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Elementary School Accreditation Assessment Using Fuzzy Tsukamoto and SMARTER Method

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Abstract.
Purpose: The primary objective of this study is to develop and validate an Elementary School Accreditation Evaluation Model that is both measurable and fair. The proposed model integrates the Fuzzy Tsukamoto method to calculate and consistently generate the final score of each alternative, and the SMARTER method to produce a prioritized ranking that serves as a practical guide for schools in their efforts to improve and strengthen quality.
Methods: This study integrates the Fuzzy Tsukamoto method to process numerical data through a rule-based inference mechanism. Simultaneously, the SMARTER method is employed to systematically assign weights to each criterion and sub-criterion using the Rank Order Centroid (ROC) approach. The evaluation is carried out on 16 alternatives based on four main criteria. The research data are derived from the IASP 2020 instrument issued by BAN-S/M, which serves as the official accreditation standard for schools and madrasahs in Indonesia.
Result: The developed structured assessment model proved effective. Through ROC weighting, Criterion K1 was identified as the main determining factor (0.611). System validation using Fuzzy Logic showed a high level of consistency (87.5% agreement) with the manual assessor's decisions, confirming the model's accuracy in replicating assessments based on data triangulation. The SMARTER ranking provides targeted recommendations, placing Alternatives A13, A2, A7, and A8 as standards to be maintained, while pointing to A3 as the priority for immediate improvement.
Novelty: This study offers a novel approach by integrating the Fuzzy Tsukamoto and SMARTER methods within the context of primary school accreditation a combination that has been rarely explored in previous research. The proposed model not only generates evaluation scores but also produces a ranking system that can serve as a reference for school evaluation.

Keywords: Fuzzy Tsukamoto, SMARTER, ROC, Accreditation assessment
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INTRODUCTION

Primary school accreditation is a crucial evaluation process to ensure that the quality of education aligns with nationally established standards [1], [2]. However, the assessment process often encounters challenges in maintaining objectivity, as many indicators are based on numerical values that remain open to varying interpretations by assessors. This condition frequently leads to inconsistencies in scoring and discrepancies in final outcomes.

To address these challenges [3], [4], [5], various approaches have been developed, one of which is fuzzy logic—particularly the Tsukamoto method—designed to handle uncertain and ambiguous data [6], [7]. Previous studies have demonstrated that this method can produce highly accurate diagnoses of livestock diseases through a rule-based inference system and structured numerical outputs [8]. In another case, the Tsukamoto fuzzy method has also been successfully applied in rainfall prediction, proving its effectiveness in processing linguistic data and managing uncertainty in information [9].

Meanwhile, alternative approaches such as the Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER) method have been applied to minimize subjectivity in the weighting process of evaluation criteria [10], [11] This approach has proven effective as a foundation for developing evaluative reports that support ongoing improvement efforts. The SMARTER method assigns weights to each criterion proportionally based on its level of priority [12], [13]. In one study, this method was

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implemented to identify dengue-endemic regions, demonstrating that SMARTER can simplify multi-criteria decision-making without compromising result accuracy, while maintaining fairness and consistency in the weighting process [14]. Other research has shown that SMARTER is a suitable approach for ranking low-income households. The method effectively simplifies the evaluation of multiple criteria such as housing conditions and asset ownership while ensuring consistent and fair weight distribution [15].

These two approaches have predominantly been used separately in previous studies. There is still limited research that integrates fuzzy methods with SMARTER in the context of educational assessment, particularly in primary school accreditation. Moreover, existing accreditation reports tend to be descriptive in nature and have yet to fully support objective ranking systems that can be utilized as a basis for continuous school evaluation.

This study proposes the development of an accreditation assessment model based on the integration of the Fuzzy Tsukamoto method and the SMARTER approach. This framework is designed to transform numerical evaluation data into more flexible assessments, while simultaneously generating evaluative reports and rankings. Accordingly, the model is expected to assist assessors in producing more objective judgments and serve as a foundation for continuous school quality improvement.

