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Defuzzification Methods Comparison of Mamdani Fuzzy Inference System in Predicting Tofu Production

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ABSTRACT

One of the tofu-producing companies in Kupang City is Bintang Oesapa. With the Covid-19 pandemic, the factory needs to reconsider the amount of production by taking into account the unpredictability of demand and resources to minimize losses due to excessive accumulation or shortages of supplies. In determining the amount of production, Mamdani's Fuzzy Inference System (FIS) can be used, which is a method for the analysis of an uncertain system. This method has three stages in the process of decision making, namely fuzzification, inferencing and defuzzification. In the defuzzification stage, the FIS Mamdani has five methods, namely Centroid, Bisector, Mean of Maximum (MOM), Smallest of Maximum (SOM), and Largest of Maximum (LOM). This study discusses an application of FIS Mamdani with five defuzzification methods for determining daily tofu production. The purpose of this study is to offer a solution by first comparing the five defuzzification methods in assessing the amount of tofu production at the Bintang Oesapa factory and then determining that which is most appropriate. The input variables used in this research are the amount of demand and the amount of available stock, while the amount of production is our variable of interest. The results showed that the best defuzzification method was the MOM method with an accuracy level of 94.73% and a small error value, 5.27%. The MOM defuzzification is expected to aid decision makers in determining the best amount of production during the pandemic.

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A. INTRODUCTION

The current Covid-19 pandemic has had adverse effects on the national economy and hence East Nusa Tenggara as well. The pandemic can precipitate a large economic crisis, which has been marked by the cessation of production activities at various companies, the decline in public consumption levels and consumer confidence index.

The Covid-19 pandemic has urged Indonesian government to implement a Large-Scale Social Restriction (LSSR) policy. This policy will cause the economy in Indonesia to decline, and especially has a big impact on Micro, Small and Medium Enterprises (MSMEs) (Bahtiar, 2021). One of the MSMEs operating under Covid-19 is the Bintang Oesapa Tofu Factory MSMEs which is located in Kupang City, East Nusa Tenggara.

The Bintang Oesapa Tofu Factory is one of the many factories that produce tofu in Kupang City. In the tofu production process, the factory produces according to market demand. Based on the interview process with the factory, it is known that on average, it can produce approximately 40,000 pieces in a day. However, due to the pandemic, production has been drastically reduced to merely 20,000-30,000 pieces per day. This is because the remaining stock is around 1000-6000 pieces per day. The Bintang Oesapa Tofu

Factory needs a plan to determine the amount of production such that market demand can be met and that profits remain optimal.

Maximum profit is achieved from maximum sales. Maximum sales means being able to meet existing demand. If the amount of goods/service provided by the company is less than the demand, the company will lose the opportunity to get maximum profit. Conversely, if amount of goods/service offered is much more than demand, the company will experience losses. Therefore, planning the amount of production in a company is very important in order to meet market demand and in the right amount. Factors that need to be considered in determining the number of products include: the amount of leftovers from previous period and the estimated demand for the next period (Abrori and Primahayu, 2015). During this pandemic, of course, these factors become uncertain or erratic.

Fuzzy set theory is a method for the analysis of uncertain systems which has more than one method in calculating the estimation of a case. In estimating the amount of tofu production at the Bintang Oesapa tofu factory, no prediction method was used previously, especially the fuzzy set theory method. The decision-making process using fuzzy set theory is called the Fuzzy Inference System (FIS). There are 3 FIS methods that can be used in determining the final decision of a problem, namely the Tsukamoto Method, the Mamdani Method and the Sugeno Method (Priyo, 2017). The three methods generally has the same stages, namely fuzzification, inferencing and defuzzification, but have a different calculation method for each stage.

(Rahakbauw, 2015) applies the FIS Sugeno method to predict the amount of bread production by paying attention to inventory data and requested data and an accuracy rate of 86.92%. Then (Rahakbauw et al., 2019) applied the Mamdani FIS method to predict the amount of rubber production by taking into account the availability of data and the requested data and an accuracy rate of 87.83%. Meanwhile, (Mada et al., 2021) compared the predictions for the amount of brick production with the Mamdani FIS and Tsukamoto FIS methods and obtained an accuracy of 99.96% for the Mamdani FIS method and 99.92% for the Tsukamoto FIS method.

In the decision-making process, especially at the defuzzification stage, the Mamdani FIS method has five methods that can be used, namely Centroid, Bisektor, Mean of Maximum (MOM), Smallest of Maximum (SOM), Largest of Maximum (LOM) (Sutikno, 2011). So far, the most frequently used defuzzification method is the Centroid method. There are several previous studies such as (Wardani et al., 2017) in predicting the amount of palm oil production, (Santya et al., 2017) in predicting the amount of banana chips production, (Sari, 2021) in predicting the amount of salt production, (Susetyo et al., 2020) in predicting t-shirt production, (Sahulata et al., 2020) and (Rianto and Manurung, 2022) in predicting the amount of bread production, all using the Centroid defuzzification method of the Mamdani. Hence, we may ask why in production always use the Centroid Mamdani type in defuzzification method? What about the other four Mamdani defuzzification methods?

