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Application of ANP Method and Fuzzy Inference System on New Product Selection and Production Capacity Determination of Fish Canning

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ABSTRACT

Jember State Polytechnic has a fish canning teaching factory with a productivity of 7 q of fish per production. The canned fish product is a superior product, but the quality and type of products produced are low quality and less desirable. Therefore, product diversification is needed to increase the added value of canned fish. The fluctuating production capacity at teaching factory (TeFa) Fish Canning is an obstacle in determining production capacity according to market demand. The aim of this research is to diversify products and optimize fish canning products. This research was carried out using two methods, namely selecting superior products for TeFa fish canning using the Analytical Network Process (ANP) method and determining production capacity using the Fuzzy Inference System (FIS)-Tsukamoto method. The research results show that TeFa fish canning's superior product was determined by considering 4 criteria and 12 sub-criteria to produce tongkol balado with the highest weight value and followed by sardines with chili sauce, yellow seasoning tuna, and tuna salt solution. Simulation results for optimizing canned fish production are 5.7863 q/day which provides the optimum supply of canned fish.

1. INTRODUCTION

In the industrial world, the selection of new products and the determination of production capacity are two key elements that play an important role in the success of an industry. Proper selection of new products can be a strategy to increase competitiveness and respond to changing market needs. According to Kotler *et al*. (2001), product innovation is one of the strategies that can improve industry sustainability by creating products that are more relevant and desirable to consumers. On the other hand, production capacity planning is a process to ensure that the industry has sufficient resources to fulfil market demand efficiently (Slack & Brandon-Jones, 2018). If the number of products produced by the company is less than the number of requests, the industry will lose the opportunity to obtain maximum profit. Conversely, if the number of products produced exceeds the number of requests, the industry may experience losses. So that planning the amount of production is very necessary for an industry in order to meet consumer demand with the appropriate amount. Without proper planning, an industry can experience under-capacity or over-capacity, both of which have a negative impact on the industry performance.

State Polytechnic of Jember (Polije) has a Teaching Factory (TeFa) for fish canning which is a form of vocational education that combines academic learning with real industrial experience. The TeFa Fish Canning is still in the development stage and faces various challenges in managing its production capacity and product innovation. Currently, the Teaching Factory does not have optimal production capacity planning, so the production process run inefficiently. This is in line with research conducted by Heizer & Render (2007) which states that capacity planning is very important in creating an effective and sustainable production system. In addition, the TeFa Fish Canning also does not have new product innovations that can provide added value to its production. Product innovation is needed to remain relevant and competitive in the food processing industry, especially amidst increasingly fierce global competition. According to Suarez & Utterback (1993), product innovation not only expands the company's product portfolio but also contributes to increasing the efficiency and quality of the products produced. Therefore, it is important for the TeFa Fish Canning to immediately develop a plan for selecting new product innovations that are in line with market trends and consumer needs.

By looking at the above problems, a comprehensive plan is needed in selecting new product innovations and determining the right production capacity. This planning must consider various factors such as market demand, availability of raw materials, and the capabilities of human resources and technology owned. Thus, TeFa Fish Canning is expected to be able to increase its production efficiency and create innovative and competitive products in the market. Determining production capacity in the industry is very important because it directly affects operational efficiency, production costs, and the quality of the final product.

This study aims to select superior products and determine the optimum production capacity. The selection of superior products is carried out by calculating the values of the sub-criteria and criteria for canned fish products using the ANP (Analytic Network Process) method to obtain the value of each canned fish product criterion so that superior products are prioritized. Furthermore, to overcome the problem of optimizing the daily production capacity of canned fish, the Fuzzy Inference System (FIS) method is used so that it can provide predicted results for the optimal production capacity for canned fish products.

2. RESEARCH METHODOLOGY

2.1. Framework of Thought

This research is holistic qualitative in nature where all factors are taken into account as a whole, interdependent with each other for the benefit of all. Therefore, much more theory is needed because it must be adjusted to the phenomena that develop in the field (David, 2013). The development of fish canning-based industries at the TeFa Fish Canning, Jember State Polytechnic, obtained through surveys and asking directly to the TeFa Fish Canning so that the actual conditions being faced are known. Supported by the opinions of experts who are compared between theory and reality, so that strategic issues can be obtained. In the calculation of production capacity is done by FIS method.

The framework of this research focuses on the selection of superior products for the TeFa Fish Canning using the Analytical Network Process (ANP) method and determining production capacity using the Tsukamoto Fuzzy Logic method. Determination of superior canned fish products based on the most influential criteria and will later be used as a consideration for TeFa Fish Canning to evaluate and select the most potential products in the market using the Analytical Network Process method (Saaty & Ozdemir, 2020).

