

MAMDANI METHOD-BASED FUZZY INFERENCE SYSTEM FOR DETERMINING THE QUALITY OF QUR'AN MEMORIZATION

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ABSTRACT

Assessing the quality of Al-Qur'an memorization is an important part of tahfidz learning that requires objectivity and consistency. In practice, memorization assessment is often subjective because it depends on the examiner's perception and uses linguistic criteria that do not have clear boundaries. This condition necessitates a systematic approach that can accommodate uncertainty in the assessment process. This study aims to apply the Mamdani Fuzzy Inference System method in determining the quality of Qur'an memorization objectively. The system is designed with three input variables, namely memorization fluency, tajwid accuracy, and fashahah, and one output variable representing memorization quality. The Mamdani method is selected due to its intuitive rule structure, which aligns with human reasoning. The inference process consists of fuzzification, rule formation, implication, aggregation, and defuzzification. The system employs three input variables with three fuzzy sets each, resulting in 27 IF-THEN rules. The min operator is used for implication, the max operator for aggregation, and the centroid method for defuzzification. The proposed system was implemented using MATLAB and validated through simulation-based case scenarios representing various combinations of input values. The results show that the Mamdani Fuzzy Inference System is able to comprehensively integrate the three assessment aspects and produce a more consistent evaluation of memorization quality compared to conventional averaging methods. This consistency is reflected in the stability of output values generated by the system, where similar input patterns produce identical outputs (e.g., 75.00 and 91.33), whereas conventional calculations yield more fluctuating results. Therefore, the developed model can serve as an alternative decision support system in evaluating Al-Qur'an memorization learning.

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INTRODUCTION

Islamic education places the Qur'an as the primary foundation in shaping a holistic human personality. The Qur'an functions not only as a source of normative teachings but also as a

guideline for developing the intellectual, spiritual, and moral dimensions of learners (Manurung et al., 2024; Nurkholifah, 2024). Therefore, intensive interaction with the Qur'an becomes an essential component of Islamic educational practice, particularly through reading and memorizing the Qur'an, which has long been a scholarly tradition within the Muslim community.

In this context, Qur'an memorization is viewed as an educational activity that holds both devotional and pedagogical value. The process of memorizing the Qur'an requires complex cognitive abilities, including concentration, long-term memory, and precise articulation of Arabic pronunciation (Kamridah et al., 2025; Zamzila & Rambe, 2025). This activity is not merely oriented toward textual mastery but also toward internalizing meaning and fostering spiritual discipline. Along with the increasing public awareness of the importance of value-based religious education, tahfidz al-Qur'an programs have grown rapidly across various educational institutions, both formal and non-formal.

This development has led to an increased demand for adequate evaluation systems. The success of tahfidz learning cannot be measured solely by the quantity of memorization but must also be assessed in terms of the quality of memorization achieved by learners. The quality of Qur'anic memorization reflects the extent to which an individual can recite verses fluently, apply tajwid rules correctly, and pronounce hijaiyah letters accurately and eloquently (Fatoni & Subando, 2024; Istikomah et al., 2025; Marpaung et al., 2025). Thus, assessing memorization quality plays a strategic role in ensuring the overall quality of tahfidz learning.

However, the practice of evaluating the quality of Qur'anic memorization in the field still faces various challenges. Assessments are often conducted directly by teachers or examiners based on experience and subjective judgment (Jamzuri, 2024). This condition results in assessment outcomes that tend to vary from one evaluator to another. Moreover, assessment criteria such as "fluent," "adequate," or "poor" are linguistic in nature and lack clear boundaries, making them difficult to quantify objectively. Such uncertainty has the potential to reduce the consistency and accuracy of assessment results.

This situation indicates the need for a more systematic and adaptive assessment approach capable of handling uncertainty. An ideal assessment system should be able to represent human reasoning in evaluating memorization quality while still producing consistent and measurable decisions. In this regard, computational-based decision support systems serve as a relevant alternative to assist the evaluation process of tahfidz al-Qur'an in a more objective manner (Jamaaluddin et al., 2021).

One computational approach suitable for handling perception-based assessments is fuzzy logic (Karnik & Mendel, 2001; Zadeh, 1988). Fuzzy logic is particularly appropriate for managing assessments based on subjective perception, including the evaluation of Qur'anic memorization quality. This approach allows for the representation of gradual values and linguistic terms, making assessments more objective, flexible, and reflective of real-world conditions. Through fuzzy logic, the concept of memorization quality can be represented more realistically according to actual field conditions.