This research aims to compare the amount of production calculated by the five Mamdani defuzzification methods. To determine the best method, the magnitude of error from the prediction results of the five methods will be calculated using the Mean Absolute Percentage Error (MAPE) formula. The smaller the MAPE value obtained, the better the prediction results (Yusuf et al., 2017).

B. LITERATURE REVIEW

1. Fuzzy Set

In (Rahakbauw, 2015), it has been explained that the concept of fuzzy set was first introduced by Prof. Lofti A. Zadeh of UC Berkley, USA in 1965 with the following definition.

Definition 1. *Let X be a set. A fuzzy subset A of X is a subset of X whose membership is defined through a function*

$$\mu_A : X \to [0,1] \tag{1}$$

which associates an element $x \in X$ to a real number $\mu_A(x)$ in $[0,1]$. The value $\mu_A(x)$ indicates the degree of membership of x in A. A fuzzy set A is written as follows:

$$A = \{(x, \mu_A(x)|x \in X)\} \tag{2}$$

The pair $(x, \mu_A(x)$ reads x has the degree of membership $\mu_A(x)$.

2. Membership Function

In this research, we used three types of membership functions;

a. Linearly Increasing Membership Function

Definition 2. (Mada et al., 2021) *A membership function μ is said to be linearly increasing (on (a, b)) if it can be represented as the following*

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$$\mu(x) = \begin{cases} 0 & ; \quad x \le a \\ \frac{x-a}{b-a} & ; \quad a \le x \le b, \\ 1 & ; \quad x \ge b \end{cases} \tag{3}$$

For more details, the geometric shape of this function can be seen in Figure 1(a)

b. Linearly Decreasing Membership Function

Definition 3. (Mada et al., 2021) *A membership function μ is said to be linearly decreasing (on (a, b)) if it satisfies the following*

$$\mu(x) = \begin{cases} 1 & ; \quad x \le a \\ \frac{b-x}{b-a} & ; \quad a \le x \le b, \\ 0 & ; \quad x \ge b \end{cases} \tag{4}$$

For more details, the geometric shape of this function can be seen in Figure 1(b)

c. Triangular Membership Function

Definition 4. (Mada et al., 2021) *A membership function μ is said to be triangular (on (a, b)) if it can be written as*

$$\mu(x) = \begin{cases} 0 & ; \quad x \le a \text{ or } x \ge c \\ \frac{x-a}{b-a} & ; \quad a \le x \le b, \\ \frac{c-x}{c-b} & ; \quad b \le x \le c, \\ 1 & ; \quad x = b \end{cases} \tag{5}$$

For more details, the geometric shape of this function can be seen in Figure 1(c)

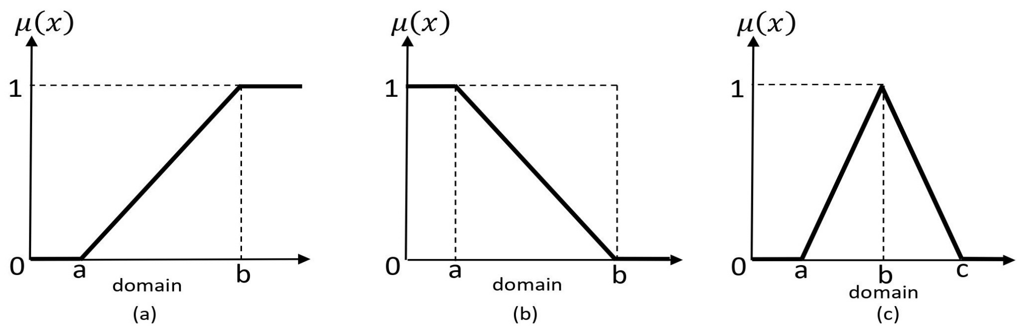

Figure 1. (a) Linearly Increasing, (b) Linearly Decreasing, and (c) Triangular Membership Function

A more detailed explanation regarding applications of the three membership functions can be found in chapter results and discussion.

3. Fuzzy Inference System (FIS)

Fuzzy inference is the process of mapping a given input space into an output space using fuzzy set theory. From this mapping process, the basis of the decisions made or the existing patterns can be seen.

According to (Priyo, 2017), in general, there are several stages needed for designing a fuzzy system, namely:

a. Fuzzification is a process of changing non-fuzzy variables (numeric variables) into fuzzy variables (linguistic variables) using appropriate membership functions.
b. Inferencing Stage (Rule Base). At this stage, rules are made which will be used as a reference in determining the output of the fuzzy system. The rules produced are in the form of If...And...Then... which is a combination of input variables and output variables.
c. Defuzzification is the process of converting fuzzy data into numerical data as the final decision.

There are 3 FIS methods, namely the Tsukamoto, Mamdani and Sugeno methods. In this study, only the Mamdani method will be discussed.

4. Mamdani Fuzzy Inference System

This method was first introduced by Ebrahim Mamdani in 1975. The creation of this method was motivated by the work of Lotfi Zadeh (1973) on the Fuzzy algorithm for complex systems and was used in the decision-making process (Sari, 2021).

