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Article

Predicting Snack Food Production (Pentol) Using Fuzzy Logic

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Abstract: Fluctuating market demand and limited inventory are challenges in determining the optimal amount of production, especially for small businesses such as meatball snack production. This study aims to determine the addition of meatball production using the Mamdani fuzzy logic method. This system uses three input variables: income, inventory, and sales demand, and one output in the form of the recommended amount of production. Each variable is modeled with a triangular membership function. The case study shows that with an income of Rp650,000, an inventory of 600 pieces, and a demand of 1,500 pieces, the fuzzy system recommends an additional production of 500 pieces. These results prove that the Mamdani fuzzy method is effective in helping production decision making amidst subjective or vague data uncertainty.

Keywords: fuzzy logic, Mamdani, meatball production, income, demand, inventory.

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1. Introduction

The snack food industry has become one of the sectors showing significant growth in line with increasing consumer demand. [1][2] To compete and fulfill market needs, snack manufacturers must perform accurate and efficient production planning. [3][4] One of the main challenges faced is the uncertainty in determining the optimal production volume, which is influenced by various factors such as market demand, raw material availability, production capacity, and consumer trends. [5][6]

Fuzzy logic is a method that can be utilized to address uncertainty and complexity in production planning. [7][8] Fuzzy logic is capable of handling uncertain data and providing more flexible prediction results compared to conventional methods. [9][10] In the context of predicting snack food production volumes, fuzzy logic can process various input variables that possess ambiguous or uncertain values—such as fluctuating market demand and shifting consumer trends—to generate more accurate decisions. [11][12]

The predictive approach using fuzzy logic not only offers advantages in terms of flexibility and precision [13] but also enhances the manufacturer's capability to optimize resource utilization and reduce the risks of overproduction or underproduction. [14] Accordingly, the application of fuzzy logic in predicting snack food production volumes is expected to contribute significantly to improving operational efficiency and consumer satisfaction. [15]

Based on the background above, this study aims to develop a prediction model for snack food production volumes using fuzzy logic and to evaluate its performance under real conditions. Through this, it is hoped that this research can provide a practical and effective solution for the snack food industry in dealing with production planning challenges amid market uncertainties.

2. Materials and Methods

Research Design

This study employs a quantitative approach with a descriptive-analytical method to describe and analyze the influence of environmental factors on the sales of *pentol* (meatballs). The study also utilizes the fuzzy logic method to build a prediction model for *pentol* production based on the identified environmental factors. This research design is structured to answer the previously formulated research questions and to achieve the specified research objectives.

Research Subjects and Objects

The subject of this research is the owner of a home-based *pentol* production facility located in my immediate relative's area. This study constitutes a descriptive type of research. The subject of this research is the prediction of snack food (*pentol*) production volumes. The object of this research is the prediction of *pentol* production as influenced by environmental factors such as inventory, sales, and customer demand.

Data Collection Methods

To obtain accurate and comprehensive data, the following data collection methods were conducted:

- **Observation:** Performing direct observations at the production site to assist the researcher in gathering visual information, such as determining the production volume and daily output.
- **Interview:** Conducting interviews with the owner of the production facility to gather information regarding *pentol* production relative to environmental conditions influenced by daily sales and demand.

Research Variables

This study utilizes several variables to be processed using the fuzzy method:

Input Variables (Environmental Factors)

- **Income (A_1):** Gross revenue from sales at that specific time. The categories used are "Low, Medium, High".
- **Sales (A_2):** Sales are the primary factor influencing income. If sales reach a high volume, income will automatically be high. If sales are at a medium or low volume, then sales and income will automatically be medium/low. The categories used are "Low, Medium, High".
- **Inventory (A_3):** The inventory factor is also influenced by income and sales. If the income and sales factors yield low, medium, or high results, the inventory will automatically follow. The categories used are "Low, Medium, High".

Output Variable (Production Volume)

- **Pentol Production Volume (B):** The production volume of *pentol* is stated in pieces (units). This amount is classified into the categories "Low", "Medium", and "High".

