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Determining Tofu Production Volume Using Fuzzy Logic Mamdani Method

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Abstract

This research focuses on determining the amount of tofu production based on the amount of consumer demand and the amount of raw material inventory. Optimization of daily tofu production is a difficult problem due to the uncertainty of supply and demand for tofu. The method used in this research is the fuzzy logic method which is one of the effective rule-based approach methods to determine the volume of tofu production. In this research, the data used is taken based on the results of previous research. The final results obtained in this study, namely the determination of the volume of tofu production based on the amount of consumer demand and the amount of raw material inventory is still less effective. This is because the amount of consumer demand received and the amount of raw material inventory available with the volume of tofu production produced is still not appropriate.

Keywords: demand amount, fuzzy logic, inventory quantity, mamdani method, tofu production.

INTRODUCTION

Indonesia is an agrarian tropical country with fertile soil. Natural resources such as grains, tubers, and legumes grow well in Indonesia (Yosifani *et al.* 2021). The people of Indonesia are encouraged to utilize this advantage by planting various types of crops. One type of staple crop needed by most Indonesians is soybeans (Andarwulan *et al.* 2018). Soybeans are commonly grown in Indonesia as a raw material to meet various domestic food needs. The demand for soybeans has continued to increase along with the growing need for soybean-based products. People generally do not consume soybeans directly but process them into various products such as tofu (Sinaini 2021). Soybeans, as the main ingredient for tofu production, contain high levels of protein and essential amino acids required by the body. In addition, soybeans contain bioactive isoflavones, which have antioxidant properties (Palupi *et al.* 2019). Soybeans can be processed into various products to add value, one of the most common soybean-based products in Indonesia being tofu.

Tofu serves as a source of protein for the body and is widely consumed by Asian communities. Besides being economical, tofu also has a high protein content (Ariyanti *et al.* 2016). Tofu is highly nutritious, containing protein (8-12%), fat (4-6%), and carbohydrates (1-6%) (Manoe *et al.* 2019). Tofu is a soybean-based product made through a coagulation process. Generally, the tofu production process involves selecting soybeans, weighing, soaking, washing, grinding, extracting, filtering, cooking, coagulating, whey separation, wrapping, pressing, cooking, and packaging (Djayanti 2015). The technology used for tofu processing is still very simple; the tofu production process largely relies on manual labor, making it less efficient. Steps such as washing, grinding, and pressing are still performed manually (Basir 2014).

Production activities are greatly influenced by consumer demand and the products produced. In production, there is often a gap between production volume and sales levels, leading to production instability (Gushelmi 2018). Therefore, daily tofu production must be optimized according to fluctuations in demand and stock levels. Optimizing daily tofu production is challenging due to uncertainties in tofu supply and demand. Additionally, determining the volume of tofu production can be modeled using conventional statistical approaches. However, conventional statistical approaches can make it more difficult for producers to determine production volume compared to rule-based statistical approaches (Verdian 2017). One effective rule-based approach for determining tofu production volume is to use fuzzy logic (Ansar e*t al.* 2024).

Fuzzy logic is a computer-based mathematical approach used to develop decision-making models from uncertain or ambiguous input. Unlike conventional binary logic, which defines a definitive value as either true (1) or false (0), fuzzy logic allows for consideration of conditions between true and false. This enables fuzzy logic to provide more accurate decisions according to uncertain conditions (Syarif *et al.* 2023).

METHOD

This research was conducted at the College of Vocational Studies, IPB University. Data collection was carried out by reviewing literature studies (literature review). Literature review is a systematic, explicit and reproducible method for identifying, evaluating and synthesizing the works of research results and thoughts that have been produced by researchers and practitioners (Cahyono *et al*. 2019). This method aims to analyze and synthesize existing knowledge related to the topic to be studied to find empty spaces for research to be carried out (Uhaq and Rahmayanti 2020). This method is carried out by collecting, reviewing, and analyzing various relevant scientific sources such as journals, articles, theses, and other scientific works related to the application of fuzzy logic and tofu production. The data collected for this study include research variables such as the amount of demand and the amount of inventory as input and the amount of tofu production as output. The data obtained is then reprocessed using the MATLAB application.

MATLAB is software for numerical analysis and computation that functions as an advanced mathematical programming language (Tjolleng 2017). This software was developed based on the concept of using matrices. MATLAB has become a very useful application for performing linear algebra processing tasks, and other mathematical calculations. MATLAB is also accompanied by various built-in functions that are very helpful for working on tasks that are usually difficult to do in numerical processing, of course, with matrix-based numerical calculations (Fatwa *et al.* 2022). Then, data processing in the MATLAB application is carried out using the fuzzy logic method.

