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APPLICATION OF MAMDANI FUZZY LOGIC IN REFRIGERATOR SELECTION

Anisa Dwi Oktarina[1*], Agus Maman Abadi[2], Syukrul Hamdi[3]

[1,2,3]*Master of Mathematics Education, Yogyakarta State University*
Jln. Colombo No. 1 Karangmalang, Yogyakarta, 55281, Indonesia

*Corresponding author's e-mail: * **anisa371fmipa.2023@student.uny.ac.id***

ABSTRACT

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Refrigerators are essential household appliances that preserve food freshness and optimize storage efficiency. Selecting a refrigerator requires careful consideration of factors such as price, capacity, and electricity consumption. This research applies the Mamdani-type Fuzzy Inference System (FIS) to recommend refrigerators based on these three criteria. Using a dataset of 82 refrigerator brands, this study implements fuzzification, rule formation, inference, and defuzzification, supported by MATLAB software. The results indicate that refrigerators with a normal price, medium capacity, and low power consumption are the most suitable choices. Based on the dataset, the Aqua AQR-415IM model meets these criteria. While this study confirms the effectiveness of fuzzy logic in structured decision-making, it does not quantitatively measure efficiency. Future research should explore alternative fuzzy logic methods, incorporate additional input variables, and consider demographic factors to enhance recommendation accuracy. Additionally, the Mamdani method can be adapted for broader applications in selecting other electronic products, contributing to both practical consumer guidance and theoretical advancements in fuzzy logic-based decision support systems.

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1. INTRODUCTION

Refrigerators are common household appliances in developed countries, essential for keeping food cold [1]. They extend food shelf life, reduce spoilage, and support the cold chain for fresh produce, preserving quality until consumption [2][3][4]. Over the past 50 years, refrigerator technology has advanced to improve energy efficiency and environmental sustainability [5][6]. Household refrigerators account for 14.88% of residential energy usage, making energy-efficient models vital for reducing emissions and supporting carbon neutrality [7][8]. Environmentally friendly refrigerants like CO_2, ammonia, and hydrocarbons are prioritized to mitigate global warming and ozone depletion [9]. Consumers face challenges when selecting refrigerators due to conflicting considerations such as energy efficiency, storage capacity, design, and price [9]. For instance, those relocating may opt for compact, lesser-known brands but still prioritize energy efficiency [10]. High costs of energy-efficient models deter some buyers, hindering energy-saving efforts [11]. Limited knowledge of technical indicators like energy labels leads many to rely on informal advice, resulting in suboptimal decisions [12]. Surveys show that warranties, alongside price, energy consumption, and storage capacity, influence consumer choices more than brand reputation [13]. Despite evaluating options, many consumers find the purchase decision challenging [14].

Fuzzy logic transfers human knowledge into machine systems and effectively links vague inputs to specific outputs using linguistic rules [15][16]. It has diverse applications, including decision-making with incomplete or inaccurate information [17]. The Mamdani fuzzy logic method supports multi-criteria decision-making by processing qualitative and quantitative data through a rule-based inference system [18][19][20]. Applications include optimizing exercise programs in sports fitness [21] and evaluating desalination facility sustainability under data uncertainty [22]. It also enhances operational efficiency in vapor compression cooling systems [23]. Granular computing within Mamdani systems reduces redundant rules, improving efficiency in complex decisions [24]. This approach aids consumers in selecting energy-efficient devices like refrigerators, significantly affecting household electricity consumption [24][25]. Additionally, Mamdani systems model consumer preferences for household appliances by aligning energy efficiency, pricing, and design with user needs, facilitating informed decisions and promoting eco-friendly technologies [25][26].

Existing studies on refrigerator selection often rely on traditional decision-making approaches or statistical models, which may not effectively handle imprecise or subjective consumer preferences. While previous research has explored energy efficiency labeling and pricing factors, limited attention has been given to holistic decision-making models that incorporate multiple consumer criteria simultaneously. This study applies the Mamdani fuzzy logic method to provide a structured approach for integrating various selection factors, addressing this gap by offering a more flexible and adaptive decision-making framework. By implementing fuzzy logic, the study contributes to better consumer decision-making and promotes energy-efficient technology adoption.

2. RESEARCH METHODS

This study applies the Mamdani fuzzy logic method to assist in refrigerator selection based on various criteria. Introduced by Ebrahim Mamdani in 1975, this method, commonly referred to as the Max-Min method, consists of four main stages to achieve the desired results. The fuzzy if-then rules applied in this method improve the interpretability of the results, provide detailed insights into the classifier structure, and support a more transparent and accurate decision-making process [27][28]. The main variables considered in this fuzzy decision-making system include price, storage capacity, and energy consumption. This study follows a structured methodology to define the fuzzy logic system and assign appropriate membership functions. Since this study focuses on the application of fuzzy logic rather than empirical data collection, no specific demographic samples are used, such as income, location, or number of family members. Instead, the refrigerator selection criteria are determined based on general consumer preferences identified in previous studies and market analysis. The fuzzy logic model is designed to accommodate a wide range of consumer needs without being limited to a particular population segment. In the next section, we describe the procedure in the fuzzy inference system depicted in Figure 1 [28].

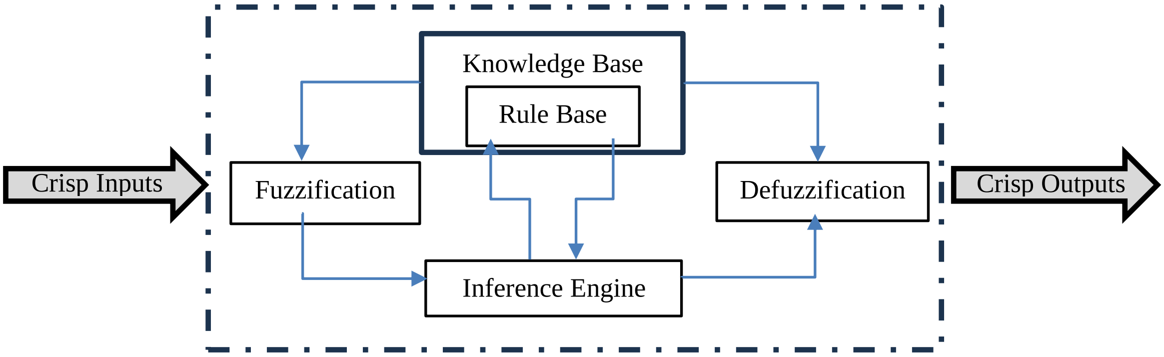

Figure 1. Framework of the General Fuzzy Inference System

Figure 1 shows the General Fuzzy Inference System (FIS) Framework, which processes numeric inputs into meaningful outputs using fuzzy logic. It starts with crisp inputs, which are transformed into fuzzy values through fuzzification. These values interact with a Knowledge Base, which contains a Rule Base that defines how decisions are made. The Inference Engine applies these rules to produce fuzzy conclusions, which are then transformed back into numeric values through defuzzification, producing crisp outputs.

The dataset utilized in this case comprises refrigerator data acquired from the Shopee marketplace (Accessed: Dec. 03, 2024. [Online]. Available: https://shopee.co.id/search?keyword=refrigerator), employed for decision-making concerning the selection of a refrigerator, encompassing a total of 82 units. The factors influencing refrigerator purchases include price (Rupiah), capacity (Liters), and power consumption (Watts). All the refrigerator units listed below are refrigerators that include a freezer.

