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Application of Fuzzy Logic in Tempe Production Using the Tsukamoto Algorithm

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Abstract

Fuzzy logic is widely used in various fields to formalize human behavior by considering inaccurate or partial reasoning. This study implements the Tsukamoto fuzzy logic method to analyze tempe production based on demand and inventory data. The research utilizes library research methods and data analysis using MATLAB (Matrix Laboratory). The Tsukamoto method was chosen for its high tolerance for data and flexibility. The system uses two input variables: demand and inventory, with output being production quantity. The fuzzy sets for demand are categorized as "Decrease" and "Increase" with a domain of [1000; 2000], inventory as "Few" and "Many" with a domain of [100; 600], and production as "Decrease" and "Increase" with a domain of [1520; 2100]. Using four fuzzy rules and the defuzzification process, the system can predict optimal production quantities. For example, with a demand of 1500 and inventory of 400, the system calculates a production quantity of 1823 units. This implementation demonstrates the effectiveness of the Tsukamoto method in automating production decisions based on demand and inventory variables.

Keywords: analysis, fuzzy logic, Tsukamoto method.

INTRODUCTION

Tempeh is a fermented food made primarily from soybeans, which is highly nutritious. Tempeh has become a popular food staple, commonly served daily as a side dish accompanying other dishes, and is widely enjoyed and sought after in Indonesian markets (Anggraini *et al*. 2020). The fermentation process of tempeh involves the fungi *Rhizopus oligosporus*and *Rhizopus oryzae*. The nutrients in tempeh include essential elements needed by the body, such as proteins, fats, carbohydrates, and minerals. Several studies have shown that the nutrients in tempeh are more easily digested, absorbed, and utilized by the body, as the mold growing on the soybeans hydrolyzes complex compounds into simpler compounds that are easier for the human body to digest (Asbur and Khairunnisyah, 2021).

Fuzzy logic is a method used to formalize human behavior by accounting for imprecise or partial reasoning. Fuzzy logic can also be understood as a bridge between human language, which emphasizes significance, and machine language, which is highly precise (Damanik *et al*. 2022). The type of logic in fuzzy logic can be true and false simultaneously, as it incorporates a degree of ambiguity or uncertainty, with a membership value between 0 and 1. One of the advantages of using fuzzy logic to solve a problem is its easy-to-understand concept, adaptability to changes or uncertainty, and its ability to describe complex linear functions (Pasaribu *et al*. 2021). In this study, the application of fuzzy logic is used to analyze the amount of tempeh production so that the produced tempeh matches the demand, inventory, and current production automatically.

The method chosen to address the problem in this study is the Tsukamoto method. The fuzzy Tsukamoto method is an approach that offers high tolerance for data and great flexibility. One of the advantages of this method is its intuitive nature and its ability to respond to qualitative, imprecise, and ambiguous information. In the Tsukamoto method, each rule is represented as a fuzzy set with a monotonic membership function, a process known as fuzzification. The result of each rule is a crisp value based on the α-predicate or the minimum value of each rule and the z-value. The final result is obtained through a defuzzification process using a weighted average (Ferdiansyah and Hidayat, 2018).

METHODS

The research in this journal uses the method of literature study and data analysis using MATLAB (Matrix Laboratory). Literature studies carried out by collecting information and data with the help of various materials in the library such as reference books, similar previous research results, articles, notes, and various journals related to the problem to be solved (Sari and Asmendri 2017). Data analysis research using MATLAB (Matrix Laboratory) was carried out with the Tsukamoto method. The Tsukamoto method is a method that has a tolerance for data and is very flexible. The advantage of the Tsukamoto method is that it is intuitive and can provide responses based on qualitative, inaccurate, and ambiguous information (Ferdiansyah and Hidayat 2018).

Data analysis using the Tsukamoto method has several stages, namely:

1. The first process carried out is to determine the fuzzy variable of the speech universe, the fuzzy set, and the domain in each set or commonly called Fuzzification. At this stage will obtain membership value by using functions that are presented in the form of curves.
    a. Ascending Linear Curve, is a straight curve that moves up starting from the lowest membership degree value which is 0 to the higher membership degree value which is in the Equation.
    b. Linear Down Curve, is a straight curve that moves down starting from 1 which is the value of the highest membership degree to the lowest membership degree which is 0.
    c. Triangle Curve, is the result of the combination of a linear curve up and a linear curve down to form a triangular plane.
2. The process of forming a fuzzy knowledge base (rules). This process is made in the form of if-then which is the formation of rules resulting from the combination of each set in the input variable.
3. The inference process is to calculate the degree of membership or membership function (μ) and find the α-predicate and crisp value on each rule that is made (Setiyawan *et.al* 2023).
4. The last step is the defuzzification process, which is using the weighted average method.