Fuzzy logic is a method for calculating with several word variables and replacing them as a number. Fuzzy logic is an approach to mapping a problem into input variables to output variables. The range of fuzzy logic values starts from zero to one (Sudrajat and Agustiani 2023). Fuzzy system is a framework for calculating based on fuzzy set theory that is utilized to make conclusions. Three commonly used fuzzy methods are the Tsukamoto method, Sugeno method, and Mamdani method (Nasyuha *et al.* 2019).

In this study using the Mamdani fuzzy logic method. Fuzzy logic Mamdani is one of the fuzzy systems used to draw the best conclusion from a problem. The uniqueness of the Mamdani method is that the assessment uses membership degrees (μ) which include the value of a variable based on its linguistic value because this technique works based on linguistic rules (Harahap *et al.* 2021). The Mamdani method is often known as the Max-Min method (Simanjuntak and Fauzi 2017).

There are steps in the Mamdani fuzzy method (Vinensia and Utami 2018), namely:

1. Formation of fuzzy sets

   In the Mamdani method, both input variables and output variables are grouped into one or more fuzzy sets. This membership function defines the degree of membership of each value in the range of input variables to the relevant fuzzy set.

2. Application of fuzzy operators

   Once the input variables are converted into fuzzy sets, fuzzy operators are applied to combine the fuzzy values of multiple rules. Fuzzy operators such as “AND” and “OR” are commonly used in fuzzy logic rules. In the Mamdani method, the commonly used operators are “min” (for “AND”) and “max” (for “OR”).

3. Application of implication function

   The implication function is used to generate fuzzy outputs from each rule based on the existing fuzzy input values, the Mamdani method uses the “min” implication function in the process.

4. Rule composition

   Inference is obtained through the combination and relationship between rules. There are three types of rules namely, Max, Additive, and probabilistic OR (probor).

5. Affirmation (defuzzification)

   The input is a fuzzy set generated from the composition of fuzzy rules. The output is a firm (crisp) value. There are five calculation methods at the defuzzification stage including, Centroid (Center of Area), bisector, Mean of Maximum (MOM). Largest of Maximum (LOM), and Smallest of Maximum (SOM).

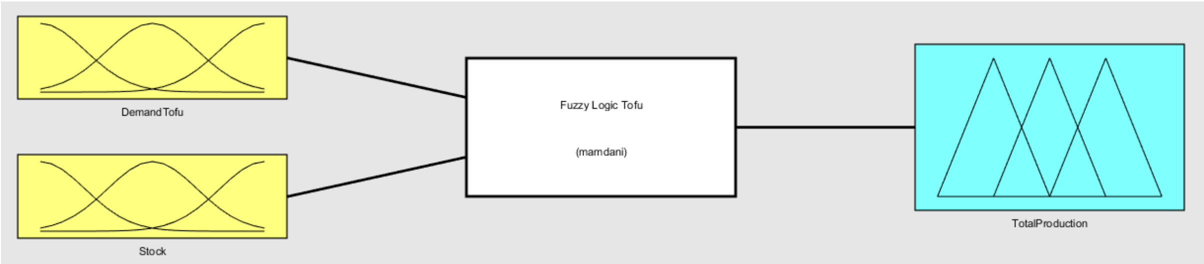
RESULTS AND DISCUSSION

The use of fuzzy logic in the tofu production process aims to be a reference for tofu craftsmen in determining production volumes. This is because fuzzy logic is able to provide solutions in determining tofu production volume. This makes it easier for craftsmen to find out the volume of tofu production that will be produced in the next period, just by entering the amount of demand for tofu and the amount of raw material inventory as input. In the input variables, the terms low, medium and high are used as terms related to the actual numerical value within a certain range. The use of the same terms is also applied to output variables to define production results related to numerical values in a certain range.

In the Mamdani type fuzzy inference system, input and output variables are divided into one or more fuzzy sets (Junaidi 2023). In determining the amount of tofu production based on data on the amount of supply and demand, the input variables are divided into two, namely data on the amount of demand and inventory while the output variable is the amount of production. The scope aims to determine the domain of input and output according to the results in the indicator (Jufriadi 2020). In the Fuzzy Inference System (FIS) process, a scope is needed. The scope for this research is presented in Table 1.