Table 1. Refrigerator Brands and Specifications

No	Brand	Price (Rp)	Capacity (liters)	Power (watts)
1	Aqua AQR-320RBG	6,649,000	292	42
2	Electrolux ESE6141A-BID	11,811,000	571	130
3	LG GC-B414FGQP	10,965,000	324	110
⋮	⋮	⋮	⋮	⋮
80	Samsung RT20FARWDSA/SE	4,299,000	203	165
81	Sharp SJ-N192N-HS	1,962,000	184	60
82	Toshiba GR-RS696WE-PMF	8,099,000	551	145

2.1 The First Stage

The first stage, data fuzzification, converts strict numeric inputs into fuzzy inputs represented as linguistic variables using membership functions to describe linguistic concepts and visualize fuzzy sets [29]. It defines the correlation between numerical values and membership degrees in fuzzy sets. Based on common fuzzy logic modeling practices and related literature, this study employs trapezoidal and triangular membership functions for their simplicity and effectiveness in representing qualitative variables [30].

Fuzzy Logic Membership Functions [31]:

1. Representation of Triangle Curve

A triangle curve is essentially formed by combining two straight lines, one rising and the other falling.

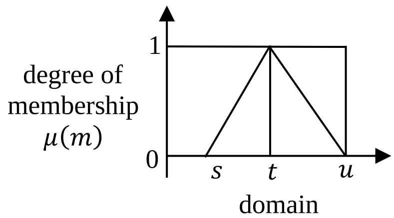

Figure 2. Triangle Curve

Figure 2 shows the Triangle Membership Function, which is commonly used in fuzzy logic. This function consists of three key points: s, t, and u, which define the shape of the triangle. This function starts at zero at s, increases linearly to a peak value of 1 at t, and then decreases back to zero at u. The vertical axis shows the degree of membership ($\mu(m)$), ranging from 0 to 1, while the horizontal axis shows the domain of the variable. The membership function of a triangle curve is formulated with:

$$\mu(m) = \begin{cases} 0 & m \leq s \text{ or } m \geq u \\ \dfrac{m-s}{t-s} & s < m < t \\ \dfrac{u-m}{u-t} & t \leq m < u \end{cases} \tag{1}$$

2. Representation of Trapezoid Curve

A trapezoid curve is a representation of a triangle curve with some points (domains) having the same degree of membership.

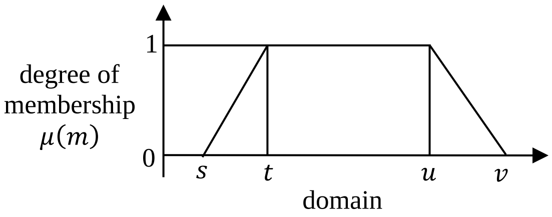

Figure 3. Trapezoid Curve

Figure 3 shows a trapezoid-shaped membership function used in fuzzy logic. The graph represents the degree of membership ($\mu(m)$) on the vertical axis, ranging from 0 to 1, and the domain on the horizontal axis, marked by points s, t, u and v. The function starts at 0, rises linearly from s to t, remains constant at 1 between t and u, and then decreases linearly to 0 at v. This shape indicates that values between t and u have full membership, while values outside the range gradually decrease in membership. The membership function of a trapezoid curve is formulated with:

$$\mu(m) = \begin{cases} 0 & m \leq s \text{ or } m \geq v \\ \dfrac{m-s}{t-s} & s \leq m \leq t \\ 1 & t \leq m \leq u \\ \dfrac{v-m}{v-u} & u \leq m \leq v \end{cases} \tag{2}$$

2.2 The Second Stage

The second step is to determine the fuzzy rules. Fuzzy rules are developed using expert knowledge, linking subsets of input and output variables to establish interrelationships and derive inferences through the combination of these rules. The fuzzy rule base functions to translate fuzzy input, enabling the inference process through linguistic rules represented as "IF a condition (premise) is met, THEN a consequence will be produced." The number of rules in the system depends on the complexity and characteristics of the model being developed, often reflecting human descriptive judgment [32][33]. Operator “and” selected because the evaluation factors are interdependent, taking the smallest membership value of the fuzzy set [34]. The rule base of the Mamdani fuzzy system is stated in the following formula [35]:

$$R_i : IF\ (m_1 \text{ is } a_1)\ AND\ \ldots\ AND\ (m_p \text{ is } a_p)\ THEN\ (n \text{ is } b_q) \tag{3}$$

where $(m_1, \ldots, m_p)$ is the input of fuzzy logic, a_p is the fuzzy set on the pth input, n is the output of fuzzy logic and consequent b_q is the fuzzy set on the qth output.

2.3 The Third Stage

The third step is to do inference. The inference engine applies rules to fuzzy inputs to produce fuzzy outputs that are then defuzzified into definitive values [36]. This research uses a fuzzy inference system based on the Mamdani Method, which is often referred to as the Min-Max Method. The fuzzy inference process involves two main stages, namely: 1) The implication stage, which utilizes the MIN method, and 2) The composition stage, which is carried out using the MAX method [37]. In the implication stage, the intersection of the membership degrees of the input variables is determined based on the applicable rules. Meanwhile, in the rule composition process, the rules with the same conclusions will be compared, and the highest value among them will be selected. Given the membership of the set $\tilde{P}$ is denoted by $\mu_{\tilde{P}}, \mu_{\tilde{Q}}$ for the set $\tilde{Q}$ and U is universe set. The intersection operation is stated in **Equation (4)**, while the union operation is stated in **Equation (5)** as follows [38].

$$\mu_{\tilde{P}\cap\tilde{Q}}(m) = \min\left[\mu_{\tilde{P}}(m), \mu_{\tilde{Q}}(m)\right], m \in U \tag{4}$$
$$\mu_{\tilde{P}\cup\tilde{Q}}(m) = \max\left[\mu_{\tilde{P}}(m), \mu_{\tilde{Q}}(m)\right], m \in U \tag{5}$$

2.4 The Fourth Stage

Defuzzification converts the fuzzy output of the inference engine into precise values that can be used for decision making or further analysis [39][40]. In Mamdani's method, the commonly used defuzzification technique is the centroid method, which produces specific recommendations based on the initial input and the applied rules, with its formula presented in **Equation (6)** [41][42].

$$z = \frac{\int \mu(z) z \, dz}{\int \mu(z) \, dz} \tag{6}$$

where z is the crisp value of the decision value in this research.

3. RESULTS AND DISCUSSION

The fuzzy simulation in this study was conducted using MATLAB R2019b with the Fuzzy Logic Toolbox [43]. This system includes three input variables (price, capacity, power) and one output variable (decision). The membership functions used in this study are trapezoidal and triangular membership functions. The selection of membership functions (MFs) in fuzzy logic systems depends on the problem characteristics, as there is no exact method for choosing the optimal MF. Among various MF shapes, triangular and trapezoidal MFs are widely used due to their simplicity and computational efficiency. Triangular MFs are preferred for their ease of implementation and fast computation, making them suitable for representing precise numerical values. Meanwhile, trapezoidal MFs are useful for representing broader ranges with clear upper and lower limits. Since MF selection is problem-dependent, an iterative approach involving tuning and evaluation is often necessary to optimize system performance. The arrangement of input and output variables in the fuzzy logic system is depicted in **Figure 4**.

