Optimization of fuzzy inference system by using table look-up method to predict white sugar price in the international market

To cite this article: N Azizah et al 2018 J. Phys.: Conf. Ser. 1097 012074

View the article online for updates and enhancements.
Optimization of fuzzy inference system 
by using table look-up method to predict white sugar price in 
the international market

N Azizah1, K A’yun2, T W Septiarini3, D U Wutsqa4 and A M Abadi4

1 Graduate Programs of Mathematics Education Yogyakarta State University, 
Kolombo Street 01, Sleman, Yogyakarta, Indonesia
2 Graduate Programs of Mathematics Gadjah Mada University, Sleman, Yogyakarta, 
Indonesia
3 Departments of Mathematics and Computer Science, Faculty of Science and 
Technology, Prince of Songla University, Pattani, Thailand
4 Mathematics Department, Faculty of Mathematics and Science Yogyakarta State 
University, Kolombo Street 01, Sleman, Yogyakarta, Indonesia

nur.azizah2016@student.uny.ac.id

Abstract. The study aims to investigate the most optimum rules of fuzzy inference 
systems to forecast the white sugar price in the international market. The fuzzy rules are
optimized by using a table look-up method. As a comparison, we also employ fuzzy 
time series methods that developed by Chen, Singh, and Heuristic. The main differences
among the four methods are on the inputs determination for prediction and on the 
algorithm to calculate the prediction. The performance of the method is evaluated using 
MAPE (Mean Absolute Percentage Error). The MAPE values of white sugar price 
forecasting yielded by a fuzzy inference system with table lookup are 2.83 % on training 
data and 7.66 % on checking data. Furthermore, the MAPE values resulted by fuzzy 
time series model of Chen, Singh, and heuristic are 8.52%, 8.62% and 8.01% on training 
data, and 6.44%, 6.47%, and 6.44% on checking data, respectively. The table lookup 
delivers the highest performance on the training data, while it delivers the lowest 
performance on checking data. However, the fluctuation of its forecasts is more 
reasonable, since it follows the fluctuation of the actual data, while the other three 
methods deliver constant forecasts which are not reasonable.

1. Introduction
White sugar is a commodity which has an important role in the world. It produces a lot of income for 
many countries. White sugar industries can absorb many workers. In Indonesia, white sugar becomes 
one of the strategic economic commodities. Historical records showed that the white sugar became the 
oldest and leading industry since the days of colonialism the pre-World War II era of 1930-1940, and 
Java became one of the largest white sugar producers in the world, as well as the second largest exporter 
of white sugar after Cuba. The on-peak production was achieved in 1931 with 3 million tons per year 
and approximately 2.40 million tons is exported. At that time, a total of 179 white sugar mills were 
operated in the Indonesian territory with productivity levels reached 14.80 tons of white sugar per
hectare or 130 tons of white sugarcane per hectare [1]. Nevertheless, white sugar market conditions and the Indonesian white sugar industry are not always running well. White sugar prices in the international market continued to decline to the lowest point in 1999. This gave a negative effect to the white sugar industry in Indonesia. The decline of white sugar prices is mainly due to almost all major producing countries and major consumers making substantial interventions to the white sugar industry and trade [1]. It clearly shows that the price of white sugar in the international market has a major impact on the development of the white sugar industry in the country. Therefore it is important to know the international white sugar price, so we can prepare the planning of production and protection efforts to guarantee the stability of domestic white sugar industry.

White sugar price data are published every month, so it corresponds to time series data. Predicting white sugar price in the international market can be done through various time series forecasting methods. The very famous classical method is an Autoregressive Integrated Moving Average (ARIMA). Now, many researches develop methods using soft computing approach. These approaches include a neural network (NN), a fuzzy inference system, and a combination of neural network and fuzzy logic which is called neuro fuzzy method. Predicting consumer price index of education, recreation, and sports in Yogyakarta [2], foreign tourist flows to Yogyakarta [3] and Islamic Month calendar effect in tourism data of Prambanan temple [4] have applied neural network, and predicting number of train passengers in Yogyakarta [5] has applied neuro fuzzy. The fuzzy inference system has been used for predicting silver prices [6], the number of fertilizers ordered [7], and the production of pottery souvenir [8]. The fuzzy inference system can also be used not only for time series prediction, but also can be used for classification the tomatoes ripeness [9], and for decision making in the selection of the used car in Sleman Yogyakarta [10]. A specific fuzzy application on time series data is known as fuzzy time series. Many researchers have developed fuzzy time series models to predict many things [11], such as predicting Jakarta Composite Index [12], the number of Trans Jogja passengers [13], stock price of Bank Mandiri (Persero) Tbk (BMRI.JK) [14] and enrollment at the Alabama University [15-18]. Some of the methods that can be used in fuzzy time series analysis are Chen [16], Heuristic [17] and Singh [18, 19]. In this study, we construct a fuzzy inference system model in predicting white sugar price in international markets. The problems in fuzzy inference system are the determination of the number of the rules and the selection of the rules involved in the system. Here, we employ lookup tables to solve those problems. The fuzzy inference system consists of four main components: fuzzification, rules, inference, and defuzzification [20]. The proposed model is compared to the fuzzy time series analysis of Chen, Heuristic, and Singh methods. The comparison is based on the Mean Absolute Percentage of prediction resulted from the method.