Table 1. Scope

Function	Variable	Scope	Details
Input	Demand	[0-8400]	Amount of tofu demand per day (pieces)
	Stock	[0-7350]	Amount of tofu stock per day (pieces)
Output	Total Production	[7350-10000]	Tofu production capacity (pieces)



A fuzzy set is a range of values where each value has a membership degree between 0 and 1 (Silvilestari 2021). Each input is given a domain or range for demand and supply. The domain of a fuzzy set is a set of real numbers that increases from left to right. The domain value can be positive or negative (Yulmaini 2015). The fuzzy sets created for each input and output variable based on data from the literature are presented in Table 2 and Table 3.

Table 2. Fuzzy Input Set

Function	**Variable**	**Fuzzy Set Name**	**Scope (pieces)**	**Domain (pieces)**
Input	Demand	Low	[0-8400]	[0-6300]
		Medium		[6000-7350]
		High		[7350-8400]
	Stock	Low	[0-7350]	[0-5250]
		Medium		[5250-6300]
		High		[6300-7350]

Table 3. Fuzzy Output Set

Function	**Variable**	**Fuzzy Set Name**	**Scope (pieces)**	**Domain (pieces)**
Output	Total Production	Low	[7350-10000]	[0-7350]
		Medium		[7350-8400]
		High		[8400-10000]

The range of demand can be observed in Table 4. The minimum demand is 1000 pieces, while the maximum demand is 8400 pieces.

Table 4. Fuzzy Demand Set for Input

Fuzzy Set Name	Model MF	Parameter	Range
Low	Trimf	[0 5000 6300]	0-6300
Medium	Trimf	[6000 6300 7350]	6000-7350
High	Trimf	[6300 7350 8400]	6300-8400

The result of the total demand can be determined from the following equation

$$(Low)\begin{cases} x = 0 & ;0 \\ 1000 < x < 5.000 & ;\frac{x-a}{b-a} \\ x = 5.000 & ;1 \\ 5.000 < x \leq 6.300 & ;\frac{c-x}{c-b} \\ x > 6.300 & ;0 \end{cases}$$

$$(Medium)\begin{cases} x < 6.000 & ;0 \\ 6.000 \leq x < 6.300 & ;\frac{x-a}{b-a} \\ x = 6.300 & ;1 \\ 6.300 < x \leq 7.350 & ;\frac{c-x}{c-b} \\ x > 7.350 & ;0 \end{cases}$$

$$(High)\begin{cases} x < 6.300 & ;0 \\ 6.300 \leq x < 7.350 & ;\frac{x-a}{b-a} \\ x = 7.350 & ;1 \\ 7.350 < x \leq 8.400 & ;\frac{c-x}{c-b} \\ x > 8.400 & ;0 \end{cases}$$

Example: If the demand values are 5780, 6500, and 8500, then the membership degrees of each fuzzy set are as follows.

5780 (low) = = = 0.4

6500 (medium) = = = 0.8

8500 (high) = 0

Its representation can be seen in Figure 1. The demand variable is defined as follows.

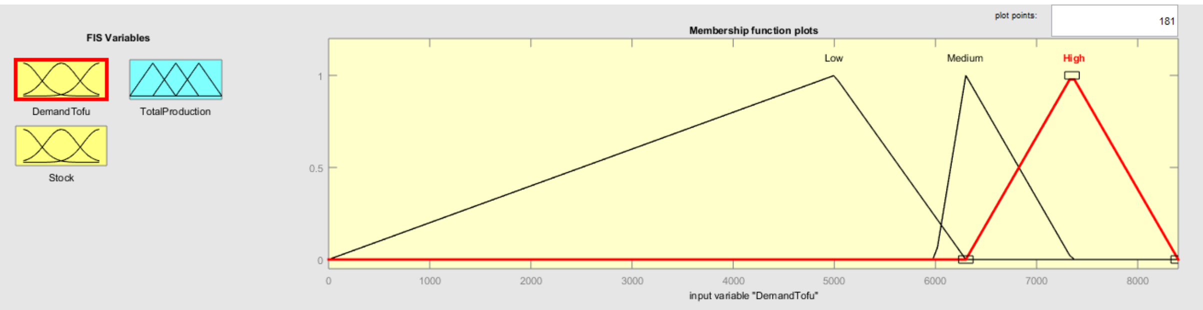


Figure 1. The Representation of Demand Variable

The range of inventory levels can be seen in Table 5. The minimum inventory level is 0, while the maximum demand is 7350.

