant impact on people's lives, especially those who depend on daily income or have limited access to food. Agriculture is also a primary industry that involves the organization of land, water, and mineral resources, as well as capital in various forms, and the management of labor to produce and market various goods needed by humans. Agricultural economics is a science that studies human behavior and efforts, both directly and indirectly related to the production, marketing, and consumption of agricultural products (Gita Srihidayati & Suhaeni, 2022).

The agricultural sector plays a vital and strategic role in Indonesia’s national economy, particularly as it employs around 29% of the workforce, mostly in rural areas, and significantly contributes to the national GDP (World Bank, 2020). It supplies food for the population, yet faces challenges like climate change, inadequate infrastructure, and global commodity price fluctuations, which often lead to unpredictable food prices. These fluctuations, driven by factors such as agricultural production, extreme weather, market demand, and geopolitical issues, can destabilize the economy and affect societal welfare, especially in rural regions like Aceh. In Aceh, where the majority work in agriculture with key commodities like rice, coffee, and cocoa, sharp price instability due to weather and policy changes directly impacts farmers’ income, making accurate price predictions essential for government, traders, and consumers to plan budgets, strategies, and purchases. Data from the Strategic Food Price Information Center (PIHPS) of Indonesia supports these efforts.

In the context of forecasting, time series models are generally used more frequently. This forecasting method utilizes two main theories: smoothing and decomposition. Smoothing, based on the principle of averaging past errors, calculates forecast values by adding previous forecast values and measuring the percentage error between actual and predicted values. Meanwhile, the decomposition method breaks down time-series data into several key components, such as Trend, Cyclical, Seasonal, and Random Effects, which are then combined to obtain a more accurate prediction for each component, except for random effects, which are difficult to predict. This approach

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provides a more detailed structure for analyzing and forecasting time-series data patterns (Fungki Wahyu & Billy Hendrik, 2023).

Fuzzy time series forecasting is a research area that addresses issues related to uncertainty, ambiguity, and inaccuracy. This forecasting method plays a crucial role in decision-making across various fields, including economics, climatology, labor sectors, agriculture, and tourism (Bose & Mali, 2019; Kadek et al., 2022).

To address the challenges of predicting food prices amidst uncertainty, the Fuzzy Time Series method offers an effective solution by combining fuzzy logic with time series analysis. Unlike traditional methods, it handles complex, non-linear historical data with high variability, transforming it into flexible fuzzy sets that capture temporal patterns and connect them with fuzzy rules for realistic forecasts. This approach excels in adapting to unpredictable external factors—such as climate shifts, government policies, and global market dynamics—making it particularly valuable for regions like Aceh. By providing more accurate predictions, Fuzzy Time Series enhances economic stability, benefiting farmers, traders, and policymakers in crafting targeted strategies to mitigate price volatility and improve planning.

LITERATURE REVIEW

Previous research that the author uses as a reference includes the following

1. According to the research by Eva Darnila, Rozzy Kesuma Dinata, and Suci Ramadani (2023), titled "Prediksi Harga Pasar Komoditi Tanaman Pangan Di Aceh Utara Pada Masa Pandemi Covid-19 Dengan Metode Fuzzy Time Series Model Chen," a web-based prediction system was successfully developed with high accuracy (≤ 10%). Using data from 2017 to 2020, the study achieved MAPE values of 3.46% for rice, 4.37% for corn, and 4.32% for soybeans in forecasting prices from 2021 to 2024. The research also noted that using less data tends to result in higher MAPE values, indicating an increased prediction error rate, underscoring the model's dependence on sufficient historical data for optimal performance.
2. A similar study by Mutammimul Ula, Bakhtiar, Desvina Yulisda, Badriana, and Andik Bintaro (2022), titled "Application Of The Fuzzy Time Series Model In Clothing Material Stock Forecasting," demonstrated that the Fuzzy Time Series model is effective in predicting clothing material stock distribution in Aceh, including school uniforms, batik, and pants, with a low error rate. The forecasting process yielded an AFER error rate of 0.22927% for pants and 0.23640% for school uniforms, alongside RMSE values of 26.10036 and 29.09439 respectively, indicating that this method provides accurate and optimal results for future planning.
3. The Fuzzy Time Series Lee method is effective in handling fluctuating time series data. Additionally, this study supports the findings of Nurul Hani Pajriati (2021), who also reported the high performance of this method in forecasting gold prices at PT. X, achieving a MAPE value of 0.4364% (Rangga et al., 2024).