Once the superior product is determined, the next step is to determine the optimal production capacity. The Tsukamoto Fuzzy Logic method is used to handle uncertainty and variability in fish canning production, which is influenced by factors such as raw material availability, production time, and market demand. With this method, production capacity can be calculated flexibly and adjusted to actual conditions, thus helping the TeFa Fish Canning achieve optimal operational efficiency, neither under-capacity nor over-capacity. The integration between ANP and Fuzzy Logic is expected to produce holistic and adaptive decisions in the development of the TeFa Fish Canning, both in terms of products and production capacity.

2.2. Research Stages

In the first stage, the research focused on the selection of superior products using the ANP method. This stage began by identifying the main objective of the research, which was to determine the winning product at TeFa Fish Canning based on criteria such as market demand, economic value, raw material availability, and production capability. The ANP model was created using Super Decisions software, which helps manage pairwise comparison data, calculate priority weights, and perform sensitivity analysis. The data used included 10 pairwise comparison matrices obtained from 5 respondents, consisting of two managers of TeFa Fish Canning, one academic food technology expert, and two fish canning industry practitioners with more than five years of experience. Based on this data, four product alternatives were analyzed, namely TSS (tuna in salt solution), TBO (tongkol balado), SCS (sardines in chilli sauce), and TYS (tuna in yellow seasoning). The results of data processing using Super Decisions showed that Tongkol Balado was the superior product with the highest priority score.

In the second stage, the determination of production capacity is carried out using the Tsukamoto Fuzzy Logic method. This model was developed with the help of Microsoft Excel to process the fuzzification, inference, and defuzzification stages. The data required includes input variables such as raw material availability in quintals (q), production time (h/day), and market demand (q/day), as well as output variables in the form of production capacity.

2.2.1. Selection of Top Products Using the ANP Method

In the first stage, the selection of superior products using the ANP method begins by identifying the main objective of the research, which is to determine the superior products for Tefa fish canning, as well as the criteria and sub-criteria that are relevant in the selection process, such as market demand, economic value, availability of raw materials, and production capability. Next, an ANP model was built to represent the inter relationships between criteria and sub-criteria in the form of a network that included product alternatives to be compared, such as the type of product to be canned. After the model is formed, data is collected through questionnaires or interviews with experts or decision makers to obtain preference weights between elements. This questionnaire contains pairwise comparisons between elements in the ANP model. This comparison data is then entered into the Super Decisions software to calculate the weight of each element, through a super matrix and synthesis process that will produce the final weight in determining the superior product. The results obtained are analysed, and the winning product is selected based on the highest weight. If necessary, a sensitivity analysis is conducted to test the stability of the product selection results.

Product selection criteria are determined based on the results of interviews with the manager of TeFa Fish Canning, namely TSS, TBO, SCS, and TYS. While the sub-criteria are determined based on the needs and characteristics of TeFa Fish Canning. These criteria and sub-criteria were then discussed and approved by TeFa Fish Canning of the Polije.

Table 1. Criteria and sub-criteria for selecting top products

Criteria	Subcriteria
Market demand	Age
	Gender
	Social culture
Economic value	Selling price
	Nutritional content
	Flavour
Raw material availability	Tongkol
	Sardines
	Tuna
Production capability	Product quality
	Human resources
	Production capacity

2.2.2. Determination of Production Capacity Using Fuzzy Logic Tsukamoto Method

In the second stage, determining production capacity using Fuzzy Logic with the Tsukamoto method begins with identifying influential input and output variables, such as raw material availability, production time, and market demand as inputs, and optimal production capacity as output. Then, each input variable is fuzzified by assigning fuzzy sets and membership functions according to the characteristics of each variable, such as low, medium, and high categories. After that, fuzzy rules (IF-THEN) are constructed to describe the relationship between inputs and outputs based on expert knowledge or historical data. The Tsukamoto method is used in this inference process, where each rule produces a linear fuzzified output, which then produces a crisp value for the production capacity. Finally, defuzzification is performed to convert the results to optimal production capacity values. The resulting production capacity is evaluated to ensure its suitability to the production needs of Tefa fish canning. If required, sensitivity analysis is conducted to see the impact of changes in inputs on production capacity.

The Tsukamoto Fuzzy Logic method has the advantage of handling uncertainty and high variation in input data in a flexible and intuitive way, especially in decision making involving uncertain parameters. In this method, each rule produces a crisp value through linear fuzzification, thus providing more realistic and interpretable results than other fuzzy methods such as Sugeno or Mamdani, which produce outputs in the form of membership degrees or constants. With its rule-based inference structure, the Tsukamoto method enables adaptive system design and is particularly suitable for production and capacity control applications, where uncertainty in market demand or raw material availability can have a major impact. A recent study by Wulandari *et al*. (2018), showed that the Tsukamoto method provides more accurate and efficient production capacity prediction performance in small industrial applications than other methods due to its ability to linearly adjust output according to dynamic input conditions. According to a study by Ross *et al*. (2013), FIS is very useful in various applications such as automatic control, complex system modelling, and decision making under uncertainty, due to its ability to handle uncertain and imprecise data. In this research, the method used is a case study. The case study method is an appropriate strategy to use when the researcher has little opportunity to control the events to be studied and the focus of the research lies on contemporary phenomena in a real-life context (Hermanuadi *et al*., 2018).