Table 5. Fuzzy Demand Set for Input

Fuzzy Set Name	**Model MF**	**Parameter**	**Range**
Low	Trimf	[0 4000 5250]	0-5250
Medium	Trimf	[4000 5250 6300]	4000-6300
High	Trimf	[5250 6300 7350]	5250 6300 7350

The result of the inventory calculation can be obtained from the following equation.

$$(Low)\begin{cases} x = 0 & ;0 \\ 0 < x < 4.000 & ;\dfrac{x-a}{b-a} \\ x = 4.000 & ;1 \\ 4.000 < x \leq 5.250 & ;\dfrac{c-x}{c-b} \\ x > 5.250 & ;0 \end{cases}$$

$$(Medium)\begin{cases} x < 4.000 & ;0 \\ 4.000 \leq x < 5.250 & ;\dfrac{x-a}{b-a} \\ x = 5.250 & ;1 \\ 5.250 < x \leq 6.300 & ;\dfrac{c-x}{c-b} \\ x > 6.300 & ;0 \end{cases}$$

$$(High)\begin{cases} x < 5.250 & ;0 \\ 5.250 \leq x < 6.300 & ;\dfrac{x-a}{b-a} \\ x = 6.300 & ;1 \\ 6.300 < x \leq 7.350 & ;\dfrac{c-x}{c-b} \\ x > 7.350 & ;0 \end{cases}$$

Example : If the inventory values are 4500, 5250, and 7500, then the membership degrees of each fuzzy set are as follows.

4500 (low) = = = 0.6

5250 (medium) = 1

7500 (high) = 0

Its representation can be seen in Figure 2. The inventory variable is defined as follows.

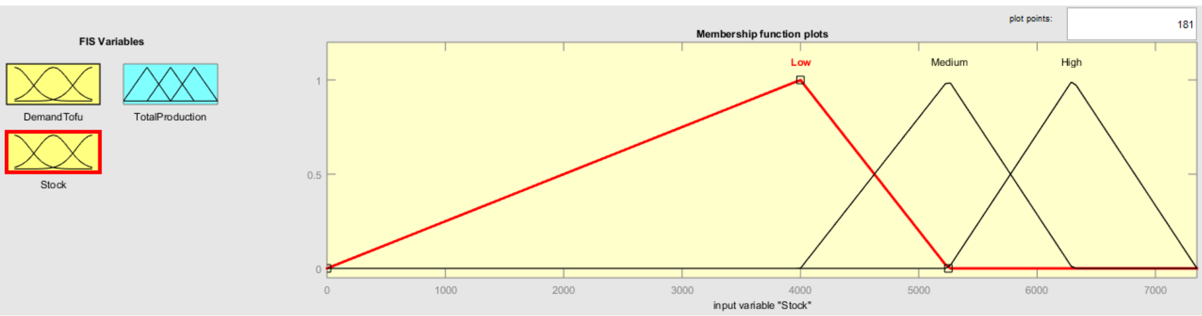


Figure 2. The Representation of Stock Variable

The range of production quantities can be seen in Table 6. The minimum production quantity is 0, while the maximum demand is 10000.

Table 6. Fuzzy Total Production Set for Output

Fuzzy Set Name	**Model MF**	**Parameter**	**Range**
Low	Trimf	[0 6300 7350]	0-7350
Medium	Trimf	[6300 7350 8400]	6300-8400
High	Trimf	[7350 8400 10000]	7350-10000

The result of the production quantity can be obtained from the following equation.

$$(Low)\begin{cases} x = 0 & ; 0 \\ 0 < x < 6.300 & ; \dfrac{x-a}{b-a} \\ x = 6.300 & ; 1 \\ 6.300 < x \leq 7.350 & ; \dfrac{c-x}{c-b} \\ x > 7.350 & ; 0 \end{cases}$$

$$(Medium)\begin{cases} x < 6.300 & ; 0 \\ 6.300 \leq x < 7.350 & ; \dfrac{x-a}{b-a} \\ x = 7.350 & ; 1 \\ 7.350 < x \leq 8.400 & ; \dfrac{c-x}{c-b} \\ x > 8.400 & ; 0 \end{cases}$$

$$(High)\begin{cases} x < 7.350 & ; 0 \\ 7.350 \leq x < 8.400 & ; \dfrac{x-a}{b-a} \\ x = 8.400 & ; 1 \\ 8.400 < x \leq 10.000 & ; \dfrac{c-x}{c-b} \\ x > 10.000 & ; 0 \end{cases}$$

Each variable has a range of values, where each value provides information for determining the production quantity. Its representation can be seen in Figure 3. The production quantity variable is defined as follows.

