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Application of Fuzzy Linear Programming to Optimize the Amount of Chicken Production Using Tsukamoto Method (Case Study: Ayam Geprek XYZ)

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ABSTRACT

Fuzzy linear Programming is the development of a linear program model to find and determine the optimal value containing fuzzy values. To optimize the amount of raw chicken production, this research uses the Tsukamoto method and Fuzzy Linear Programming (FLP). This case study is focused on Ayam Geprek XYZ. Market demand, raw material availability, and production capacity are some of the factors that affect raw chicken production. The FLP method with Tsukamoto approach is used to handle diversity and uncertainty in decision making about chicken production. A case study was conducted to show that this technique is effective in improving production efficiency and resulting in more optimized raw chicken production management decisions. The results of this study are expected to increase our understanding of the application of FLP with Tsukamoto method in the food industry, particularly on how to optimize raw chicken production.

Keyword: Fuzzy Linear Programming, Tsukamoto Method, Production

1. INTRODUCTION

Linear Program (PL) is a mathematical modelling for decision making that optimizes existing resources. To obtain PL results, each resource is converted into abstract or mathematical symbols that resemble the actual situation (Eky, Irwanto & Ratnasari, 2016). For optimization, OT can only be used on data that is accurate and easy to understand. Thus, the concept of fuzzy sets is used in PL modelling.[1].

A fuzzy set is a set with vague membership boundaries. The degree of membership of a fuzzy group is indicated (George & Yuan, 1995). In the branch of mathematics, the concept of fuzzy set appears clearly and implicitly as a basic concept. In the case of vague set decision making, an OT model known as fuzzy linear programming (FLP) is used [1]. In decision making, FLP combines concepts from fuzzy sets and PL with coefficients that are not probabilistic or uncertain constraint functions (Abdullah & Abidin, 2014). In addition, FLP is also known as a model used to find the optimum solution of the objective function (Z) by optimizing the constraint function in the form of a vague set (Kusumadewi & Purnomo, 2010).[1].

Optimizing the amount of production or called production optimization is a strategy used to overcome market competition. By using production optimization, manufacturers can optimally meet customer demand without hoarding goods in warehouses. Since there are many factors that get in the way of making decisions about production quantities, performing production optimization requires an understanding of certain methods and auxiliary sciences. Fuzzy logic is one of the mathematical techniques that can be used to solve optimization problems.[2]. The food industry, particularly raw chicken production, continues to grow and become a key focus in meeting consumer needs. As such, production efficiency is crucial to ensure the smooth and successful operation of a business. Due to its delicious taste and ease of serving, raw chicken, especially in the form of processed products such as geprek chicken, has become a popular choice among customers [3]. However, companies managing raw chicken production face complicated issues such as fluctuations in market demand, uncertainty in raw material availability, and limited production capacity. To address these issues and improve production efficiency, a careful and precise approach is required when making decisions on resource allocation[3].

Ayam Geprek XYZ is a small and medium-sized business that produces geprek chicken according to consumer demand. This is done because it is very important to ensure that the products produced match the tastes and preferences of customers, making it easier to sell and be accepted by the market, as well as to ensure that the products produced match the specified quality standards. This geprek chicken entrepreneur always coordinates with customers and collects input from customers to determine the products to be produced and improve existing products according to customer needs.[3]. According to Surbakti et al., there are three methods in fuzzy inference systems that can be used to calculate production quantities; they are Tsukamoto method, Mamdani method, and Sugeno method. In this research, we will use the Tsukamoto method to calculate the amount of production. This method is used because each consequent of an IF-THEN rule must be represented by a fuzzy set with a monotone membership function. Therefore, the inference result of each rule is given strictly (crisp) based on α-predicate. According to Kusumadewi et al., the final result can be obtained by using a weighted average.[4].