Food is one of the essential sectors for human life, as it fulfills a fundamental need—food consumption. Over time, food prices in Indonesia have often been unstable. This instability significantly impacts both society and farmers. Several factors contribute to these price fluctuations, including environmental conditions, pest and insect infestations, and drought-affected agricultural land (Rahmadini et al., 2023).

Data Mining is a technique used to discover, search for, and extract information and new insights from large datasets. This process integrates various disciplines, such as statistics, artificial intelligence, and machine learning, to generate useful information (Pujiono et al., 2024).Data Mining is a method used to uncover hidden information within large databases, playing a crucial role in automated analysis and knowledge extraction as part of the Knowledge Discovery in Database (KDD) process. By integrating disciplines like statistics, artificial intelligence, and machine learning, it identifies meaningful patterns, trends, anomalies, and relationships in complex data that traditional analysis might overlook, using specialized tools to provide deep, valuable insights. In business, Data Mining enables companies to understand customer behavior, spot new market opportunities, and boost operational efficiency, while in science, it uncovers patterns in research data, driving innovation. Beyond mere data analysis, its results can be paired with decision-support tools to enhance strategic, data-driven decision-making across diverse applications, such as marketing, fraud detection, risk management, and more, making it an essential component of modern decision-making strategies (Almufqi & Voutama, 2023).

Prediction is the process of estimating future events, encompassing aspects like time, quality, quantity, and location to meet the demand for goods or services, and can be classified by timeframe into short-term (days to months), medium-term, and long-term. Its primary function is to analyze past data behavior to provide systematic solutions and enhance confidence in the outcomes, using two main approaches: qualitative, which relies on opinions, surveys, and expert judgment, and quantitative, which uses historical data and includes time series and causal models. Widely applied to optimize raw material and product inventory, prediction techniques help meet consumer needs and achieve production targets efficiently, ultimately maximizing profits (Lestari et al., 2023).

Machine learning is a term used to refer to a branch of computer science that studies methods for designing algorithms capable of learning or adapting to data patterns without being explicitly programmed. Machine learning utilizes various computational methods to improve performance by leveraging knowledge gained from experience during the learning process (Kurniawan et al., 2023). In addition to their various applications, machine learning

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and deep learning have also raised concerns over issues such as data privacy, transparency, and bias. With the increasing use of these technologies in various industries, it is crucial to develop ethical frameworks and guidelines to ensure their responsible use (Mahajan et al., 2024; Xin et al., 2018)

Fuzzy Logic, a key component of Soft Computing, is grounded in fuzzy set theory, where the degree of membership plays a critical role in determining an element's presence in a set, developed by Prof. Lotfi Zadeh at the University of California, USA, in 1965. Zadeh modified traditional set theory by introducing fuzzy sets, in which each member has a membership degree between 0 and 1, allowing a value to be simultaneously true and false depending on its membership weight. Fuzzy Logic encompasses three main types: Tsukamoto, Mamdani, and Sugeno, each offering distinct approaches to handling such imprecise or "fuzzy" data (Yoka Fathoni et al., 2021).

Fuzzy Time Series (FTS) is an approach in time series analysis that integrates fuzzy logic with traditional time series methods to model and forecast data with inherent uncertainty, introduced by Song and Chissom in 1993. Unlike conventional time series, which rely on precise numerical values, FTS uses fuzzy sets—based on real numbers within a defined universe of discourse—expressed through linguistic terms, making it a non-parametric forecasting method. In FTS, the universe of discourse, denoted as U = {u1, u2, u3, ..., un}, consists of possible linguistic values (ui), where fuzzy sets represent and manage uncertainty, distinguishing it from standard approaches by accommodating imprecise data through membership degrees (Aprianto et al., 2023).

$$A_i = \frac{f_{A_i}(u_1)}{u_1} + \frac{f_{A_i}(u_2)}{u_2} + \cdots + \frac{f_{A_i}(u_n)}{u_n} \quad (1)$$

Where:
f_{A_i} : The membership function of the fuzzy set A_i, such that f_(A_i) → [0, 1]
u_n : An element of the fuzzy set A_i
$f_{A_i}(u_n)$: The degree of membership of u_n in A_i, where n = 1, 2, 3, ..., n.