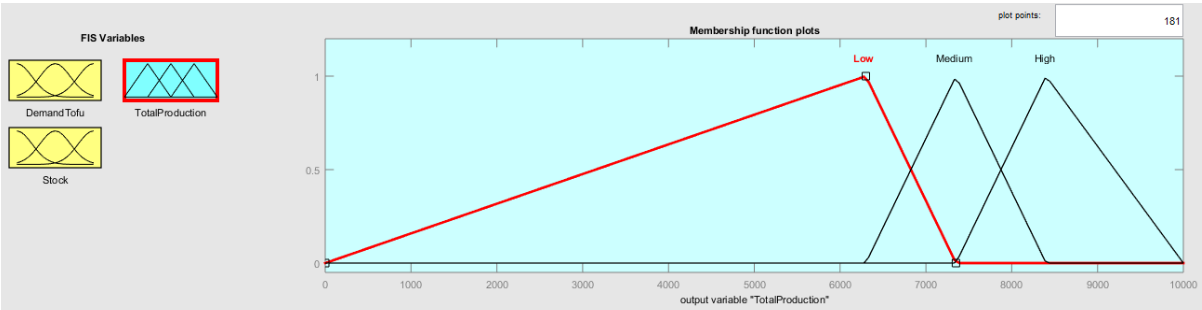


Figure 3. The Representation of Total Production Variable

Based on the above equation and representation of the production quantity variable, calculations can be performed by taking one of the known values as an example:

If the production quantity value is x = 6300 for the variable 'Demand', then the membership degrees in each category are as follows:

a. For low category [0,6300, 7350]

   μ_Low (6300) = 0 (out of membership degrees)

b. For medium category [6300, 7350, 8400]

   μ_Medium (6300) = (7350 – 6300) / (8400 – 6300) = 1050 / 2100 ≈ 0.5

c. For high category [6300, 7350, 10000]

   μ_High (6300) = (7350 – 6300) / (10000 – 6300) = 1050 / 3400 ≈ 0.3

Applying Fuzzy Operators

After obtaining the membership degree results for each input and output, the next step is to apply fuzzy operators. There are 2 fuzzy variables that can be used, namely using a simple implication If x is A Then Y is B or y=f((x,A),B). If then rules known as fuzzy rules, fuzzy implications or fuzzy conditionals are rules used to formulate conditional relationships between two or more fuzzy sets, with the general form If (X1 is A1) (X2 is A2) .... (Xn is An) Then Y is B (Setia and Ramadan 2019).

The fuzzy rules made in this tofu production are formed to represent the relationship between input variables and output variables. The fuzzy rule used is If-Then and the operator between input variables is the “And” operator. The question after “If' is called the statement that follows ‘Then’ is called the consequent (Basriati *et al.* 2020). The following is a fuzzy rule to determine the amount of tofu production based on demand:

1. If the demand for tofu is small and the supply of tofu is small then the amount of tofu produced is small.
2. If tofu demand is little and tofu inventory is medium then the quantity of tofu production is little.
3. If tofu demand is little and tofu inventory is much then the quantity of tofu production is little.
4. If medium tofu demand and little tofu inventory then the quantity of tofu production is medium.
5. If medium tofu demand and medium tofu inventory then total tofu production is medium.
6. If tofu demand is little and tofu inventory is much then the quantity of tofu production is little.
7. If tofu demand is high and tofu inventory is low then the quantity of tofu production is high.
8. If demand for tofu is a lot and tofu inventory is medium then the quantity of tofu production is a lot.
9. If demand for tofu is a lot and tofu inventory is a lot then the quantity of tofu production is little.

Determination of fuzzy operator values using the "AND" operator. Therefore, the membership value is determined by taking the minimum value from the results of the fuzzy rule formation operation (Rules) (Rizqi *et al.* 2024). The calculation is based on the specified demand and inventory counts. Then:

- IF low demand (5780) and stock medium (5250) then total production is low = Min (0.4, 1) = 0.4
- IF medium demand (6500) and stock low (4500) then total production is medium = Min (0.8, 0.6) = 0.6
- IF high demand (8500) and stock low (4500) then total production is high = Min (0, 0.6) = 0

Fuzzy Set Area

In the fuzzy area, it shows the membership of several categories, namely Low, Medium, and High. Each variable has a range of values that provides information about the amount of production generated (Nurdini *et al.* 2021). The representation can be seen in Figure 4.