Fuzzification

At this stage, the input variables such as income, sales, and inventory will be converted into fuzzy values. These variables will be transformed using specific membership functions, such as triangular or trapezoidal functions, according to the designated categories. All input variables ("Income", "Sales", "Inventory") utilize the same categories, namely ("Low", "Medium", "High"). In this study, I used a triangular curve formula as an example.

Fuzzy Rules

Fuzzy rules are logical statements used within a fuzzy logic system to connect the input variables (income, sales, inventory) with the output variable (Production Volume) in the form of IF–THEN statements.

Defuzzification

Defuzzification is the process of converting the fuzzy output into a crisp value according to the designated membership function.

$$Z = \frac{\alpha\text{Predicate}_1 \times Z_1 + \alpha\text{Predicate}_2 \times Z_2 + \alpha\text{Predicate}_3 \times Z_3}{\alpha\text{Predicate}_1 + \alpha\text{Predicate}_2 + \alpha\text{Predicate}_3}$$

Program Design and Implementation

The program development in this study was carried out using a software approach via MATLAB, specifically through the utilization of the Fuzzy Logic Toolbox. Different from a graphical user interface (GUI GUIDE) approach, the program in this section was constructed using the rule viewer method, which serves to display the fuzzy inference process interactively and transparently.

The program was built based on a Mamdani-type fuzzy logic system, featuring three input variables—namely Number of Items Sold, Item Price, and Operational Costs—along with one output variable, which is the Pentol Production Volume. Each variable is defined in the fuzzy logic designer and equipped with linguistic membership functions such as low, medium, and high.

Once all fuzzy sets and the rule base are defined, the system is saved in a .fis (Fuzzy Inference System) file format. The program is then executed using the ruleview command, allowing users to directly see how input values are processed through fuzzification, rule inference, and defuzzification to produce the final output.

With this method, users can easily understand the influence of each input on the production results, as well as observe which fuzzy rules are active based on the combination of entered input values.

3. Results and Discussion

Data Collection

Table 1. Data results obtained from interviews.

Criteria	Set	Interval
	Low	≤ Rp.400,000
Income/Day	Medium	Rp.400,000 - Rp.650,000
	High	≥ Rp.650,000
	Low	≤ 500 pieces
Sales/Day	Medium	500 - 700 pieces
	High	≥ 700 pieces
Inventory/Day	Low	≤ 500 pieces

Criteria	Set	Interval
	Medium	500 - 600 pieces
	High	≥ 600 pieces
	Low	≤ 800 pieces
Production Volume/Day	Medium	800 - 1,300 pieces
	High	≥ 1,300 pieces

Based on the table above, the interval calculation data was obtained through informants via interviews and observations conducted by the author. This calculation will be used to apply the previously mentioned research methods.

Fuzzification

At this stage, the input and output variables will be converted using specific membership functions, such as trapezoidal or triangular curves. What I am using at this stage is a formula from a triangular curve.

Income Amount

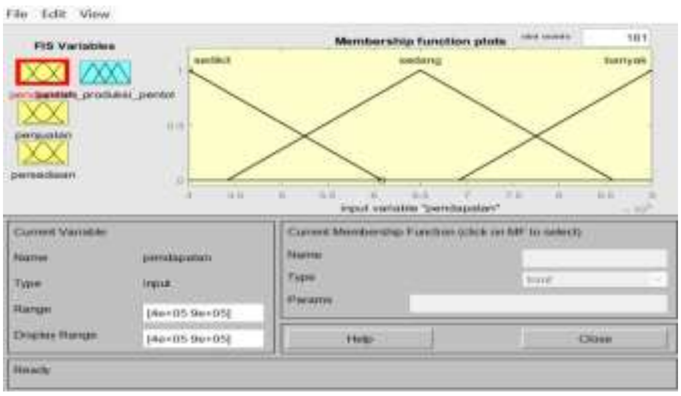

Figure 1. Income triangular curve graph.