2.3. Data Collection Technique

The research technique used is the survey method. The data used are primary and secondary data. Primary data was obtained directly from respondents through observations and interviews guided by questionnaires. Secondary data were obtained from related institutions, such as the Central Bureau of Statistics (BPS), the Agriculture Office, journals, books, and internet media that are relevant to this research.

2.4. Respondent Collection Technique

The sample size was 3 industry players, namely TeFa Fish Canning of the Polije, which was determined purposively with the provisions that industry players who were sampled (respondents) were owners of the fish canning industry who had been running the business for at least 5 years. In addition to samples from industry players, informants were also taken who were determined purposively, namely 1 academic and 1 head of the industry and trade office of Jember Regency.

2.5. Data Analysis

Analytic Network Process or ANP is a mathematical theory that allows a decision maker to deal with dependence and feedback factors systematically (Saaty & Vargas, 2006). ANP is one of the decision-making methods based on many criteria (parameters) developed by Thomas L Saaty. This method is a new approach to qualitative methods that is an advanced development of previous methods, namely the Analytic Hierarchy Process (AHP) (Saaty & Vargas, 1987). According to Kasutjianingati *et al*. (2020), ANP is used to solve problems that depend on alternatives and criteria. ANP networks can have criteria and alternatives in them, which are now called nodes. In addition to the use of hierarchical networks, decision making can also be done by creating a feedback network. This network more accurately describes the condition of a very complex research problem as stated earlier. The ANP method is able to improve the weakness of AHP in the form of the ability to accommodate interrelationships between criteria or alternatives (Novitasari *et al*., 2020).

Data analysis in the study that uses the Fuzzy Logic method to determine production capacity starts with fuzzification of input data, where variables such as market demand, raw material availability, and production are converted into fuzzy sets with specific membership functions (e.g. low, medium, and high). After that, fuzzy rules (IF-THEN) are applied to form logical relationships between input and output variables. In the Tsukamoto method, each rule produces an output in the form of a crisp value calculated based on a linear membership function. This inference process allows each rule to produce realistic production capacity predictions according to the conditions of the input variables. Once all rules have been evaluated, aggregation and defuzzification are performed to convert the final result into an optimal production capacity value. Analysis of these results involves assessing how well the obtained production capacity meets market demand and resource efficiency, allowing for adjustments to the model where necessary to more accurately match real conditions.

3. RESULTS AND DISCUSSION

3.1. Determination of Diversified Processed Fish Canning Products

In determining product selection priorities using the Analytic Network Process (ANP) approach, the modelling is initially conducted using Super Decisions software, which is specifically designed for this purpose. From ANP modelling, a pairwise comparison matrix is carried out. In the pairwise comparison matrix there is an interrelationship between elements in one cluster (inner dependence) and the relationship between elements between different clusters (outer dependence).

Super Decisions is software specifically designed to facilitate the application of the Analytic Network Process (ANP) method. It offers significant advantages, such as the ease of building network structures and managing complex relationships between influencing elements, which enhances the reliability of the decision-making process. Users can quickly enter pairwise comparison data, calculate priority weights, and perform synthesis to determine the optimal decision (Olfat *et al.*, 2016). In addition, Super Decisions supports sensitivity analysis, allowing users to evaluate the impact of changes in inputs on the final outcome. This makes it an efficient and reliable tool in support of ANP-based decision making, especially in situations where interrelationships and feedback between decision criteria are crucial (Djinovic *et al.*, 2020). The robustness of the results is further validated by the empirical evidence supporting the interdependencies among criteria, which is essential for accurate decision-making. Image 1 shows the ANP method using Super Decisions.

Based on method shown in Image 1, a complex decision-making model can be seen by considering the interrelationships between criteria and alternatives. In this model, some elements are interdependent, which means that changes in one element can affect other elements. At the top of the alternative identification, there are four product alternatives namely TSS, TBO, SCS, and YST. These alternatives are product choices that will be assessed based on several criteria.

As for the determination of criteria, there are four groups of criteria that are the basis for alternative assessment, namely "Economic Value" which has sub-criteria such as Price, Nutrition, and Taste; "Revenue Consumer" has sub-criteria such as Gender, Age, and Social Culture; "Raw Material" considers raw materials such as Tongkol, Sardines, and Tuna; and "Production" consists of Quality, Human Resources, and Capacity. Each of these criteria has more specific sub-criteria.