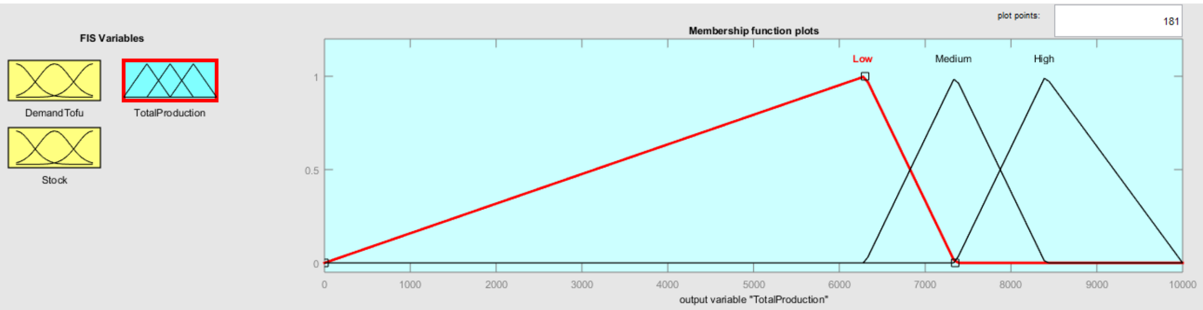


Figure 4. Fuzzy Set Area

Based on the representation in the figure above, the calculation can be performed as follows.

$$0{,}4 = \frac{x-0}{6.300-0} \rightarrow 2.520 = x - 0 \rightarrow x = 2.520$$

$$0{,}4 = \frac{7.350-x}{7.350-6.300} \rightarrow 420 = 7350 - x \rightarrow x = 6.930$$

$$0{,}6 = \frac{x-6.300}{7.350-6.300} \rightarrow 630 = x - 6.300 \rightarrow x = 6.930$$

$$0{,}6 = \frac{8.400-x}{8.400-7.350} \rightarrow 630 = 8.400 - x \rightarrow x = 7.770$$

In this calculation, it shows the method for determining threshold values based on membership values, in this case, 0.4 and 0.6 for several categories. The threshold value in the low category with a membership of 0.4 yields a calculation result of 2520 within a range of 0 to 6300. The next calculation result also shows the method for determining the threshold for other categories, where a value of 6930 falls within the medium category range with a membership of 0.4. Then, for a membership of 0.6, it shows a value of 7770, which falls within the high category range.

Compose All Output

Following the implication stage, a composition process is applied to all fuzzy outputs. This step aims to aggregate all the processed information, resulting in a final fuzzy output that is more representative and accurate in handling data uncertainty (Nasyuha *et al.* 2019). Based on these conditions, the optimal production quantity is obtained from the following equation.

$$\mu sf[z]\begin{cases} \dfrac{x-0}{6.300-0} & ; 0 \le x \le 5.520 \\ 0{,}4 & ; 5.520 \le x \le 6.930 \\ \dfrac{7.350-x}{7.350-6.300} & ; 6.930 \le x \le 7.350 \\ \dfrac{x-6.300}{7.350-6.300} & ; 6.300 \le x \le 6.930 \\ 0{,}6 & ; 6.930 \le x \le 7.770 \\ \dfrac{8.400-x}{8.400-7.350} & ; 7.770 \le x \le 8.400 \\ x = 0 & ; x > 8.400 \end{cases}$$

The simplified equation is:

$$\mu sf[z]\begin{cases} 0{,}00016x & ; 0 \le x \le 5.520 \\ 0{,}4 & ; 5.520 \le x \le 6.930 \\ 7-0{,}00095x & ; 6.930 \le x \le 7.350 \\ 0.00095x-6 & ; 6.300 \le x \le 6.930 \\ 0{,}6 & ; 6.930 \le x \le 7.770 \\ 8-0{,}00095x & ; 7.770 \le x \le 8.400 \\ x = 0 & ; x > 8.400 \end{cases}$$

Defuzzification

In this stage, the results of each fuzzy rule, represented as fuzzy sets, are converted into crisp values (Sihombing 2024). The crisp value is determined from the composition of all outputs, specifically by finding the maximum value from each membership function (Klau *et al*. 2023). The first step in defuzzification involves calculating the area of each region, as follows.

