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Forecasting USD to Rupiah Exchange Rate with the Fuzzy Time Series Singh Approach

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ABSTRACT

The exchange rate plays a crucial role in determining a country's economic stability, especially for countries like Indonesia that rely heavily on international trade. In recent years, the fluctuations in global currency values have intensified, particularly after the trade war between the United States and China began in 2018. These fluctuations have significantly impacted the exchange rate between the Indonesian Rupiah and the US Dollar, which in turn affects the competitiveness of Indonesian exports, increases the cost of imports, and influences key economic decisions made by investors, importers, and exporters. The problem of this research lies in the challenge of predicting exchange rate movements amidst economic uncertainty and currency volatility. This study aims to address this problem by forecasting the exchange rate of the Indonesian Rupiah against the US Dollar using the Fuzzy Time Series Singh method. This method is chosen due to its ability to capture complex data patterns with high accuracy and simpler computational requirements. The primary objective of the research is to evaluate the effectiveness and accuracy of the Fuzzy Time Series Singh method in predicting the exchange rate of the Rupiah against the US Dollar. The results of this study show that the forecasting model achieved an accuracy rate with a MAPE value of less than 10%, indicating that the method can provide highly reliable predictions, which can assist economic actors in making better-informed decisions in the face of currency volatility.

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1. INTRODUCTION

The exchange rate is a comparison of prices or values in a country's currency measured in the currency of another country[1]. Currency is a medium used to conduct economic transactions in a country[2]. Since 2018 there has been a trade war between the United States and China when US President Donald Trump signed a presidential memorandum imposing massive tariffs on Chinese imports[3][4]. The existence of the trade war has an impact on the world economy, including Indonesia[5]. The tension that occurs between the two countries with the largest economic power in the world is characterized by mutual imposition of high import tariffs, export restrictions, and other protectionist policies[6]. The conflict not only affects the uncertainty in the global market but also has an impact on Indonesia's currency exchange rate against the US Dollar as these fluctuations impact the competitiveness of Indonesian products in the global market, as well as potentially making imported goods more expensive for the Indonesian people[7].

The US dollar is designated as the universal reserve currency due to confidence in the economy and politics of the United States. Therefore, the US dollar has become the standard for international trade transactions and investments[8]. Therefore, the exchange rate of the rupiah against the US dollar greatly affects the Indonesian economy and is an important indicator for analyzing the Indonesian economy[9]. The economic stability of a country can be seen from the stability of the rupiah exchange rate against foreign currencies[10].The instability of the exchange rate can make this research important to do forecasting related to the exchange rate of the rupiah with the currencies of the two countries. The results of this forecasting aim to help estimate whether in the next period there is an increase or decrease in the exchange rate of the US Dollar in order to prevent global economic fluctuations and be able to estimate the right time to export or import with these two countries.

Forecasting has an important role in the decision-making process, because the success of a decision is often influenced by things that have not been seen or have not occurred when the decision is made[11]. Within forecasting, the goal is for the forecasted values to approximate the real data as accurately as possible [12][13]. Forecasting helps in detecting past patterns of fluctuation within the data [14][15]. Time series analysis is a method that can be applied to predict future events using past data. [16][17]. The goal is to understand and define a specific mechanism, to predict future values[18]. One of the new methods developed is the Fuzzy Time Series method, this method is the application of fuzzy mathematics in the field of time series. This method can capture patterns from existing data in the past and then will be used to predict the future[19]. Singh's Fuzzy Time Series is a finding obtained by Shiva Raj Singh which presents a simple computational algorithm to obtain fuzzy relational equations using maximum-minimum acquisition operations that can reduce the difficulty in determining defuzzification. This finding can produce better prediction accuracy compared to the method found by Song and Chissom[20]. The purpose of this research is to see how the fluctuations of the US Dollar exchange rate against the Rupiah for the upcoming period.