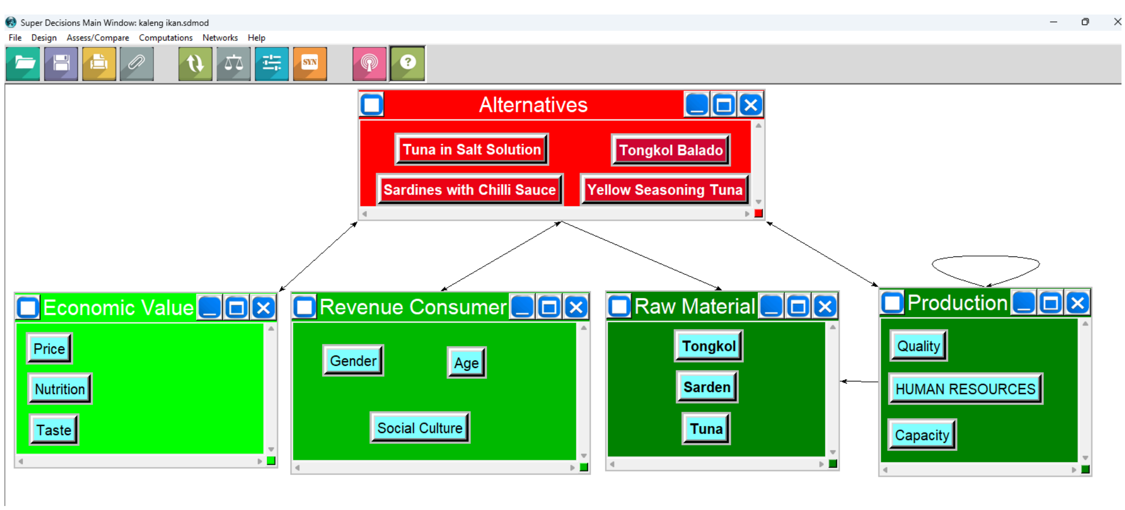

Image 1. ANP model for selecting diversified processed fish canning products using Super Decisions.

In the ANP method, each criterion and sub-criteria is interconnected, meaning that changes to one element can affect other elements. In the product at TeFa Fish Canning Polije, the quality of raw materials (Raw Material) will have an impact on the Production criteria, because quality raw materials will produce quality final products. This is in accordance with the research of Wijaya *et al*. (2022), which states that the quality of raw materials has a significant impact on the quality of the final product in the fish canning industry. Quality raw materials will produce final products that not only have good shelf life, but also meet high food safety standards. This research shows that raw materials that comply with standards will reduce the rate of product defects in the production stage and increase consumer confidence in the final product. In addition, economic value will also affect consumer income, as product prices and nutrition can influence consumer preferences based on their income, age or social culture. This is in accordance with research by Wijaya & Putri (2021), the economic value of food products - including price and nutrition - can directly influence consumer preferences and purchasing power. Products with high economic value tend to be favoured by consumers with a certain income and influence the demand for products in the market. In addition, these preferences also depend on demographic factors such as age and different social cultures.

After ANP modelling, pairwise comparisons, priority selection of diversified processed fish canning products is obtained with the help of Super Decision Software. From the calculation results using Super Decisions, the selected diversified fish canning products were obtained. Image 2 shows the ranking of each alternative. Based on the figure, it can be seen that the highest value of diversified fish canning products is TBO. By employing the ANP methodology, all these interrelationships and mutual influences are accounted for, leading to a more comprehensive and reliable decision in selecting the best alternative product from the four existing options.

Image 2. Comparisons for super decision

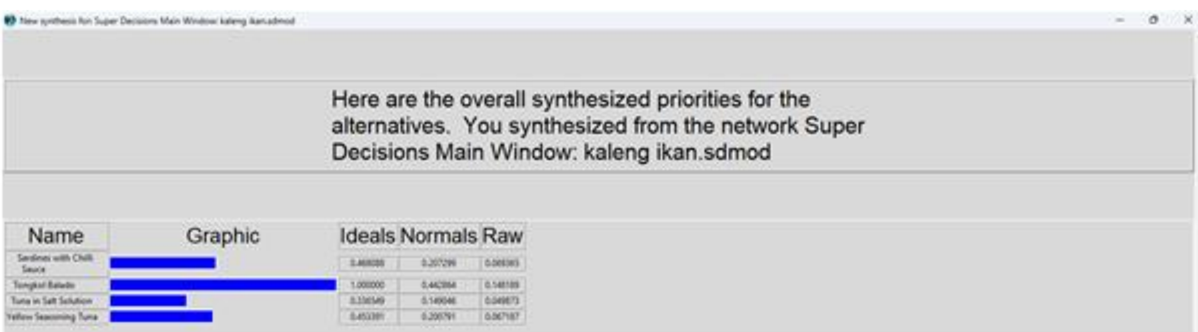

Image 3. The results of the priority analysis of the selection of diversified processed fish canning products using Super Decisions

