Mamdani Fuzzy Analysis and Application for Assessing Student Intelligence Levels

Indah Lestari, Rian Farta Wijaya

Abstract
Determining the intelligence level of students is one of the important steps in supporting the evaluation process of learning in a more objective and systematic manner. However, intelligence assessment is often still conducted conventionally and tends to be subjective because it is influenced by many criteria that cannot always be precisely evaluated. This research aims to analyse and implement the Fuzzy Mamdani method in determining the intelligence level of students based on several assessment indicators. The Fuzzy Mamdani method was chosen because it can process data that is vague and uncertain into more logical and structured decisions. The research stages include data collection, determination of input and output variables, formation of fuzzy sets, formulation of fuzzy rules, inference process, and defuzzification to produce the final value of student intelligence levels. The variables used in this study include academic scores, activity, discipline, and comprehension ability as inputs, while the output is the category of student intelligence levels. The research results show that the Fuzzy Mamdani method can be applied to assist in the decision-making process in determining students' intelligence levels more flexibly, objectively, and efficiently. The system built is capable of providing intelligence level recommendations based on the combination of scores from each predetermined criterion. Thus, the implementation of the Fuzzy Mamdani method is expected to become a decision-support solution for the school in conducting student assessments more accurately.
Keywords: *Fuzzy Mamdani, Decision Support System, Intelligence Level, Students, Fuzzy Logic*

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Introduction

Education plays an important role in shaping the quality of human resources capable of adapting to the development of science, technology, and social needs. In the educational process, assessment of students becomes one of the most determining elements because the results of the assessment are not only used to measure learning achievements but also serve as the basis for academic decision-making. The two primary activities in education are teaching and learning, which are related ideas. Repetition of the content in simpler language is the teacher's method for dealing with sluggish learners. [1], [2]. Through accurate assessments, schools can understand students' conditions more deeply, both in terms of their ability to comprehend lessons, participation in learning, discipline, and academic achievements. Therefore, the process of determining the level of students' abilities or intelligence needs to be conducted carefully, objectively, and systematically so that the results obtained can truly serve as a foundation to support the development of students' potential. Learning can raise educational standards and equip the next generation to compete on a global scale [3].

In practice, the determination of students' intelligence levels in the school environment is often still done conventionally. The assessment generally relies only on academic grades or general teacher observations without using a structured analytical approach. This condition gives rise to several weaknesses. First, the assessment tends to be subjective because it is influenced by the perceptions of each evaluator. Second, the determination of students' intelligence levels often does not consider that students' abilities are multidimensional. A variety of general and specialised skills combine to form human intelligence The fundamental method for resolving those issues through the educational system is covered by the character construct. [4], [5]. Reading proficiency assessments, student engagement observation forms, and documentation are among the research tools [6].

Third, not all assessment indicators can be clearly expressed in the form of definite numbers. For example, categories such as active, fairly active, disciplined, less disciplined, understanding, or fairly understanding are forms of assessment that contain elements of uncertainty and ambiguity. If such conditions are forced to be assessed with strict logic, then the decision results are likely to poorly represent the actual state of the students. The findings of the study demonstrate how crucial emotional intelligence is to learning performance [7]. Conceptually, a student's intelligence cannot be understood merely as the result of a cognitive test. In the context of school learning, the assessment of intelligence is often related to a combination of several indicators that reflect the overall learning ability of students. Students with high exam scores do not necessarily demonstrate a consistent level of understanding in their learning. Conversely, students who are active, disciplined, and have a good ability to comprehend the material can show strong academic potential even if their numerical scores are not yet fully outstanding. This indicates that determining a student's intelligence level requires a model that can accommodate multiple variables simultaneously and process the relationships between these variables more flexibly. Project-based learning is generally successful in improving students' comprehension of IPAS, fortifying Pancasila students' character, and cultivating their critical thinking and teamwork abilities [8].