The Mamdani method is a type of fuzzy inference where the fuzzy sets resulted from each rule are combined using aggregation operator and produces a fuzzy set which is then defuzzified to produce a certain output from a system. The output requires several stages, including:

a. Generating The Fuzzy Sets

In the Mamdani method, both input and output variables are divided into one or more fuzzy sets (Sari, 2021).

b. Applying Implication Function

(Sari, 2021) states that in the Mamdani method, the function used is the Min function can be written as:

$$\mu_{A\cap B} = \min\{\mu_A(x), \mu_B(x)\} \tag{6}$$

c. Composing The Rules

Unlike monotonic reasoning, if the system consists of several rules, then inference is obtained from the collection and correlation between rules. There are 3 methods used in performing fuzzy system inference, namely max, additive and probabilistic OR (probor).

The Max (Maximum) method takes the solution of the fuzzy set obtained by taking the maximum value of the rule, then using it to modify the fuzzy area, and applying it to the output using the OR (union) operator. If all propositions have been estimated, then the output will contain a fuzzy set that reflects the contribution of each proportion (Sari, 2021). In general it can be written as:

$$\mu_{A\cup B} = \max\{\mu_A(x), \mu_B(x)\} \tag{7}$$

d. Defuzzification

There are several defuzzification methods on MAMDANI composing rules (Sutikno, 2011);

− Centroid (Composite Moment) Method

In the centroid method, the crisp solution is obtained by taking the center point of the fuzzy area. In general, it can be written as:

For continuous universe of discourse (Generally for nonlinear cases),

$$z^* = \frac{\int_{z_l}^{z_u} z\mu(z)dz}{\int_{z_l}^{z_u} \mu(z)dz}; z_l \le z \le z_u \tag{8}$$

For discrete universe of discourse,

$$z^* = \frac{\sum_{i=1}^{n} z_i\mu(z_i)}{\sum_{i=1}^{n} \mu(z_i)} \tag{9}$$

– Bisector Method

In the bisector method, the crisp solution is obtained by taking the domain which has a value from the number of membership values in the fuzzy area. Generally this is written

$$z = \frac{1}{2}\sum_{i=1}^{n} z_i \mu(z_i) \tag{10}$$

– Mean of Maximum (MOM) Method

In the MOM method, the crisp solution is obtained by taking the average value of the domain that has the maximum membership value

– Largest of Maximum (LOM) Method

In the LOM method, the maximum solution is obtained by taking the largest value from the domain that has the maximum membership value.

– Smallest of Maximum (LOM) Method

In the SOM method, the crisp solution is obtained by taking the smallest value from the domain that has the maximum membership value.

5. Mean Absolute Percentage Error (MAPE)

According to (Wardani et al., 2017), forecasting techniques are not always appropriate because they are not necessarily in accordance with the nature of the data. Therefore, it is necessary to evaluate forecasting so that it can be known whether the forecasting technique used is appropriate or not, so that a more precise forecasting technique can be selected and determined by setting tolerance limits for deviations that occur.

In principle, forecasting evaluation is done by predicting the results of what actually happened. The use of forecasting techniques that produce deviations is the most suitable forecasting technique to use.

The magnitude of the forecast error is calculated by subtracting the real data from the estimated size. In calculating the forecast error, the Means Absolute Percentage Error (MAPE) is used, which is the average absolute percentage of a forecast:

$$MAPE = \frac{\sum_{i=1}^{N}\left|\frac{X_t - \widehat{X}_t}{X_t}\right|}{N} \times 100\% \tag{11}$$

where N = the number of forecasting periods, X_t = the true value at time t, $\widehat{X}_t$ = the forecasting value at time t.

According to (Azmi et al., 2020), the forecasting ability is very good if it has a MAPE value of less than 10% and has good forecasting ability if the MAPE value is less than 20%.

C. RESEARCH METHOD

1. Place and Funding Sources

The research was conducted for 2 months (January 2022 – February 2022). The type of data used in this research is secondary, obtained from the Bintang Oesapa Tofu Factory. Data regarding demand and supply taken is daily data starting from January 02, 2022 to February 10, 2022 and several days for data processing.

2. Data Identification

Data identification was carried out to determine the variables and the universe of discourse for calculations and problem analysis. This process is detail explained in the results and discussion chapter.

3. Data Processing

Data processing was carried out using the five Mamdani FIS defuzzification methods with Matlab R2013a software. Subsequently, the magnitude of the error for each defuzzification method is calculated using MAPE and the accuracy of each defuzzification method is determined.

4. Drawing Conclusion

The FIS method and the model are said to be adequate if it has the smallest predicting error value. The error rates are calculated based on Mean Absolute Percentage Error (MAPE).

D. RESULT AND DISCUSSION

Based on the data collection process regarding the data on the amount of tofu production that is influenced by demand and supply, the data obtained are as presented in Table 1.