Weighting and Inter-Criteria Assessment is obtained from calculating the weight of each criterion and alternative through a pairwise comparison matrix. In this case, each criterion is compared with each other to assess their relative influence on the decision-making objective. Then, these weights will be used to evaluate alternatives based on existing criteria. Based on the weighting and relationship between criteria, the final priority for each alternative is obtained. These results show which product alternatives are most suitable based on the analysis of the relationship between criteria. Based on these results, it is known that TBO is the preferred product (Image 3). It can be seen that TBO gets a value of 0.1427, SCS gets a value of 0.087, then YST gets a value of 0.085, while TSS gets the lowest value of 0.072. Tongkol balado is an alternative canned fish product with the highest weight, so it is chosen as a superior product in the development of product innovation at Tefa Fish Canning. This is because TBO in terms of economic value criteria, consumer needs, raw materials, and production capacity has a high assessment weight compared to other canned fish products.

3.2. Determination of Production Capacity

3.2.1. Factor Limitation

In a production system supported by fuzzy logic, inventory and demand are treated as input variables. These two variables have high uncertainty and fluctuations that are difficult to predict, so fuzzy logic can help in managing production decisions more flexibly and adaptively. According to Azadegan *et al.* (2011), explained the use of fuzzy logic to control production under uncertain demand conditions. Empirical results show that fuzzy logic models are able to flexibly adjust production levels as needed, reduce storage costs, and reduce the risk of overstocking. The data used is data from interviews with the production manager of Tefa Fish Canning and documentation of fish canning production data for 2022-2024. From the interview, data on the maximum and minimum limits of demand, inventory, and fish canning production were obtained. The following is the maximum and minimum limit data of demand, supply, and production.

Table 2. Factor limitation data

Raw Materials	Limit	Factors		
		Supplies (q)	Inquiry (q)	Production (q/day)
Fish	Maximum	20	8	9
	Minimum	5	4	3

Table 3. Fuzzy rules

R1	If Inventory	A little	and Demand	Low	Then Production	Declining
R2	If Inventory	A little	and Demand	High	Then Production	Increased
R3	If Inventory	Many	and Demand	Low	Then Production	Declining
R4	If Inventory	Many	and Demand	High	Then Production	Increased

Based on the demand for canned fish from 2022 to the present, it is known that the maximum demand is 8 q/day (Table 2). Minimum demand is 4 q/day. Tefa Fish Canning provides a minimum inventory limit for *safety stock of* 5 q and a maximum limit of 20 q. Maximum production capacity for fish canning is 9 q/day. The minimum production capacity for fish canning is 3 q/day. Fuzzy Inference System-Tsukamoto data processing consists of 4 main stages, namely the formation of membership functions, determination of membership values, inference systems, and defuzzification. The membership function is formed based on the *rule* determined to obtain the *z* value (goal) (Oktaviani, 2014). The rules used in this study to determine production capacity can be seen in Table 3, where R1 is the first rule, R2 is the second rule, R3 is the third rule, and R4 is the fourth rule. Based on the fuzzy rules in Table 3, there are 3 fuzzy variables to be modelled, namely demand, inventory, and production. To form a fuzzy membership function, it is necessary to create a membership function graph for each variable to make it easier to determine its membership function. The membership function graph created is based on the constraints in Table 3.

3.2.2. Membership Function

Fuzzy logic membership functions for variables such as demand and supply of canned fish play an important role in determining the right production level. Based on historical data, membership functions can be formed and verified to ensure accurate representation of these variables. The selection of membership forms, such as "low" or "high," is done by considering data distribution, system requirements, and guidance from supporting literature.

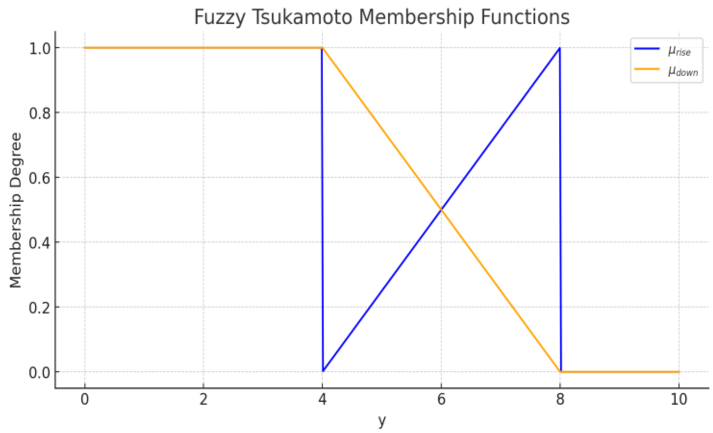

Image 4. Fuzzy set of demand variable

1. Canned Fish Demand Variable Membership Function

Based on the membership function of the canned fish demand variable has a maximum limit of 8 q and a minimum limit of 4 q of cans, so the demand variable in the fuzzy set membership function is presented in Image 4. The membership function of the canned fish demand variable has a maximum limit of 8 q and a minimum limit of 4 q of cans, so it can be concluded that the membership value μ of canned fish demand has the following limits:

$$\mu \text{ rise} = \begin{cases} 1 & ; y < 4 \\ \frac{y-4}{4} & ; 4 \leq y \leq 8 \\ 0 & ; y > 8 \end{cases}$$

$$\mu \text{ down} = \begin{cases} 1 & ; y < 4 \\ \frac{8-y}{4} & ; 4 \leq y \leq 8 \\ 0 & ; y > 8 \end{cases}$$

In the Tsukamoto method of fuzzy logic, the membership function for the canned fish demand variable is designed to convert quantitative data (in this case, demand in q) into corresponding membership degree (μ) values in the range [0.1]. Based on a maximum limit of 8 q and a minimum of 4 q, the membership function has an ascending and descending linear shape between these two limit points. For canned fish demand values below 4 q, the membership (μ) is considered full (μ = 1), reflecting a low demand level. In the interval $4 \leq y \leq 8$, the ascending membership function (μ ascending) is defined by the linear formula μ ascending = $\frac{y-4}{4}$, which results in an increase in the degree of membership from 0 to 1 as the value of y increases from 4 to 8 q.

In contrast, the descending membership function (μ descending) is defined as μ descending = $\frac{8-y}{4}$, which indicates a decrease in membership degree from 1 to 0 as y moves from 4 to 8 q. Values above 8 q result in a membership value of 0, indicating that demand no longer falls into the low category. This linear membership function provides a gradual transition between low and high levels of demand, allowing for a smoother production response. Literacy related to this basic concept can be found in "Fuzzy Sets and Fuzzy Logic" by Klir & Yuan (1995), which discusses how simple linear membership functions are applied to represent uncertainty in fuzzy-based decision making.

2. Membership Function of Fish Inventory Variable

Based on the membership function of the fish inventory variable has a maximum limit of 20 q and a minimum limit of 5 q, so the inventory variable in the fuzzy set membership function is presented in Image 5. The membership function of the fish inventory variable has a maximum limit of 20 q and a minimum limit of 5 q, so it can be concluded that the membership value μ of canned fish inventory has the following limits:

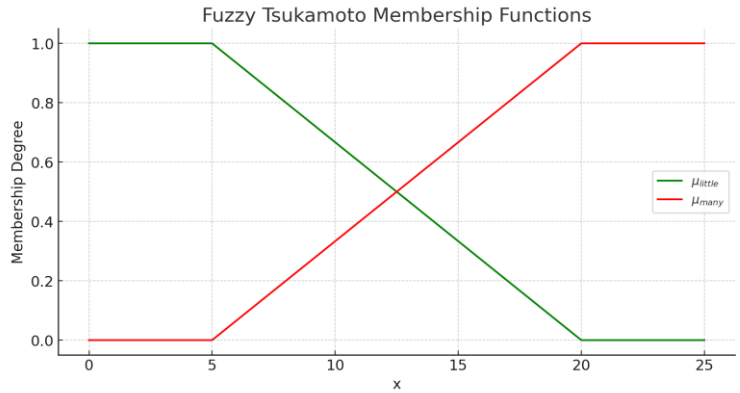

Figure 5. Fuzzy set of inventory variable

$$\mu \text{ little} = \begin{cases} 1 & ; x < 5 \\ \frac{20-x}{15} & ; 5 \le x \le 20 \\ 0 & ; x > 20 \end{cases}$$

$$\mu \text{ many} = \begin{cases} 0 & ; x < 5 \\ \frac{x-5}{15} & ; 5 \le x \le 20 \\ 1 & ; x > 20 \end{cases}$$

In decision-making systems involving membership functions, such as the fish stock variable, there are boundary values that define the membership categories, namely "few" and "many." With a minimum limit of 5 q and a maximum of 20 q, the membership function μ for fish stock in the "few" category indicates that if the stock is below 5 q, the value is 1 (meaning the stock must be few), and starts to decrease linearly to 0 when the stock reaches 20 q. Conversely, for the category "a lot," the membership value μ is 0 if the stock is below 5 q, then increases linearly to 1 when the stock reaches or exceeds 20 q. This membership model helps determine stock priorities based on existing inventory levels, which in turn can influence stock management and raw material procurement decisions more efficiently. This approach is in accordance with the concept of fuzzy sets described by Zadeh *et al*. (1996), where membership functions are used to represent uncertainty in decision-making based on non-rigid categories.

3. Membership Function of Fish Canning Production Variable

Based on the membership function of the canned fish production variable has a maximum limit of 9 q and a minimum limit of 3 q of canned fish, so the production variable in the fuzzy set membership function is presented in Figure 6.