The problem indicates the need for a computational approach that can assist in the decision-making process for determining students' intelligence levels. More consistent humidity and temperature settings can be generated by fuzzy logic [9]. One of the relevant methods to use is fuzzy logic. The Fuzzy Logic Controller technique is used to regulate the ideal temperature according to the amount of people in the space. Mamdani fuzzy logic can make highly accurate and useful recommendations for the choosing of canned beverages. [10], [11].

Fuzzy logic is an approach designed to handle uncertain, vague, and ambiguous data. Unlike classical logic, which only recognises absolute true or false conditions, fuzzy logic allows a value to belong to a certain degree of membership in multiple categories simultaneously. This approach is more suitable for representing real conditions in the world of education, as many student assessment indicators cannot be rigidly defined. Thus, fuzzy logic can be a more adaptive alternative in supporting the evaluation and classification process of students' intelligence levels.

The Tsukamoto approach of fuzzy logic can suggest majors that correspond with high-grade subjects [12].

One of the methods widely used in fuzzy systems is the Fuzzy Mamdani method. This method is known for its ability to model reasoning that approaches human thinking through language-based rules, such as "if academic performance is high and activity is good, then intelligence level is high." The advantage of the Fuzzy Mamdani method lies in its ability to process various input variables into easily understandable rules, so the decision outcomes are not only mathematical but also conceptually logical. In the context of this research, the Fuzzy Mamdani method can be used to process several student assessment indicators, such as academic performance, activity, discipline, and comprehension ability, to produce outputs in the form of student intelligence level categories. With a model like this, the assessment process becomes more systematic, transparent, and accountable. The Tsukamoto, Sugeno, and Mamdani fuzzy logic algorithms were compared in the study [13].

The use of the Fuzzy Mamdani method in the field of education also has high practical value. The system built with this method can help teachers or school authorities reduce subjectivity in assessments, accelerate the process of analysing student data, and produce more consistent decisions. In addition, the application of this method also supports digital transformation in education management, particularly in the development of decision support systems. This research is important because schools need tools that can integrate various assessment indicators into a single measure.

Literature Review

2.1 Fuzzy Concept

Fuzzy, in linguistic terms, is defined as vague or ambiguous, meaning that a value can be both true and false simultaneously. In fuzzy logic, the degree of membership is known, which has a value range from 0 (zero) to 1 (one). Fuzzy logic is a type of logic that has a degree of ambiguity or vagueness between true and false. In fuzzy logic theory, a value can be both true and false simultaneously. However, the extent of truth and falsity depends on the membership weight it possesses. Fuzzy logic has a degree of membership in the range of 0 to 1 and fuzzy logic indicates the extent to which a value is true and the extent to which a value is false. Fuzzy logic is an appropriate way to map an input space into an output space and has continuous values. Fuzzy is expressed in degrees of membership and degrees of truth. Therefore, something can be said to be partially true and partially false at the same time.

In everyday life, many instances of ambiguity can be found. Take an example, in a class a teacher asks the student who has a bicycle to raise their hand, then the student who has a bicycle will easily raise their hand. However, when the teacher asks the smart students to raise their hands, there will be hesitation, whether they belong to the smart group or not. The boundary between "having a bicycle" and "not having a bicycle" is clear and definite, but the same cannot be said for "smart" and "not smart." In other words, the set of students who are smart and not smart seems to be defined in a vague or ambiguous manner. Therefore, a new scientific language is needed that can capture the vagueness/ambiguity of everyday language terms adequately [14].

2.1.1 Fuzzy Set

A crisp set is a set that is clearly defined in the sense that for every element in its universe, it can always be clearly determined whether it is a member of the set or not. In other words, there is a clear boundary between the elements that are members of a set and those that are not. It is difficult for us to accept that a person who is 26 years old does not belong to the young group. This shows that the boundary between the group of young people and the group of non-young people cannot be clearly defined [14].