Table 1. Tofu Production Data at Bintang Oesapa Tofu Factory on January 2, 2022 – February 10, 2022

No.	Date	Demand	Stock	Production	No.	Date	Demand	Stock	Production
1	Jan 2, 2022	18,400	2,200	22,400	21	Jan 22, 2022	25,200	4,500	27,500
2	Jan 3, 2022	21,000	3,600	24,200	22	Jan 23, 2022	28,800	1,400	31,100
3	Jan 4, 2022	22,400	4,600	29,200	23	Jan 24, 2022	18,200	2,600	32,800
4	Jan 5, 2022	27,200	1,600	28,600	24	Jan 25, 2022	23,600	2,800	23,600
5	Jan 6, 2022	20,400	600	29,400	25	Jan 26, 2022	20,400	3,200	29,600
6	Jan 7, 2022	18,800	1,400	22,400	26	Jan 27, 2022	26,400	2,800	26,400
7	Jan 8, 2022	22,800	1,000	21,200	27	Jan 28, 2022	25,000	1,600	30,800
8	Jan 9, 2022	25,600	3,200	27,000	28	Jan 29, 2022	20,200	4,400	31,000
9	Jan 10, 2022	17,600	3,800	32,600	29	Jan 30, 2022	18,800	1,600	26,200
10	Jan 11, 2022	21,600	4,800	26,200	30	Jan 31, 2022	24,400	2,400	22,800
11	Jan 12, 2022	19,200	4,400	30,800	31	Feb 01, 2022	23,150	3,200	30,000
12	Jan 13, 2022	19,600	5,400	29,000	32	Feb 02, 2022	24,342	6,400	32,750
13	Jan 14, 2022	24,400	3,200	28,200	33	Feb 03, 2022	19,200	1,800	32,542
14	Jan 15, 2022	24,000	800	28,400	34	Feb 04, 2022	17,200	1,200	22,200
15	Jan 16, 2022	20,464	4,200	29,000	35	Feb 05, 2022	18,000	5,200	23,600
16	Jan 17, 2022	24,800	6,380	31,044	36	Feb 06, 2022	24,400	3,600	26,800
17	Jan 18, 2022	18,800	1,000	32,180	37	Feb 07, 2022	21,200	3,000	31,000
18	Jan 19, 2022	25,200	2,800	22,600	38	Feb 08, 2022	23,000	4,800	29,000
19	Jan 20, 2022	20,400	4,400	32,400	39	Feb 09, 2022	21,800	2,200	30,000
20	Jan 21, 2022	23,200	3,600	28,400	40	Feb 10, 2022	25,200	3,400	27,400

1. Fuzzification

It can be seen from Table 1 that from 2 January 2022 to 10 February 2022, the highest demand was on 23 January with a total of 28,800 pieces, while the least was on 4 February with a mere 17,200 pieces. Then the highest supply was on 2 February with 6,400 pieces in total, and the least supply was on 6 January with only 600 pieces. As for productions, the highest was on 24 January with a total of 32,800 pieces, while the minimum was on 8 January with 21,200 pieces. Hence, based on the data of least and most of each of the variables above, the universe of discourse for these variables can be defined as shown in Table 2. Then, for each of the variables, three fuzzy sets are constructed; Low, Medium, and High, with their respective domains also presented in Table 2.

Table 2. Fuzzy Sets

Function	Variable	Universe of Discourse	Fuzzy Set	Domain
Input	Demand	$[17,200,\ 28,800]$	Low	$[17,200,\ 23,000]$
			Medium	$[20,100,\ 25,900]$
			High	$[23,000,\ 28,800]$
	Stock	$[600,\ 6,400]$	Low	$[600,\ 3,500]$
			Medium	$[2,050,\ 4,950]$
			High	$[3,500,\ 6,400]$
Output	Production	$[21,200,\ 32,800]$	Low	$[21,200,\ 27,000]$
			Medium	$[24,100,\ 29,900]$
			High	$[27,000,\ 32,800]$

Based of equations (3), (4) and (5), the membership functions for demand, supply and production are defined as follows:

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$$\mu_{Low-DEMAND}(x) = \begin{cases} 1 & ; \quad x \leq 17,000 \\ \frac{23,000-x}{5,800} & ; \quad 17,000 \leq x \leq 23,000, \\ 0 & ; \quad x \geq 23,000 \end{cases} \tag{12}$$

$$\mu_{MEDIUM-DEMAND}(x) = \begin{cases} 0 & ; \quad x \leq 20,100 \ or \ x \geq 25,900 \\ \frac{x-20,100}{2,900} & ; \quad 20,100 \leq x \leq 23,000 \\ \frac{25,900-x}{2,900} & ; \quad 23,000 \leq x \leq 25,900 \\ 1 & ; \quad x = 25,900 \end{cases} \tag{13}$$

$$\mu_{HIGH-DEMAND}(x) = \begin{cases} 0 & ; \quad x \leq 23,000 \\ \frac{x-23,000}{5,800} & ; \quad 23,000 \leq x \leq 28,800 \\ 1 & ; \quad x \geq 28,800 \end{cases} \tag{14}$$