2. Fuzzy time series analysis

Fuzzy time series is a forecasting method using time series data. Some of the methods that can be used in the fuzzy time series are Chen[16], Heuristic[17], and Singh [18, 19]. These three methods have similarities in the procedure of compiling the system but have differences in the number of inputs involving in the models, and calculation algorithm. The procedure for preparing the system is (1) Define the universe of discourse and the intervals of the input-output variables; (2) Define the fuzzy sets and fuzzify the data of the input-output variables; (3) Define the fuzzy relationships by rules; (4) Forecast [16-19].

The first difference of the three methods is in the input determination. Chen method is a first order fuzzy time series model [16]. Let \( x_t \) represents the time series variable at time \( t \). In Chen method, the variable at time lag \( t - 1 \) denoted as \( x_{t-1} \) is set as the influencing factor of \( x_t \) [18]. The heuristic method is basically a fuzzy time series first order model similar to the Chen model and has easy calculations and better estimates. In a Heuristic model, domain-specific knowledge (or heuristics) is integrated with the Chen model to increase estimates [17]. The Singh method is a fuzzy time series of third order models, this means we predict the value of variable \( x_t \) by using the values of variables at time lag \( t - 1, t - 2 \), and \( t - 3 \) denoted as \( x_{t-3}, x_{t-2} \) and \( x_{t-1} \) [18, 19].
The differences of Chen method with other methods is in the process of calculation algorithm. The calculation by using Chen method needs to consider the following conditions (1) If the fuzzified data of year \(i\) is \(A_j\), and there is only one fuzzy logical relationship in the fuzzy logical relationship groups in which the current state of the data is \(A_k\), which is shown as follows \(A_j \rightarrow A_k\), where \(A_j\) and \(A_k\) are fuzzy sets and the maximum membership value of \(A_k\) occurs at interval \(u_k\), and the midvalue of \(u_k\) is \(m_k\), then the forecasted data of year \(i + 1\) is \(m_k\); (2) If the fuzzified data of year \(i\) is \(A_j\), and then are the following fuzzy logical relationships in the fuzzy logical relationship groups in which the current states of the fuzzy logical relationships are \(A_j\), respectively, which is shown as \(A_j \rightarrow A_{k1}, A_j \rightarrow A_{k2}, \ldots, A_j \rightarrow A_{kp}\) where \(A_j, A_{k1}, A_{k2}, \ldots, A_{kp}\) are fuzzy sets, and the maximum membership values of \(A_j, A_{k1}, A_{k2}, \ldots, A_{kp}\) occur at intervals \(u_1, u_2, \ldots, u_p\), respectively, and the midvalue of \(u_1, u_2, \ldots, u_p\) are \(m_1, m_2, \ldots, m_p\), respectively, then the forecasted data of year \(i + 1\) is \(\frac{m_1 + m_2 + \ldots + m_p}{p}\); and (3) If the fuzzified data of year \(i\) is \(A_j\), and there do not exist any fuzzy logical relationship groups whose current state of data is \(A_j\), where the maximum membership value of \(A_j\) occurs at interval \(u_j\), and the midvalue of \(u_j\) is \(m_j\), then the forecasted data of year \(i + 1\) is \(m_j\) [16].