2. THEORETICAL FOUNDATION

2.1 Fuzzy set

Set theory is a branch of mathematical logic that studies the idea of sets, which are informally defined as collections of objects [5]. As stated by Ferreiros (2007), set theory is the basis of the progress of mathematics. In other words, other branches of mathematics, such as geometry and algebra, have been influenced by the application of set theory [6]. In the real world, modeled processes are often imprecise. In most cases, modeling of reality associated with uncertainty cannot be done as it is, and modeling can be done only within certain limits. Fuzzy sets allow working in uncertain and ambiguous situations and solving problems with incomplete information. Fuzzy sets consist of elements that have different degrees of membership. L. A. Zadeh introduced fuzzy sets in 1965 as an extension of the classical set understanding. Fuzzy theory uses linguistic variables rooted in natural language and their values are fuzzy words, or expressions, rather than numbers. Fuzzy words are inaccurate but easy to understand and widely used in everyday language. A fuzzy set is a collection of fuzzy variables that represent a certain condition or state. The membership value of an item x in a set A, usually referred to as μA[x], has two possibilities in the crisp set, namely:

1. One (1), which means that an item is a member of a set, or
2. Zero (0), which means that an item does not belong to a set.Jika pada himpunan crisp, nilai keanggotaan hanya ada 2 kemungkinan, yaitu 0 dan 1, pada himpunan *fuzzy* nilai keanggotaan terletak pada rentang 0 sampai 1. Himpunan *fuzzy* $\mu A[x] = 0$ berarti x tidak menjadi anggota himpunan A, demikian pula apabila x memiliki nilai keanggotaan *fuzzy* $\mu A[x] = 1$ berarti x menjadi anggota penuh pada himpunan A[7].

Sometimes, there is a similarity between fuzzy membership and the possibility of confusion. Although both have values in the interval [0,1], the way they interpret the values is very different from each other. While fuzzy membership indicates a measure of decision or opinion, probability indicates the proportion of times an outcome is true in the long run [8].

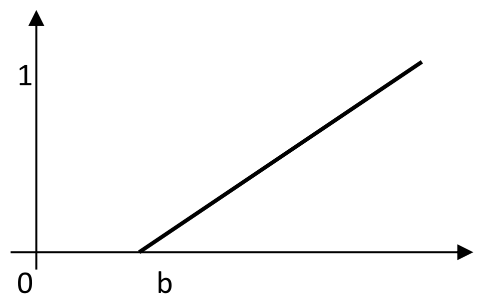
Fuzzy membership provides a measure of opinion or decision, while probability indicates the proportion of times a result is true in the long run [9]. Fuzzy sets have 2 attributes, namely:

1. Linguistic, namely naming a group that represents a certain state or condition using natural language, such as: Young, Middle-aged, Old.
2. Numerical, which is a value (number) that shows the size of a variable such as: 25, 40,60

2.2 Membership Function

A membership function, also known as membership degree, is a curve that projects input data points into membership values, which have an interval between 0 and 1. The function approach is one method that can be used to calculate membership values. Some functions that can be used include[10]:

a. Linear Representation

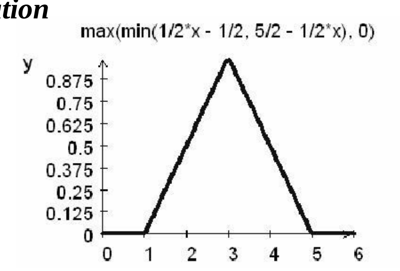


Gambar 1 – 1. Linear membership function representation

Membership function:

$$\mu[x] = \frac{x-b}{a-b} \tag{1}$$

b. ***Triangular Curve Representation***

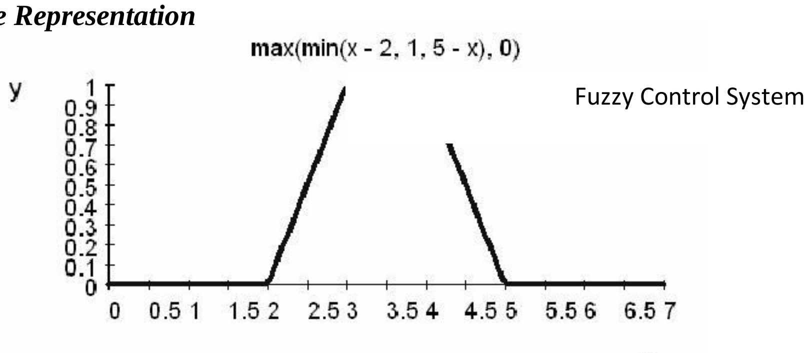


Gambar 1 – 2. Triangular membership function representation

Membership function :

$$\mu[x] = \max\left(\min\left(\frac{h-c+x}{h}, \frac{c+h-x}{h}\right), 0\right) \tag{2}$$