The geometric representation of the membership function of the three fuzzy sets for demand is presented in Figure 2(a). Furthermore, the membership function for the stock variable is defined in the following way:

$$\mu_{LOW-STOCK}(x) = \begin{cases} 1 & ; \quad x \leq 600 \\ \frac{3,500-x}{2,900} & ; \quad 600 \leq x \leq 3,500 \\ 0 & ; \quad x \geq 3,500 \end{cases} \tag{15}$$

$$\mu_{MEDIUM-STOCK}(x) = \begin{cases} 0 & ; \quad x \leq 2,050 \ or \ x \geq 4,950 \\ \frac{x-2,050}{1,450} & ; \quad 2,050 \leq x \leq 3,500 \\ \frac{4,950-x}{1,450} & ; \quad 3,500 \leq x \leq 4,950 \\ 1 & ; \quad x = 4,950 \end{cases} \tag{16}$$

$$\mu_{HIGH-STOCK}(x) = \begin{cases} 0 & ; \quad x \leq 3,500 \\ \frac{x-3,500}{2,900} & ; \quad 3,500 \leq x \leq 6,400 \\ 1 & ; \quad x \geq 6,400 \end{cases} \tag{17}$$

The geometric representation of the membership functions of the three fuzzy sets for supply is presented in Figure 2(b). Next, the membership function for the production variable is defined as follows:

$$\mu_{LOW-PRODUCTION}(x) = \begin{cases} 1 & ; \quad x \leq 21,200 \\ \frac{27,000-x}{5,800} & ; \quad 21,200 \leq x \leq 27,000 \\ 0 & ; \quad x \geq 27,000 \end{cases} \tag{18}$$

$$\mu_{MEDIUM-PRODUCTION}(x) = \begin{cases} 0 & ; \quad x \leq 24,100 \ or \ x \geq 29,900 \\ \frac{x-24,100}{2,900} & ; \quad 24,100 \leq x \leq 27,000 \\ \frac{29,000-x}{2,900} & ; \quad 27,000 \leq x \leq 29,900 \\ 1 & ; \quad x = 29,900 \end{cases} \tag{19}$$

$$\mu_{HIGH-PRODUCTION}(x) = \begin{cases} 0 & ; \quad x \leq 27,000 \\ \frac{x-27,000}{5,800} & ; \quad 27,000 \leq x \leq 32,800 \\ 1 & ; \quad x \geq 32,800 \end{cases} \tag{20}$$

And the geometric representation of the membership functions of the three fuzzy sets for the productions is presented in Figure 2(c).

As an illustration, take the data from Table 1 on 2 January 2022, where there were 18,400 pieces of demand, 2,200 pieces of supply and 22,400 pieces of production. Then it can be seen from Table 2 that this demand is part of the low-demand fuzzy set category, the supply is in of low-and-medium-stock fuzzy set, while the production is in the low-production fuzzy set category. By using the membership functions (12), (15), (16) and (18), the degrees of membership for each of these numbers have also been obtained. Their geometric representations can be seen in Figure 2.