Average-based Fuzzy Time Series is a time series forecasting method that leverages fuzzy logic principles to address uncertainty and vagueness in data, differing from traditional time series methods that rely on precise numerical data by using linguistic terms and fuzzy sets to model real-world ambiguities. To establish accurate fuzzy relationships, determining an effective interval length is crucial for enhancing the precision of Fuzzy Time Series, with the average-based approach being a commonly used technique for this purpose. Setting the interval length using the average-based method improves the accuracy of the applied technique, where an interval is considered effective if it has a normal value; overly large intervals eliminate fluctuations in Fuzzy Time Series, while excessively small intervals diminish its meaning. Thus, the interval length should ideally be at least half the fluctuation in the time series pattern, with fluctuations defined by the absolute value of the first difference between two consecutive data points, making the average-based method a formulated approach for determining an effective interval length (Tama & Saputro, 2022).

METHOD

This research is conducted in the city of Lhokseumawe, specifically at Malikussaleh University, starting in July 2024 and will continue until completion. The research is carried out online using data from the Strategic Food Price Information Center (PIHPS) website, which provides historical food price data that is open and accessible for public use.

The steps taken by the author in completing this final project refer to the system workflow. The first stage begins with data input, leading up to the prediction results. The complete sequence of these stages can be seen in the following diagram:

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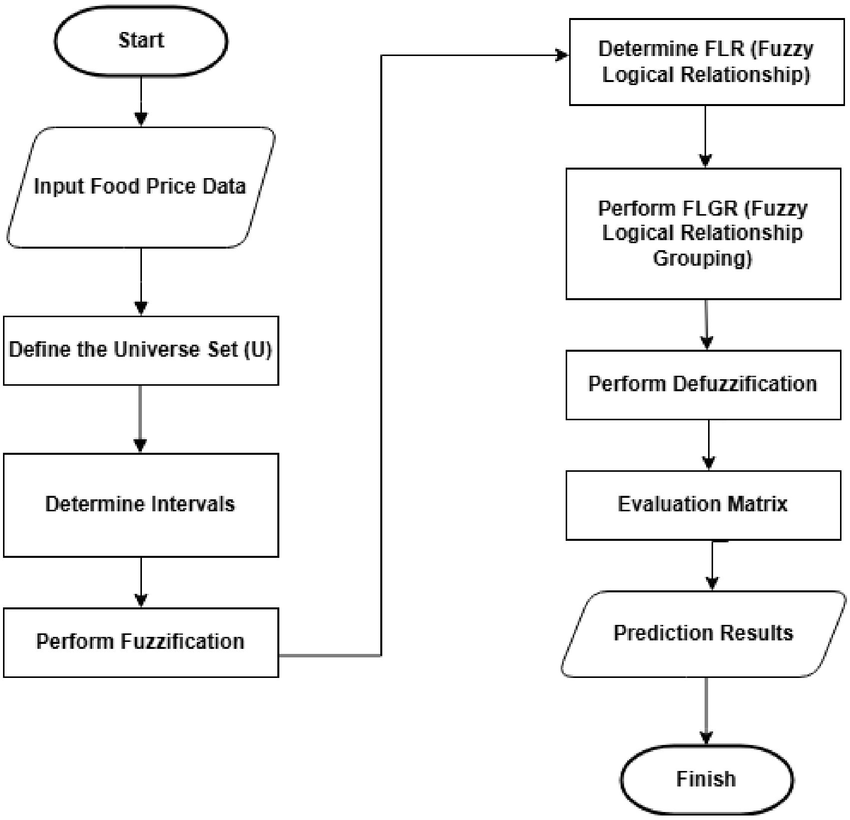