This function is called a membership function, and the value of that function is called the degree of membership of an element in the set, which is subsequently called a fuzzy set. A fuzzy set is a range of values, each value having a degree of membership between 0 and 1. A fuzzy set

Â in the universe of discourse X is expressed with a membership function μ in the interval [0,1], which can be expressed as:

$$\mu Â: X \rightarrow [0,1]$$

There are several things to know in understanding fuzzy systems, namely:

a. Fuzzy variables
   Fuzzy variables are the variables to be discussed in a fuzzy system. Examples: age, temperature, demand, etc.
b. Fuzzy sets
   Fuzzy sets are a group that represents a certain condition or state in a fuzzy variable.

2.1.2 Membership Functions

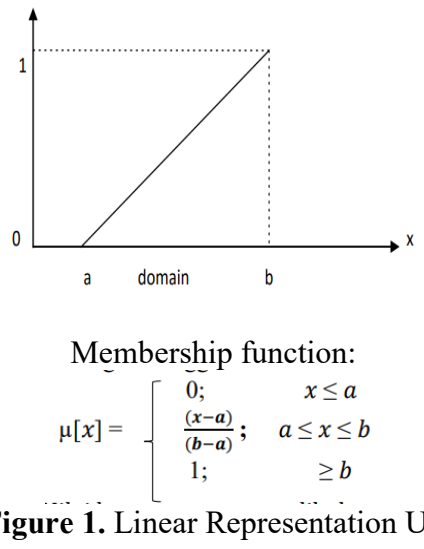
The membership function is a curve that shows the mapping of input data points into their membership values (often also referred to as degrees of membership) which have an interval between 0 and 1. One way to obtain membership values is through a functional approach. There are several functions that can be used:

a. Linear Representation

In the linear representation, the mapping of input to its degree of membership is depicted as a straight line.

There are 2 states of linear fuzzy sets, namely:

1. The rise of the set starts at a domain value with a membership degree of zero (0) moving to the right towards a domain value with a higher membership degree.



Membership function:

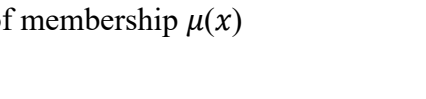
$$\mu[x] = \begin{cases} 0; & x \le a \\ \frac{(x-a)}{(b-a)}; & a \le x \le b \\ 1; & \ge b \end{cases}$$

Figure 1. Linear Representation Up

Explanation:
x = The membership value being discussed
a = The lowest member value
b = The member value

Membership function for the HOT set on the room temperature variable as shown in Figure 2.

$$\mu \text{ HOT } [32] = (32\text{-}25) / (35\text{-}25)$$
$$= 7/10 = 0{,}7$$



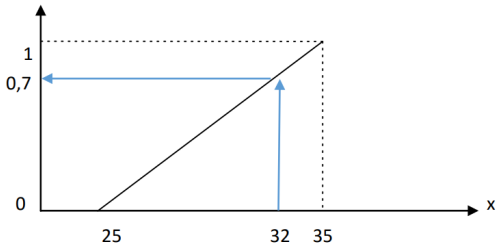
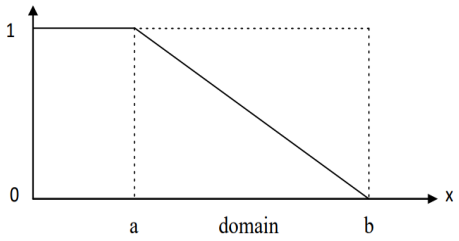


Figure 2. Fuzzy set: HOT.

The straight line starts from the domain value with the highest membership degree on the left side, then moves down to the domain value with a lower membership degree.

degree of membership $\mu(x)$



$$\mu[x] = \begin{cases} 1; & x \le a \\ \frac{(x-a)}{(b-a)}; & a \le x \le b \\ 0; & x \ge b \end{cases}$$

Figure 3. Downward Linear Representation

2.2 Fuzzy Mamdani Logic

Mamdani fuzzy logic is a branch of logic that introduces the concept of membership degrees in sets, allowing for membership that is either false or true. The main structure of the Mamdani fuzzy logic system is explained in figure 2.6. In fuzzy inference, reasoning can be performed by utilising the input and the fuzzy rules that have been established for the output of the fuzzy system. Additionally, it offers a more flexible alternative compared to boolean logic, which assigns absolute true or false values without membership degrees, whereas fuzzy logic allows for membership degrees with values between 0 and 1.

