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Comparative Analysis of Mamdani, Sugeno and Tsukamoto Fuzzy Inference Systems to Support Decisions on Selecting Outstanding Employees

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ABSTRACT
The awarding of exceptional employees is founded on legality, objectivity, and transparency, as determined by authorized officials following a rigorous assessment process. However, it has been observed that during the assessment procedure, there are instances where the established principles of objectivity may be compromised. To address this challenge, the utilization of the Fuzzy Logic Method is proposed as a means to enhance the decision-making process in evaluating outstanding employees. This method involves the comparison of three distinct Fuzzy Inference Systems (FIS): the Mamdani, Sugeno, and Tsukamoto Methods. The employment of these methods ensures the attainment of precise calculation outcomes. The proposed approach involves the incorporation of attendance, performance, and behavior data as input variables, with employee assessments serving as the output variables. The study was conducted using input data from three employees in the form of attendance, performance, and behavior data, as well as a set of rules (rule sets) determined by experts. The results of the study indicate that the Tsukamoto fuzzy inference system provides accurate and appropriate assessments for the decision-making process involving various sets of rules.

1. INTRODUCTION

Decision support systems (DSS) are information systems that support business or organizational decision-making activities. DSS serves the management, operations, and planning levels of an organization (usually middle and upper management) and helps people make decisions about issues that can change rapidly and are not easily determined in advance such as unstructured and semi-structured decision problems. Decision support systems can be fully computerized or human-powered, or a combination of both (Keen, 1980).

Outstanding employees are employees who have demonstrated real and useful innovation and creativity and have good performance compared to the performance of other employees after being assessed and determined by authorized officials. The awarding of awards to outstanding employees aims to increase employee productivity and performance. The assessment of outstanding employees is a series of employee selection or assessment processes carried out at each level of the work unit (Kemendikbud-Indonesia, 2019). The awarding of awards to outstanding employees is based on the principles of legality, objectivity, and openness.

However, in the assessment process, sometimes there are violations of the established principle of objectivity, thus affecting the results. On the other hand, decision making for selecting high-performing employees involves the process of collecting most of the information or data that is interrelated and related to the established personnel rules.

To support decision making in determining high-performing employees, it is proposed to use the Fuzzy Logic Method. This study will compare 3 types of Fuzzy Inference Systems (FIS), namely the Mamdani Method, the Sugeno Method, and the Tsukamoto Method. The aim is to find out which method provides efficient results and is easy to apply in the decision-making process, using attendance data, performance data, and behavioral data as input variables, and employee assessments as output variables.

Several similar studies that have been conducted previously, including The Comparative Analysis of Mamdani, Sugeno, and Tsukamoto Method of Fuzzy Inference System for Air Conditioner Energy Saving (Saepullah & Wahono, 2015) which shows that the best method in terms of reducing electricity consumption in the AC system is the Tsukamoto method, where the average electricity efficiency is 74.2775%. In a study conducted by Auliya Burhanuddin entitled Comparative Analysis of Fuzzy Inference Tsukamoto, Mamdani and Sugeno on Rice Productivity in Indonesia (Burhanuddin, 2023), it was concluded that the Tsukamoto fuzzy method and the Sugeno fuzzy method had the best accuracy. Meanwhile, in the paper Estimating Ergonomic Compatibility of Cars: A Fuzzy Approach (Dutta & Rathore, 2020) it was concluded that Mamdani has better expressiveness and interpretability than Sugeno and Mamdani is intuitive and suitable for human input so it is more popular. Another study entitled A comparative study on fuzzy Mamdani-Sugeno-Tsukamoto for the diagnosis of childhood tuberculosis (Sari et al., 2016) concluded that the best accuracy is the Sugeno fuzzy inference system which has advantages in interpreting the rules of fuzzy inference calculations and defuzzification compared to fuzzy Mamdani and Tsukamoto.

This research will discuss several parts, including the Definition of Fuzzy Logic, Fuzzification, Inference Systems, Defuzzification, experiments and results obtained from the comparison of 3 types of fuzzy inference systems, as well as research conclusions.

2. LITERATURE REVIEW

Decision Support System

Decision Support System (DSS) is a special information system designed to support management in making decisions related to problems that have a structure level that is not fully defined (Bazhrullah et al., 2022; Nofriansyah & Defit, 2017). DSS plays a role in filtering and analyzing large volumes of data, collecting comprehensive data that is useful for solving problems and carrying out the decision-making process (Frieyadie, 2016).

3. METHOD

Fuzzy Logic

Fuzzy logic was introduced in 1965 by Lotfi A. Zadeh from the University of California in his scientific paper Fuzzy Set Theory (Zadeh, 1965). The term Fuzzy refers to things that are unclear or fuzzy, which provide invaluable flexibility for reasoning so that we can consider the inaccuracy and uncertainty of any situation (Ross, 2005). If in the truth table of classical logic/boolean logic, 1 represents absolute truth, while 0 represents absolute error, but in Fuzzy Logic, there are values between 1 and 0, which represent partly true and partly false.