$$A1 = \frac{(2.520-0)\times 0{,}4}{2} = 504$$

$$A2 = (6.930-2.520) \times 0{,}4 = 1.764$$

$$A3 = \frac{(7.350-6.930)\times 0{,}4}{2} = 84$$

$$A4 = \frac{(6.930-6.300)\times 0{,}6}{2} = 189$$

$$A5 = (7.770-6.930) \times 0{,}6 = 504$$

$$A6 = \frac{(8.400-7.770)\times 0{,}6}{2} = 189$$

After obtaining the area values, the moment calculation is then performed as follows.

$$M1 = \int_{0}^{2.520} (0{,}00016z)\, z\, dz = \int_{0}^{2.520} (0{,}00016\, z^2)\, dz = \; 0{,}00005z^3 \mid_{0}^{2.520} = 800.150$$

$$M2 = \int_{2.520}^{6.930} (0{,}4) z\, dz = \int_{2.520}^{6.930} (0{,}4\, z)\, dz = \; 0{,}2z^2 \mid_{2.520}^{6.930} = 8.334.900$$

$$M3 = \int_{6.930}^{7.350} (7 - 0{,}00095z)\, z\, dz = \int_{6.930}^{7.350} (7z - 0{,}00095\, z^2)\, dz = 3{,}5z^2 - 0{,}00032z^3 \mid_{6.930}^{7.350}$$

$$= 430.698$$

$$M4 = \int_{6.300}^{6.930} (0{,}00095z - 6)\, z\, dz = \int_{6.300}^{6.930} (0{,}00095\, z^2 - 6z)\, dz = 0{,}00032z^3 - 3z^2 \mid_{6.300}^{6.930} \mid$$

$$= 1.480.278$$

$$M5 = \int_{6.930}^{7.770} (0{,}6) z\, dz = \int_{6.930}^{7.770} (0{,}6\, z)\, dz = \; 0{,}3z^2 \mid_{6.930}^{7.770} = 3.704.400$$

$$M6 = \int_{7.770}^{8.400} (8 - 0{,}00095z)\, z\, dz = \int_{7.770}^{8.400} (8z - 0{,}00095\, z^2)\, dz = 4z^2 - 0{,}00032z^3 \mid_{7.770}^{8.400}$$

$$= 1.194.299$$

The final step in defuzzification is to calculate the centroid point as follows.

$$z = \frac{800.150 + 8.334.900 + 430.698 + 1.480.278 + 3.704.400 + 1.194.299}{(1.104 + 564 + 84 + 189 + 504 + 189)}$$

$$= \frac{15.944.725}{2.634} = \mathbf{6.053}$$

The defuzzification calculation, comparing the total area with the total moment, shows that the tofu production amount is 6053 pieces based on the previously determined demand and supply quantities. The defuzzification calculation was verified using Matlab software. The results obtained from Matlab are shown in Figure 5, indicating a slight difference between the manual defuzzification calculations and the Matlab results; however, this still reflects a high level of accuracy, considering possible error factors. A representation of the defuzzification results can be seen in Figure 6.