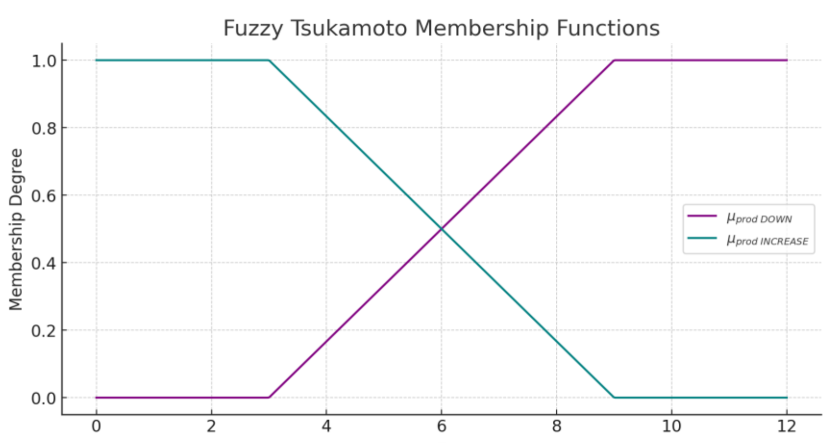

Image 6. Fuzzy set of production variable

The membership function of the canned fish production variable has a maximum limit 9 q and a minimum limit 3 q of canned fish, so it is concluded that the membership value μ of TeFa fish canning production has the following limits:

$$\mu \text{ prod DOWN } [z] = \begin{cases} 1 & ; z < 9 \\ \frac{z-3}{6} & ; 3 \leq z \leq 9 \\ 0 & ; z > 9 \end{cases}$$

$$\mu \text{ prod INCREASE } [z] = \begin{cases} 0 & ; z < 3 \\ \frac{9-z}{6} & ; 3 \leq z \leq 9 \\ 1 & ; z > 9 \end{cases}$$

In the context of canned fish production, the membership function μ on the production variable shows certain boundaries that describe the "DECREASE" and "INCREASE" categories based on the amount of production. With a minimum limit of 3 q and a maximum of 9 q, the "DECREASING" membership function has a value of 1 when production is below 9 q and decreases linearly from 1 to 0 when production reaches the upper limit. Conversely, the "INCREASING" membership function has a value of 0 below 3 q and increases linearly from 0 to 1 when it reaches or exceeds 9 q. This membership function approach allows for prioritization of production based on the number of quintals available, thereby facilitating the production decision-making process under conditions of uncertainty. The fuzzy theory introduced by Zadeh (2023), underlies this method, where membership functions are used to resolve ambiguities in qualitative variable-based systems that have value constraints.

3.2.3. Membership Value

After forming the formula of the membership function of demand and demand, then the membership value of each rule is obtained. The membership value sought is the membership value of demand and supply. The membership value obtained varies depending on the current demand and inventory data. The membership value of demand down is 1 if the demand data ≤ the minimum demand limit of 4 q. The membership value of falling demand is 0 if the demand data ≥ the maximum limit of 8 q. The inventory membership value is slightly valued at 1 if the inventory data ≤ the minimum limit of 5 q. The membership value of a small decrease in inventory is 0 if the demand data ≥ the maximum limit of 20 q. The membership value of h i g h demand and high inventory is the opposite of the membership value of low demand and low inventory. If the data lies between the minimum and maximum limits, it will be calculated based on equations 1 and 2. The results of the membership values of μ demand down, μ demand up, μ inventory little, and μ inventory lots of TeFa Fish Canning are calculated based on equations 1 and 2, which are presented in full in Table 4.

Table 4. Membership values

DATE	MEMBERSHIP FUNCTION			
	TeFa Fish Canning			
	μ DEMAND DOWN	μ DEMAND UP	μ INVENTORY LITTLE	μ INVENTORY LOTS
1	0.14	0.43	0.33	0.73

3.2.4. System Inference

The inference system stage is the stage of determining the value of α-*predicate*$_1$ against R_i. Determining the value of α-*predicate*$_i$ is formulated in equation 4 by finding the minimum value of each variable according to its fuzzy rules. The following is the Fish Canning inference system on 1 July 2022 as an example of the formation of the formula.

1. *First Rule Inference:* "if supplies are low and demand is low, then production is reduced".

α-predicate1 = μpersLOW ∩ μpermLOW
= min(μpersLOW) ∩ μpermLOW
= min(0.33;0.14)
= 0.14, then production is reduced,
(z-3)/6 = 0.14 eat z1 = 3.84

2. *Second Rule Inference:* "if supply is low and demand is high, then production increases".