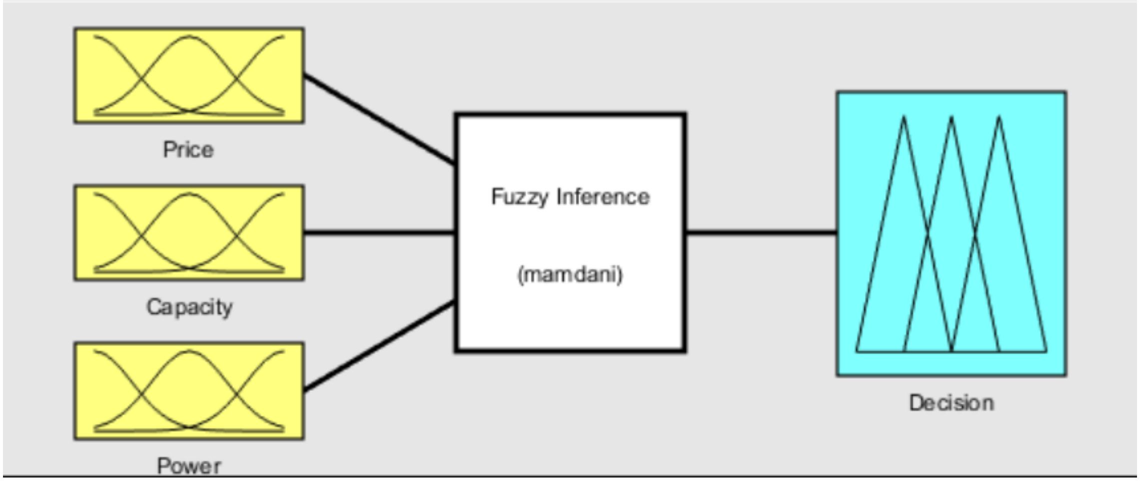

Figure 4. Input and Output Variables

Figure 4 shows a fuzzy inference system using the Mamdani approach. This system uses three input variables, namely Price, Capacity, and Power, each represented by a fuzzy membership function. These inputs are processed by the fuzzy inference system, which applies fuzzy logic rules to produce outputs. The final output, shown as “Decision,” is also represented by a fuzzy membership function, indicating that the system evaluates several factors to make decisions in a structured yet flexible manner.

3.1 Fuzzification

Quantitative input and output data are transformed into linguistic variables represented as fuzzy sets, with membership values assigned based on predefined functions. Price is categorized as "Cheap" and "Expensive" using trapezoidal membership functions, while "Normal" uses a triangular function. Similarly, storage capacity is classified as "Small" and "Large" with trapezoidal functions, and "Medium" with a triangular function. Energy consumption follows the same pattern, with "Low" and "High" using trapezoidal functions and "Medium" using a triangular function. These classifications are based on general refrigerator specifications and market price ranges, while variable domains are determined according to manufacturer specifications.

1. Price Input Variable

Table 2. Price Input Variable

Universe of Discourse	Linguistic Variables	Domain
	Cheap	[1,000,000 – 3,500,000]
[1,000,000 – 15,000,000]	Normal	[4,000,000 – 6,500,000]
	Expensive	[7,000,000 – 15,000,000]

Table 2 shows that the input variable price is subject to three fuzzy criteria: cheap [1,000,000 – 3,500,000], normal [4,000,000 – 6,500,000], and expensive [7,000,000 – 15,000,000], with a membership function:

$$\mu_{Cheap}(m) = \begin{cases} 0 & m \geq 3{,}500{,}000 \\ \dfrac{3{,}500{,}000 - m}{3{,}500{,}000 - 1{,}000{,}000} & 1{,}000{,}000 < m < 3{,}500{,}000 \\ 1 & m \leq 1{,}000{,}000 \end{cases} \tag{7}$$

$$\mu_{Normal}(m) = \begin{cases} 0 & m \leq 1{,}000{,}000\,;\; m \geq 6{,}500{,}000 \\ \dfrac{m - 1{,}000{,}000}{4{,}000{,}000 - 1{,}000{,}000} & 1{,}000{,}000 < m < 4{,}000{,}000 \\ \dfrac{6{,}500{,}000 - m}{6{,}500{,}000 - 4{,}000{,}000} & 4{,}000{,}000 \leq m < 6{,}500{,}000 \end{cases} \tag{8}$$

$$\mu_{Expensive}(m) = \begin{cases} 0 & m \leq 4{,}000{,}000 \\ \dfrac{m - 4{,}000{,}000}{7{,}000{,}000 - 4{,}000{,}000} & 4{,}000{,}000 < m < 7{,}000{,}000 \\ 1 & m \geq 7{,}000{,}000 \end{cases} \tag{9}$$

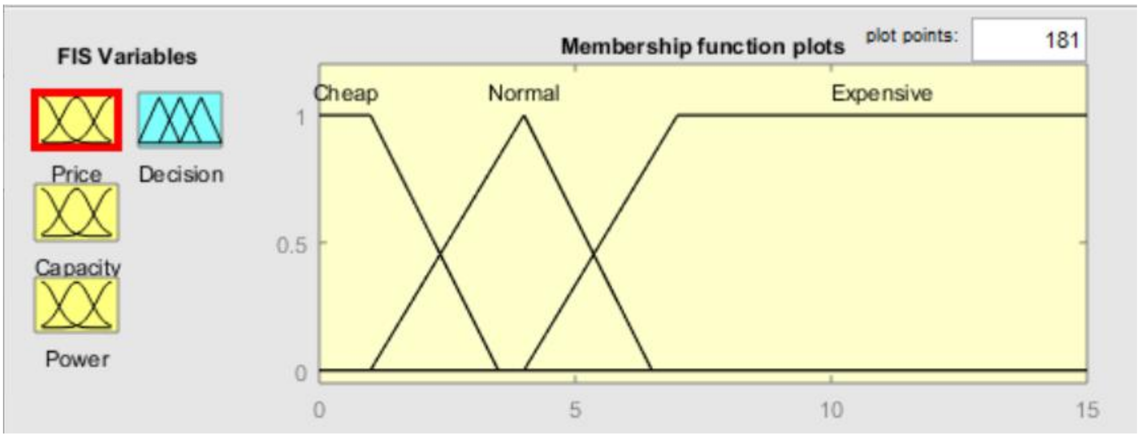

Figure 5. Membership Function of Price Variable

Figure 5 depicts fuzzy sets for the price variable: cheap, normal, and expensive. The membership function for the price variable is defined by **Equation (7)**, **Equation (8)**, and **Equation (9)**.