Slightly different from Chen method, the calculation in Heuristic method still uses the same principle as in Chen method. This study assumes that there is a heuristic knowledge showing the increase or decrease of data for the next year. With this characteristic, the Heuristic model yields better prediction than the other models [17]. Meanwhile, Singh method has considerable differences in the computational algorithm as illustrated in the process of rule arrangement for forecasting enrollment in the University of Alabama. Before forecasting, the fuzzification process of actual data is performed and established logical fuzzy relations using rules “If \(A_i\) is the fuzzy production of year \(n\) and \(A_j\) is the fuzzify production of year \(n + 1\), then the fuzzy logical relation is denoted as \(A_i \rightarrow A_j\). Here \(A_i\) is called current state and \(A_j\) is next state” [18].

3. Fuzzy inference system

Fuzzy inference system (FIS) is a system that can be used to forecast the time series data. Fuzzy inference system has three important points to note, they are setting of the input-output variables, the fuzzy set defined in the input-output variables and the rules used in the inference [21]. In fuzzy systems, the fuzzy membership functions of input and output parameters are determined based on the survey results of a particular area and with the help of expert knowledge [21]. Furthermore, a set of if-Then fuzzy rules is used to represent the structure of the fuzzy model. The fuzzy rule has two elements, antecedent and the consequence. The antecedent variable contains information about the operating conditions of the process. The consequence is an element to show the model validity for given operating conditions [22]. Lookup tables are used in the rule formation process. In this study, the process of predicting the white sugar price in the international market is illustrated in Figure 1.

![Figure 1. Fuzzy Inference System](image-url)
The lookup tables are developed through five steps i.e (1) Define fuzzy sets that is cover the input and output spaces, (2) Develop rule from one input-output pair, (3) Assign a degree of every rule generated in step 2, (4) Create the fuzzy rule to forecasting and (5) Construct the fuzzy system based on the fuzzy rule base [23]. In the compiled model, each rule has the same weight so that step 3 is not performed. The building of a fuzzy system proceeds as follows.

Step 1: Determine the system of inputs and output. The number of inputs in the forecast depends on the parameters model used. At this step, the inputs are set based on the time series theory. The data are further split into training data (TRD) and checking data (CHD). Training data serve to build the system, checking data intend to check the system that has been made [23].

Step 2: Determine the universal set of inputs and output. The set of universes in this model is determined by $U = [D_{min} - D_1, D_{max} - D_2]$ where $D_1$ and $D_2$ are two proper positive numbers. It is important to note that the universal set compiled contains all the data that will be used for predicting[23].

Step 3: Define the fuzzy set membership function on inputs and output. In this model, the membership functions used in the inputs and output are the pseudo-trapezoid membership function [23].

Step 4: Define fuzzy rules by following five steps in lookup tables. After fuzzification, then the rules are made. The established rules represent the relationship between input and output. Each rule is in implication form. The operator used to connect between two inputs is the AND operator, and that maps between input-output is IF-THEN. Propositions that follow the IF are called antecedents, whereas the propositions that follow THEN are consequent. In the process of making the rules, if we find several rules with the same antecedents producing different consequences, we need reduce the rule by taking the highest degree of membership of the rule [23].

Step 5: Perform the Mamdani inference. Mamdani inference uses min implication function and composition between max rules. In the min implication function, it will be taken the minimum value of the fuzzy set of each rule. The inference is done through formula (1) [23].

$$\mu_{B'}(y) = \max_{i=1}^{M} \sup_{x \in U} \min(\mu_{A'_i}(x), \mu_{A'_i}(x_1), ..., \mu_{A'_i}(x_n), \mu_{B'_i}(y))$$  \hspace{1cm} (1)

Step 6: Perform defuzzification with the center of gravity defuzzifier method. The fuzzy set obtained from the inference process will be changed using the defuzzifier to be a crisp set. The centroid defuzzifier is expressed as[23].

$$y^* = \frac{\int_{y} y \mu_{B'}(y) dy}{\int_{y} \mu_{B'}(y) dy}$$  \hspace{1cm} (2)

where $\mu_{B'}(y)$ is a fuzzy set membership function after inference. The white sugar price prediction in international market $\hat{x}_{(t)}$ is the crisp set obtained using formula (2).