Fuzzy logic is an effective approach for mapping an input space into an output space. Unlike classical logic, which produces crisp decisions with binary values 0 for false conditions and 1 for true conditions fuzzy logic allows degrees of tolerance in decision-making through membership values ranging from 0 to 1 (Sekhi et al., 2025). Moreover, fuzzy logic is developed based on natural language, enabling it to bridge the gap between machine language, which demands high precision, and human language, which emphasizes interpretative meaning (Utama et al., 2020).

The implementation of fuzzy logic in the form of a Fuzzy Inference System (FIS) enables the simultaneous integration of multiple assessment criteria (Peckol, 2021). This system is capable of processing various input variables and producing decisions based on predefined rules. Among the

various fuzzy inference methods, the Mamdani method offers advantages in terms of interpretability and its closeness to human reasoning patterns (Prokopowicz et al., 2017). The IF-THEN rule structure of the Mamdani method allows the expertise of Qur'an Memorization experts to be systematically embedded into the assessment system.

Several previous studies have applied fuzzy logic and Fuzzy Inference Systems (FIS) in educational assessment and decision-making contexts. For example, Jamaaluddin et al. (2021) implemented an Interval Type-1 FIS to analyze Qur'anic memorization quality, demonstrating the potential of fuzzy approaches in handling uncertainty. However, their study primarily focused on system performance without explicitly structuring the integration of core assessment components such as memorization fluency, tajwid accuracy, and fashahah. Similarly, other studies on fuzzy-based decision support systems (Utama et al., 2020) tend to emphasize technical implementation rather than domain-specific modeling of linguistic assessment criteria.

In addition, many existing approaches rely on generalized or domain-independent rule structures, which may not fully capture the multidimensional and nuanced nature of Qur'anic recitation assessment. As a result, the interpretability of the decision-making process in relation to expert judgment remains limited. These gaps indicate the need for a more domain-specific fuzzy inference model that systematically incorporates key recitation variables and aligns closely with the evaluative practices of tahfidz learning.

Based on these considerations, this study focuses on the application of a Mamdani-based Fuzzy Inference System to determine the quality of Qur'anic memorization. While previous studies have applied fuzzy logic in decision-making contexts, most of them are limited to general evaluation systems or do not specifically address the multidimensional aspects of Qur'anic memorization quality (Wildan & Pratowo, 2022; Zahra et al., 2025). In addition, prior works often lack a structured integration of key recitation components such as memorization fluency, tajwid accuracy, and fashahah within a unified inference framework.

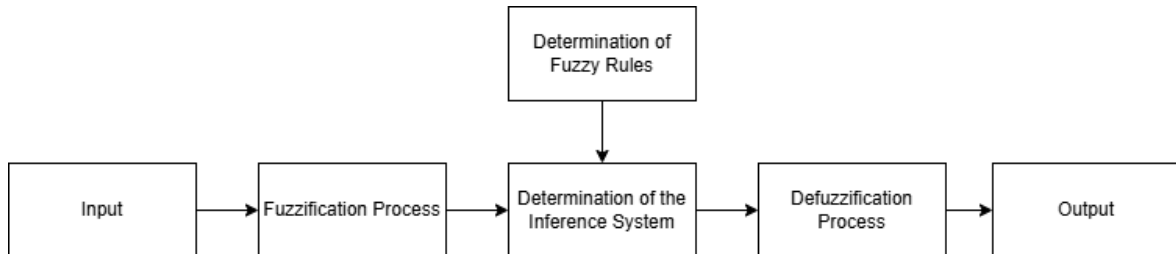
To address this gap, the present study develops a Mamdani-based Fuzzy Inference System that explicitly integrates these three fundamental aspects into a comprehensive rule-based model. The system is designed to transform qualitative assessment criteria into measurable outputs, thereby reducing subjectivity and improving consistency in evaluation. The resulting output, in the form of memorization quality, is expected to provide a more objective and systematic assessment compared to conventional methods.

Thus, the implementation of this model contributes theoretically by extending the application of fuzzy logic within the domain of Islamic education, particularly in tahfidz assessment, and practically by offering a more structured and interpretable decision support system. This approach is anticipated to support continuous quality improvement in tahfidz education with a strong orientation toward excellence.