2. Capacity Input Variable

Table 3. Capacity Input Variable

Universe of Discourse	Linguistic Variables	Domain
	Small	[42 – 130]
[42 – 700]	Medium	[170 – 390]
	Large	[430 – 700]

Table 3 shows that the input variable capacity is subject to three fuzzy criteria: small [42 – 130], medium [170 – 390], and large [430 – 700], with a membership function:

$$\mu_{Small}(m) = \begin{cases} 0 & m \geq 130 \\ \dfrac{130 - m}{130 - 42} & 42 < m < 130 \\ 1 & m \leq 42 \end{cases} \tag{10}$$

$$\mu_{Medium}(m) = \begin{cases} 0 & m \leq 42, m \geq 390 \\ \dfrac{m - 42}{170 - 42} & 42 < m < 170 \\ \dfrac{390 - m}{390 - 170} & 170 \leq m < 390 \end{cases} \tag{11}$$

$$\mu_{Large}(m) = \begin{cases} 0 & m \leq 170 \\ \dfrac{m - 170}{430 - 170} & 170 < m < 430 \\ 1 & m \geq 430 \end{cases} \tag{12}$$

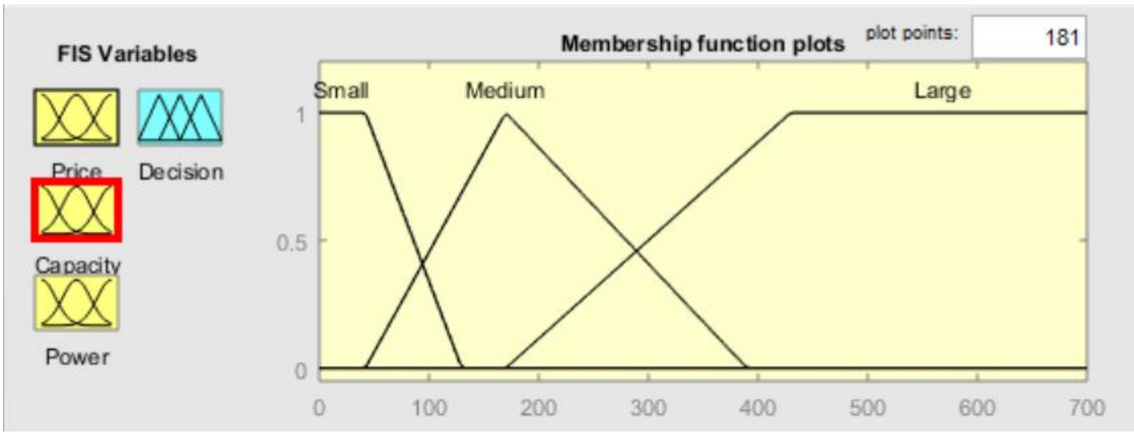

Figure 6. Membership Function of Capacity Variable

Figure 6 depicts fuzzy sets for the capacity variable: small, medium, and large. The membership function for the capacity variable is defined by **Equation (10)**, **Equation (11)**, and **Equation (12)**.

3. Power Input Variable

Table 4. Power Input Variable

Universe of Discourse	Linguistic Variables	Domain
	Low	[20 – 80]
[20 - 200]	Medium	[90 – 130]
	High	[150 – 200]

Table 4 shows that the input variable power is subject to three fuzzy criteria: low [20 – 80], medium [90 – 130], and high [150 – 200], with a membership function:

$$\mu_{Low}(m) = \begin{cases} 0 & m \geq 80 \\ \dfrac{80-m}{80-20} & 20 < m < 80 \\ 1 & m \leq 20 \end{cases} \tag{13}$$

$$\mu_{Medium}(m) = \begin{cases} 0 & m \leq 20, m \geq 130 \\ \dfrac{m-20}{90-20} & 20 < m < 90 \\ \dfrac{130-m}{130-90} & 90 \leq m < 130 \end{cases} \tag{14}$$

$$\mu_{High}(m) = \begin{cases} 0 & m \leq 90 \\ \dfrac{m-90}{150-90} & 90 < m < 150 \\ 1 & m \geq 150 \end{cases} \tag{15}$$

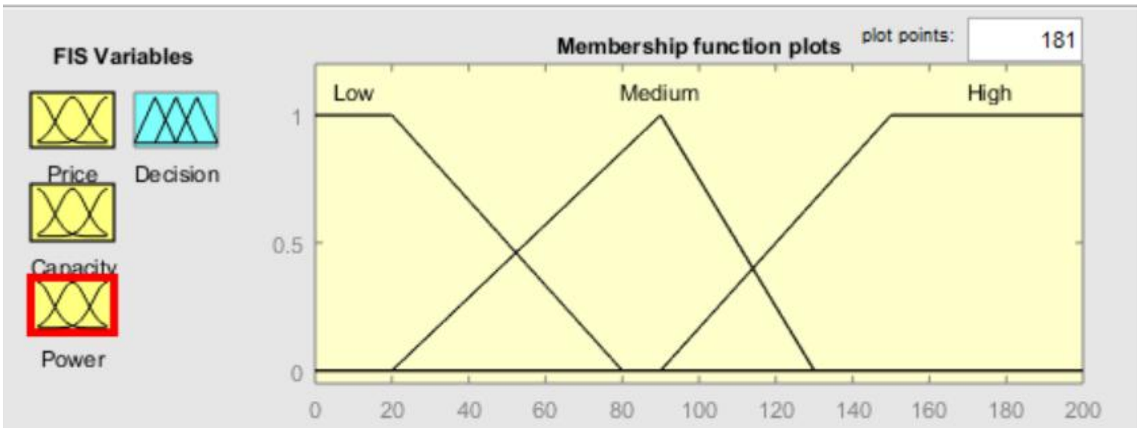

Figure 7. Membership Function of Power Variable

Figure 7 depicts fuzzy sets for the power variable: low, medium, and high. The membership function for the power variable is defined by **Equation (13)**, **Equation (14)**, and **Equation (15)**.

4. Decision Output Variable

Table 5. Decision Output Variable

Universe of Discourse	Linguistic Variables	Domain
	Not Buy	[0 – 30]
[0 - 100]	Considered	[40 – 65]
	Buy	[70 – 100]

Table 5 shows that the output variable decision is subject to three fuzzy criteria: not buy [0 – 30], considered [40 – 65], and buy [70 – 100], with a membership function:

$$\mu_{Not\ Buy}(m) = \begin{cases} 0 & m \geq 30 \\ \dfrac{30-m}{30-20} & 20 < m < 30 \\ 1 & m \leq 20 \end{cases} \tag{16}$$

$$\mu_{Considered}(m) = \begin{cases} 0 & m \leq 20, m \geq 65 \\ \dfrac{m-20}{40-20} & 20 < m < 40 \\ \dfrac{65-m}{65-40} & 40 \leq m < 65 \end{cases} \tag{17}$$

$$\mu_{Buy}(m) = \begin{cases} 0 & m \leq 40 \\ \dfrac{m-40}{70-40} & 40 < m < 70 \\ 1 & m \geq 70 \end{cases} \tag{18}$$

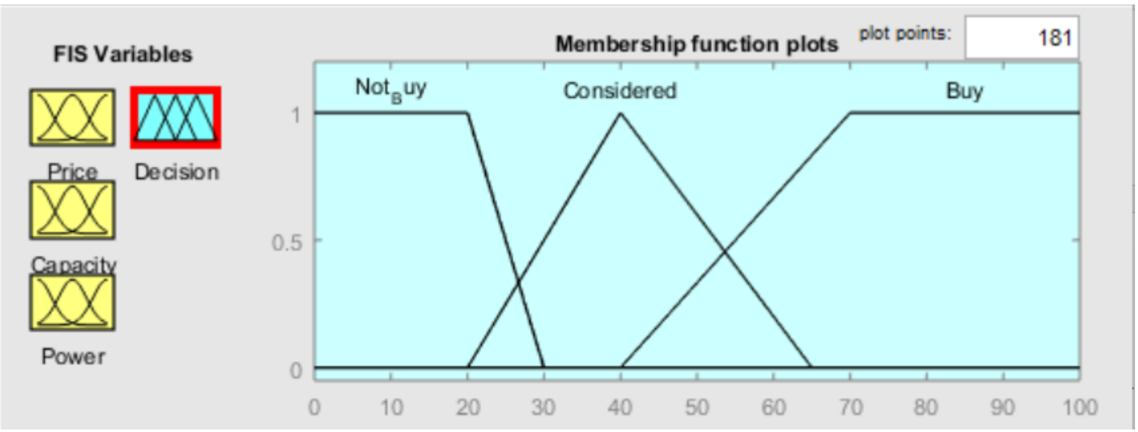

Figure 8. Membership Function of Decision Variable

Figure 8 depicts fuzzy sets for the decision variable: not buy, considered, and buy. The membership function for the decision variable is defined by **Equation (16)**, **Equation (17)**, and **Equation (18)**.