In the fuzzy logic calculation system, there is a determination of a fuzzy set for each fuzzy variable that will be used as input and output from the fuzzy inference system. In this journal the input is demand and supply of tempeh. Demand variables consist of up and down, while supply variables are few and many. The output in this journal is in the form of production with variables that increase or decrease.

RESULTS AND DISCUSSION

Fuzzy logic is a problem-solving control system methodology that can be applied to various types of systems, both simple and complex. This method has numerous applications, one of which is tempeh production. Fuzzy logic serves as an effective method to systematically connect the input space to the output space (Irawan and Herviana, 2018). In tempeh production, fuzzy logic is highly beneficial as it provides a structured approach to managing uncertainties caused by fluctuations in demand and inventory levels. By applying fuzzy logic in production planning, producers can optimally balance supply and demand, thereby minimizing the risk of overproduction or stock shortages.

Variable Fuzzy

Determining the variables to be used is the first step in building the system fuzzy. Define variables fuzzy is determining the variables that will be discussed in a system fuzzy (Samudra *et al.* 2024). In this research, the system that will be observed is the tempeh production process which aims to predict tempeh production based on demand and supply. Based on this, the variables used are demand (X), supply (Y), and production (Z). Demand and supply will be used as input, where the input is a factor that influences the output and results to be achieved or the output is the amount of tempe production that must be carried out. Determining this variable is based on the need to balance consumer demand, existing supplies, and production that must be carried out so that there is no shortage or excess production. Based on the research carried out, what is the prediction of tempe production that will be made if the demand is 1500 and the supply is 400.

Fuzzy Sets

Fuzzy sets is a form of expansion and at the same time to anticipate the weaknesses of using strict sets (crisp) (Rifanti *et al.* 2023). Fuzzy sets will represent a condition or state in a variable fuzzy. Fuzzy sets have elements that have different degrees of membership (Basriati *et al*. 2020). On the use of fuzzy methods, input and output variables are divided into one or more fuzzy sets. So the input variables are divided into demand and supply variables, as well as the output variable, namely production or the amount of production that must be carried out based on supply and demand data. The fuzzy set used in this research is shown in Table 2.

In the demand variable there are two categories in the set fuzzy, namely "Down" and "Up". The domain used for this variable is in the range [1000; 2000]. This shows that the demand variable is interpreted within a range to determine whether demand is decreasing or increasing. Using these two categories allows the system to understand changes in demand and will direct actions such as if demand increases then production increases. In the inventory variable there are two categories in the set fuzzy, namely “Few” and “Many” with domains [100; 600]. This grouping can allow the system to map inventory to a predetermined range so that it provides actions such as if inventory is in the "Few" category, actions to increase inventory can be recommended. In the production variable there are two categories in the set fuzzy, namely “Decrease” and “Increase” with domain [1520; 2100]. In this set, production can be adjusted to be reduced or added based on demand and supply conditions so that the range used can help adjust production to maintain a balance between market demand and supply.

Fuzzification

Fuzzification is the process of mapping input and output values into fuzzy sets. Input data, which is in the form of crisp sets, is then converted into fuzzy sets based on the range for each input variable. In the fuzzification process, there are two important things to consider, namely the input and output values, as well as the membership function which will be used to determine the fuzzy value of the crisp input and output data. The membership function used is Gaussian for input variables because it is suitable for natural data such as weather data. In addition, the Gaussian function is chosen because it has a high level of accuracy in reading data compared to other functions. At the fuzzification stage, an iterative process is carried out by changing the range of values and parameters used to construct the membership function, and it is also possible to change the type of membership function used (Siswoyo and Zaenal 2018).

There are 3 variables that are modeled using a linear representation membership function, namely:

a. Demand

The membership function of the decreasing and increasing set of the demand variable:

$$\mu x\ [Decrease] = \frac{b-x}{b-a} = \frac{2000-1500}{2000-1000} = \frac{500}{1000} = 0,5$$

$$\mu x\ [Increase] = \frac{x-a}{b-a} = \frac{1500-1000}{2000-1000} = \frac{500}{1000} = 0,5$$

b. Inventory

The membership function of the few and many sets of the inventory variable:

$$\mu y\ [Few] = \frac{b-y}{b-a} = \frac{600-400}{600-100} = \frac{200}{500} = 0,4$$

$$\mu y\ [Many] = \frac{y-a}{b-a} = \frac{400-100}{600-100} = \frac{200}{500} = 0,6$$

c. Production

The membership function of the decreasing and increasing sets of the production variable:

$$\mu y\ [Decrease] = \frac{b-z}{b-a} = \frac{2100-1823}{2100-1520} = \frac{277}{580} = 0,5$$

$$\mu y\ [Increase] = \frac{z-a}{b-a} = \frac{1823-1520}{2100-1520} = \frac{303}{580} = 0,5$$

Fuzzy Rules

Fuzzy rules are rules based on fuzzy logic used to make decisions or determine the output of a system based on uncertain or ambiguous input. Fuzzy rules operate on the principle of fuzzy logic, which allows membership values to range from 0 to 1, in contrast to binary logic, which only recognizes values of 0 or 1.