METHOD

This study employs a quantitative approach in the form of simulation-based applied research. The research focuses on developing a Qur'anic memorization quality assessment system based on a Mamdani-type Fuzzy Inference System (FIS) implemented using MATLAB software. The system development process involves stages of design, implementation, and testing through simulation scenarios to evaluate system performance. Validation is conducted using case-based inputs representing various combinations of memorization fluency, fashahah, and tajwid scores to observe the consistency and behavior of the system output. The system utilizes three main input variables, namely memorization fluency, fashahah, and tajwid, while the output produced is a decision regarding the quality of Qur'anic memorization.

Data analysis is conducted through the application of Mamdani fuzzy logic using the Fuzzy Inference System (FIS) program available in Matlab R2014b software. The data analysis process consists of four main stages, as described below.



First, fuzzification is the process of forming fuzzy sets, in which crisp input values are transformed into fuzzy sets using triangular membership functions. This type of function is chosen because it requires fewer parameters, simplifies computation, and effectively models linear transitions between fuzzy regions. Moreover, triangular functions are suitable for representing subjective linguistic assessments, such as fluency, tajwid accuracy, and fashahah, which do not require highly nonlinear representations. Second, the construction of the rule base, which is formulated in the form of IF-THEN statements to establish relationships between input and output variables. Third, fuzzy inference, which involves the application of the Mamdani method to generate fuzzy outputs from the given inputs using the Max-Min inference mechanism. Fourth, defuzzification is the process of converting fuzzy output sets back into crisp values using the centroid method, enabling the resulting output to be clearly interpreted (Mendel, 2005; Putri, 2021). This study is expected to produce an assessment system that can assist tahfidz teachers in evaluating memorization in a more objective and standardized manner while minimizing subjectivity. The implementation of this system is also expected to contribute to improving the quality of Qur'anic memorization development in educational institutions.

RESULTS

In this study, the assessment of Qur'anic memorization quality employs the Mamdani method. The output of fuzzy rules in this method is obtained using the minimum (min) operator and inferred using the maximum (max) operator, which is why the Mamdani method is often referred to as the Max-Min method (Harliana & Rahim, 2017). The evaluation of Qur'anic memorization quality using the Mamdani method follows the Max-Min principle, where the minimum value is determined at the implication stage and the maximum value is selected at the aggregation stage. Input variables such as memorization fluency, *fashahah*, and *tajwid* are processed simultaneously to generate a comprehensive and realistic output representing memorization quality.

This article discusses how the determination of Qur'anic memorization quality can be implemented using fuzzy logic with the assistance of a Fuzzy Inference System (FIS) in Matlab software. The first step involves defining the desired input and output variables. In this study, three input variables are used memorization fluency, *fashahah*, and *tajwid* while the output variable represents memorization quality.

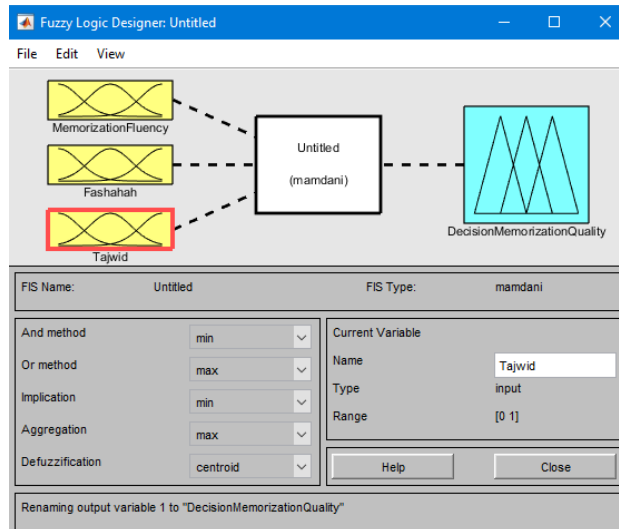


Figure 1. Determining Input and Output Variables

The memorization fluency variable is divided into three fuzzy sets: NOT FLUENT, MODERATE, and FLUENT. The NOT FLUENT and FLUENT sets employ shoulder-shaped membership functions, while the MODERATE set uses a triangular membership function.