b. ***Trapezoidal Curve Representation***

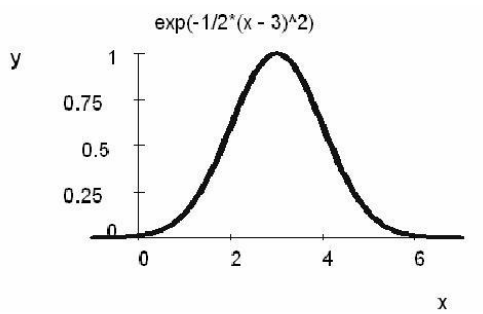


Gambar 1 – 3. Trapezoidal membership function representation

Membership Function :

$$\mu[x] = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right) \tag{3}$$

b. Gauss curve representation:

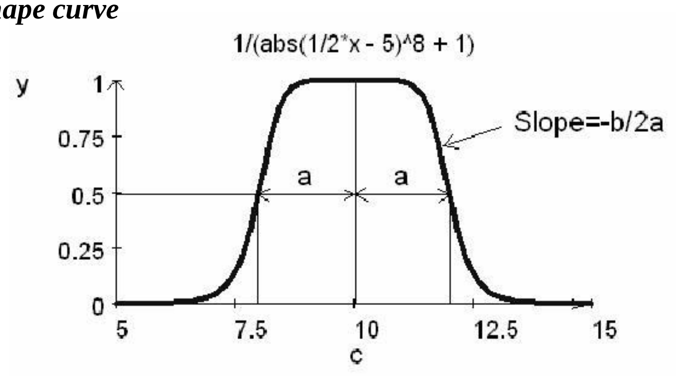


Gambar 1 – 4. Representasi fungsi keanggotaan Gauss

Membership Function :

$$\mu[x] = e^{-\frac{(x-c)^2}{2s^2}} \tag{4}$$

c. ***Generalized bell shape curve***

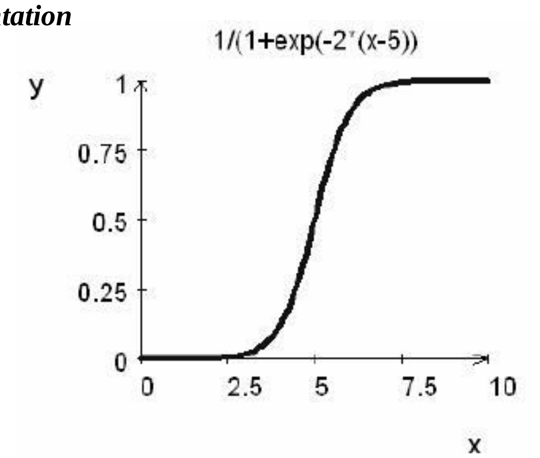


Gambar 1 – 5. Bell shape membership function representation

Membership Function:

$$\mu[x] = \frac{1}{\left|\frac{x}{a} - \frac{c}{a}\right|^{2b} + 1} \tag{5}$$

d. ***Sigmoid curve representation***



Gambar 1 – 6. Sigmoid membership function representation

Membership Function:

$$\mu[x] = \frac{1}{e^{-a(x-c)} + 1} \tag{6}$$

2.3 Tsukamoto Method

In Tsukamoto's method, each consequence of an "if-then" rule must be represented by an ill-defined set with a monotonous membership function, according to Kusumadewi et al. Therefore, the inference result of each rule is given in a crisp manner based on α-predicates, and then the final result is obtained using a weighted average. There are 4 stages in completing a decision support system using Tsukamoto fuzzy logic:

1. Fuzzyfikasi

Determine all variables involved in the process to be determined. For each input variable, determine an appropriate fuzzification function.

1. Fuzzy Rule Formation

Fuzzy rules are formed to obtain results that state the relationship between input variables and output variables. The fuzzy rule used is an "if-then" rule with the operator between input variables is the "and" operator. Questions that follow "if" are referred to as antecedents and statements that follow "then" are referred to as consequences.