Membership function for Low Income:

$$\mu_{\text{low}}(x) = \begin{cases} 1; & x \leq 400{,}000 \\ \dfrac{600{,}000 - x}{600{,}000 - 400{,}000}; & 400{,}000 \leq x \leq 600{,}000 \\ 0; & x \geq 600{,}000 \end{cases}$$

Membership function for Medium Income:

$$\mu_{\text{medium}}(x) = \begin{cases} 0; & x \leq 450{,}000 \text{ or } x \geq 850{,}000 \\ \dfrac{x - 450{,}000}{650{,}000 - 450{,}000}; & 450{,}000 \leq x \leq 650{,}000 \\ 1; & x = 650{,}000 \\ \dfrac{850{,}000 - x}{850{,}000 - 650{,}000}; & 650{,}000 \leq x \leq 850{,}000 \end{cases}$$

Membership function for High Income:

$$\mu_{\text{high}}(x) = \begin{cases} 0; & x \le 700{,}000 \\ \dfrac{x - 700{,}000}{900{,}000 - 700{,}000}; & 700{,}000 < x \le 900{,}000 \\ 1; & x \ge 900{,}000 \end{cases}$$

Sales Volume

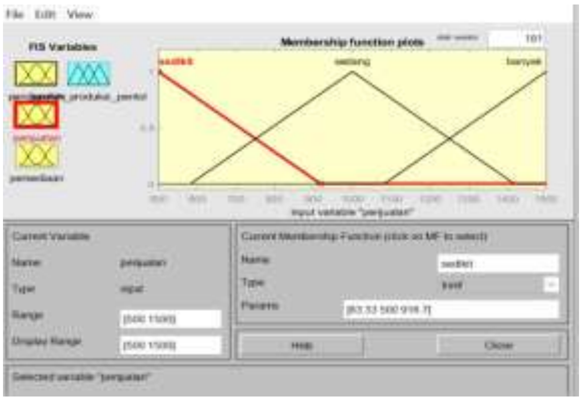

Figure 2. Sales triangular curve graph.

Membership function for Low Sales:

$$\mu_{\text{low}}(x) = \begin{cases} 1; & x \le 500 \\ \dfrac{900 - x}{900 - 500}; & 500 \le x \le 900 \\ 0; & x \ge 900 \end{cases}$$

Membership function for Medium Sales:

$$\mu_{\text{medium}}(x) = \begin{cases} 0; & x \le 600 \text{ or } x \ge 1400 \\ \dfrac{x - 600}{1000 - 600}; & 600 \le x \le 1000 \\ 1; & x = 1000 \\ \dfrac{1400 - x}{1400 - 1000}; & 1000 \le x \le 1400 \end{cases}$$

Membership function for High Sales:

$$\mu_{\text{high}}(x) = \begin{cases} 0; & x \le 1100 \\ \dfrac{x - 1100}{1500 - 1100}; & 1100 < x \le 1500 \\ 1; & x \ge 1500 \end{cases}$$

Inventory

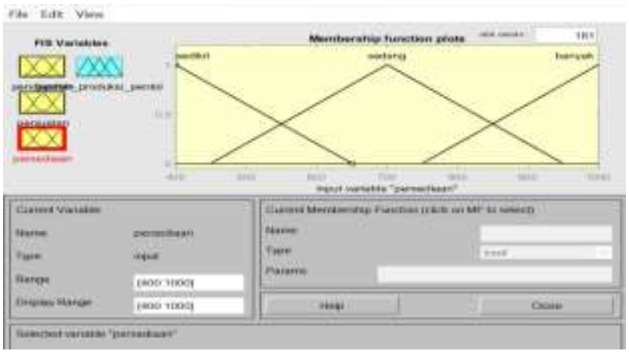

Figure 3. Inventory triangular curve graph.