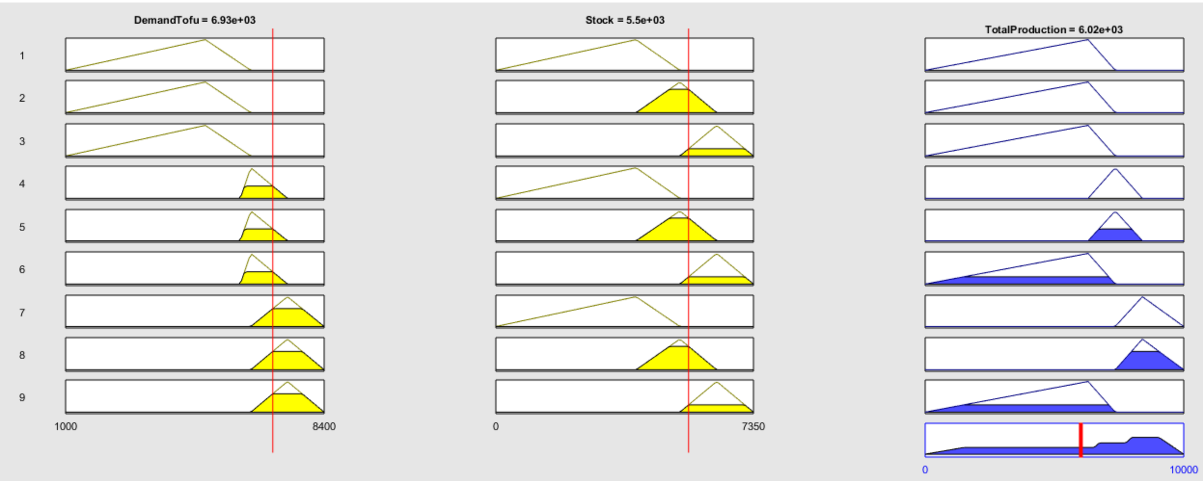


Figure 5. Fuzzy System Model for Optimal Production Quantity using Matlab

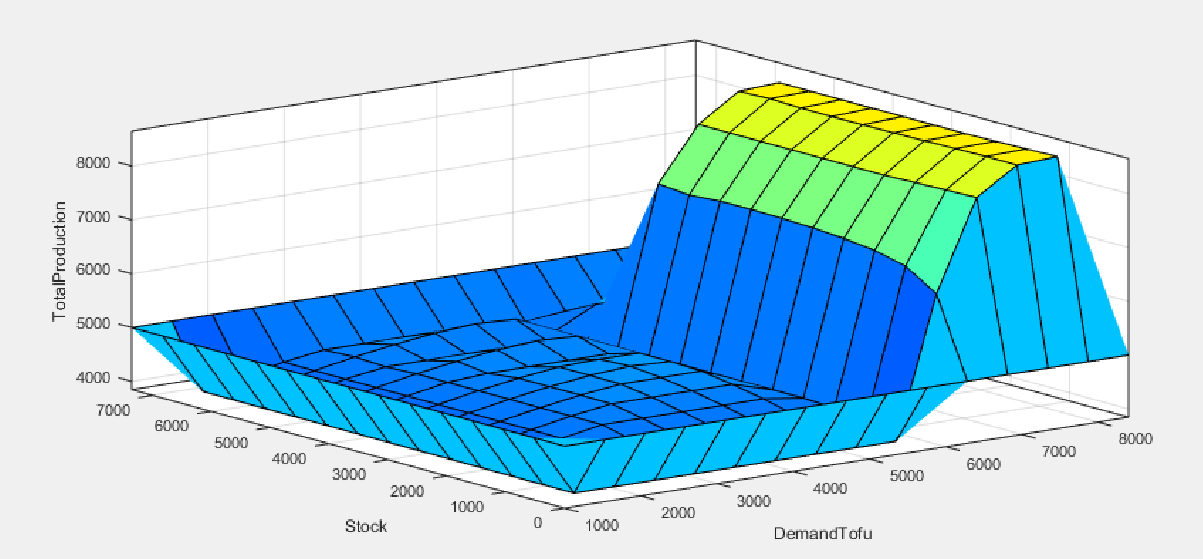


Figure 6. Defuzzification Surface Result

Based on the results of research conducted by Verdian I (2017), the output of manual calculation of tofu production volume was compared with the output using the Mamdani fuzzy inference system method using Mathlab. Based on the results of manual calculations, it was obtained that the defuzzification value obtained in the manual calculation had a different number with the defuzzification results obtained from the Mathlab system. However, the difference in data was in the same range as the defuzzification results obtained in the system. By using fuzzy logic, tofu producers can determine production volume more accurately.

CONCLUSION

In this research, fuzzy logic was used with inputs of tofu demand and stock, and an output of total production. The input membership levels for demand are: low (0-6300 pieces with a peak at 5000 pieces), medium (6000-7350 pieces with a peak at 6300 pieces), and high (6300-8400 pieces with a peak at 7350 pieces). Meanwhile, the input membership levels for stock are: low (0-5250 pieces with a peak at 4000 pieces), medium (4000-6300 pieces with a peak at 5250 pieces), and high (5250-7350 pieces with a peak at 6300 pieces). The membership levels for the output are: low (0-7350 pieces with a peak at 6300 pieces), medium (6300-7350 pieces with a peak at 7350 pieces), and high (7350-10000 pieces with a peak at 8400 pieces). The Mamdani fuzzy logic method has proven effective in determining the amount of tofu that should be produced. The calculation result using this method closely aligns with the manual calculation result, with the fuzzy logic calculation yielding 6020 and the manual calculation yielding 6053. By using fuzzy logic, tofu producers can make more informed decisions regarding production volume.

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