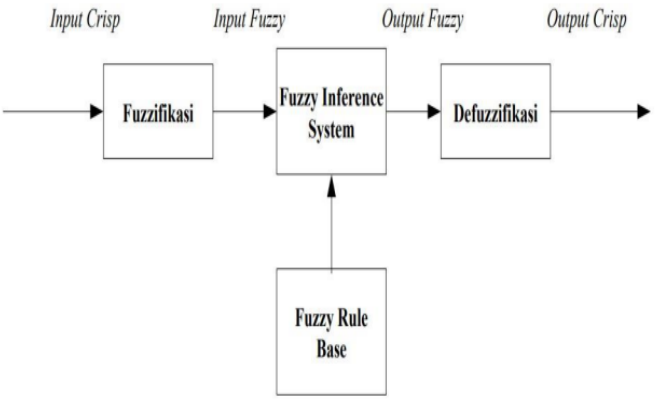


Figure 4. Mamdani Fuzzy Logic Structure

The formula for the increasing linear membership function is as follows (Fuzzy Logic with Matlab, 2018):

$$\mu(x) = \begin{cases} 0; & x \leq a \\ \frac{x-a}{b-a}; & a \leq x \leq b \\ 1; & x \geq b \end{cases}$$

The equation of the descending linear membership function is as follows (Fuzzy Logic with Matlab, 2018):

$$\mu(x) = \begin{cases} \frac{b-x}{b-a}; & a \leq x \leq b \\ 0; & x \geq b \end{cases}$$

The formula for the triangular membership function is as follows (Fuzzy System, 2019):

$$\mu(x) = \begin{cases} 0; & x \leq a \text{ atau } x \geq c \\ \frac{x-a}{b-a}; & a \leq x \leq b \\ \frac{b-x}{c-b}; & b \leq x \leq c \end{cases}$$

In the implementation of real-time fuzzy control, the defuzzification process uses the center of area (COA). The following is the equation for the defuzzification formula (Djalal & Robandi, 2022:91):

$$Z = \sum \frac{\mu(x).(x)}{\mu(x)}$$

Explanation:
z = output value
$\mu(x)$ = membership degree value
x = output range value

Research Methodology

The research methodology in the study titled "Analysis and Implementation of Fuzzy Mamdani in Determining Student Intelligence Levels" uses an applied quantitative approach with a descriptive and implementative research type. This research aims to analyse the process of determining students' intelligence levels through the Mamdani fuzzy inference system and to implement it into a structured decision-making model. The research object focuses on student data assessed based on several relevant input variables, such as academic grades, comprehension ability, logical reasoning, creativity, and learning activity, in accordance with the needs and indicators set by the school or researchers. Data collection techniques were carried out through observation, interviews, documentation, and literature study to obtain information regarding the criteria for assessing students' intelligence. The data obtained is then analysed using the stages of the Mamdani fuzzy system, namely the determination of fuzzy variables, the formation of fuzzy sets, the formulation of fuzzy rules, the inference process, and defuzzification to produce the final intelligence level score of the students.

The implementation stage is carried out by designing a system capable of processing input data into intelligence-level decisions more objectively and systematically. The analysis process begins by identifying each assessment criterion, then each variable is converted into linguistic forms, such as low, medium, and high, which are represented through specific membership functions. Next, decision rules in the form of IF-THEN are formulated based on expert or teacher logic to describe the relationships between variables in determining the level of intelligence. The fuzzy inference results are then converted into crisp values using the centroid method to provide easily interpretable final results. With this methodology, the research is expected to produce a model for determining students' intelligence levels that is more flexible, adaptive, and closer to human assessment patterns compared to conventional methods that are rigid.

Results

In the input form, input is provided as below to test the output generated.