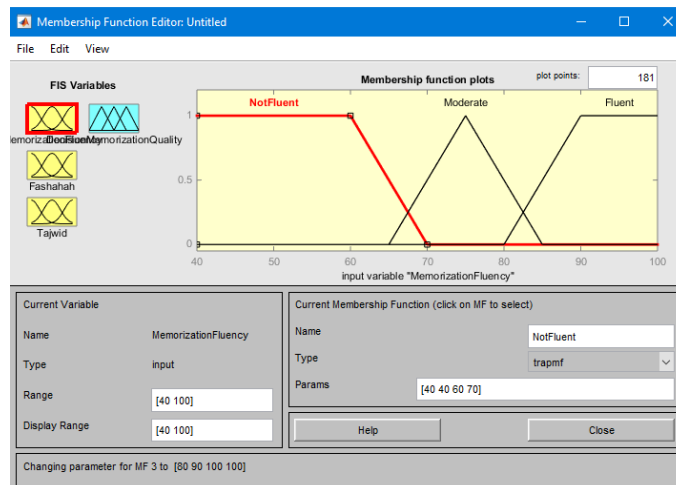


Figure 2. Memorization Fluency Variable Graph

To clarify the memorization fluency graph above, it can be seen in Table 1 below.

Table 1. Description of the Memorization Fluency Variable

Universe of Discouse	Fuzzy Set Name	Domain
[50,100]	Not Fluent	[50,70]
	Moderate	[65,85]
	Fluent	[80,100]

Based on Figure 2 and Table 1, the domains of each fuzzy set are defined as follows. The NOT FLUENT set has a domain of [50, 70], indicating that memorization fluency below 70 is categorized as not fluent, with membership values decreasing as they approach the upper boundary. The MODERATE set has a domain of [65, 85], where memorization fluency within this range is classified as moderate. The FLUENT set has a domain of [80, 100], indicating that memorization fluency values

above 80 are categorized as fluent, with full membership values that decrease as they approach the lower boundary.

For the *fashahah* variable, it is divided into three fuzzy sets: LOW, MODERATE, and HIGH. The LOW and HIGH sets employ shoulder-shaped membership functions, while the MODERATE set uses a triangular membership function.

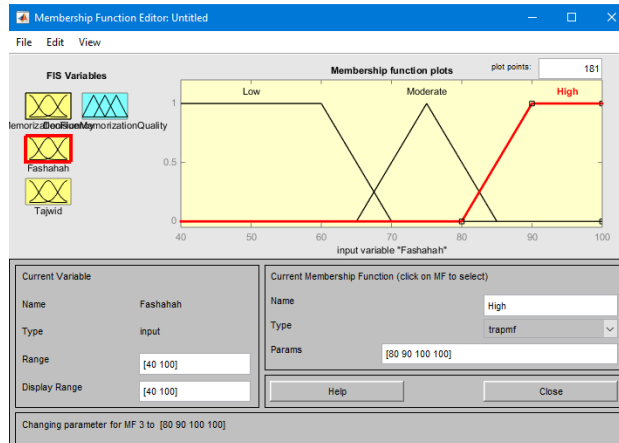


Figure 3. Fashahah Variable Graph

To further clarify the graph above, the details are presented in Table 2 below.

Table 2. Description of the Fashahah Variable

Universe of Discourse	Fuzzy Set Name	Domain
[50,100]	Low	[50,70]
	Moderate	[65,85]
	High	[80,100]

Based on Figure 3 and Table 2, the domains of each fuzzy set are defined as follows. The LOW set has a domain of [50, 70], indicating that *fashahah* values below 70 are categorized as low, with membership values decreasing as they approach the upper boundary. The MODERATE set has a domain of [65, 85], where *fashahah* values within this range are classified as moderate. The HIGH set has a domain of [80, 100], indicating that *fashahah* values above 80 are categorized as high, with full membership values that decrease as they approach the lower boundary.

For the *tajwid* variable, it is divided into three fuzzy sets: POOR, FAIR, and GOOD. The POOR and GOOD sets employ shoulder-shaped membership functions, while the FAIR set uses a triangular membership function.