Membership function for Low Inventory:

$$\mu_{\text{low}}(x) = \begin{cases} 1; & x \le 400 \\ \dfrac{650 - x}{650 - 400}; & 400 \le x \le 650 \\ 0; & x \ge 650 \end{cases}$$

Membership function for Medium Inventory:

$$\mu_{\text{medium}}(x) = \begin{cases} 0; & x \le 450 \text{ or } x \ge 950 \\ \dfrac{x - 450}{700 - 450}; & 450 \le x \le 700 \\ 1; & x = 700 \\ \dfrac{850 - x}{850 - 700}; & 700 \le x \le 850 \end{cases}$$

Membership function for High Inventory:

$$\mu_{\text{high}}(x) = \begin{cases} 0; & x \le 750 \\ \dfrac{x - 750}{1000 - 750}; & 750 < x \le 1000 \\ 1; & x \ge 1000 \end{cases}$$

Production Volume

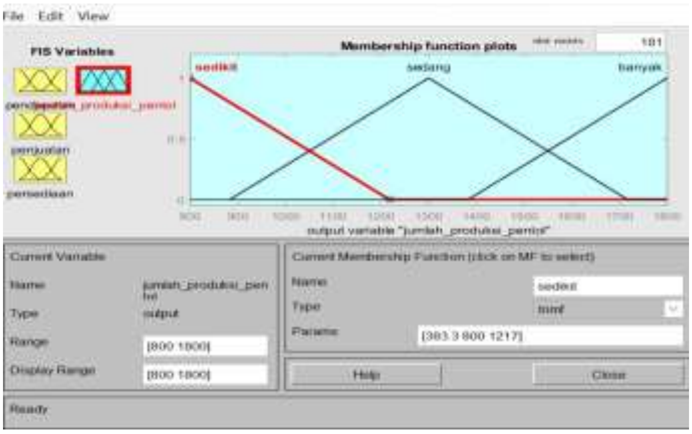

Figure 4. Production volume triangular curve graph (output).

Membership function for Low Production Volume:

$$\mu_{\text{low}}(x) = \begin{cases} 1; & x \le 800 \\ \dfrac{1200 - x}{1200 - 800}; & 800 \le x \le 1200 \\ 0; & x \ge 1200 \end{cases}$$

Membership function for Medium Production Volume:

$$\mu_{\text{medium}}(x) = \begin{cases} 0; & x \le 900 \text{ or } x \ge 1700 \\ \dfrac{x - 900}{1300 - 900}; & 900 \le x \le 1300 \\ 1; & x = 1300 \\ \dfrac{1700 - x}{1700 - 1300}; & 1300 \le x \le 1700 \end{cases}$$

Membership function for High Production Volume:

$$\mu_{\text{high}}(x) = \begin{cases} 0; & x \le 1400 \\ \dfrac{x - 1400}{1800 - 1400}; & 1400 < x \le 1800 \\ 1; & x \ge 1800 \end{cases}$$

Based on the figures and calculations above, these are the implementation results of the fuzzification method using the triangular curve formula, where the formulas' calculations adjust from the interval calculation inputs into the MATLAB application.

Fuzzy Rules

1. If income is high, sales are medium, and inventory is high, then production volume is high.
2. If income is medium, sales are high, and inventory is low, then production volume is medium.
3. If income is low, sales are high, and inventory is high, then production volume is medium.
4. If income is high, sales are low, and inventory is high, then production volume is medium.
5. If income is low, sales are low, and inventory is medium, then production volume is low.
6. If income is medium, sales are low, and inventory is high, then production volume is medium.
7. If income is high, sales are high, and inventory is low, then production volume is high.
8. If income is low, sales are medium, and inventory is high, then production volume is medium.
9. If income is high, sales are low, and inventory is medium, then production volume is medium.
10. If income is medium, sales are medium, and inventory is low, then production volume is low.
11. If income is low, sales are low, and inventory is low, then production volume is low.
12. If income is medium, sales are high, and inventory is medium, then production volume is medium.
13. If income is low, sales are high, and inventory is low, then production volume is low.
14. If income is high, sales are medium, and inventory is low, then production volume is medium.
15. If income is high, sales are high, and inventory is medium, then production volume is high.
16. If income is low, sales are medium, and inventory is medium, then production volume is low.
17. If income is medium, sales are medium, and inventory is high, then production volume is medium.
18. If income is high, sales are low, and inventory is low, then production volume is low.
19. If income is medium, sales are low, and inventory is medium, then production volume is low.
20. If income is low, sales are low, and inventory is high, then production volume is low.
21. If income is medium, sales are medium, and inventory is medium, then production volume is medium.
22. If income is high, sales are high, and inventory is high, then production volume is high.
23. If income is medium, sales are low, and inventory is low, then production volume is low.
24. If income is medium, sales are high, and inventory is high, then production volume is high.