In some previous studies, many studies have used Singh's Fuzzy Time Series method and not a few have also compared it with other methods. In research [21] which compares the Fuzzy Time Series methods of Chen, Cheng, and Singh on trend data,. The MAPE obtained from the Chen method is 7.2181%, the Cheng method is 5.7505%, and the Singh method is 2.82%. Then in research conducted by [20], which in his research compared the Fuzzy Time Series Lee and Fuzzy Time Series Singh methods to predict PDAM water usage in DKI Jakarta. The MAPE obtained from the Lee method was 3.696% and the Singh method was 0.875%. It can be concluded that the Fuzzy Time Series Singh method is better used for forecasting because of its higher accuracy compared to other methods. This study contributes by applying the Fuzzy Time Series Singh method to forecast the exchange rate of the Indonesian Rupiah against the US Dollar, demonstrating higher accuracy compared to other methods. The novelty of this research lies in the use of the Fuzzy Time Series Singh method for forecasting exchange rates subjected to high volatility, particularly in the context of the Indonesian economy, an approach that has not been extensively applied in previous studies of a similar nature. This study aims to explore how the fluctuation of the rupiah exchange rate against the US Dollar can be predicted for future periods, offering a systematic approach to evaluate the accuracy of forecasting results using this method. The findings aim to assist investors, importers, exporters, and tourists in making informed budget design decisions amid currency volatility. This research was conducted because there was no currency forecasting using the Singh Fuzzy Time Series method.

2. RESEARCH METHOD

This research uses the Fuzzy Time Series Singh method in forecasting the USD and Yuan exchange rates against the Rupiah. The stages carried out in this forecasting are as shown in Figure 1.

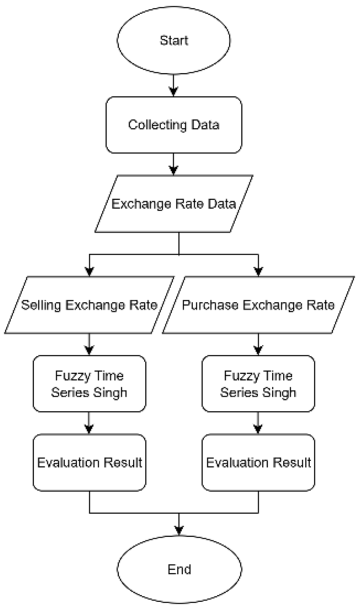

Figure 1. Research Stages

2.1 Data Collection

The data used in this study are daily data on the exchange rate of the rupiah against the US Dollar from January 2, 2024 to January 10, 2025 which obtained from the official website of Bank Indonesia (BI).

Table 1. US Dollar Exchange Rate Data [23]

Date	Selling Rate US Dollar	Purchase Rate US Dollar
2024-01-02	16319,19	15361.81
2024-01-03	16282	15395.64
2024-01-04	16249,84	15417.52
2024-01-05	16273,97	15447.38
2024-01-08	16298,08	15440.41
⋮	⋮	⋮
2024-01-10	15516,19	16156,81

US Dollar exchange rate data obtained from the Bank Indonesia website consists of the selling and purchase rates. This study used 245 datasets.

2.2 Forecasting

In this research, the method used for forecasting is Fuzzy Time Series Singh. The steps in forecasting using Singh's Fuzzy Time Series are as follows.[20].

1. Determining the Universe Set (U)

In determining the universe set (U), it can be done by finding the maximum and minimum values in the historical data. The formula for finding the universe set is as in Equation 1.

$$U = [D_{min} - D_1; D_{max} + D_2] \quad (1)$$

2. Determining the Number and Width of Intervals

To get the value of the number of intervals using the Sturges formula found in Equation 2.

$$n = 1 + 3.3 \log N \quad (2)$$

Where N is the amount of historical data.

To get the width of the interval use the formula in Equation 3.

$$l = \frac{[(D_{max} + D_2) - (D_{min} - D_1)]}{n} \quad (3)$$

Where l is the length of the interval and n is the number of intervals.

3. Performing Fuzzyfication

Fuzzification is the process of mapping numerical values into the fuzzy set of universe U. If a data collected belongs to the interval u_i , then the data is fuzzified into the Fuzzy Logical Relationship (FLR). A_i[24].

4. Determining Fuzzy Logical Relationship (FLR)

Fuzzy Logical Relationship (FLR) is the relationship between each data sequence to the next data sequence formed in a fuzzy set [25].

5. Determining Fuzzy Logical Relationship Group (FLRG)

Fuzzy Logical Relationship Group (FLRG) is the merger of each state shift, namely the current state and the next state.