Figure 1. System Schema

The explanation of the steps in the system flowchart above is as follows:

This flowchart illustrates the process of food price prediction using the Fuzzy Time Series Based Average method. The process begins with "Start" and continues with the input of food price data. After that, the universe of discourse (U) is defined and the appropriate intervals are determined. The next step is fuzzification, which converts the input data into fuzzy sets, followed by determining the Fuzzy Logical Relationships (FLR). Then, Fuzzy Logical Relationship Grouping (FLGR) is carried out. After FLGR, defuzzification is performed to convert the fuzzy results back into numerical values. The prediction result is evaluated using evaluation metrics to assess the prediction accuracy. Finally, the prediction result is obtained and the process ends with "End."

This research uses food price data in the Province of Aceh covering the period from 2018 to 2023. The data analyzed includes the prices of various major food items, such as super-quality rice, fresh chicken meat, chicken eggs, bulk cooking oil, granulated sugar, and other food items. The data source is obtained from daily market price records that have been consistently collected over the past five years, with daily recording frequency. The main variables analyzed include daily average price trends, seasonal price fluctuation patterns, and potential price anomalies during certain periods. This data provides a comprehensive overview of the dynamics of food prices in the Province of Aceh, influenced by various factors such as season, logistics distribution, and government policies.

RESULT

This study aims to apply the Average-based Fuzzy Time Series method to predict food prices in Aceh Province. The data used includes the prices of major food items such as super-quality rice, fresh chicken meat, fresh layer eggs, bulk cooking oil, and premium-quality sugar from 2018 to 2023. The analysis is conducted to identify price change patterns and seasonal factors that influence price fluctuations.

This approach is expected to provide accurate and informative prediction results, which can be used to support policy decisions in maintaining food price stability. In addition, this study also evaluates the effectiveness of the Average-based Fuzzy Time Series method in modeling the price movement patterns based on historical data.

Predicting food prices is a complex challenge because it is influenced by various factors, such as demand and supply fluctuations, weather conditions, logistics distribution, and government policies. Accurate understanding of price change patterns is crucial, especially in Aceh Province, where food is a basic necessity that significantly impacts economic stability and public welfare. However, conventional approaches that rely solely on simple

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statistical analysis often fail to capture the complexity of food price change patterns, which can result in inaccuracies in predictions.

The application of the Average-based Fuzzy Time Series method presents a relevant solution to address this challenge due to its ability to model time-series data more flexibly and adaptively. This method is designed to analyze historical food price data by considering seasonal factors and price fluctuation patterns. In this study, historical data on food prices, such as super-quality rice, fresh chicken meat, fresh layer eggs, bulk cooking oil, and premium-quality sugar from 2018 to 2023, are analyzed to identify price change patterns in Aceh Province.

With this approach, it is hoped that the resulting prediction model can provide more objective and accurate insights. Furthermore, the prediction results are expected to serve as a foundation to support more strategic policy decisions in maintaining food price stability and minimizing the impact of price fluctuations on the community.