25. If income is low, sales are high, and inventory is medium, then production volume is medium.
26. If income is medium, sales are medium, and inventory is low, then production volume is low.
27. If income is high, sales are medium, and inventory is medium, then production volume is medium.

In the case study regarding the prediction of *pentol* production volume, there are three primary inputs: Income, Sales, and Inventory. Each input is divided into three linguistic categories: low, medium, and high. For example, Income can be low, medium, or high; Sales can also be low, medium, or high; Inventory is the same. Because each variable has three categories, the total number of rule combinations is: $3 \times 3 \times 3 = 27$ fuzzy rules.

Application of Fuzzy Inference

The fuzzy rules connecting input variables to output variables are formulated in the "IF... THEN..." format. For instance, the rules can be evaluated based on the given inputs:

- **Rule 14:** If the Number of Items Sold is Medium, Item Price is Medium, and Operational Costs are Medium, then the Pentol Production Volume is Medium.
    - Degree of membership: $\min(0.575, 0.3126, 0.8333) = 0.3126$
    - Output: Medium (e.g., 400 – 1,600 pentol)
- **Rule 15:** If the Number of Items Sold is Medium, Item Price is Medium, and Operational Costs are High, then the Pentol Production Volume is Medium.
    - Degree of membership: $\min(0.575, 0.3126, 0) = 0$
    - Output: Not active/irrelevant
- **Rule 17:** If the Number of Items Sold is Medium, Item Price is High, and Operational Costs are Medium, then the Pentol Production Volume is Medium.
    - Degree of membership: $\min(0.575, 0.06225, 0.8333) = 0.06225$
    - Output: Medium (400 – 1,600 pentol)
- **Rule 18:** If the Number of Items Sold is Medium, Item Price is High, and Operational Costs are High, then the Pentol Production Volume is Low.
    - Degree of membership: $\min(0.575, 0.06225, 0) = 0$
    - Output: Not active/irrelevant

Case Study:

If my uncle obtains an income of Rp. 650,000, an inventory of 600 pieces, while the sales demand is 1,500 pieces, what is the required addition to the *pentol* production to meet that demand?

First, calculate the fuzzy membership values for each input variable.

[Rule] If income is Medium (Rp. 650,000), sales are Medium (700 pieces), and inventory is Medium (600 pieces), then pentol production is Medium.

Income (Rp. 650,000)

- $\mu_{\text{low}}(650{,}000) = 0$ (since $x > 600{,}000$)
- $\mu_{\text{medium}}(650{,}000) = \frac{650{,}000-450{,}000}{650{,}000-450{,}000} = 1$
- $\mu_{\text{high}}(650{,}000) = 0$ (since $x < 700{,}000$)

Inventory (600 pieces)

- $\mu_{\text{low}}(600) = \frac{650-600}{650-400} = \frac{50}{250} = 0.2$
- $\mu_{\text{medium}}(600) = \frac{600-450}{700-450} = \frac{150}{250} = 0.6$
- $\mu_{\text{high}}(600) = 0$ (since $x < 750$ pieces)

Sales (1,500)