Nutrition and Health (C1)
Home Environment (C2)
Interpersonal (C3)
Visual-Spatial (C4)
Linguistic-Verbal (C5)
Learning Methods (C6)
Critical/Logical Thinking (C7)
Reading Habits (C8)

Here are the criteria needed for decision-making, based on the general requirements for laptop selection. The criteria that have been determined are Price (C1), Processor (C2), Memory Capacity (C3), Screen Size (C4), VGA (C5), Hard Disc Capacity (C6), Bluetooth (C7), and Webcam (C8).

Assuming the candidate's suitability range against the criteria used is:
Very Poor = (0, 0, 0.25)
Poor = (0, 0.25, 0.50)
Moderate = (0.25, 0.50, 0.75)
Good = (0.50, 0.75, 1.00)
Very Good = (0.75, 1.00, 1.00)

Then, after the candidate assessment is completed, the next step is to create a level of criterion importance based on the weight values that have been determined into fuzzy numbers.

Nutrition and Health Criteria

Based on the criteria and rating of the requirements needed for decision-making based on value. Here are the Nutrition and Health intervals that have been converted into fuzzy numbers below.

Table 1. Nutrition and Health Criteria

Nutrition and Health	Value
< 1.000.000	2,5
1.000.000 – 1.500.000	5
1.500.000 – 2.000.000	7,5
3.000.000	10

Home Environment Criteria

Based on the criteria and rating requirements needed for decision-making based on value. Below are the value intervals that have been converted with fuzzy numbers.

Table 2. Home Environment

Home Environment	Value
Play	2.5
Rest	5
Study	7.5
Parenting	10

Interpersonal Criteria

Based on the criteria and rating of the requirements needed for decision-making based on value. Here are the value intervals that have been converted with fuzzy numbers below.

Table 3. Interpersonal

Interpersonal	Value
Social	2.5
Cooperation	5
Intelligence	7.5
Self-Understanding	10

Visual-Spatial Criteria

Based on the criteria and rating of the requirements needed for decision-making based on value. Here are the value intervals that have been converted with fuzzy numbers below.

Table 4. Visual-Spatial Criteria

Visual-Spatial Criteria	Value
Imagination	2.5
Skill	5
Physique	7.5
Motor	10

Linguistic-Verbal Criteria

Based on the criteria and rating of the requirements needed for decision-making based on Linguistic-Verbal. Here are the value intervals that have been converted with fuzzy numbers below.

Table 5. Linguistic-Verbal Criteria

Linguistic-Verbal	Nilai
Language	0,33
Write	0,66
Logic Ability	1,00

Learning Methods Criteria

Based on the criteria and rating requirements needed for decision-making based on Learning Methods. Below are the value intervals that have been converted using fuzzy numbers.

Table 6. Learning Methods Criteria

Learning Methods	Nilai
Model Pembelajaran	0,25
Diskusi	0,50
Keterlibatan	0,75
Interpersonal	1,00

Critical/Logical Thinking Criteria

Based on the criteria and rating of the requirements needed for decision-making based on Critical/Logical Thinking. Here are the value intervals that have been converted into fuzzy numbers below.

Table 7. Critical/Logical Thinking Criteria

Critical/Logical Thinking	Nilai
Penalaran	0,50
Visual-Spasial	1,00

Reading Habits Criteria

Based on the criteria and rating requirements needed for decision-making based on Reading Habits. Here are the value intervals that have been converted into fuzzy numbers below.