(If $\alpha_1 is\ A_1)\ \cap \dots \cap (\alpha_n is\ A_n)\ so\ (b\ is\ k)$

2. Fuzzy Logic Analysis

Each rule formed is an implication statement. In the Tsukamoto fuzzy method, the implication function used is the Min implication function. The Min implication function is to take the smallest membership value between elements in the fuzzy set concerned. In general it can be written:

$$\mu_{A\cap B} = \min(\mu_A(x_i), \mu_B(y_i))$$

3. Defuzzification

The defuzzification process in the Tsukamoto method uses the centered average method (Average).

$$\rho = \frac{\sum a_i p_i}{\sum a_i}$$

By:

ρ : Variabel *output*

a_i : Predicate α-value

p_i : Output variable value

2.4 Forecasting Accuracy Measure

If you want to determine the accuracy of the model, you can use MSE (Mean Square Error) and MAPE (Mean Absolute Percentage Error).

1. MSE (Mean Square Error)

MSE is a prediction criterion by squaring each error and dividing by the amount of data. The equation form is as follows:

$$MSE = \frac{\sum_{i=1}^{n}(p_i - \hat{p}_i)^2}{n} \qquad (7)$$

By :

p_i : Original data value of the i-th observation

$\hat{p}_i$: Predicted value of the i-th observation

n : Amount of data

2. MAPE (Mean Absolute Percentage Error)

MAPE is a measure of the forecasting accuracy of a forecasting method. The equation form is as follows:

$$MAPE = \frac{\sum_{i=1}^{n}\frac{|p_i - \hat{p}_i|}{p_i}100\%}{n} \qquad (8)$$

After obtaining the MAPE value to find out the truth value can be done with :

Degree of Correctness = 100% - MAPE

The MAPE value criteria according to (Chang, Wang & Liu, 2007) are as follows:

1. <10% (very good forecasting ability)
2. 10% - 20% (good forecasting ability)
3. 20% - 50% (moderate forecasting ability)
4. >50% (poor forecasting ability).

However, according to Makridakis, the right model is a model that has a MAPE value of around 0% - 30%.

3. RESEARCH METHODS

3.1 Location and Time of Research

This research started from Wednesday, March 6, 2024 to Saturday, March 30, 2024. The data used in this research is primary data, where researchers conducted interviews with the owner of the UMKM Ayam

Geprek XYZ which is located in Gg. Susuk I, Padang Bulan, Kec. Medan Baru (Pintu Jebol USU).

3.2 Data Analysis Stages

Tsukamoto method is one of the popular methods used in Fuzzy Linear Programming (FLP) to solve optimization problems with uncertain or ambiguous data. This method combines a fuzzy approach with linear programming to produce a more realistic and flexible solution. The following are the stages of data analysis of the Tsukamoto method in Fuzzy Linear Programming:

1. Problem Definition

The first step is to clearly define the FLP problem. This includes determining the objective function, decision variables, constraints, and membership values for each variable and parameter.

2. Establishment of Membership Function

Membership functions are used to represent the degree of certainty or ambiguity of each variable and parameter. The shape of the membership function can be triangular, trapezoidal, or any other shape that fits the data.

3. Fuzzy Data Aggregation

Fuzzy data aggregation is required to combine information from different fuzzy sources or variables. Commonly used aggregation methods are average, maximum, and minimum.

4. Fuzzy Inference

Fuzzy inference is used to generate an optimal solution based on previously created fuzzy rules. These fuzzy rules connect input and output variables using fuzzy logic.

5. Defuzzification

Defuzzification is the process of converting fuzzy inference results into numerical values that can be interpreted. Frequently used defuzzification methods are the centroid method and the maximum method.

6. Interpretation of Results

The results of the Tsukamoto method data analysis are the optimal values for the decision variables and the objective function values. These results need to be interpreted by considering the level of certainty or ambiguity of the data used.

4. RESULTS AND DISCUSSION

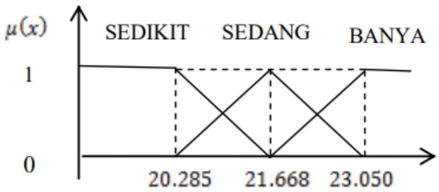
The data used in this study are data obtained from the Habibi Campus Geprek Chicken Restaurant in March 2024. The data used to determine the optimum production amount using the Tsukamoto fuzzy method is data on the amount of demand, the amount of inventory, and the amount of raw materials. In this study there are four variables, namely: input variables (including demand variables, sales variables, and inventory variables) while the output variable is the production variable. Based on the minimum and maximum values of the input variables and output variables, it can be seen in the following table.