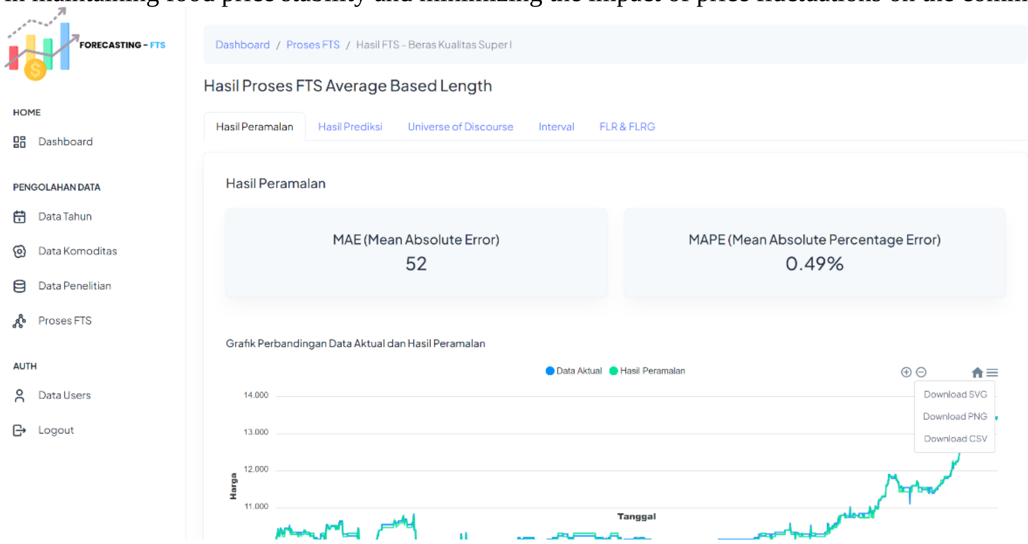

Figure 2. Evaluation Matrix Predict

The evaluation results using the Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) metrics indicate a high level of accuracy in the prediction model. The MAE, with a value of 52, suggests that the average absolute error of the predictions compared to the actual data is only 52 price units, which represents a very small error relative to the price data scale. Meanwhile, the MAPE value of 0.49% means that the average prediction error covers only 0.49% of the actual value. This value is very small, indicating that the predictions generated by the model are highly accurate. The combination of low MAE and MAPE values reflects that the FTS-based prediction model is capable of producing results that closely align with the actual data.

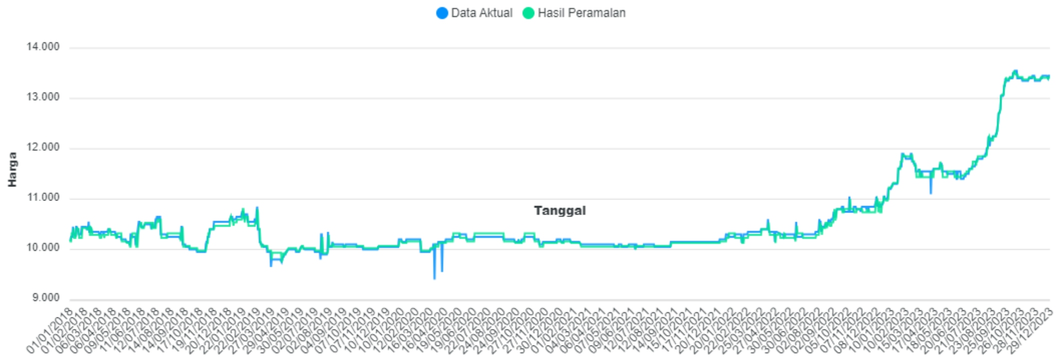

Figure 3. Comparison Chart Actual Vs Prediction

The comparison chart of actual data and prediction results provides a visual representation of how well the Fuzzy Time Series (FTS) model captures the price change patterns of commodities. The actual data is shown as a blue line, while the prediction results are represented by a green line. This chart aims to visualize the alignment between historical patterns and predictions, making it easier for users to understand the model's performance.

The chart clearly demonstrates that the prediction results successfully follow the historical data trends, whether in price increases, decreases, or stability. The alignment between the actual data and the prediction results indicates that the prediction model is capable of accurately capturing price change dynamics. This chart serves as an essential

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tool to provide intuitive insights into the prediction quality, allowing users to perform direct analysis on the system's performance.