Fuzzy rules have a structure consisting of two main parts: the premise (antecedent) and the conclusion (consequent). The premise is located in the IF part, which contains conditions or situations based on fuzzy input variables. These conditions may include logical operators such as AND or OR to combine multiple variables. The conclusion is found in the THEN part, which specifies the output or action to be taken if the premise is satisfied. By using fuzzy logic, fuzzy rules enable the system to handle uncertain data and produce flexible decisions.

In this fuzzy rule set, four fuzzy rules are used, as shown in Table 3.

The following is the inference process using the Tsukamoto method for calculating the α-predicate:

a. *Rule* 1 = MIN (0,5 ; 0,4)

$\alpha 1$ = 0,4

Decreasing Demand

$z1 = \frac{b-x}{b-a}$

$0,4 = \frac{2100-x}{2100-1520}$

2100 - x = 0,4 * 580

2100 - x = 232

x = 2100 - 232

x = 1868

b. *Rule* 2 = MIN (0,5 ; 0,4)

α2 = 0,4

Decreasing Demand

$z2 = \frac{b - x}{b - a}$

$0,4 = \frac{2100 - x}{2100 - 1520}$

2100 - x = 0,4 * 580

2100 - x = 232

x = 2100 - 232

x = 1868

c. *Rule* 3 = MIN (0,5 ; 0,4)

α3 = 0,5

Increasing Demand

$z3 = \frac{x - a}{b - a}$

$0,4 = \frac{x - 1520}{2100 - 1520}$

x - 1520 = 0,5 * 580

x - 1520 = 290

x = 290 + 1520

x = 1810

d. *Rule* 4 = MIN (0,5 ; 0,4)

α4 = 0,4

Increasing Demand

$z4 = \frac{x - a}{b - a}$

$0,4 = \frac{x - 1520}{2100 - 1520}$

x - 1520 = 0,4 * 580

x - 1520 = 232

x = 232+ 1520

x = 1752

Defuzzification

Defuzzification is the process in fuzzy logic that converts output in the form of fuzzy values (degree of membership) into crisp (numerical) values that can be used in the real world. After drawing conclusions from fuzzy rules, defuzzification generates a final concrete output. Common methods used in defuzzification include centroid (taking the average of the center of the area) and mean of maxima (taking the average value of the maximum points). In this process, the defuzzification value is calculated using the following formula:

$$Z = \frac{(Predicate\ 1\ x\ Z1) + (Predicate\ 2\ x\ Z2) + (Predicate\ 3\ x\ Z3) + (Predicate\ 4\ x\ Z4)}{Predicate\ 1 + Predicate\ 2 + Predicate\ 3 + Predicate\ 4}$$

$$Z = \frac{(1868\ x\ 0,4) + (1868\ x\ 0,4) + (1810\ x\ 0,5) + (1752\ x\ 0,4)}{0,4 + 0,4 + 0,5 + 0,4}$$

$$Z = \frac{747 + 747 + 905 + 701}{1,7}$$

$$Z = \frac{3100}{1,7}$$

Z = 1823

Table 1 Variable Fuzzy

Variable	Information
Demand	X
Inventory	Y
Production	Z

Table 2 Fuzzy sets

Variable	Fuzzy set	Domain
Demand	Decrease; Increase	[1000; 2000]
Inventory	Few; Many	[100; 600]
Production	Decreasing; Increase	[1520; 2100]

Table 3 Fuzzy rules

Rule	**Demand**	**Inventory**	**Production**
1	Decrease	Many	Decrease
2	Decrease	Few	Decrease
3	Increase	Many	Increase
4	Increase	Few	Increase