Table 1. Minimum and maximum values of input and output variables on random data

Input	*Request*	[20.000, 25.000]
	Supply	[2.500, 3.500]
	Raw Materials	[10.000, 12.000]
Output	*Production*	[18.000, 21.000]

Problem solving using Tsukamoto fuzzy method

Here is how to get the degree of membership based on the given linguistic variables and numerical variables. Demand (x), consists of 3 fuzzy sets, namely little, medium, a lot. The membership function for the demand variable can be formulated as follows



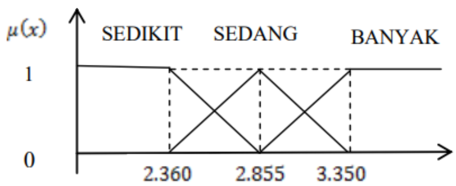
Gambar 1. Membership Function of Demand Variable

$$\mu_{reqFEW[x]} = \begin{cases} 1; x \leq 20.285 \\ \frac{21.668-x}{21.668-20.285}; \ 20.285 \leq x \leq 21.668 \\ 0; \ x \geq 21.668 \end{cases} \quad (9)$$

$$\mu_{reqMEDIUM[x]} = \begin{cases} 0; x \leq 20.285 \ atau \ x \geq 23.050 \\ \frac{x-20.285}{21.668-20.285}; \ 20.285 \leq x \leq 21.668 \\ \frac{23.050-x}{23.050-21.668}; \ 21.668 \leq x \leq 23.050 \end{cases} \quad (10)$$

$$\mu_{reqMANY[x]} = \begin{cases} 0; x \leq 21.668 \\ \frac{x-21.668}{23.050-21.668}; 21.668 \leq x \leq 23.050 \\ 1; \ x \geq 23.050 \end{cases} \quad (11)$$

a. Inventory (y), consists of 3 fuzzy sets, namely few, medium and many. The membership function for the inventory variable can be formulated as follows.



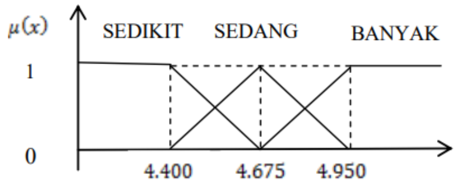
Gambar 2. Membership Function of the Inventory Variable

$$\mu_{splyFEW[y]} = \begin{cases} 1; y \le 2.360 \\ \frac{2.855-y}{2.855-2.360}; \ 2.360 \le y \le 2.855 \\ 0; \ y \ge 2.855 \end{cases} \tag{12}$$

$$\mu_{splyMEDIUM[y]} = \begin{cases} 0; y \le 2.360 \ atau \ y \ge 3.350 \\ \frac{y-2.360}{2.855-2.360}; 2.360 \le y \le 2.855 \\ \frac{3.350-y}{3.350-2.855}; \ 2.855 \le y \le 3.350 \end{cases} \tag{13}$$

$$\mu_{splyMANY[y]} = \begin{cases} 0; y \le 2.855 \\ \frac{y-2.855}{3.350-2.855}; \ 2.855 \le y \le 3.350 \\ 1; \ y \ge 3.350 \end{cases} \tag{14}$$

b. Raw materials (z) consist of 3 fuzzy sets, namely few, medium, and many. The membership function for the raw material variable can be formulated as follows.



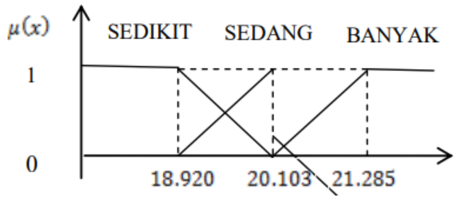
Gambar 3. Membership Function of Raw Material Variable

$$\mu_{materialFEW[Z]} = \begin{cases} 1; z \le 4.400 \\ \frac{4.675-z}{4.675-4.400}; \ 4.400 \le z \le 4.675 \\ 0; \ z \ge 4.675 \end{cases} \tag{15}$$

$$\mu_{materialMEDIUM[Z]} = \begin{cases} 0; z \le 4.400 \ atau \ z \ge 4.950 \\ \frac{z-4.400}{4.675-4.400}; \ 4.400 \le z \le 4.675 \\ \frac{4.950-z}{4.950-4.675}; \ 4.675 \le z \le 4.950 \end{cases} \tag{16}$$

$$\mu_{materialMANY[Z]} = \begin{cases} 0; z \le 4.675 \\ \frac{z-4.675}{4.950-4.675}; 4.675 \le z \le 4.950 \\ 1; \ z \ge 4.950 \end{cases} \tag{17}$$

c. Production (p) consists of 3 fuzzy sets, namely reduced, medium, and increased. The membership function for the Production variable can be formulated as follows.