α-predicate2 = μpersLIT⌒μpermGREATER
= min(μpersLESS)⌒μpermHIGHER
= min(0.33;0.43)
= 0.43, then production increases,
(9-z)/6 = 0.43 eat z2 = 9-2.58 = 6.42

3. *Third Rule Inference:* "if supply is high and demand is low, production is reduced".

α-predicate3 = μpersLARGE ⌒ μpermLOW
= min(μpersLOW) ⌒ μpermLOW
= min(0.73;0.14)
= 0.14, then production is reduced,
(z-3)/6 = 0.14 eat z3 = 3.84

4. *Fourth Rule Inference:* "if supplies are plentiful and demand is high, then production increases".

α-predicate4 = μpersBANY ⌒ μpermGREEN
= min(μpersBANY) ⌒ μpermTINGGI
= min(0.73;0.43)
= 0.43, then production increases,
(9-z)/6 = 0.43 eat z4 = 9-2.58 = 6.42

The inference system stage in fuzzy logic is the process of determining the α-predicate value for each inference rule (Ri) based on supply and demand conditions. This process includes selecting the minimum value of the membership degree of each variable in each fuzzy rule. At Tefa Fish Canning, four inference rules are applied in fish canning production. The first rule reads: "if there is little supply and low demand, then production is reduced," where the α-predicate value is 0.14 with a production yield of 3.84 q. The second rule: "if there is little supply and high demand, then production increases," gives an α-predicate value of 0.43 and a production of 6.42 q. The third rule, for the condition "high inventory and low demand," yields an α-predicate value of 0.14 with production reduced to 3.84 q. Finally, the fourth rule states "if inventory is plentiful and demand is high, then production increases," with an α-predicate value of 0.43 resulting in a production of 6.42 q. Using this approach, the fuzzy inference system effectively integrates various conditions to determine the optimal production level based on actual conditions, thereby enhancing the reliability of the production decision-making process.

3.2.5. Defuzzification

The defuzzification calculation uses the Weighted Average (WA) or Centroid method to determine the final output of the fuzzy system. This process involves combining the α-predicate results of each previously calculated inference rule. In this case, there are four rules with different α-predicate and output values (z1, z2, z3, z4). The value of α-predicate is multiplied by the result of each rule, then summed up. Next, the total result of this multiplication is divided by the sum of all α-predicate values to get the final defuzzification value, which is 5.7863 q. This process is crucial in fuzzy-based decision-making systems as it translates fuzzy results into crisp values that can be operated, ensuring that production decisions are based on quantifiable outputs rather than ambiguous fuzzy values.

$$\text{Defuzzification} = \frac{\alpha pred1 * z1 + \alpha pred2 * z2 + \alpha pred3 * z3 + \alpha pred4 * z4}{\alpha pred1 + \alpha pred2 + \alpha pred3 + \alpha pred4} = \frac{0.14*3.84+0.43*6.42+0.14*3.84+0.43*6.42}{0.14+0.43+0.14+0.43} = 5.7863 \text{ q/day}$$

The calculated defuzzification value of approximately 5.7863 q indicates the optimal production level that the fuzzy logic model recommends based on the current inventory and demand conditions. This value is derived from the weighted contributions of each inference rule, reflecting the underlying uncertainties and variabilities in the production environment. The defuzzified output is significant as it translates fuzzy logic results into actionable production targets. This allows TeFa Fish Canning to make informed decisions regarding production levels, ensuring that they can meet demand while managing inventory effectively. The validation of the production model output of 5.7863 q/day is supported by the detailed calculations of the defuzzification process using the WA method. This process ensures that the production decisions are based on quantifiable outputs derived from the fuzzy logic model, thereby enhancing the reliability and operational effectiveness of the production planning at TeFa Fish Canning.

The WA defuzzification is one of the commonly used methods in the application of fuzzy systems, especially in industrial control. This method is particularly advantageous as it produces a representative output value based on the weight of each rule, thereby enhancing the accuracy of the output in reflecting actual conditions. According to Fons *et al*. (2004), this method considers each fuzzy rule that contributes to the output value proportionally, resulting in reliable defuzzification results. This approach is especially beneficial in industries such as fish canning, where precision in production quantities directly impacts production efficiency and product availability in the market.

5. CONCLUSION

Based on research that has been conducted by researchers in determining the selection of diversified processed fish canning products at TeFa Fish Canning Polije, it can be concluded that there are 1 diversified processed fish canning products. Priority selection is carried out using the (ANP) approach. Based on calculations using Super Decisions, it is obtained that the TBO (tongkol balado) fish canning can be used as a diversified fish canning product. The results of the average production capacity of fish canning using the Fuzzy Inference System-Tsukamoto method are 5.7863 q/day. The amount of inventory indicates that the production capacity can be said to be the optimum production capacity. In the next production planning, Tefa fish canning can further optimize its production capacity and can prioritize Tongkol balado product in canned fish production activities to meet market demand.

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