6. Calculating forecasting results

In Fuzzy Time Series Singh, forecasting results are calculated using a process called defuzzification. This defuzzification is the final step of the fuzzy logic system which aims to produce the results of the forecasting value. The following are the steps in calculating forecasting.

$$D_z = \left| |(E_i - E_{i-1})| - |(E_{i-1} - E_{1-2})| \right| \quad (4)$$

$$X_i = E_i + \frac{D_z}{2} \quad (5)$$

$$XX_i = E_i - \frac{D_z}{2} \quad (6)$$

$$Y_i = E_i + D_z \quad (7)$$

$$YY_i = E_i - D_z \quad (8)$$
$$P_i = E_i + \frac{D_z}{4} \quad (9)$$
$$PP_i = E_i - \frac{D_z}{4} \quad (10)$$
$$Q_i = E_i + 2 \times D_z \quad (11)$$
$$QQ_i = E_i - 2 \times D_z \quad (11)$$
$$G_i = E_i + \frac{D_z}{6} \quad (12)$$
$$GG_i = E_i - \frac{D_z}{6} \quad (13)$$
$$H_i = E_i + 3 \times D_z \quad (14)$$
$$HH_i = E_i - 3 \times D_z \quad (15)$$

After getting the result of the calculation, it will be continued by using the following rule.

$$If\ Xi \geq L[*A_i]\ and\ Xi \leq U[*A_i]$$
$$Then\ R = R + Xi\ and\ S = S + 1$$
$$If\ XXi \geq L[*A_i]\ and\ XXi \leq U[*A_i]$$
$$Then\ R = R + XXi\ and\ S = S + 1$$
$$If\ Yi \geq L[*A_i]\ and\ Yi \leq U[*A_i]$$
$$Then\ R = R + Yi\ and\ S = S + 1$$
$$If\ YYi \geq L[*A_i]\ and\ YYi \leq U[*A_i]$$
$$Then\ R = R + YYi\ and\ S = S + 1$$
$$If\ Pi \geq L[*A_i]\ and\ Pi \leq U[*A_i]$$
$$Then\ R = R + Pi\ and\ S = S + 1$$
$$If\ PPi \geq L[*A_i]\ and\ PPi \leq U[*A_i]$$
$$Then\ R = R + PPi\ and\ S = S + 1$$
$$If\ Qi \geq L[*A_i]\ and\ Qi \leq U[*A_i]$$
$$Then\ R = R + Qi\ and\ S = S + 1$$
$$If\ QQi \geq L[*A_i]\ and\ QQi \leq U[*A_i]$$
$$Then\ R = R + QQi\ and\ S = S + 1$$
$$If\ Gi \geq L[*A_i]\ and\ Gi \leq U[*A_i]$$
$$Then\ R = R + Gi\ and\ S = S + 1$$
$$If\ GGi \geq L[*A_i]\ and\ GGi \leq U[*A_i]$$
$$Then\ R = R + GGi\ and\ S = S + 1$$
$$If\ Hi \geq L[*A_i]\ and\ Hi \leq U[*A_i]$$
$$Then\ R = R + Hi\ and\ S = S + 1$$
$$If\ HHi \geq L[*A_i]\ and\ HHi \leq U[*A_i]$$
$$Then\ R = R + HHi\ and\ S = S + 1$$

In this rule, if the value meets, the value of R corresponds to the result of the calculation and the value of S is 1. If it does not meet, the value of R and S is 0. Then the values of R and S obtained are summed up and calculate the forecasting value like the following Equation:

$$Fj = \frac{R + M[*A_i]}{S + 1} \quad (16)$$

If the values of R and S are 0 then the forecasting value is calculated as the following Equation:

$$Fj = M[*A_i] \quad (17)$$

With :
D_z = relationship between data n, n - 1, and n -2
E_i = n data
E_{i-1} = data to n - 1
E_{i-2} = data to n - 2
F_j= n + 1 forecasting value
$M[*A_i]$ = middle value of the intervalu_i of A_i
$L[*A_i]$ = lower limit of the interval u_i
$U[*A_i]$ = upper limit of the interval u_i

7. Future Forecasting

Data forecasting for the next period is done by combining the forecast data from the last period with the actual data. The combined data is then reprocessed to forecast data for the next period.

2.3 Evaluation of Results

Model evaluation is done to determine the error rate in the forecasting results. This error rate can be measured by calculating the difference between the actual value and the predicted value, known as the error [26]. In this research, the evaluation method used is Mean Absolute Percentage Error (MAPE). MAPE calculates the average of the absolute percentage errors by taking the absolute value of the difference of each period, then dividing it by the actual value of that period [27]. Mathematically, MAPE can be expressed by the following formula [28]:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} \frac{|Y(t) - F(t)|}{Y(t)} \times 100\% \qquad (18)$$

Where:
$Y(t)$ = actual value at the t-th data
$F(t)$ = the value of the forecasting result for the t-th data
n = the number of data
MAPE has criteria for the level of accuracy, which are as follows [29]:

a. Forecasting accuracy is very good if the MAPE value is <10%.
b. Forecasting accuracy is good if the value is 10% ≤ MAPE < 20%.
c. Forecasting accuracy is sufficient if the value of 20% ≤ MAPE < 50%.
d. Forecasting accuracy means inaccurate if the MAPE value is> 50%.