Gambar 4. Membership Function of Production Variable

$$\mu_{prodFEW[p]} = \begin{cases} 1; p \leq 18.920 \\ \frac{20.103-p}{20.103-18.920};\ 18.920 \leq p \leq 20.103 \\ 0;\ p \geq 20.103 \end{cases} \quad (18)$$

$$\mu_{prodMEDIUM[p]} = \begin{cases} 1; p \leq 18.920\ atau\ p \geq 21.285 \\ \frac{p-18.920}{20.103-18.920};\ 18.920 \leq p \leq 20.103 \\ \frac{21.285-p}{21.285-20.103};\ 20.103 \leq p \leq 21.285 \end{cases} \quad (19)$$

$$\mu_{prodADDED[p]} = \begin{cases} 0; p \leq 20.103 \\ \frac{p-20.103}{21.285-20.103}; 20.103 \leq p \leq 21.285 \\ 1;\ p \geq 21.285 \end{cases} \quad (20)$$

The following is a solution using the tsukamoto fuzzy method

1. Problem on day-1

Demand: 22.885

Inventory: 2.960

Raw materials: 4.950

The degree of membership can be obtained as follows:

If the known demand is 22,885, then:

$\mu_{reqFEW[22.885]}=0$

$$\mu_{reqSEDANG[22.885]} = \frac{23.050 - 22.885}{23.050 - 21.668} = 0{,}12$$

$\mu_{reqBANYAK[22.885]}$

$$= \frac{22.885 - 21.668}{23.050 - 21.668} = 0{,}88$$

If the inventory is known to be 2,960, then:

$\mu_{splyFEW[2.960]} = 0$

$\mu_{splyMEDIUM[2.960]}$

$$= \frac{3.350 - 2.960}{3.350 - 2.855} = 0{,}79$$

$\mu_{splyMANY[2.960]}$

$$= \frac{2.960 - 2.855}{3.350 - 2.855} = 0{,}21$$

If the raw materials are known to be 4,950, then:

$\mu_{materialFEW[4.950]} = 0$

$\mu_{materialMEDIUM[4.950]} = 0$

$\mu_{materialMANY[4.950]} = 1$

Furthermore, the rules that can be used and find α-predicates using the AND operation equation are as follows:

[R1] IF DEMAND IS LITTLE, SUPPLY IS LITTLE and RAW MATERIALS IS LITTLE, THEN THE PRODUCTION AMOUNT LOWERS

$$\alpha_1 = \mu_{reqFEW} \cap \mu_{splyFEW} \cap \mu_{materialFEW}$$

$\alpha_1 = min\,(\mu_{reqFEW(21.500)}$

$\cap\ \mu_{splyFEW(2.650)} \cap \mu_{materialFEW(10.500)})$

$\alpha_1 = min(0; 0; 0)$

$\alpha_1 = 0$

Based on the REDUCED production set, the value of p_1=0 is obtained.

Furthermore, with the same steps in rule R1, rules R2 to R27 will be obtained. Then to get the defuzzification value, the centered average equation is used as follows: 1.
as follows:

$$p = \frac{\sum \propto_i p_i}{\sum \propto_i}$$

$$= \frac{0(0) + 0(0) + 0(0) + 0(0) + 0(0) +}{0 + 0 + 0 + 0 + 0 +}$$
$$\frac{0(0) + 0(0) + 0(0) + 0(0) + 0(0) +}{0 + 0 + 0 + 0 + 0 +}$$
$$\frac{0(21.285) + 0(20.103) + 0(0) +}{0 + 0 + 0 +}$$
$$\frac{0(20.103) + 0{,}12(20.245) + 0(0) + 0(0) +}{0 + 0{,}12 + 0 + 0 +}$$
$$\frac{0(0) + 0(0) + 0(20.103) + 0(20.103) +}{0 + 0 + 0 + 0 +}$$
$$\frac{0(0) + 0(20.103) + 0{,}79(21.037) + 0(0)}{0 + 0 + 0{,}79 + 0 +}$$
$$\frac{0(20.103) + 0{,}21(20.351) +}{0 + 0{,}79}$$

= 20.823

Then the number of chickens produced on day 1 using the Tsukamoto fuzzy method is 20,823.