4. Research method
This study is conducted to see how fuzzy inference system by using a look up table can predict the price of white sugar on the international market. The data of white sugar prices in the international market in USD / Ton are published by the Ministry of Trade of the Republic of Indonesia [24]. The procedure of fuzzy inference system by using a look up table is performed using all the steps described above. The prediction accuracy of the fuzzy inference system by using a look up table is compared to the prediction accuracies of Chen, Heuristic, and Singh methods. The proposed method to predict the white sugar price is constructed based on theories in time series analysis, and then perform the fuzzy inference system by using a look up table. The steps are presented in the flowchart in Figure 2.
In time series analysis, a data stationary is a required assumption to obtain the proper model. So, we need to check the data stationary before the prediction process. A time series data is said to be stationary if the mean, covariance and variance are constant over time. The stationary test is done by the Augmented Dickey Fuller (ADF) test [25]. In the Augmented Dickey Fuller test, the data are stationary if the p-value <0.05. After doing this test, if the data are stationary then the prediction process can be continued. If the data have not been stationary, it needs data differencing. The stationary of the differenced data is then tested again. After obtaining the stationary data, we have to specify the inputs of fuzzy inference system for the differenced data. We adopt the procedure in classical time series analysis (Autoregressive model) that the inputs are determined by the partial autocorrelation function (PACF) analysis. The inputs are the time lags of the variable whose partial autocorrelations are significantly different from zero [26]. The next step is processing the inputs-output pair by using fuzzy inference system with a look up table to get the prediction values and calculate the MAPE values using formula (3) [23]

\[
\text{MAPE} = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{x_t - \hat{x}_t}{x_t} \right|
\]  
(3)

Where \(x_t\) is actual value in time period \(t\) and \(\hat{x}_t\) is prediction value in time period \(t\).

5. Empirical result
The original data used in this research are time series data of sugar prices in USD / Ton in the international market. They are available in the book published by the Ministry of Trade of the Republic of Indonesia. The data consist of 47 data and are reported from January 2012 to November 2015. Time series plot of the original data are presented in Figure 3 (a). The plot shows a non-stationary pattern since it shows the different data fluctuations in different time periods and tends to decrease. The result of Augmented Dickey Fuller test is \(p = 0.5827\). It indicates that the original data are not stationary. Therefore, it needs to difference the original data. In this study, we perform differencing processes at time lag 1 and then at time lag 4. The differenced data are tested using Augmented Dickey Fuller which provides value \(p = 0.0134\). Now, we have obtained the stationary time series data.

The process of forecasting the sugar price in the international market with a fuzzy inference system model using lookup tables starts with the determination of the inputs and outputs of the differenced data.
To specify the inputs, we observe the plot of the partial autocorrelation function which is presented in Figure 3 (b). The Figure 3 (b). depicts that partial autocorrelation functions at time lag 1 and lag 2 are different from zero. This leads to the inputs \( x_{t-1} \) and \( x_{t-2} \) which influence the output \( x_t \). After this process, we have 40 pairs of inputs-output of the differenced data. We split the data as 32 pairs of inputs output for training data and 8 pairs of inputs output for checking data.

Figure 3. (a) Actual Data of White Sugar Prices, (b) The PACF Plot of Differenced White Sugar Price Data

The inputs and output variables of the system are in crisp numbers which have the same universal set \([-78, 66]\). So, they have the same fuzzy membership number. In this paper, we use a triangle member function

\[
\mu_{A_1}(x) = \begin{cases} 
\frac{-60 - x}{18} & -78 \leq x \leq -60 \\
0 & x \geq -60 
\end{cases} 
\]

\[
\mu_{A_2}(x) = \begin{cases} 
\frac{x + 78}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 78 \\
\frac{x - 78}{18} & x \geq 60 
\end{cases} 
\]

\[
\mu_{A_3}(x) = \begin{cases} 
\frac{x + 60}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 42 \\
\frac{x - 60}{18} & x \geq 24 
\end{cases} 
\]

\[
\mu_{A_4}(x) = \begin{cases} 
\frac{x + 42}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 24 \\
\frac{x - 42}{18} & x \geq 12 
\end{cases} 
\]

\[
\mu_{A_5}(x) = \begin{cases} 
\frac{x + 24}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 12 \\
\frac{x - 24}{18} & x \geq 6 
\end{cases} 
\]

\[
\mu_{A_6}(x) = \begin{cases} 
\frac{x + 12}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 6 \\
\frac{x - 12}{18} & x \geq 3 
\end{cases} 
\]

\[
\mu_{A_7}(x) = \begin{cases} 
\frac{x + 6}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 3 \\
\frac{x - 6}{18} & x \geq 1 
\end{cases} 
\]

\[
\mu_{A_8}(x) = \begin{cases} 
\frac{x + 3}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 3 \\
\frac{x - 3}{18} & x \geq 1 
\end{cases} 
\]

\[
\mu_{A_9}(x) = \begin{cases} 
\frac{x + 1}{18} & -60 \leq x \leq -60 \\
\frac{18}{18} & 0 \leq x \leq 1 \\
\frac{x - 1}{18} & x \geq 0 
\end{cases} 
\]

and set nine fuzzy sets \( A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8 \) and \( A_9 \). They are shown on Figure 4.