- $\mu_{\text{low}}(1{,}500) = 0$ (since $x > 900$)
- $\mu_{\text{medium}}(1{,}500) = 0$ (since $x > 1400$)
- $\mu_{\text{high}}(1{,}500) = \frac{1500-1100}{1500-1100} = \frac{400}{400} = 1$

Membership Values:

- $\alpha\text{-predicate}_1 = \min(\mu_{\text{medium}}(\text{Income}), \mu_{\text{medium}}(\text{Inventory}), \mu_{\text{medium}}(\text{Sales})) = \min(1{,}0.6{,}0) = 0)$

$$z_1 = 600 - \alpha\text{-predicate}_1 \times (600 - 400) = 600 - 0 \times 200 = 600$$

- $\alpha\text{-predicate}_2 = \min(\mu_{\text{low}}(\text{Income}), \mu_{\text{medium}}(\text{Inventory}), \mu_{\text{high}}(\text{Sales})) = \min(0{,}0.6{,}1) = 0)$

$$z_2 = 600 - 0.33 \times (600 - 400) = 600$$

- $\alpha\text{-predicate}_3 = \min(\mu_{\text{high}}(\text{Income}), \mu_{\text{medium}}(\text{Inventory}), \mu_{\text{high}}(\text{Sales})) = \min(1{,}0.2{,}1) = 0.2)$

$$z_3 = 600 - \alpha\text{-predicate}_3 \times (600 - 400) = 600 - 0.2 \times 200 = 600 - 40 = 560$$

Defuzzification:

$$Z_{\text{final}} = \frac{\alpha\text{Predicate}_1 \times Z_1 + \alpha\text{Predicate}_2 \times Z_2 + \alpha\text{Predicate}_3 \times Z_3}{\alpha\text{Predicate}_1 + \alpha\text{Predicate}_2 + \alpha\text{Predicate}_3}$$

$$Z_{\text{final}} = \frac{(0.6 \times 480) + (0 \times 600) + (0.2 \times 560)}{0.6 + 0 + 0.2}$$

$$Z_{\text{final}} = \frac{288 + 0 + 112}{0.8} = \frac{400}{0.8} = 500$$

The defuzzification result indicates that the additional *pentol* production required to meet the demand is **500 pieces**.

Explanation

The additional production of 500 pieces of *pentol* was calculated based on the Mamdani Fuzzy method, which considers three main input variables:

- Income (Rp. 650,000) → categorized as **Medium**
- Inventory (600 pieces) → categorized as **Medium**
- Sales (1,500 pieces) → categorized as **High**

From the established fuzzy rules, the system determined that if income is Medium, inventory is Medium, and sales are High, then the recommended production falls into the Medium-to-High range.

Reason for Adding 500 Pieces

After performing calculations using the defuzzification (Centroid) method, the system output value is 500 pieces. This implies:

1. The initial inventory of 600 pieces is insufficient to meet the demand of 1,500 pieces. By adding 500 pieces of *pentol*, the total production becomes 1,100 pieces, which is closer to the demand volume.
2. The fuzzy system does not directly suggest a full production of 1,500 pieces because it factors in the medium income level, preventing excessive overproduction.
3. The value of 500 pieces represents an optimal compromise among current demand, inventory, and existing income.

Program Creation

In this study, the development process was carried out utilizing software via MATLAB, specifically through the use of the Fuzzy Logic Toolbox. Distinguishable from an interface-driven approach (GUI GUIDE), the program in this section was constructed using the rule viewer method, which functions to display the fuzzy inference process interactively and transparently.

The program was built based on a Mamdani-type fuzzy logic system, with three input variables, namely Number of Items Sold, Item Price, and Operational Costs, alongside one output variable, the Pentol Production Volume. Each variable is defined within the fuzzy logic designer and equipped with linguistic membership functions like low, medium, and high.

Once all fuzzy sets and the rule base are defined, the system is saved in a .fis (Fuzzy Inference System) file format. The program is then executed using the ruleview command, enabling users to directly see how input values are processed via fuzzification, rule inference, and defuzzification to yield the final output.