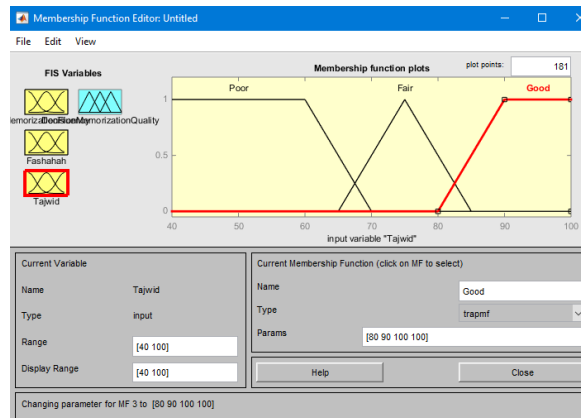


Figure 4. Tajwid Variable Graph

To further clarify the graph above, the details are presented in Table 3 below.

Table 3. Description of the Tajwid Variable

Universe of Discourse	Fuzzy Set Name	Domain
[50,100]	Poor	[50,70]
	Fair	[65,85]
	Good	[80,100]

Based on Figure 4 and Table 3, the domains of each fuzzy set are defined as follows. The POOR set has a domain of [50, 70], indicating that *tajwid* values below 70 are categorized as poor, with membership values decreasing as they approach the upper boundary. The FAIR set has a domain of [65, 85], where *tajwid* values within this range are classified as fair. The GOOD set has a domain of [80, 100], indicating that *tajwid* values above 80 are categorized as good, with full membership values that decrease as they approach the lower boundary. Using this approach, each fuzzy set related to memorization fluency can simultaneously belong to more than one category, depending on its degree of membership.

Meanwhile, the output variable represents the decision on Qur'anic memorization quality, which consists of three fuzzy sets: RE-MEMORIZE, REPEAT, and PROCEED. The RE-MEMORIZE and PROCEED sets employ shoulder-shaped membership functions, while the REPEAT set uses a triangular membership function.

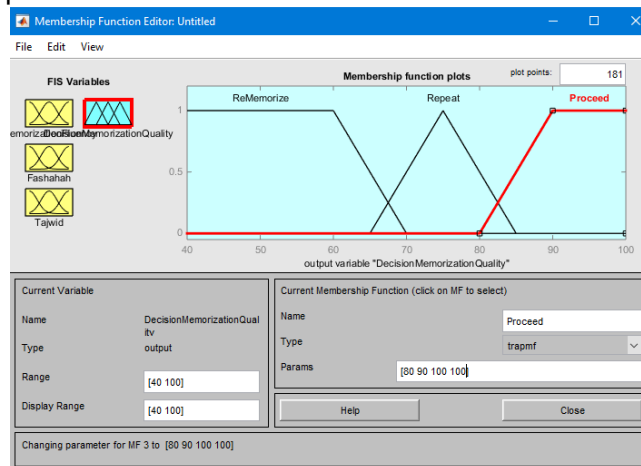


Figure 5. Output Graph of Memorization Quality Decision

To further clarify the graph above, the details are presented in Table 4 below.

Table 4. Description of the Output Variable

Universe of Discourse	Fuzzy Set Name	Domain
[50,100]	Re-Memorize	[50,70]
	Repeat	[65,85]
	Proceed	[80,100]

Based on Figure 5 and Table 4, the universe of discourse and the value boundaries for each fuzzy set in determining memorization quality are illustrated. The universe of discourse uses a range of [50, 100], which is divided into three decision categories: "Re-Memorize" (values 50-70), "Repeat" (values 65-85), and "Proceed" (values 80-100). These categories represent considerations in determining memorization quality decisions, where the values within each range

indicate the strength of the decision to re-memorize, repeat memorization, or proceed to the next memorization stage.

The next step involves entering the rule data, as presented in the following table.