Figure 4. Fuzzy sets of Input-Output Variables
The next step is composing fuzzy rules by using the lookup table. The rules are generated only on the training data set. Since we have 32 pairs of inputs-output, we initially compose 32 rules. Several rules denote contradictory rules since the same inputs produce the different outputs. In this case, we select the rule having the maximum degree of membership and remove the rule with less degree of membership. The result of the rule reduction by using the lookup table is shown in Table 1.

**Table 1.** The Rules using FIS with table lookup.

| Rule | Input | Output | Rule | Input | Output |
|------|-------|--------|------|-------|--------|
| 1    | A2    | A4     | 12   | A6    | A3     |
| 2    | A2    | A9     | 13   | A6    | A5     |
| 3    | A3    | A6     | 14   | A6    | A6     |
| 4    | A3    | A7     | 15   | A6    | A5     |
| 5    | A4    | A4     | 16   | A7    | A2     |
| 6    | A4    | A6     | 17   | A7    | A3     |
| 7    | A4    | A7     | 18   | A7    | A4     |
| 8    | A5    | A4     | 19   | A7    | A5     |
| 9    | A5    | A5     | 20   | A7    | A4     |
| 10   | A5    | A6     | 21   | A9    | A2     |
| 11   | A5    | A9     | 22   | A9    | A3     |

To generate the prediction, we implement the Mamdani method which produces the fuzzy output, then perform defuzzification to the fuzzy output using the center of gravity defuzzifier method. The prediction value of the white sugar price in the international market is the crisp output resulted by the formula of the center of gravity defuzzifier (2). The prediction values on checking data set are calculated using the rules developed on training data set as presented in Table 1. Thus, we don’t need to generate the rules on checking data set. The accuracy of the model is evaluated using MAPE criteria. The accuracy of the model is compared to the accuracy of Chen, Heuristic, and Singh models. The MAPE values for training and checking data for all models are given in Table 2.

**Table 2.** The MAPE (%) values of the white sugar price predictions

| Method          | MAPE  | MAPE  |
|-----------------|-------|-------|
|                 | Training | Checking |
| FIS with table lookup | 2.83   | 7.66   |
| Chen            | 8.52   | 6.44   |
| Heuristic       | 8.62   | 6.47   |
| Singh           | 8.01   | 6.44   |

Table 2. reveals that FIS with lookup table method surpasses to other models on training data. The method performs very well with small MAPE value of 2.83 %, much smaller than the MAPE values of other methods which have values around 8 %. On checking data, the Chen, Heuristic, and Singh methods deliver almost the same MAPE values around 6 %, while the FIS with lookup table method delivers slightly greater MAPE value 7.66%.

The pattern of prediction result can be perceived using time series plot. Figure 5. (a). demonstrate the time series plots of prediction values and the actual values for training data. As a comparison, the prediction results of Chen, Singh, and Heuristic methods are provided in Figure 5. (b), (c), (d).
Figure 5. shows that all the methods can well predict the white sugar price, but the plot of prediction values resulted by inference system with table lookup is closer to the actual values than prediction values resulted by the other methods.

In this paper, the prediction results on checking data are given for differenced data, not for original data. The prediction results of four methods for checking data are presented in Figure 6. As described in Table 2 that the fuzzy time series methods produce smaller MAPE values than FIS, but Figure 6 shows that the fuzzy time series methods deliver constant predictions. These results are not realistic because different inputs produce the same outputs and their patterns are totally different from the non-constant pattern of the actual differenced data. The pattern of the prediction values on checking data yielded by FIS with table lookup is more realistic and has the similar fluctuation to the actual data. Thus, we still can conclude that the FIS with table lookup is a more preferable method to predict the white sugar prices in the international market.