With this method, users can easily understand the influence of each input on production results and see which fuzzy rules are active based on the combination of input values entered.

Rule Viewer Visualization

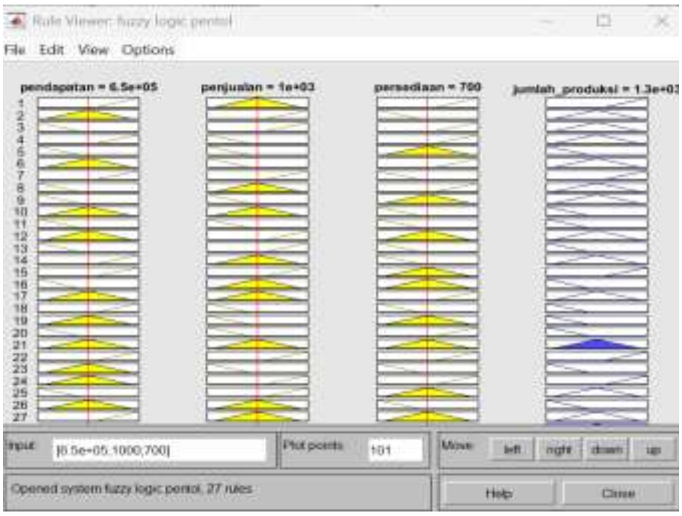

Figure 5. Implementation/application result of the rule viewer.

The Rule Viewer in MATLAB is used to demonstrate how each fuzzy rule operates based on the given inputs. In this *pentol* fuzzy logic system, there are three inputs: Income, Sales, and Inventory, and one output: Pentol Production Volume.

How the Rule Viewer Works

- Each row represents a single fuzzy rule.
- The yellow color indicates the membership degree value of the input against each respective membership function.
- The vertical red line on the inputs indicates the crisp (numerical) values entered.
- The blue color on the output side shows the result of the fuzzy inference based on the combination of inputs and rules.

Example of Reading the Rule Viewer

Based on the inputs: Income = 6.5×10^5, Sales = 1000, Inventory = 700, the fuzzy system will evaluate all 27 rules and identify the relevant (active) rules.

Example of an Active Rule:

For instance, Rule 17: If income is Medium, sales are Low, and inventory is Medium, then the production volume is Medium. With the membership degrees of each input:

- Income membership Medium: 0.7
- Sales membership Low: 0.8
- Inventory membership Medium: 0.6

Thus, the minimum value = min(0.7,0.8,0.6) = 0.6. This result of 0.6 is then used to determine the production output level (number of pentol) on the "Medium" output membership function.

Advantages of the Rule Viewer

- **Detecting Active Rules:** Allows seeing which rules are active based on a specific input.
- **Understanding the Inference Process:** Makes it easier to see how the output value is determined from the inputs.
- **Interactive and Real-Time:** Can be used to test input values directly and see instant output changes.
- **Fuzzy System Debugging:** Helps identify if there are rules not working as expected.

Disadvantages of the Rule Viewer

- **Less Comprehensive for Many Rules:** If there are too many rules, the display becomes complex and confusing.
- **Does Not Display the Output Surface:** It does not show visual output results over a range like the Surface Viewer does.
- **Unsuitable for Global Analysis:** Only suitable for analyzing one input combination at a time, rather than the entire system as a whole.

4. Conclusion

Based on the research results, it can be concluded that the Mamdani fuzzy logic method is effectively utilized to assist decision-making in determining the production volume of *pentol* snack food. By considering three input variables—income, inventory, and sales demand—and using triangular membership functions, this system is capable of providing recommendations that align with real business conditions.

In the case study with an income of Rp650,000, an inventory of 600 pieces, and a demand of 1,500 pieces, the system recommends an additional production of 500 pieces of *pentol*. This demonstrates that fuzzy logic can accommodate data uncertainty and provide a more flexible and adaptive solution for micro-business owners in production planning.

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