Table 8. Reading Habits Criteria

Reading Habits	Nilai
Expanding Horizons	0,50
Verbal Ability	1,00

Based on the initial data, the alternative intelligence levels of the students above can be formed into decision matrix X, which has been converted into fuzzy numbers, as follows:

Alternative	C1	C2	C3	C4	C5	C6	C7	C8
A1	5	5	5	6.6	5	7.5	5	10
A2	7.5	7.5	5	6.6	2.5	7.5	5	10
A3	10	10	51	6.6	2.5	7.5	5	10
A4	7.5	5	5	6.6	2.5	7.5	10	10
A5	7.5	5	5	6.6	5	7.5	5	10

Decision-making involves assigning weights based on the importance level of each criterion needed as follows:

Vektor bobot: W= [7.5, 5, 5, 6.6, 2.5, 7.5. 10,10]

Before the weight adjustment is made so that ΣW=1, the calculations are as follows:

$$W_1 = \frac{5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{5}{54.1} = 0.14$$
$$W_2 = \frac{5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{5}{54.1} = 0.09$$
$$W_3 = \frac{5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{5}{54.1} = 0.09$$
$$W_4 = \frac{6.6}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{6.6}{54.1} = 0.12$$
$$W_5 = \frac{5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{5}{54.1} = 0.05$$
$$W_6 = \frac{7.5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{7.5}{54.1} = 0.14$$
$$W_7 = \frac{5}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{5}{54.1} = 0.18$$
$$W_8 = \frac{10}{7{,}5+5+5+6.6+2.5+7.5+10+10} = \frac{10}{54.1} = 0.18$$

Then the vector S can be calculated as follows:

$S_1 = (5^{-0.14})(5^{0.09})(5^{0.09})(6.6^{0.12})(5^{0.05})(7.5^{0.14})(5^{0.18})(10^{0.18})$ =3.362548
$S_2 = (7.5^{-0.14})(7.5^{0.09})(5^{0.09})(6.6^{0.12})(2.5^{0.05})(7.5^{0.14})(5^{0.18})(10^{0.18})$ =2.805742
$S_3 = (10^{-0.14})(10^{0.09})(5^{0.09})(6.6^{0.12})(2.5^{0.05})(7.5^{0.14})(5^{0.18})(10^{0.18})$ =3.626375
$S_4 = (5^{-0.14})(5^{0.09})(5^{0.09})(6.6^{0.12})(2.5^{0.05})(7.5^{0.14})(10^{0.18})(10^{0.18})$ =4.25314
$S_5 = (7.5^{-0.14})(5^{0.09})(5^{0.09})(6.6^{0.12})(5^{0.05})(7.5^{0.14})(5^{0.18})(10^{0.18})$ =3.672172

The value of vector V that will be used for ranking can be calculated as follows:

$$V_1 = \frac{3.362548}{3.362548+2.805742+3.626375+4.25314+3.672172} = \frac{3.362548}{17.71998} = 0.18976$$
$$V_2 = \frac{2.805742}{3.362548+2.805742+3.626375+4.25314+3.672172} = \frac{2.805742}{17.71998} = 0.158338$$
$$V_3 = \frac{3.626375}{3.362548+2.805742+3.626375+4.25314+3.672172} = \frac{3.626375}{17.71998} = 0.258145$$
$$V_4 = \frac{4.25314}{3.362548+2.805742+3.626375+4.25314+3.672172} = \frac{4.25314}{17.71998} = 0.240019$$
$$V_5 = \frac{3.672172}{3.362548+2.805742+3.626375+4.25314+3.672172} = \frac{3.672172}{17.71998} = 0.207233$$

Conclusion

The Mamdani Fuzzy Method can be used as an effective approach to assist in the process of determining students' intelligence levels in a more systematic, flexible, and objective manner. This method is capable of processing various subjective assessment criteria into more measurable decisions through the stages of fuzzification, rule formation, inference, and defuzzification. Thus, the system developed not only facilitates teachers or school authorities in conducting assessments but also provides more consistent results compared to conventional evaluations.

Furthermore, the implementation of the Fuzzy Mamdani method shows that decision-making in determining students' intelligence levels can be conducted by adjusting to real conditions in the field through the use of linguistic variables and expert knowledge-based rules. The results of this study affirm that fuzzy logic is highly relevant to be applied in the field of education, particularly to support student evaluations involving multiple indicators. Therefore, this research is expected to serve as a foundation for developing a more accurate, efficient, and beneficial decision support system for schools in identifying students' intelligence potential more precisely.

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