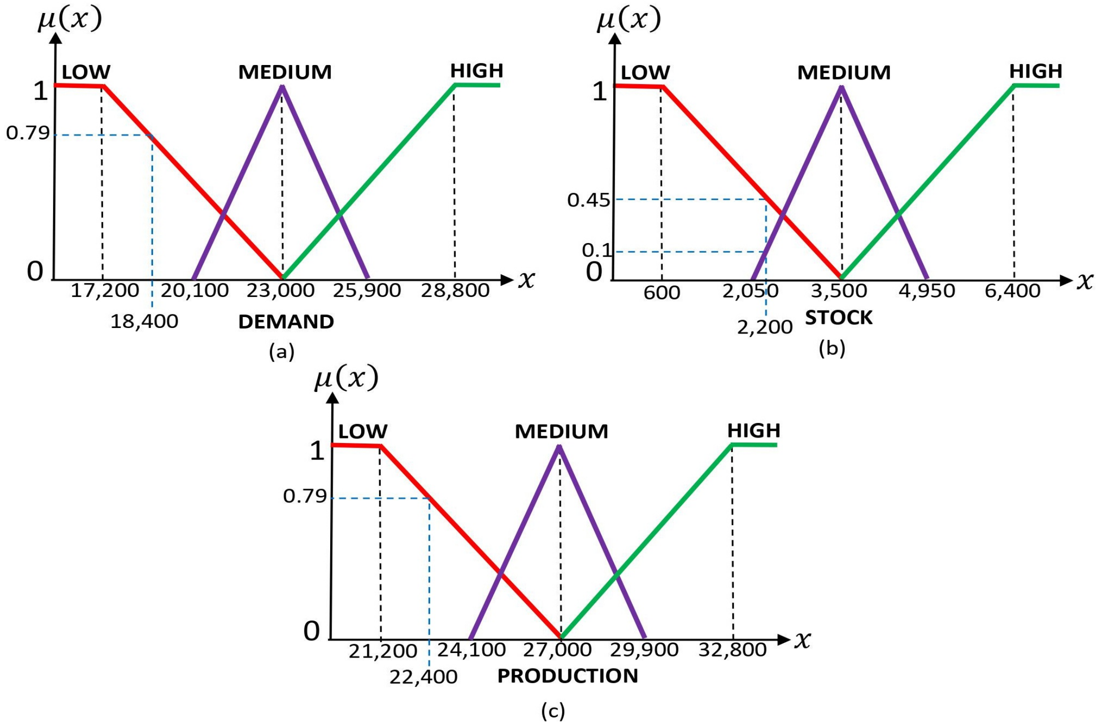

Figure 2. Fuzzification Stage

2. Inferencing (Rule based)

At this stage, rules are made which will be used as a reference in determining the output of the fuzzy system. The rule in question is in the form of If...And...Then... which is a combination of 3 variables (2 input variables and 1 output variable). At the stage of forming fuzzy sets, it is known that each variable has 3 fuzzy sets, namely Low, Medium and High fuzzy sets. So the number of rules that can be made in this case is obtained from $3^3 = 27$ rules. However, to simplify the calculations and to make the rules more representative, the rules are based on the data that has been obtained (Table 1). So, based on the data in Table 1, the previous 27 rules were reduced to 18 rules that represent every situation that might occur at the Bintang Oesapa Tofu Factory.

With the help of Matlab R2013a software, the 18 rules are as follows:

$[R1]$: If (DEMAND is **L**) and (STOCK is **L**) then (PRODUCTION is **L**)
$[R2]$: If (DEMAND is **L**) and (STOCK is **L**) then (PRODUCTION is **M**)
$[R3]$: If (DEMAND is **L**) and (STOCK is M) then (PRODUCTION is **L**)
$[R4]$: If (DEMAND is **L**) and (STOCK is M) then (PRODUCTION is **M**)
$[R5]$: If (DEMAND is **L**) and (STOCK is **H**) then (PRODUCTION is **L**)
$[R6]$: If (DEMAND is **L**) and (STOCK is **L**) then (PRODUCTION is **L**)
$[R7]$: If (DEMAND is **M**) and (STOCK is **L**) then (PRODUCTION is **M**)
$[R8]$: If (DEMAND is **M**) and (STOCK is **L**) then (PRODUCTION is **H**)
$[R9]$: If (DEMAND is **M**) and (STOCK is **M**) then (PRODUCTION is **M**)
$[R10]$: If (DEMAND is **M**) and (STOCK is **M**) then (PRODUCTION is **H**)
$[R11]$: If (DEMAND is **M**) and (STOCK is **H**) then (PRODUCTION is **L**)
$[R12]$: If (DEMAND is **M**) and (STOCK is **H**) then (PRODUCTION is **M**)
$[R13]$: If (DEMAND is **H**) and (STOCK is **L**) then (PRODUCTION is **M**)
$[R14]$: If (DEMAND is **H**) and (STOCK is **L**) then (PRODUCTION is **H**)
$[R15]$: If (DEMAND is **H**) and (STOCK is **M**) then (PRODUCTION is **M**)

$[R16]$: If (DEMAND is **H**) and (STOCK is **M**) then (PRODUCTION is **H**)
$[R17]$: If (DEMAND is **H**) and (STOCK is **H**) then (PRODUCTION is **L**)
$[R18]$: If (DEMAND is **H**) and (STOCK is **H**) then (PRODUCTION is **M**)
where **L** = Low, **M** = Medium and **H** = High.

For example, at the fuzzification stage, the degree of membership of low-demand for $x = 18,400$ is 0.79, the degree of membership of low-stock for $x = 2,200$ is 0.1, the degree of membership of medium-stock for $x = 2,200$ is 0.45 and The degree of membership of the low-production for $x = 22,400$ is $0,79$. Based on the fuzzy set that corresponds to each data, there are 2 possible rules, namely $[R1]$ and $[R3]$. Next, the $\alpha - predicate$ value will be searched for each rule using the Min function in the equation 6.

$[R1]$: If (DEMAND is **L**) and (STOCK is **L**) then (PRODUCTION is **L**)

$$\begin{aligned} \alpha - predicate_1 &= \mu_{LOW-DEMAND \,\cap\, LOW-STOCK} \\ &= \min\{\mu_{LOW-DEMAND}(18,400), \mu_{LOW-STOCK}(2,200)\} \\ &= \min(0.79, 0.45) \\ &= 0.45 \end{aligned}$$

Because the output of $[R1]$ is Low-Production then by using the equation (18) we get $z_1 = 24,390$. The geometric interpretation of the calculation $[R1]$ can be seen in Figure 3.

$[R3]$: If (DEMAND is **L**) and (STOCK is M) then (PRODUCTION is **L**)

$$\begin{aligned} \alpha - predicate_2 &= \mu_{LOW-DEMAND \,\cap\, MEDIUM-STOCK} \\ &= \min\{\mu_{LOW-DEMAND}(18,400), \mu_{MEDIUM-STOCK}(2,200)\} \\ &= \min(0.79, 0.1) \\ &= 0.1 \end{aligned}$$

Because the output of $[R3]$ is Low-Production then by using the equation (18) we get $z_2 = 26,420$. The geometric interpretation of the calculation $[R3]$can be seen in Figure 3.