3. RESULTS AND DISCUSSION

This section describes the results of the research flow that has been carried out along with the evaluation results obtained from using this method.

3.1 Forecasting

1. Determining the Universe Set (U)

Based on the US Dollar Selling Rate data, D_{min} is 15167.46 and D_{max} is 16540.29. Based on the USD Purchase Rate data, D_{min} is 15016.54 and D_{max} is 16375.71. The value of D_1 is 0 and D_2 is 0. So that the results universe set of US Dollar selling is [15167.46;16540.29] and universe set of US Dollar purchase rate is [15016.54; 16375.71]. This was also done in research by [30].

2. Determining the Number and Width of Intervals

a. Determine the number of intervals using equation 2.

$$n = 1 + 3.3 \log\log N$$
$$n = 1 + 3.3 \log\log 245$$
$$n = 8.88 \approx 9$$

The calculation shows that the intervals formed from the US Dollar selling rate and purchase rate data are 9 intervals because the amount of data is the same.

b. Determine the width of the interval using the formula from equation 3.

$$l = \frac{[(D_{max} + D_2) - (D_{min} - D_1)]}{n}$$
$$l = \frac{[(16540.29 + 0) - (15167.46 - 0)]}{9}$$
$$l = 152.54$$

From the calculations of the US Dollar selling rate data, the width of each interval is determined to be 152.54. This division of the universe set U into intervals, as shown in Table 2, is crucial for the forecasting analysis. This methodology aligns with previous research [21] and [31]where the Fuzzy Time Series methods were used to categorize data into intervals for predicting economic trends. The calculated midpoints are essential for establishing the foundation for future predictions, similar to how methods like Singh's Fuzzy Time Series are applied in earlier studies.

Table 2. Intervals and Midpoint of US Dollar Selling Rate

Intervals	Midpoint
$u_1 = [15167.46, 15320.00]$	15243.73
$u_2 = [15320.00, 15472.53]$	15396.26
$u_3 = [15472.53, 15625.07]$	15548.80
$u_4 = [15625.07, 15777.61]$	15701.34
$u_5 = [15777.61, 15930.14]$	15853.88
$u_6 = [15930.14, 16082.68]$	16006.41

$u_7 = [16082.68, 16235.22]$	16158.95
$u_8 = [16235.22, 16387.75]$	16311.49
$u_9 = [16387.75, 16540.29]$	16464.02

Meanwhile, the calculation of the interval width and midpoint fot US Dollar purchase rate data is:

$$l = \frac{[(D_{max} + D_2) - (D_{min} - D_1)]}{n}$$

$$l = \frac{[(16375.71 + 0) - (15016.54 - 0)]}{9}$$

$$l = 151.02$$

Similarly, for the US Dollar purchase rate, a value of 151.02 is obtained as the width of each interval. As shown in Table 3, these intervals categorize the purchase rates into classes, with midpoints calculated to represent the central values within each range. This is in line with the method employed by [22] and [32] in comparing Fuzzy Time Series for forecasting, where categorizing data into intervals aids in improving the precision of the forecasting model.

Table 3. Intervals and Midpoint of US Dollar Purchase Rate

Intervals	Midpoint
$u_1 = [15016.54, 15167.56]$	15092.05
$u_2 = [15167.56, 15318.58]$	15243.07
$u_3 = [15318.58, 15469.60]$	15394.09
$u_4 = [15625.07, 15777.61]$	15545.11
$u_5 = [15469.60, 15620.62]$	15696.12
$u_6 = [15771.63, 15922.65]$	15847.14
$u_7 = [15922.65, 16073.67]$	15998.16
$u_8 = [16073.67, 16224.69]$	16149.18
$u_9 = [16224.69, 16375.71]$	16300.20

3. Performing Fuzzification

The fuzzification process for the US Dollar selling and purchase rates is shown in Table 4 and Table 5. These tables categorize the selling and purchase rates into fuzzy sets, with fuzzification values indicating the degree of membership in each set. This process closely follows the established methodology from previous studies, where fuzzification is used to capture the uncertainty in the data. The use of fuzzification here demonstrates the continuation of Singh's method, which has proven effective in enhancing forecasting accuracy as seen in [21], [22] and [33].