Table 5. Decision Rules for Determining Memorization Quality

No.	Memorization Fluency	Fashohah	Tajwid	Decision
1.	Not Fluent	Low	Poor	Re-Memorize
2.	Not Fluent	Low	Fair	Re-Memorize
3.	Not Fluent	Low	Good	Re-Memorize
4.	Not Fluent	Moderate	Poor	Re-Memorize
5.	Not Fluent	Moderate	Fair	Re-Memorize
6.	Not Fluent	Moderate	Good	Repeat
7.	Not Fluent	High	Poor	Re-Memorize
8.	Not Fluent	High	Fair	Repeat
9.	Not Fluent	High	Good	Repeat
10.	Moderate	Low	Poor	Re-Memorize
11.	Moderate	Low	Fair	Repeat
12.	Moderate	Low	Good	Repeat
13.	Moderate	Moderate	Poor	Repeat
14.	Moderate	Moderate	Fair	Repeat
15.	Moderate	Moderate	Good	Proceed
16.	Moderate	High	Poor	Repeat
17.	Moderate	High	Fair	Proceed
18.	Moderate	High	Good	Proceed
19.	Fluent	Low	Poor	Repeat
20.	Fluent	Low	Fair	Repeat
21.	Fluent	Low	Good	Proceed
22.	Fluent	Moderate	Poor	Repeat
23.	Fluent	Moderate	Fair	Proceed
24.	Fluent	Moderate	Good	Proceed
25.	Fluent	High	Poor	Repeat
26.	Fluent	High	Fair	Proceed
27.	Fluent	High	Good	Proceed

DISCUSSION

The results of the calculation analysis performed using MATLAB can be seen in Table 6. The table presents the scores of the Memorization Fluency, Fashahah, and Tajwid variables that were entered into the system, which then produces output values representing decisions on memorization quality.

Table 6. Results of Matlab calculations for research analysis

Case	Memorization Fluency	Fashohah	Tajwid	Result	Decision
1.	50	75	85	75.00	Repeat
2.	55	75	85	75.00	Repeat
3.	60	75	85	75.00	Repeat
4.	65	75	85	75.00	Repeat
5.	70	75	85	91.33	Proceed
6.	75	75	85	91.33	Proceed
7.	80	75	85	91.33	Proceed
8.	85	75	85	91.33	Proceed
9.	90	75	85	91.33	Proceed
10.	95	75	85	91.33	Proceed
11.	100	75	85	91.33	Proceed

Table 6 shows that, although the input values vary, the resulting outputs tend to stabilize at specific values, namely 75.00 and 91.33. This phenomenon is consistent with the theoretical characteristics of the Mamdani Fuzzy Inference System, particularly the effects of overlapping membership functions, rule base structure, and centroid-based defuzzification. According to fuzzy logic theory (Karnik & Mendel, 2001; Zadeh, 1988), overlapping membership functions allow multiple rules to be activated simultaneously with varying degrees of membership, leading to smooth and gradual transitions in the output space.

In this study, such overlap causes different input combinations to activate similar sets of rules with comparable firing strengths. The use of the min operator in the implication stage and the max operator in aggregation further emphasizes dominant rules, resulting in aggregated fuzzy regions with similar shapes across nearby input scenarios. As explained in previous studies (Utama et al., 2020), this mechanism contributes to the stability and robustness of fuzzy systems in handling uncertain and linguistic data.

Furthermore, the centroid defuzzification method calculates the center of gravity of the aggregated fuzzy set, which tends to produce stable crisp outputs when the aggregated membership functions are similar. This explains why the system frequently generates identical output values (e.g., 75.00 and 91.33) despite variations in input values. Similar findings have been reported in fuzzy-based decision systems, where output clustering occurs due to dominant rule regions (Harliana & Rahim, 2017).

In contrast, conventional averaging methods directly reflect numerical differences in input values, resulting in more fluctuating outputs. Therefore, the stability observed in the Mamdani FIS indicates its ability to generalize decision patterns and reduce sensitivity to minor input variations, which contributes to more consistent and robust evaluation results. This result is different if the final score is calculated by summing all the inputs and then dividing by three, as shown in Table 7 below.

Table 7. Output values using ordinary calculations

Case	Memorization Fluency	Fashohah	Tajwid	Result	Decision
1.	50	75	85	70.00	Repeat
2.	55	75	85	71.67	Repeat
3.	60	75	85	73.33	Repeat
4.	65	75	85	75.00	Repeat
5.	70	75	85	76.67	Repeat
6.	75	75	85	78.33	Repeat
7.	80	75	85	80.00	Repeat
8.	85	75	85	81.67	Repeat
9.	90	75	85	83.33	Repeat
10.	95	75	85	85.00	Proceed
11.	100	75	85	86.67	Proceed

Table 7 shows variations in the input values, while the MATLAB-based Fuzzy Inference System (FIS) produces outputs that tend to remain constant at certain points. This behavior is primarily influenced by the structure of the rule base, the overlap of membership functions, and the defuzzification mechanism. From an analytical perspective, inputs that fall within overlapping regions of the fuzzy sets (e.g., Moderate fluency, High fashahah, and Fair tajwid) activate multiple rules with comparable firing strengths. Due to the use of the min operator in implication and the max operator in aggregation, a subset of dominant rules consistently shapes the aggregated output. When these activated rules correspond to the same output category (e.g., "Repeat"), the resulting aggregated membership function has a similar shape across nearby input variations, leading to stable centroid values (e.g., 75.00).