The membership function or what is called a fuzzy set is symbolized by μ, containing elements that have values between 1 and 0 with different degrees of membership in each set. Fuzzy sets have 2 attributes, namely linguistic, which is a group that represents a certain situation using natural language; and numeric, a group that is represented by a value/number to determine the size of the variable. The value of the universe/universe of speech is all values that are allowed to operate on fuzzy variables (Honda & Ohsato, 1986). The domain of a fuzzy set is all values that are allowed in the universe of speech and may be operated on fuzzy sets.

Operations on fuzzy sets include combined operations or "OR" operations (symbolized by ∪), which are operations determined by the maximum value of 2 or more fuzzy sets; intersection operation or "AND" operation (denoted by ∩), which is an operation determined by the minimum value of 2 or more fuzzy sets.

Fuzzy Inference System is a method that interprets a value in an input vector based on several sets of rules, then assigns that value to the output vector (Olajide et al., 2024), as shown in Figure 1. Fuzzy Inference System (FIS) also known as fuzzy inference engine, can reason with the same principle as humans who can reason with their instincts.

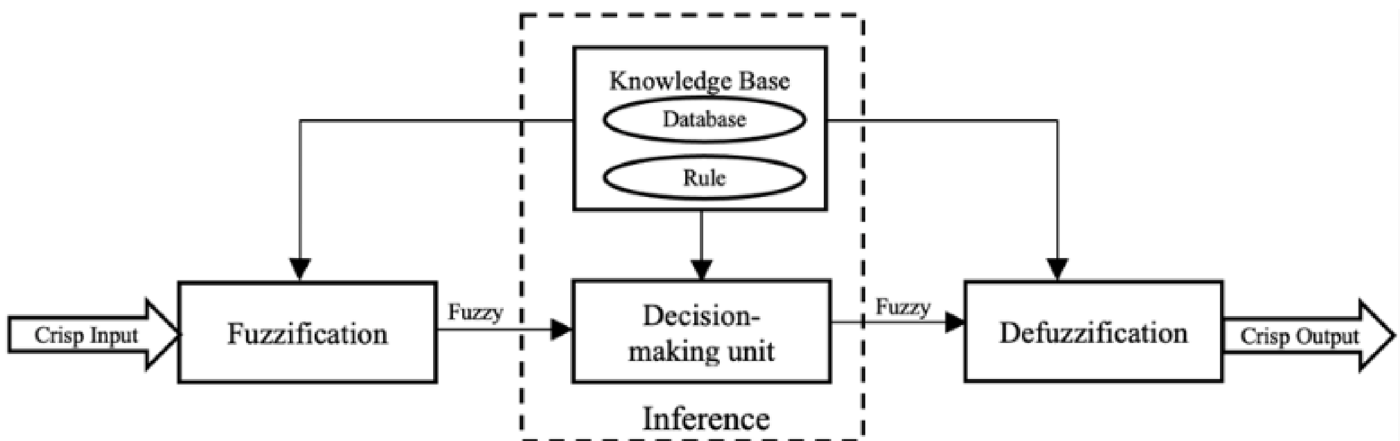

Figure 1. Fuzzy Inference System

Fuzzification is the process of converting system input in the form of firm values into fuzzy set variables using membership stored in the knowledge base. Inference is the process of converting fuzzy input into fuzzy output by following the rules (IF-THEN rules or constants) that have been set in the fuzzy knowledge base (Chen & Pham, 2000). Defuzzification is the process of processing fuzzy values obtained from the Fuzzy Inference Engine into firm values. Defuzzification can also be interpreted as the process of converting fuzzy values into crisp values. These crisp values will later be used in implementation and analysis.

4. RESULT AND DISCUSSION

In this study, attendance data, performance data and employee behavior data are used as input variables, by dividing each data into 3 (three) fuzzy sets, namely the Bad/low set = [0 6], the Normal set = [3 9], the Good/high set = [6 9]. While for the output variables in the Mamdani and Tsukamoto methods, assessment data is used which is divided into 4 (four) fuzzy sets, namely the extraordinary set = [90 100], the best set = [80 100], the good set = [50 90], the bad set = [30 70], as can be seen in Figure 2.

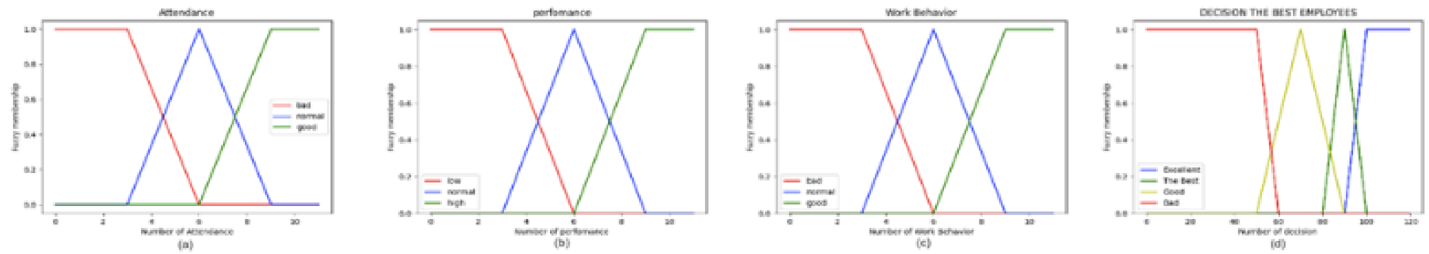

Figure 2. Fuzzy set input (a), (b), (c), Fuzzy set output (d)