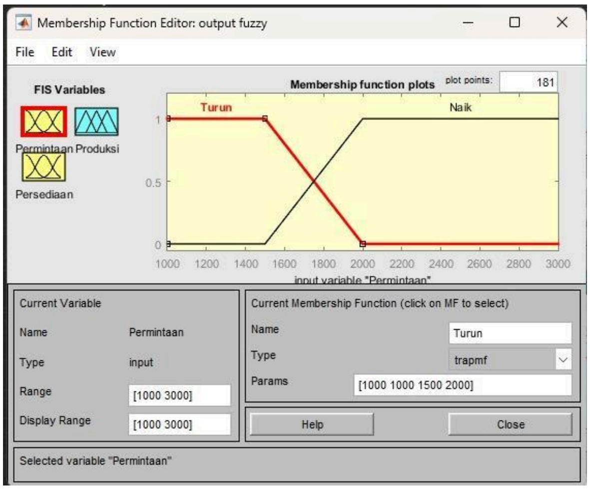

Figure 1 Membership function editor: Demand

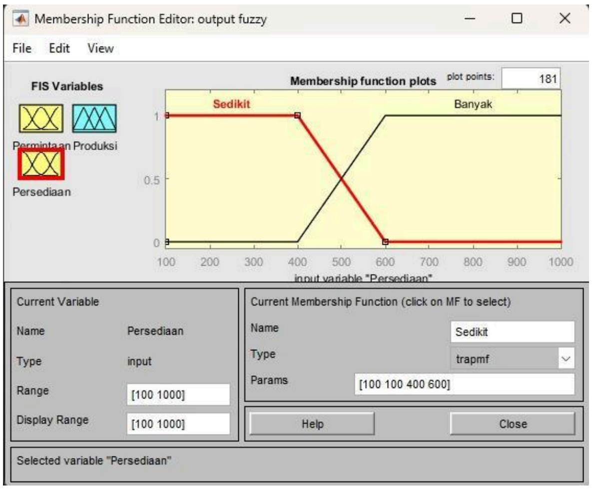

Figure 2 Membership function editor: Inventory

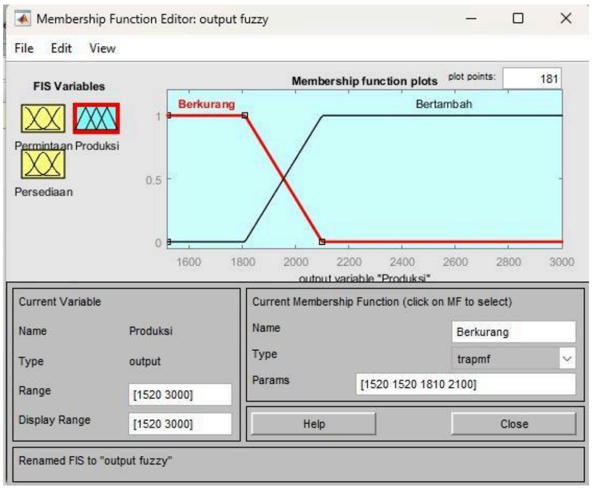

Figure 3 Membership function editor: Production

Figure 4 Rule viewer

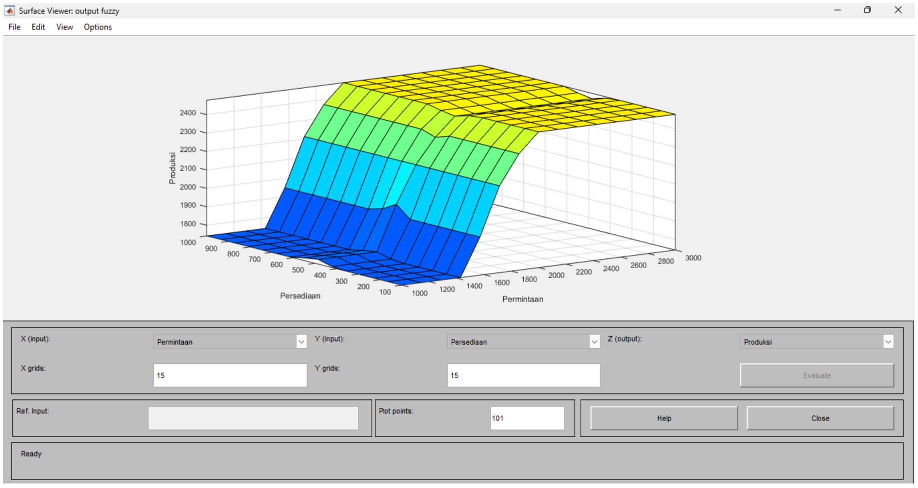

Figure 5 Surface viewer

CONCLUSION

Based on the research conducted, the implementation of the Tsukamoto fuzzy method has been successfully applied to analyze and predict the production quantity of tempeh based on demand and inventory variables. The developed system demonstrates the ability to provide precise calculations by considering two input variables through four established fuzzy rules. This is evidenced by the calculation results showing that with a demand input of 1500 and an inventory of 400, the system is able to recommend a production quantity of 1823 units, reflecting a balance in production decision-making. The Tsukamoto method has proven effective in handling uncertainty and providing flexibility in production decision-making, allowing for automatic adjustments in production based on current demand and inventory conditions. Thus, this system can assist tempeh producers in optimizing production quantities to avoid shortages or overproduction, ultimately enhancing operational efficiency and reducing potential losses.

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