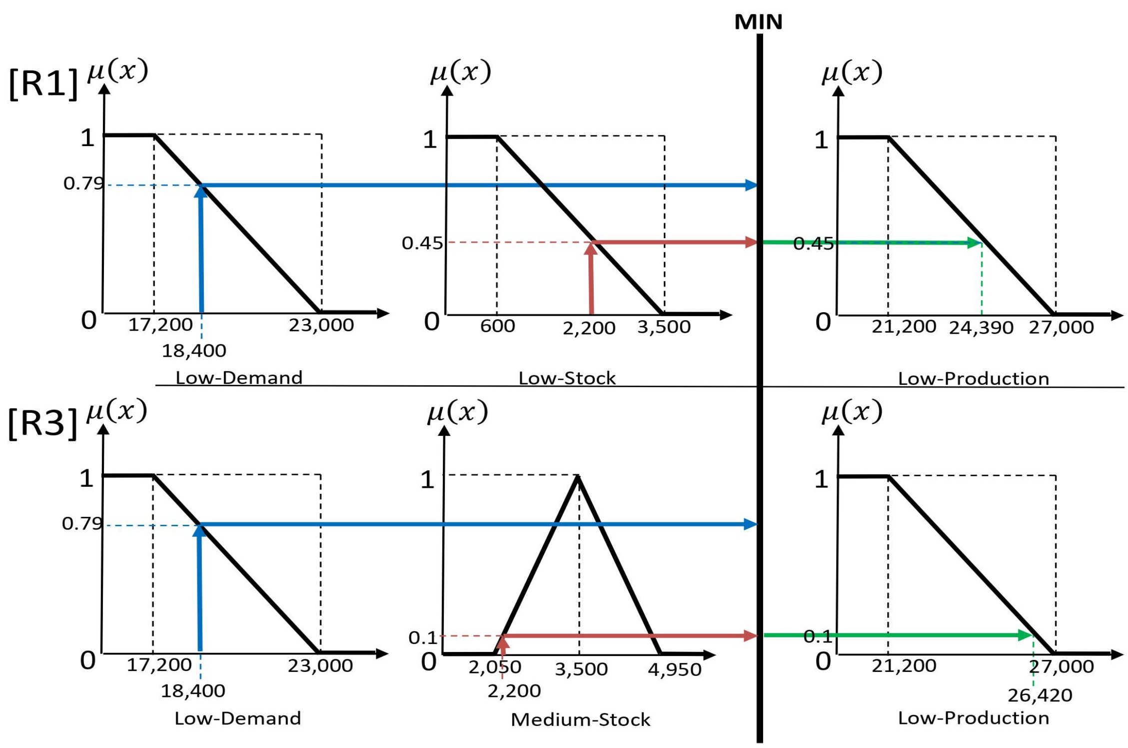

Figure 3. Inferencing Stage

From the calculation process, 2 values of z are obtained, then in the defuzzification stage a single value of z will be calculated which is the output of the data on January 2, 2022.

3. Defuzzification

In this stage, the final fuzzy data is transformed into crisp data. The defuzzification process is performed by using the five methods mentioned above. For example, based on the process of fuzzification and inferencing of data on January 2, 2022, we get 2 values of z namely $z_1 = 24,390$ with $\mu_{z_1} = 0,45$ and $z_2 = 2,420$ with $\mu_{z_2} = 0,1$. The defuzzification process generates $z* = 23,400$ with Centroid method, $z* = 23,200$ with Bisector method, $z* = 22,900$ with MOM method, $z* = 27,500$ with LOM method, and $z* = 18,400$ with SOM method. The crisp data obtained from the defuzzification is the compared to the actual data in Table 1. The comparison result is presented in Table 3.

Table 3. Comparison Between Calculations Obtained Through FIS Methods and The Actual Data