3.2 The Determination of Fuzzy Rules

After the fuzzification process is complete, the next step is to determine the rule base. To connect between inputs, the AND operator is used. Rule creation is done with the help of MATLAB R2019b software, resulting in a total of 27 rules. Fuzzy rules are presented in **Table 6**.

Table 6. Fuzzy Rules

Rule Number	Price	Capacity	Power	Decision
[R1]	Cheap	Small	Low	Considered
[R2]	Cheap	Small	Medium	Not Buy

Rule Number	Price	Capacity	Power	Decision
[R3]	Cheap	Small	High	Not Buy
[R4]	Cheap	Medium	Low	Buy
[R5]	Cheap	Medium	Medium	Considered
⋮	⋮	⋮	⋮	⋮
[R25]	Expensive	Large	Low	Buy
[R26]	Expensive	Large	Medium	Considered
[R27]	Expensive	Large	High	Not Buy

Table 6 shows the fuzzy rules used in the decision-making system. The table consists of four variables, namely Price, Capacity, Power, and Decision. Each row represents a rule that combines different levels of these variables (for example, Cheap price, Small capacity, and Low power) to determine an outcome, such as "Buy," "No Buy," or "Considered."

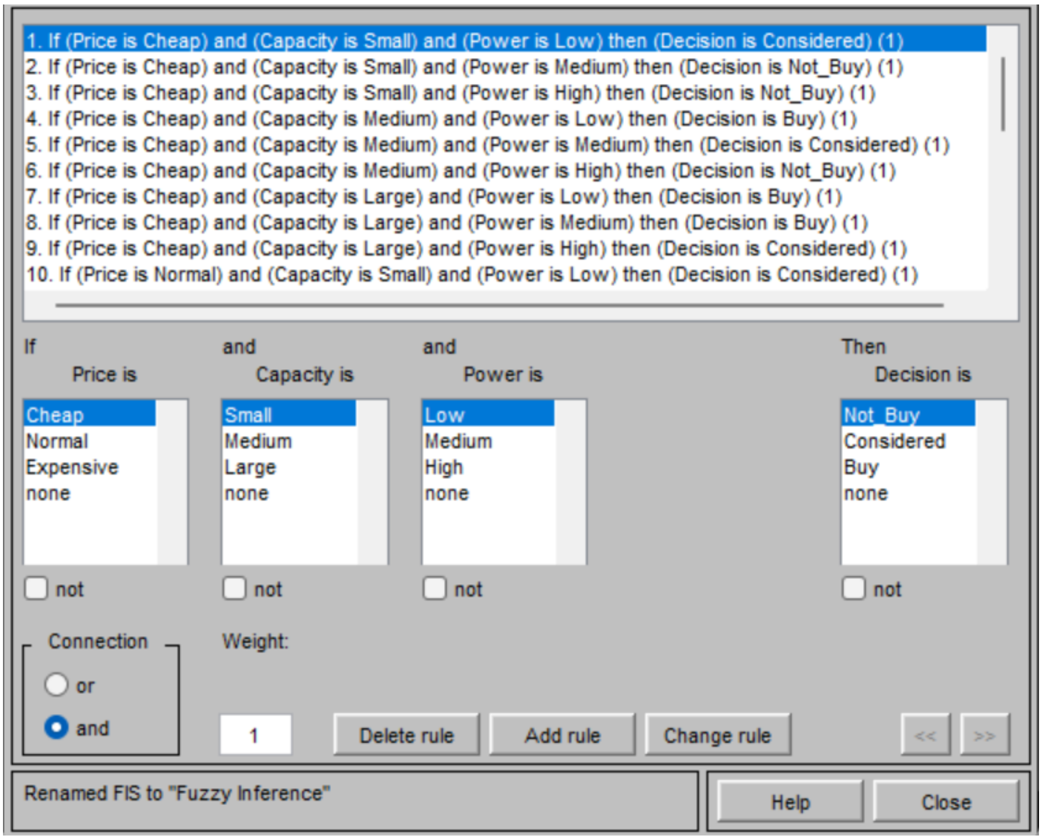

Figure 9. Pairs of Rules

Figure 9 depicts the relationship between input variables (price, capacity, power) and output (decision) using matlab application. Fuzzy rules, such as rule 1, which states that if the price is cheap, capacity is small, and power is low, then the output is considered, become the framework for the system to respond to certain inputs.

3.3 The Doing of Fuzzy Inferences

After determining the rules, the next step is to do fuzzy inference using the Mamdani method. For example, a refrigerator with a price of 4,288,700, a capacity of 357, and a power of 41. This step begins by determining the degree of membership of each input variable using the appropriate membership function formula.

$$\mu_{Price\ Normal}(4{,}288{,}700) = \frac{6{,}500{,}000 - 4{,}288{,}700}{6{,}500{,}000 - 4{,}000{,}000} = 0.88 \tag{19}$$

$$\mu_{Price\ Expensive}(4.288.700) = \frac{4,288,700 - 4,000,000}{7,000,000 - 4,000,000} = 0.096 \quad (20)$$