A sensitivity analysis can be observed through the following case: for input values of memorization fluency = 72, fashahah = 85, and tajwid = 65, the system produces an output of 75, which falls into the “Repeat” category. If the memorization fluency is slightly varied within the overlapping region (e.g., between 65 and 75), while the other variables remain constant, the activated rules and their firing strengths do not change significantly. As a result, the aggregated fuzzy region remains nearly identical, and the defuzzified output stays around 75. However, when the input crosses a critical threshold (e.g., fluency ≥ 80 , entering the “Fluent” region with stronger membership), the rule activation pattern changes more substantially, shifting the dominant rules toward the “Proceed” category. This transition results in a noticeable jump in the output value (e.g., from 75.00 to 91.33).

These findings indicate that the Mamdani FIS exhibits low sensitivity within overlapping regions (robust to small input variations) and higher sensitivity near decision boundaries, where changes in membership dominance alter the rule activation pattern. This characteristic enhances the stability and consistency of the system while still allowing meaningful differentiation when significant input changes occur. For more details, the MATLAB program can be seen in Figure 6 below.

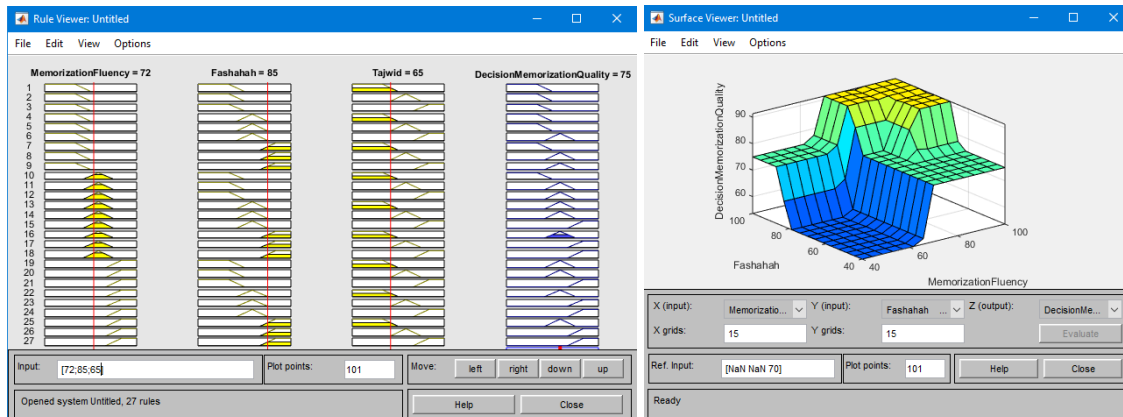


Figure 6. Rules and Surface of Qur'anic Memorization Quality Decision

CONCLUSION

This study demonstrates that a Mamdani-based Fuzzy Inference System (FIS) can effectively evaluate Qur'anic memorization quality by integrating memorization fluency, fashahah, and tajwid into a single rule-based framework, producing stable and consistent outputs with defuzzified values clustering at 75.00 (“Repeat”) and 91.33 (“Proceed”) despite variations in input values. This stability indicates robustness to minor input changes and clearer decision boundaries compared to conventional averaging methods, which yield more fluctuating results. However, the model is limited by the use of only three input variables, simulation-based validation in MATLAB R2014b, and the absence of empirical testing with real student data or multi-expert validation of the rule base. Therefore, future research should expand the input variables (e.g., retention consistency and error frequency), validate the model using real-world datasets from schools or pesantren, and compare or integrate the approach with other methods such as Sugeno FIS or machine learning to improve accuracy and generalizability.

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authors of this article and take full responsibility for its content in accordance with COPE recommendations.

INFORMED CONSENT

The authors have obtained informed consent from all participants involved in this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding this research.

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