No.	Date	Actual Production	Mamdani FIS Method				
			Centroid	Bisector	MOM	LOM	SOM
1	Jan 2, 2022	22,400	23,400	23,200	22,900	27,500	18,400
2	Jan 3, 2022	24,200	23,500	23,400	23,200	27,900	18,400
3	Jan 4, 2022	29,200	27,800	27,800	28,100	32,800	23,400
4	Jan 5, 2022	28,600	28,000	27,800	28,700	32,800	24,400
5	Jan 6, 2022	29,400	30,000	30,100	30,900	32,800	28,900
6	Jan 7, 2022	22,400	23,200	23,400	22,400	26,500	18,400
7	Jan 8, 2022	21,200	23,100	23,400	22,200	26,000	18,400
8	Jan 9, 2022	27,000	27,800	27,800	28,300	32,800	23,700
9	Jan 10, 2022	32,600	30,400	30,600	32,100	32,800	31,400
10	Jan 11, 2022	26,200	23,400	23,400	22,900	27,500	18,400
11	Jan 12, 2022	30,800	29,900	29,900	30,600	32,800	28,300
12	Jan 13, 2022	29,000	27,900	27,800	28,500	32,800	24,200
13	Jan 14, 2022	28,200	27,900	27,800	28,300	32,800	23,900
14	Jan 15, 2022	28,400	25,600	27,800	28,700	32,800	24,400
15	Jan 16, 2022	29,000	27,800	27,800	28,200	32,800	23,600
16	Jan 17, 2022	31,044	29,900	29,900	30,600	32,800	28,300
17	Jan 18, 2022	32,180	30,300	30,500	31,900	32,800	30,900
18	Jan 19, 2022	22,600	23,400	23,400	23,100	27,800	18,400
19	Jan 20, 2022	32,400	29,900	29,900	30,600	32,800	28,300
20	Jan 21, 2022	28,400	28,100	27,800	29,600	32,800	25,500
21	Jan 22, 2022	27,500	27,700	27,800	28,000	32,800	23,300
22	Jan 23, 2022	31,100	25,600	25,600	25,600	25,600	25,600
23	Jan 24, 2022	32,800	27,700	27,800	28,000	32,800	23,200
24	Jan 25, 2022	23,600	23,300	23,400	22,900	27,300	18,400
25	Jan 26, 2022	29,600	30,000	30,100	30,900	32,800	28,900
26	Jan 27, 2022	26,400	27,900	27,800	28,300	32,800	23,900
27	Jan 28, 2022	30,800	29,800	29,900	30,500	32,800	28,200
28	Jan 29, 2022	31,000	23,400	23,400	23,100	27,800	18,400
29	Jan 30, 2022	26,200	28,000	27,800	28,700	32,800	24,400
30	Jan 31, 2022	22,800	25,600	25,700	25,600	32,800	18,400
31	Feb 1, 2022	30,000	30,400	30,600	32,100	32,800	31,400
32	Feb 2, 2022	32,750	30,100	32,200	31,100	32,800	29,500
33	Feb 3, 2022	32,542	30,100	30,400	31,400	32,800	29,900
34	Feb 4, 2022	22,200	23,200	23,400	22,400	26,300	18,400
35	Feb 5, 2022	23,600	23,300	23,400	22,700	27,000	18,400
36	Feb 6, 2022	26,800	27,900	27,800	28,300	32,800	23,900
37	Feb 7, 2022	31,000	29,900	29,900	30,600	32,800	28,300
38	Feb 8, 2022	29,000	23,400	23,400	22,900	27,500	18,400
39	Feb 9, 2022	30,000	30,000	30,100	30,900	32,800	28,900
40	Feb 10, 2022	27,400	27,800	27,800	28,100	32,800	23,400

Based on the calculation comparison process in Table 3, several comparisons of the five Mamdani FIS defuzzification methods were obtained based on the level of accuracy, error in analysis, manual calculation time and calculation complexity level. The comparison is presented in Table 4.

Table 4. Comparison of The Five Mamdani FIS Defuzzification Methods

No.	Indicator	Centroid	Bisector	MOM	LOM	SOM
1	Accuracy in analyzing	$94,17\%$	$76,83\%$	$94,73\%$	$86,61\%$	$85,27\%$
2	Error in analyzing	$5,83\%$	$23,17\%$	$5,27\%$	$13,39\%$	$14,73\%$
3	Time	The manual calculation process for the centroid defuzzification method takes a long time.	The manual calculation process for the bisector defuzzification method does not take too long, when compared to the centroid.	The manual calculation when process for the MOM defuzzification method requires less time, compared to the centroid and bisector.	The manual calculation process for the SOM defuzzification method requires less time, when compared to centroids, bisector and MOM.	The manual calculation process for the LOM defuzzification method takes the same time as the SOM method.
4	Calculation	The calculation of this method is quite complicated.	The calculation of this method is quite complicated.	The calculation of this method is somewhat simpler when compared to the centroid and bisector.	The calculation of this method is the simplest when compared to centroids, bisectors, and MOM.	The calculation of this method is as simple as the SOM method.

The level of accuracy presented in Table 4 was calculated using MAPE formula in equation (11). Based on the comparison result in Table 4, for the case of determining the amount of tofu production at the Bintang Oesapa Tofu Factory by considering the stock and demand obtained that the MOM method has a higher level of accuracy than the Centroid method with the difference in accuracy between the two is $0,56\%$. Because each case has its own characteristics, it is better if the Mamdani method does not use the centroid method directly as the defuzzification method, but instead uses the centroid method as a defuzzification method it is necessary to review other defuzzification methods first. Based on the results of the calculations in Table 4 it can be said that that for this case, the accuracy of the calculation results of the Mamdani method ranges from $76\% - 95\%$ which can be said to be very good or very similar to the decision making by the Bintang Oesapa Tofu Factory. This is in line with the statement (Kaur and Kaur, 2012) in their research, Mamdani method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more human-like manner.

E. CONCLUSION AND SUGGESTION

From data processing and relevant journals, we conclude that the best FIS Mamdani defuzzification method to predict the amount of tofu production at the Bintang Oesapa Tofu Factory was the Mean of Maximum (MOM) defuzzification method. The first reason is that the accuracy value of the other 5 methods is 94.73% and the value of error or small error is 5.27%. Bisides that, the manual calculations require a substantial amount of time and are not complicated.

Thus, when carrying out the process of determining the production of tofu using the Mamdani fuzzy inference system method, it is highly recommended to use the MOM method in the defuzzification process. Not only in the case of tofu production, this method is also highly recommended for determining the production of other goods.

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