$$\mu_{Capacity\ Medium}(357) = \frac{390 - 357}{390 - 170} = 0.15 \quad (21)$$

$$\mu_{Capacity\ Large}(357) = \frac{357 - 170}{430 - 170} = 0.7 \quad (22)$$

$$\mu_{Power\ Low}(41) = \frac{80 - 41}{80 - 20} = 0.65 \quad (23)$$

$$\mu_{Power\ Medium}(41) = \frac{41 - 20}{90 - 20} = 0.3 \quad (24)$$

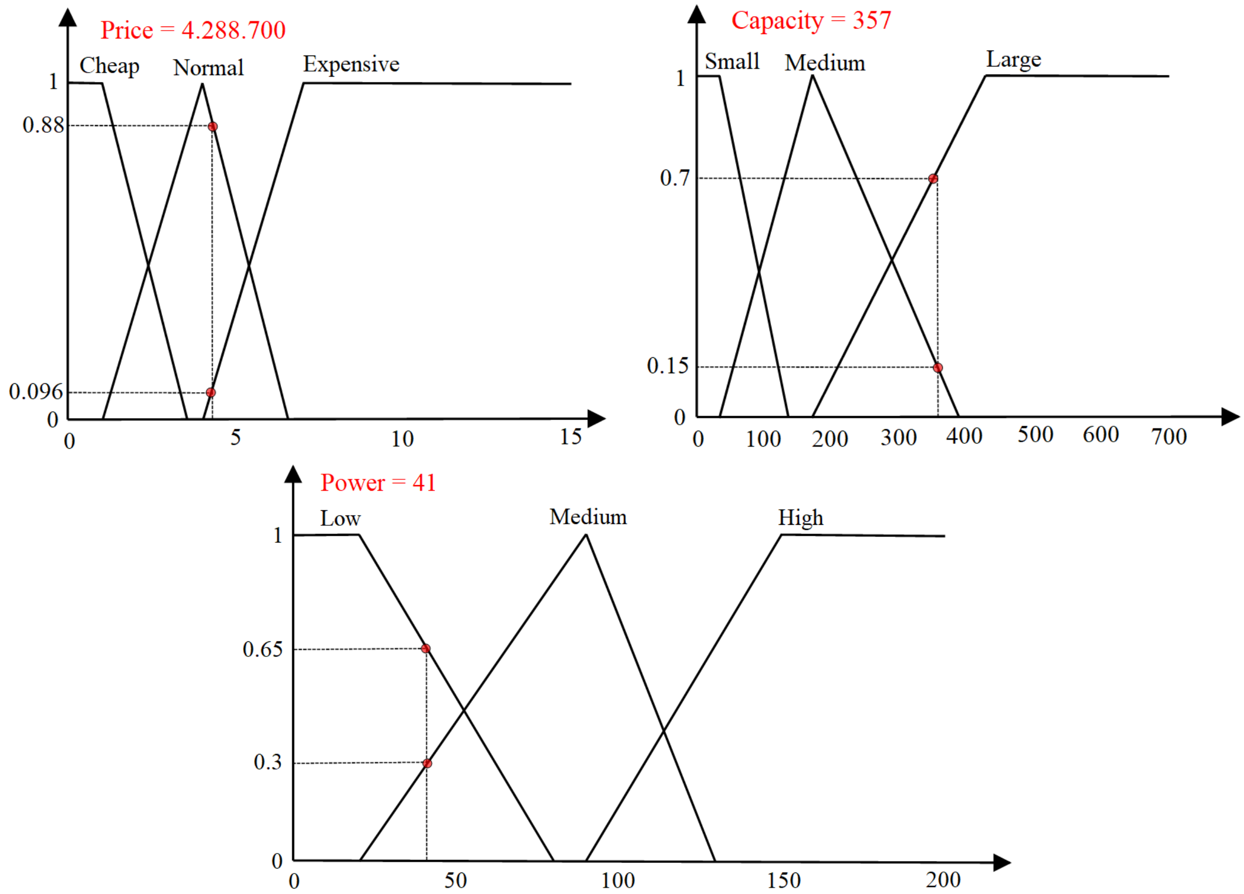

Figure 10. Representation of Input Variable Membership Functions

Figure 10 shows that when a vertical line is drawn from each location of the input variable value, the price of 4.288.700 is obtained, cutting the normal and expensive price curve; the capacity of 357 cuts the medium and large capacity curve; and the power of 41 cuts the low and medium power curve.

Based on the previous process, 8 appropriate rules were obtained.

[R13] IF price is normal AND capacity is medium AND power is low THEN decision is buy
[R14] IF price is normal AND capacity is medium AND power is medium THEN decision is considered
[R16] IF price is normal AND capacity is large AND power is low THEN decision is buy
[R17] IF price is normal AND capacity is large AND power is medium THEN decision is buy
[R22] IF price is expensive AND capacity is medium AND power is low THEN decision is buy
[R23] IF price is expensive AND capacity is medium AND power is medium THEN decision is considered
[R25] IF price is expensive AND capacity is large AND power is low THEN decision is buy
[R26] IF price is expensive AND capacity is large AND power is medium THEN decision is considered

The next stage is the implication of rules that utilize the MIN method. We will find the alpha value of the predicate of each previous rule.

[R13] IF price is normal AND capacity is medium AND power is low THEN decision is buy

$$\alpha_{13} = \mu_{p.n} \cap \mu_{c.m} \cap \mu_{p.l} = \min(\mu_{p.n}; \mu_{c.m}; \mu_{p.l}) = \min(0.88; 0.15; 0.65) = 0,.15 \tag{25}$$

[R14] IF price is normal AND capacity is medium AND power is medium THEN decision is considered

$$\alpha_{14} = \mu_{p.n} \cap \mu_{c.m} \cap \mu_{p.m} = \min(\mu_{p.n}; \mu_{c.m}; \mu_{p.m}) = \min(0.88; 0.15; 0.3) = 0.15 \tag{26}$$

[R16] IF price is normal AND capacity is large AND power is low THEN decision is buy

$$\alpha_{16} = \mu_{p.n} \cap \mu_{c.l} \cap \mu_{p.l} = \min(\mu_{p.n}; \mu_{c.l}; \mu_{p.l}) = \min(0.88; 0.7; 0.65) = 0.65 \tag{27}$$

[R17] IF price is normal AND capacity is large AND power is medium THEN decision is buy

$$\alpha_{17} = \mu_{p.n} \cap \mu_{c.l} \cap \mu_{p.m} = \min(\mu_{p.n}; \mu_{c.l}; \mu_{p.m}) = \min(0.88; 0.7; 0.3) = 0,3 \tag{28}$$

[R22] IF price is expensive AND capacity is medium AND power is low THEN decision buy

$$\alpha_{22} = \mu_{p.e} \cap \mu_{c.m} \cap \mu_{p.l} = \min(\mu_{p.e}; \mu_{c.m}; \mu_{p.l}) = \min(0.096; 0.15; 0.65) = 0.096 \tag{29}$$

[R23] IF price is expensive AND capacity is medium AND power is medium THEN decision is considered

$$\alpha_{23} = \mu_{p.e} \cap \mu_{c.m} \cap \mu_{p.m} = \min(\mu_{p.e}; \mu_{c.m}; \mu_{p.m}) = \min(0.096; 0.15; 0.3) = 0.096 \tag{30}$$

[R25] IF price is expensive AND capacity is large AND power is low THEN decision is buy

$$\alpha_{25} = \mu_{p.e} \cap \mu_{c.l} \cap \mu_{p.l} = \min(\mu_{p.e}; \mu_{c.l}; \mu_{p.l}) = \min(0.096; 0.7; 0.65) = 0.096 \tag{31}$$

[R26] IF price is expensive AND capacity is large AND power is medium THEN decision is considered

$$\alpha_{26} = \mu_{p.e} \cap \mu_{c.l} \cap \mu_{p.m} = \min(\mu_{p.e}; \mu_{c.l}; \mu_{p.m}) = \min(0.096; 0.7; 0.3) = 0.096 \tag{32}$$

Figure 11 explains [R13] aggregation of **Equation (25)**. **Figure 12** explains [R14] aggregation of **Equation (26)**. **Figure 13** explains [R16] aggregation of **Equation (27)**. **Figure 14** explains [R17] aggregation of **Equation (28)**. **Figure 15** explains [R22] aggregation of **Equation (29)**. **Figure 16** explains [R23] aggregation of **Equation (30)**. **Figure 17** explains [R25] aggregation of **Equation (31)**. **Figure 18** explains [R26] aggregation of **Equation (32)**.