For the next day, the same method is used to obtain the results of the amount of production, so that the following is obtained:

Day	Request	Supply	Raw Material	Production	Tsukamoto Fuzzy Result
Ke-1	22.885	2.960	4.950	21.285	20.823
Ke-2	20.535	2.880	4.400	18.920	19.340
Ke-3	21.925	2.360	4.750	20.425	20.497
Ke-4	20.89	2.445	4.600	19.780	19.606
Ke-5	22.55	3.230	4.900	21.070	20.792
Ke-6	22.09	2.970	4.700	20.210	20.599
Ke-7	21.98	2.600	4.950	21.285	20.594
Ke-8	21.55	2.545	4.850	20.640	20.794
Ke-9	21.455	3.065	4.650	19.995	19.749

Day	Request	Supply	Raw Material	Production	Tsukamoto Fuzzy Result
Ke-10	23.050	3.350	4.950	21.285	21.285
Ke-11	21.320	2.875	4.600	19.780	19.817
Ke-12	21.120	2.560	4.750	20.425	20.583
Ke-13	22.380	3.290	4.900	21.070	20.763
Ke-14	20.285	2.790	4.400	18.920	19.188
Ke-15	22.985	2.925	4.900	21.070	20.978
Ke-16	21.990	2.580	4.750	20.425	20.631
Ke-17	22.250	2.670	4.800	20.640	20.682
Ke-18	21.780	2.495	4.750	20.425	20.548
Ke-19	23.015	3.310	4.950	21.285	21.091
Ke-20	21.460	2.675	4.750	20.425	20.573
Ke-21	21.870	2.450	4.600	19.780	19.645
Ke-22	22.920	2.985	4.900	21.070	20.883
Ke-23	21.150	2.655	4.700	20.210	20.600
Ke-24	20.980	2.400	4.600	19.780	19.637

Truth Value of Production Quantity Tsukamoto Fuzzy Method

The results of chicken production by applying the Tsukamoto fuzzy method can be compared with the chicken production of the Geprek XYZ Chicken Restaurant using the average percentage or Mean Absolute Percentage Error (MAPE) as follows:

$$MAPE = \frac{\sum_{i=1}^{24} \frac{p_i - \hat{p}_i}{p_i} x100\%}{n} = 1{,}084728\% \quad (21)$$

Furthermore, to obtain the accuracy level of the Tsukamoto fuzzy method can be seen as follows:

$$100\% - 1{,}084728\% = 98{,}91\%$$

so that the results of predicting the amount of chicken production using the calculation of the average percentage error of the Tsukamoto fuzzy method is 1.09%. While the truth rate of the calculation results using the Tsukamoto, fuzzy method is 98.91%. The MAPE value obtained is <10%, so it can be concluded that the truth value of the amount of chicken production using the Tsukamoto fuzzy method is very good.

5. CONCLUSION

Based on the additional information provided, the conclusions that can be made are:

1. The Tsukamoto fuzzy method can be used to determine the optimal amount of chicken production based on factors such as the amount of demand, stock, and availability of raw materials.
2. On day 7, the amount of chicken production using the Tsukamoto fuzzy method is lower than the production of the Habibi Campus Geprek Chicken Restaurant. However, on day 2, the amount of chicken production using the Tsukamoto fuzzy method is actually higher.

3. The truth value of forecasting using the Tsukamoto fuzzy method reaches 98.91%, or the MAPE (Mean Absolute Percentage Error) value is only 10%. This shows that optimizing the amount of chicken production with the Tsukamoto fuzzy method is very good.
4. Overall, the application of the Tsukamoto fuzzy method has proven effective in optimizing the amount of chicken production at the Geprek XYZ Chicken Restaurant, with results that are more optimal than the previous production method.

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