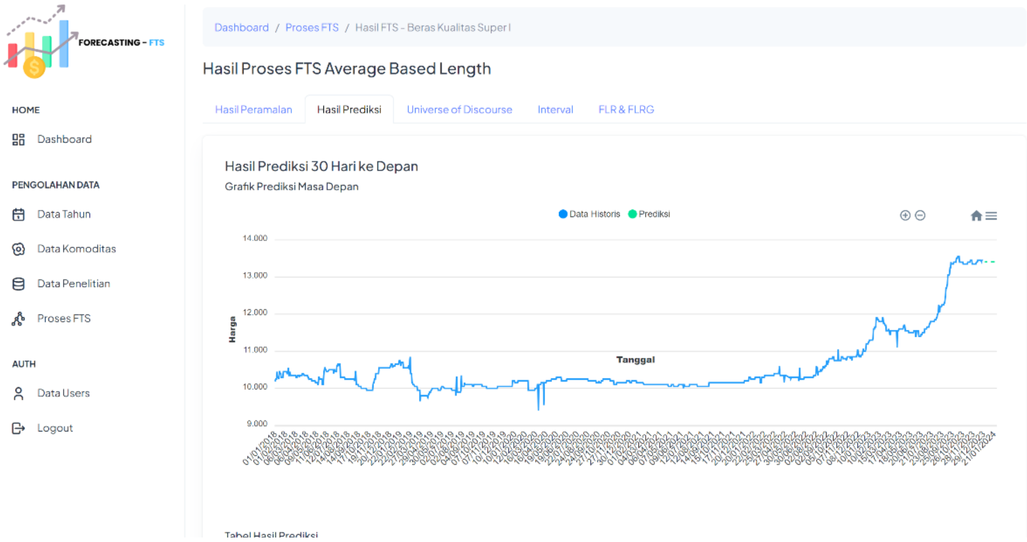

Figure 4. Future Prediction Chart

The future prediction results for Super Quality Rice (Beras Kualitas Super I) show a price increase trend that is consistent with historical data patterns. This prediction covers the next 30 days or according to the user-defined parameters, with results indicating a stable to slightly increasing price projection. The Fuzzy Time Series model successfully captured previous fluctuations, providing a strong foundation for projecting future price changes. As a result, this model can serve as a valuable reference for making strategic decision-making.

The prediction results for Super Quality Rice (Beras Kualitas Super I) show an excellent level of accuracy based on the evaluation using MAE and MAPE. The MAE value of 52 and MAPE value of 0.49% indicate that the Fuzzy Time Series model generates predictions that closely align with the actual data. The comparison chart of actual data and prediction results also demonstrates consistent alignment between historical patterns and future projections.

Furthermore, the future prediction trend indicates a potential price increase that aligns with historical dynamics, providing an accurate outlook for users to make informed decisions in the future. With the calculation method employed, the system proves to be effective in predicting commodity prices with a very low error rate.

DISCUSSIONS

The results of this study demonstrate that the Average-based Fuzzy Time Series (FTS) method is highly effective in predicting food prices in Aceh Province, with MAE of 52 and MAPE of 0.49%, indicating minimal prediction error. The comparison between actual data and predictions shows consistent alignment with historical price trends, reflecting the model's ability to accurately capture price fluctuations. When compared to conventional statistical methods, FTS outperforms in handling the complexities of seasonal fluctuations and external factors like weather, logistics, and government policies. Furthermore, the model successfully forecasts a potential price increase in line with historical patterns, offering valuable insights for policymakers to stabilize food prices. However, while FTS is effective, its performance could be further enhanced by incorporating additional external factors or exploring alternative models.

CONCLUSION

Based on the research conducted to predict food commodity prices using the Average-Based Fuzzy Time Series (FTS) method with a case study of commodity price data from 2018 to 2023, the findings highlight the model's effectiveness. The prediction system demonstrated high accuracy across five tested commodities—Super Quality I Rice, Fresh Broiler Chicken, Fresh Layer Chicken Eggs, Bulk Cooking Oil, and Premium Granulated Sugar—with Mean Absolute Percentage Error (MAPE) values ranging from 0.49% (lowest for Super Quality I Rice) to 1.44% (highest for Fresh Broiler Chicken). Comparative graphs of actual versus predicted data revealed consistent and aligned patterns, even for commodities with dynamic fluctuations like Fresh Broiler Chicken and Bulk Cooking Oil, affirming the model's ability to capture historical price trends and project future prices. The average-based FTS method proved flexible, effectively handling diverse price patterns—whether highly volatile or relatively stable—across different commodities. With its high accuracy and detailed trend analysis, this system

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serves as a reliable tool for strategic decision-making, supporting tasks such as distribution planning, price control, and food commodity market policies over the five-year analysis period.

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