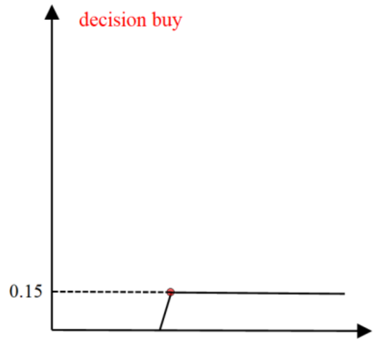

Figure 11. R13 Aggregation

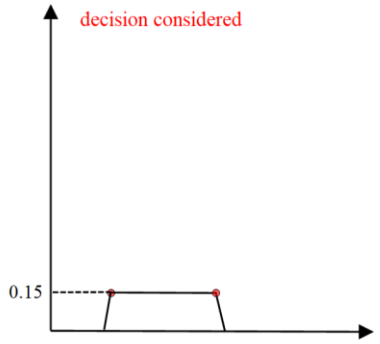

Figure 12. R14 Aggregation

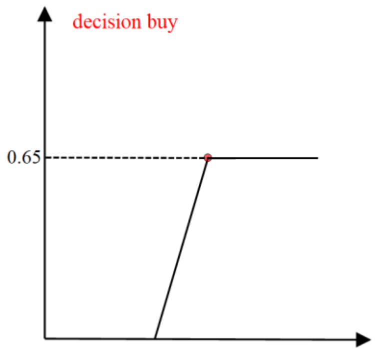

Figure 13. R16 Aggregation

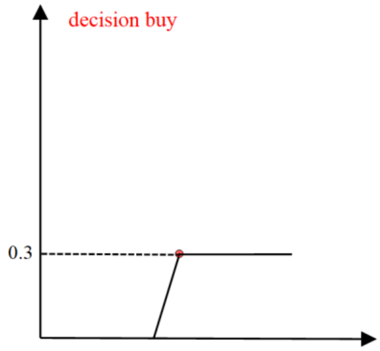

Figure 14. R17 Aggregation

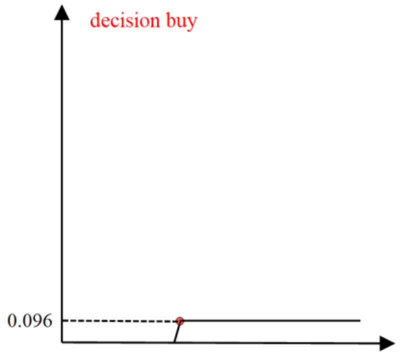

Figure 15. R22 Aggregation

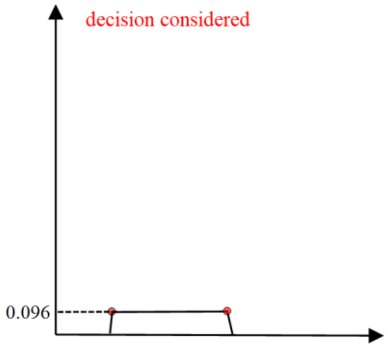

Figure 16. R23 Aggregation

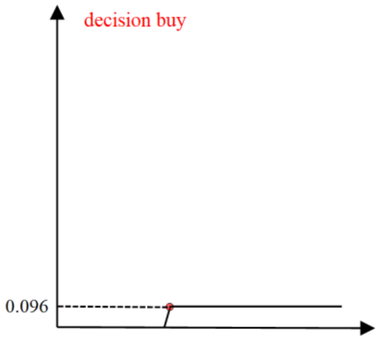

Figure 17. R25 Aggregation

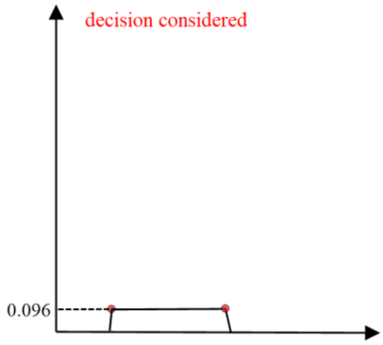

Figure 18. R26 Aggregation

Next, the aggregation results of the rules that provide similar conclusions will be compared. The highest value among the rules is then selected using the MAX method.

$$\mu_{decision\ considered} = \max(0.15\ ; 0.096) = 0.15 \tag{33}$$

$$\mu_{decision\ buy} = \max(0.15\ ; 0.65\ ; 0.3\ ; 0.096) = 0.65 \tag{34}$$

The combined results of the aggregation process show that the area is divided into four parts with unknown boundaries m_1, m_2, and m_3 as shown in Figure 19 below. Next, the value of each unknown boundary will be searched.

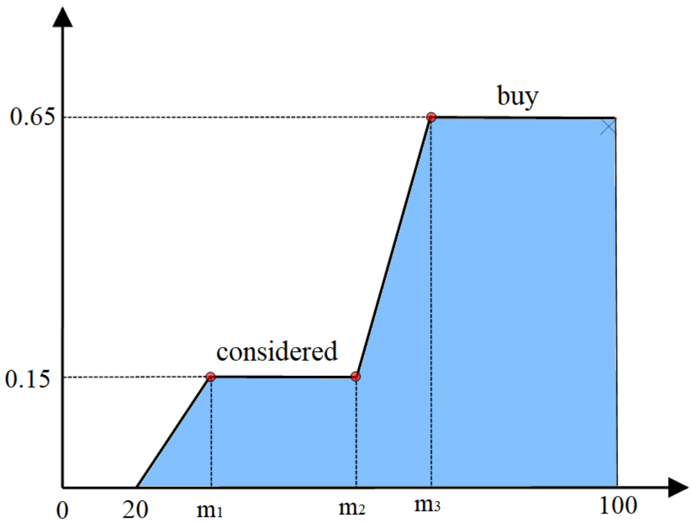

Figure 19. Combined Rule Aggregation

$$\alpha_1 = 0.15 \ \rightarrow \ \frac{m_1 - 20}{40 - 20} = 0.15 \ \rightarrow \ m_1 = 23 \tag{35}$$

$$\alpha_2 = 0.15 \ \rightarrow \ \frac{m_2 - 40}{70 - 40} = 0.15 \ \rightarrow \ m_2 = 44.5 \tag{36}$$

$$\alpha_3 = 0.65 \ \rightarrow \ \frac{m_3 - 40}{70 - 40} = 0.65 \ \rightarrow \ m_3 = 59.5 \tag{37}$$

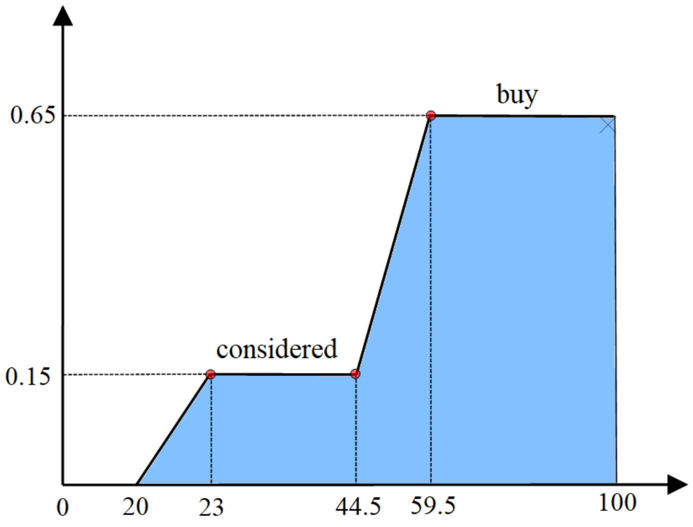

Figure 20. Decision Area

Figure 20 shows the complete decision area curve with the boundaries m_1, m_2, and m_3 obtained in the previous calculation. The decision area membership function is presented as in **Equation (38)** below:

$$\mu_{decision}(z) = \begin{cases} \frac{z-20}{20} & 20 \le z < 23 \\ 0.15 & 23 \le z < 44.5 \\ \frac{z-40}{30} & 44.5 \le z < 59.5 \\ 0.65 & 59.5 \le z \le 100 \end{cases} \tag{38}$$