Table 4. US Dollar Selling Rate Fuzzification Result

Date	Selling Rate	Fuzzification
2024-01-02	15516.19	A_3
2024-01-03	15550.36	A_3
2024-01-04	15572.48	A_3
⋮	⋮	⋮
2025-01-10	16319.19	A_8

Table 5. US Dollar Purchase Rate Fuzzification Result

Date	Purchase Rate	Fuzzification
2024-01-02	15361.81	A_3
2024-01-03	15395.64	A_3
2024-01-04	15417.52	A_3
⋮	⋮	⋮
2025-01-10	16156.81	A_6

4. Determining Fuzzy Relation Group (FLR)

The FLR relationship formed between fuzzification in consecutive periods is shown in Table 6 (selling rate) and Table 7 (purchase rate). These tables demonstrate how previous fuzzification values influence the current period's fuzzification, capturing the dynamics of the exchange rate shifts. This method of analyzing relationships over time is consistent with the FLR methodology used in earlier research, where the transition from one fuzzification level to another was crucial for improving predictive accuracy[33]

Table 6. FLR US Dollar Selling Rate

Date	Fuzzification	FLR
2024-01-02	A_3	
2024-01-03	A_3	$A_3 \rightarrow A_3$
2024-01-04	A_3	$A_3 \rightarrow A_3$
⋮	⋮	⋮
2025-01-10	A_8	$A_8 \rightarrow A_8$

Table 7. FLR US Dollar Purchase Rate

Date	Fuzzifikasi	FLR
2024-01-02	A_3	
2024-01-03	A_3	$A_3 \rightarrow A_3$
2024-01-04	A_3	$A_3 \rightarrow A_3$
⋮	⋮	⋮
2025-01-10	A_8	$A_8 \rightarrow A_8$

5. Determining Fuzzy Logical Relationship Group (FLRG)

The FLRG results are presented in Table 8, combining both the selling and purchase rates. The shared FLRG values show the transition between fuzzification levels for both rates. This combined approach, as seen in Table 8, highlights the connection between selling and purchasing rates and reinforces the predictive capabilities discussed in [34], where similar patterns were observed when analyzing fuzzy relationships

Table 8. FLRG Selling Rate and Purchase Rate

Group	**FLRG**
G_1	$A_1 \rightarrow A_1, A_2$
G_2	$A_2 \rightarrow A_1, A_2, A_3$
G_3	$A_3 \rightarrow A_2, A_3, A_4$
G_4	$A_4 \rightarrow A_2, A_3, A_4, A_5$
G_5	$A_5 \rightarrow A_4, A_5, A_6$
G_6	$A_6 \rightarrow A_4, A_5, A_6, A_7, A_8$
G_7	$A_7 \rightarrow A_6, A_7, A_8$
G_8	$A_8 \rightarrow A_7, A_8, A_9$
G_9	$A_9 \rightarrow A_8, A_9$

6. Forecasting result

The forecast values for both the US Dollar selling and purchase rates are shown in Table 9 and Table 10. These results, generated using Python software, are based on previous fuzzification data and demonstrate the forecasting model's ability to predict future exchange rates. The methodology mirrors the predictive approaches used in past research, where Fuzzy Time Series methods were employed to forecast trends with high accuracy, similar to findings in [21] , [22] and [35]

Table 9. Forecast Selling Rate

Date	Selling Rate	Forecast
2024-01-02	15516.19	NaN
2024-01-03	15550.36	NaN
2024-01-04	15572.48	NaN
2024-01-05	15602.63	15570.66
2024-01-08	15595.59	15596.14
⋮	⋮	⋮
2025-01-09	16282.00	16254.58
2025-01-10	16319,19	16284.27

Table 10. Forecast Purchase Rate

Date	Purchase Rate	Forecast
2024-01-02	15361.81	NaN
2024-01-03	15395.64	NaN
2024-01-04	15417.52	NaN
2024-01-05	15447.38	15415.72
2024-01-08	15440.41	15440.94
⋮	⋮	⋮
2025-01-09	16282.00	16092.85
2025-01-10	16319,19	16122.24

After calculating the forecast, a comparison will be made between the actual data and the prediction using a plot. The following is a plot comparing the actual data and the prediction.