In the Sugeno method, the assessment data as output variables are in the form of mathematical functions determined by the following constant values: Excellent [100]; Best [90]; Good [70]; Bad [50]. The experiment used 3 pieces of sampling data as follows:

Table 1. Data sampling

Test	Employee Name	Attendance data	Performance data	Behavioral data
1	Anwar	8	7	9
2	Barry	7	6	8
3	Charles	8	9	9

Tsukamoto Method

Fuzzification was carried out in experiment I, using the formula:

$$\mu[x] = \begin{cases} 0\,;\, x \le a, x \ge c \\ \dfrac{x-a}{b-a}\,;\, a < x \le b \\ \dfrac{c-x}{c-b}\,;\, b < x \le c \end{cases}$$

So that it produces the following membership functions: $\mu_{att.normal}[8] = 0.33$; $\mu_{att.good}[8] = 0.67$; $\mu_{perf.normal}[7] = 0.67$; $\mu_{perf.high}[7] = 0.33$; $\mu_{behavior.good}[9] = 1$.

At the inference stage, use some of the rules in table 2.

H = Presence, K = Performance, P = Behavior, N = Assessment

Table 2. Rule Base

Code	Rules
R [1]	IF H is good AND K is high AND P is good, THEN N is excellent
R [2]	IF H is good AND K is high AND P is normal, THEN N is the best
R [3]	IF H is good AND K is high AND P is bad, THEN N is good
R [4]	IF H is good AND K is normal AND P is good, THEN N is the best
R [5]	IF H is good AND K is normal AND P is normal, THEN N is good
R [6]	IF H is normal AND K is low AND P is normal, THEN N is good
R [7]	IF H is normal AND K is low AND P is bad, THEN N is bad

The defuzzification process is carried out using the average value method, with the formula:

$$Z* = \frac{\sum(\propto -predicate-i * Zi)}{\sum \propto -predicate-i}$$

Which produces a value of 81.35.

Where α = alpha predicate (minimum value of membership degree), Zi = crisp value obtained from the fuzzy set membership degree formula which is the output value, and Z = mean-centered defuzzification.

Sugeno Method

This method was developed by Michio Sugeno in 1985, still using the same fuzzification and defuzzification principles as Tsukamoto. However, in the inference process, Sugeno uses linear equations or mathematical functions to determine the conclusion rules, which in this study use constant values.

$$\alpha\text{ - predicate} = \mu_{\text{att;good}}[7]\ \text{DAN}\ \mu_{\text{perf;normal}}[6]\ \text{and}\ \mu_{\text{behavior;good}}[8] = \text{MIN}(0{,}3;1;0{,}67) = 0{,}3.$$

Where the z value as output is set in the rule 90.

The defuzzification process uses the average score method, as in the Tsukamoto inference system. The second experiment using the Sugeno method produced a value of 73.82.

Mamdani Method

This method was developed by Prof. Ebrahim Mamdani from the University of London in 1975. In the inference process, only by finding the alpha predicate value with the same formula as Tsukamoto and Sugeno. After that, using the alpha predicate value to determine the crisp value of each output, which is known as aggregation or using the maximum value of the fuzzy set area.

The defuzzification process is carried out by dividing the output area into several parts, then finding the moment and area of the region with an integral. The result is dividing the number of moments by the total area known as the centroid method.

$$Z^* = \frac{\sum \text{Momen}-i}{\sum \text{wideArea}-i}$$

Table 3. Simulation results

FIS	Experiment 1	Experiment 2	Experiment 3
Mamdani	79.05	74.02	94.67
Sugeno	88.01	73.82	96.7
Tsukamoto	81.35	64.37	92.7

5. CONCLUSION

Based on the experiments that have been conducted in this study, it can be concluded that fuzzy logic can be used as a support in the decision-making process to determine outstanding employees, but provides varying results, depending on the inference system used. The Tsukamoto method uses MIN implications on the inference evaluation engine and the centralized average method for defuzzification. The Sugeno method uses MIN implications and equation functions on the inference evaluation engine, and the centralized average method for defuzzification. The Mamdani method uses the MIN function and composition rules for the MAX function on the inference engine, and the centroid method in the defuzzification process.

From the comparison of the three fuzzy inference systems, it can be concluded that the Tsukamoto method provides accurate results and is more suitable for supporting the decision-making process. The Tsukamoto method is simpler, tolerates existing data, is faster in calculating, is more intuitive, and is more suitable for input received from humans rather than machines when compared to the Sugeno and Mamdani methods.

For future research, a larger dataset can be used to obtain varied and accurate results in determining the appropriate decision-making model.

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