3.4 Defuzzification

The next step is defuzzification, namely changing the fuzzy output into quantitative values using the centroid approach.

$$M_1 = \int_{20}^{23} \left(\frac{z-20}{20}\right) z\, dz = 4.95 \tag{39}$$

$$M_2 = \int_{23}^{44.5} (0{,}15) z\, dz = 108.84375 \tag{40}$$

$$M_3 = \int_{44.5}^{59.5} \left(\frac{z-40}{30}\right) z\, dz = 321.375 \tag{41}$$

$$M_4 = \int_{59.5}^{100} (0.65) z\, dz = 2099.4187 \tag{42}$$

$$\int \mu(z) z\, dz = M_{total} = 2{,}534.58745 \tag{43}$$

$$A_1 = \int_{20}^{23} \left(\frac{z-20}{20}\right) dz = 0.225 \tag{44}$$

$$A_2 = \int_{23}^{44.5} (0{,}15)\, dz = 3.225 \tag{45}$$

$$A_3 = \int_{44.5}^{59.5} \left(\frac{z-40}{30}\right) dz = 6 \tag{46}$$

$$A_4 = \int_{59.5}^{100} (0{,}65)\, dz = 26.325 \tag{47}$$

$$\int \mu(z)\, dz = A_{total} = 35.775 \tag{48}$$

$$z = \frac{\int \mu(z) z\, dz}{\int \mu(z)\, dz} = \frac{2{,}534.58745}{35.775} = 70.848 \tag{49}$$

Based on the calculation, the results obtained are that if the price variable is Rp 4,288,700, capacity 357 liters, and power 41 watts, then the defuzzification value is 70.848, which is in the range of 70 - 100, which means it is recommended to buy. While the Mamdani fuzzy inference process using the Matlab application is carried out by entering input data [4.2887; 357; 41] in the rule viewer menu, as in Figure 21.

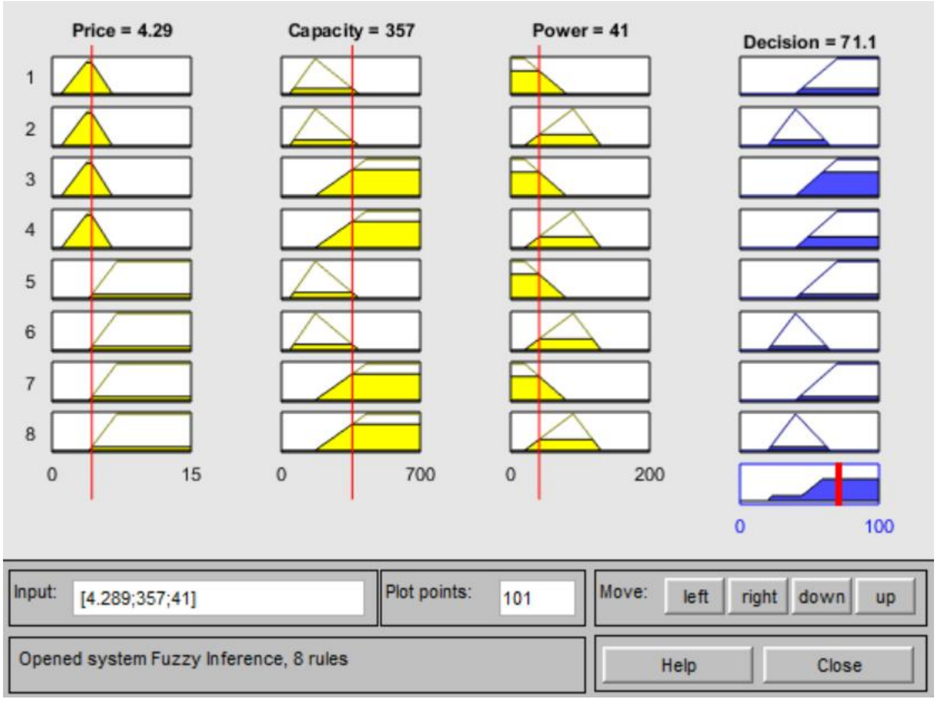

Figure 21. Inference Rules

Figure 21 shows the inference results with the Matlab application, obtaining a defuzzification value of 71.1, which is in the domain range of 70 - 100, which means it is recommended to be purchased.

3.5 Discussion

Based on the calculation results, a refrigerator with a price of 4,288,700, a capacity of 357, and a power of 41 has a defuzzification value of 70.85. While using the MATLAB application, the defuzzification value obtained is 71.1. The two values are not much different. So, to determine the defuzzification value of the other 81 refrigerator units, we use the MATLAB R2019b application.

Table 7. Defuzzification Results

No	Merk	Price (Rp)	Capacity (liters)	Power (watts)	Defuzzification Value	Decision
1	Aqua AQR-415IM	4,288,700	357	41	71.1	Buy
2	Sharp SJ-IS50MA-SL	8,196,000	472	36	70.4	Buy
3	Aqua AQR-D270	2,899,000	220	50	63.7	Considered
⋮	⋮	⋮	⋮	⋮	⋮	⋮
80	Sharp SJ-50MB-XW	1,700,000	45	75	19.8	Not Buy
81	Polytron PRB219	3,638,000	200	130	13.1	Not Buy
82	Sharp SJ-IF51PG-BK	9,119,000	472	180	12.4	Not Buy

Table 7 shows that the Aqua AQR-415IM and Sharp SJ-IS50MA-SL refrigerator brands both produce a decision to buy. However, the Aqua AQR-415IM refrigerator has a higher defuzzification value than the Sharp SJ-IS50MA-SL refrigerator, thus, the Aqua AQR-415IM refrigerator is more recommended to buy. If reviewed further, the Aqua AQR-415IM refrigerator has specifications of a normal price, medium capacity, and low power. While the Sharp SJ-IS50MA-SL refrigerator has specifications of an expensive price, large capacity, and low power. Although the capacity of the Sharp SJ-IS50MA-SL refrigerator is larger, its price is twice as expensive as the Aqua AQR-415IM refrigerator. So, for the best decision-making, the Aqua AQR-415IM refrigerator was chosen to be purchased. The Aqua AQR-D270 refrigerator has a defuzzification value that falls into the "considered" decision category. For those looking for a refrigerator with a low price, medium capacity, and low power, this brand is one that is worth choosing.

4. CONCLUSIONS

This study demonstrates that applying fuzzy logic with the Mamdani approach can provide structured recommendations for refrigerator selection based on price, capacity, and energy consumption, with results favoring models with normal prices, medium capacity, and low power consumption. However, buyer preferences remain the primary factor in decision-making. The Mamdani technique is implemented through fuzzification, rule formation, inference, and defuzzification, using a minimal approach for membership functions, the maximum method for composition, and the centroid method for defuzzification, supported by MATLAB software. While the approach proves effective in generating recommendations aligned with predefined criteria, efficiency is not quantitatively measured. A key limitation is the absence of demographic factors such as income, location, or family size, making recommendations general rather than tailored. Future research should explore alternative fuzzy methods for performance comparison, incorporate demographic variables for more precise recommendations, and extend the approach to decision-making for other electronic products..

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