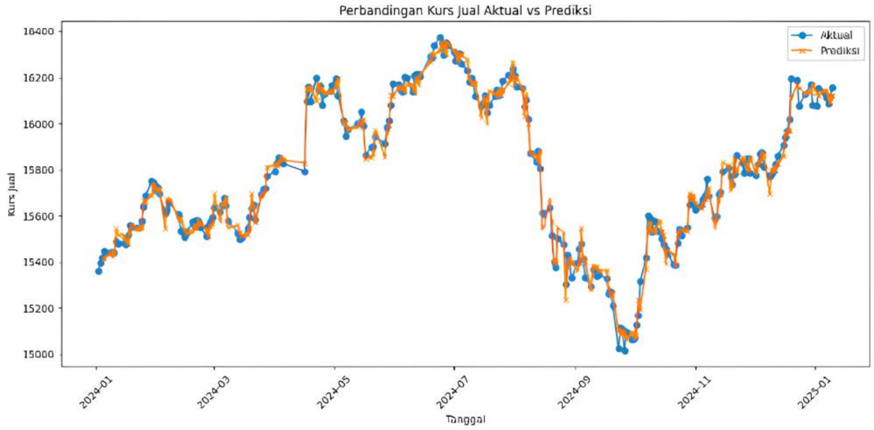

Figure 2. Comparison of Actual and Forecasting Data US Dollar Selling Rate

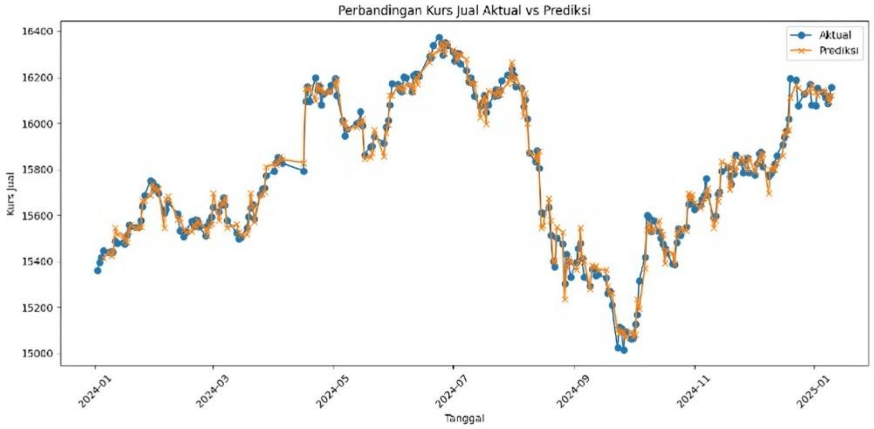

Figure 3. Comparison of Actual and Forecasting Data US Dollar Purchase Rate

Figures 2 and 3 compare the forecasted results with the actual US Dollar selling and buying rates. The forecast closely follows the actual data pattern from January 2, 2024, to January 10, 2025, showing that the forecasting model captures the fluctuations accurately. This alignment is consistent with earlier research findings, where Singh's method was highlighted for its ability to closely predict real-world data. The comparison here further validates the robustness of the forecasting model [36]

7. Future forecasting

After model evaluation, Table 11 presents the forecast for the next 5 periods. The results are aligned with previous studies, where future forecasting extends the predicted trends. These forecast values, based on the fuzzification levels and the established model, provide insight into the potential future movements of the US Dollar exchange rates, similar to the forecasting methodologies applied in earlier studies [32]

Table 11. Future Forecasting

Date	Selling Rate	Purchase Rate
2025-01-13	16251.16	16089.46
2024-01-14	16255.80	16094.05
2025-01-15	16278.45	16116.48
2025-01-16	16285.71	16123.67
2025-01-17	16287.69	16125.63

3.2 Evaluation of Results

The MAPE value can describe the average error between the forecast data and the actual data in percentage form. The following are the evaluation results for the selling rate and buying rate. The MAPE calculation results for the selling rate and buying rate forecast data are 0.58%, which is below 10%, meaning that the selling and purchase rate forecast is very good.

4. CONCLUSION

Based on the research results obtained, the forecast results for the next five periods tend to increase significantly. This is because the calculations in this method are highly dependent on previous values, especially when the forecasting process is carried out sequentially using the prediction results themselves. The researchers' recommendation for the Singh Fuzzy Time Series method is that this method is more accurate for forecasting one or two periods in advance and uses exogenous variables for forecasting. Therefore, other methods such as ARIMA, Random Forest, and even hybrid methods for time series data forecasting can be tried for forecasting the next few periods and as a comparison with the Singh Fuzzy Time Series method. The Singh Fuzzy Time Series method can also be tried and applied to other case studies.

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