Figure 5. (a) Prediction results of inference system with table lookup, (b) Chen, (c) Singh, (d) Heuristic methods on training data.
6. Conclusion
In this paper, we proposed fuzzy inference systems to predict sugar white prices in international market. The rules arrangement is optimized using a table look-up method. The prediction result is compared to the results of the fuzzy time series methods of Chen, Singh, and Heuristic. The differences among the four methods lie in the determination of the inputs and the process of the rules arrangement. The input in the proposed method is the time lag variables whose partial autocorrelation values are significantly different from zero. Meanwhile, in fuzzy time series analyze, the input on Chen and heuristic method is the variable at time lag t-1 and the input on Singh method are the variables at time lag $t - 1$, $t - 2$, and $t - 3$. This study shows that the use of lookup tables in optimizing the rules arrangement shows satisfactory results. Based on the MAPE values, the proposed method delivers the smallest value compared to other models on training data. On the checking data, even though the error of the proposed method is slightly larger than the other three methods, the pattern of the prediction is more reasonable, since the other methods produce constant predictions.
References

[1] Marpaung Y T F, Hutagaol P, Limbong W H and N Kusnadi 2011 *Indonesian. J. Agric. Econ.* **2** 1
[2] Wutsqa D U, Kusumawati R, and Subekti R 2014 *The 10th Proc. Int. Conf. on Natural Computation* (Xiamen, China/IEEE) pp 192-196
[3] Yasfi S M and Wutsqa D U 2015 *The 1st Inter: Conf. on Statistical Methods in Engineering Science Economy and Education* (Yogyakarta) pp 1-6
[4] Wutsqa D U and Abadi A M 2012 *The 2nd Inter. Conf. on Computation for Science and Technology* (Turkey) pp 1-9
[5] Abadi A M and Wutsqa D U 2014 *Inter. Conf. on Fuzzy Systems and Knowledge Discovery* (China/IEEE) pp 178-182
[6] Ralmugiz U, Wahyudi E and Abadi A M 2017 *Inter. Conf. on Research, Implementation, and Education of Mathematics and Science* (Yogyakarta) pp 107-116
[7] Fitriani, Kurniasih N R, Mandini G W and Abadi A M 2017 *Inter. Conf. on Research, Implementation, and Education of Mathematics and Science* (Yogyakarta) pp 27-34
[8] Indiani V, Yanianti A, Widiawati S D and Abadi A M 2017 *Inter. Conf. on Research, Implementation, and Education of Mathematics and Science* (Yogyakarta) pp 117-124
[9] Wahyudi W, Ralmugiz U, Nurwijayanti K and Abadi A M 2017 *Inter. Conf. on Research, Implementation, and Education of Mathematics and Science* (Yogyakarta) pp 9-20
[10] Agus, Ningsih S W, Fitriani and Abadi A M 2017 *Inter. Conf. on Research, Implementation, and Education of Mathematics and Science* (Yogyakarta) pp 35-44
[11] Abadi A M, Subanar, Widodo and Saleh 2009 *J. Ilmu Dasar* **10** 190
[12] Abadi A M, Nurhayadi and Musthofa 2017 *J. Eng. Appl. Sci.* **12** 5672
[13] A’yun K, Abadi A M and Saptaningtyas F Y 2015 *Inter. J. Appl. Phys. Math* **5** 76
[14] Nurhayadi, Subanar, Abdurakhman and Abadi A M, 2014 *Appl. Math. Sci.* **8** 2113
[15] Nurhayadi, Subanar, Abdurakhman and Abadi A M, 2014 *J. Math. Stat.* **10** 26
[16] Chen S M 1996 *Fuzzy set and System* **81** 311
[17] Huargh K 2001 *Fuzzy set and System* **123** 369
[18] Singh S R 2008 *Fuzzy set and System* **79** 539
[19] Singh S R 2007 *Appl. Math. Comput.* **186** 330
[20] Singhala P, Shah D N and Patel B 2014 *Inter. J. Instrum. Control System* **4** 1
[21] Sarkar A, Sahoo G and Sahoo U C 2012 *Inter. J. on Soft Computing* **3** 1
[22] Sharma B, Katiyar V K and Gupta A K 2014 *Inter. J. Comput. Appl.* **107** 1
[23] Li-Xin W 1997 *A course in fuzzy systems and control* (Hongkong: Prentice-Hall International)
[24] Kementrian Perdagangan [Ministry of Trade] Indonesia 2015 *Analisis perkembangan harga bahan pangan pokok di pasar domestik dan internasional* [Analyze of staple food prices development in domestic and international markets] (Jakarta: Kementrian Perdagangan [Ministry of Trade] Indonesia)
[25] Rusdi 2011 *Statistika* **11** 67
[26] Makridakis S, Wheelwright S C and McGee V E 1983 *Forecasting: methods and application* (New York, NY: Wiley)