METHODS

This study integrates the Fuzzy Tsukamoto method with the SMARTER approach to develop an objective assessment system. The process begins with the collection of data consisting of document review scores, interview scores, and observation scores. These data are then processed using the Fuzzy Tsukamoto method to generate scores for each alternative. Subsequently, the alternative scores obtained are combined with the document review, interview, and observation data through the SMARTER method, which assigns proportional weights to each criterion based on its level of importance to produce a final ranking of values, as illustrated in the flowchart in Figure 1.

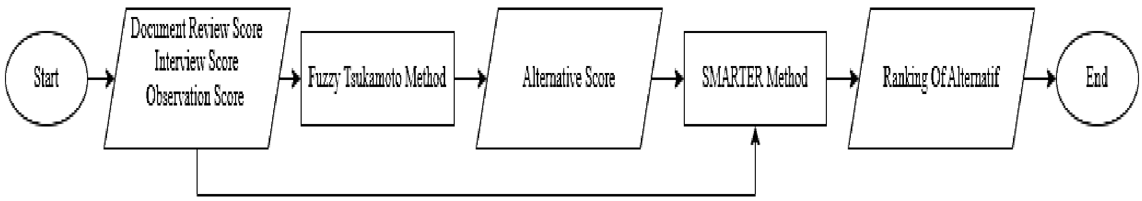

Figure 1. Flowchart of Data Processing Steps

A. Fuzzy Tsukamoto

The Fuzzy Tsukamoto method is an approach used to handle uncertain data through monotonic IF–THEN rules, producing outputs in the form of numerical values [16], [17]. The process involves integrated stages of fuzzification, inference, and defuzzification, which work together to generate more measurable and logical decisions [9], [17].

- Document Review

At the data collection stage, one of the criteria evaluated is the document review. This process involves examining various school documents to assess several aspects of performance. Table 1 presents the fuzzy set domains for the Document Review variable, which are divided into several categories with specific value ranges. Figure 2 illustrates the corresponding membership functions for each category, mapping score values to their degrees of membership to enable a more proportional and objective assessment.

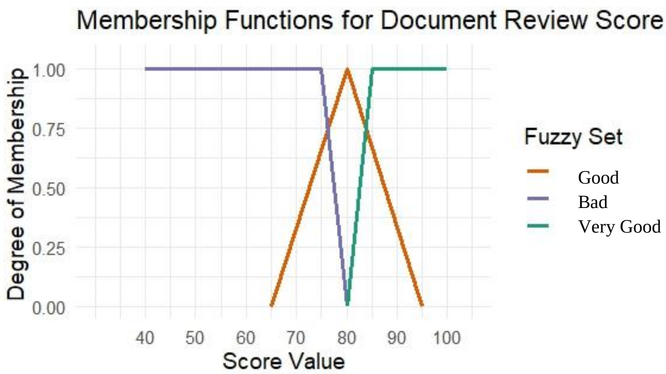

Figure 2. Membership Function for Document Review

Table 1. Fuzzy Set Domains for Document Review

Fuzzy Set	Value Interval
Very Good	[85,100]
Good	[70,90]
Bad	[40,75]

$$\mu_{Sangat\ Baik}[x]\begin{cases} 0, & x \leq 85 \\ \frac{x-85}{90-85}, & 85 < x < 90 \\ 1, & 90 \leq x \leq 100 \end{cases} \quad [1]$$

$$\mu_{Baik}[x]\begin{cases} 0, & x \leq 70 \\ \frac{x-70}{80-70}, & 70 < x < 80 \\ 1, & x = 80 \\ \frac{90-x}{90-80}, & 80 < x < 90 \\ 0, & x \geq 90 \end{cases} \quad [18], [19]$$

$$\mu_{Buruk}[x]\begin{cases} 1, & x \leq 70 \\ \frac{75-x}{75-70}, & 70 < x < 75 \\ 0, & x \geq 75 \end{cases} \quad [3]$$

- Interview

At the data collection stage, interviews are employed to capture stakeholders' perspectives on various aspects of school performance. Table 2 presents the fuzzy set domains for the Interview variable within specific value ranges. Figure 3 illustrates the fuzzy membership functions for each category, where interview scores are mapped into degrees of membership to support a more objective evaluation.

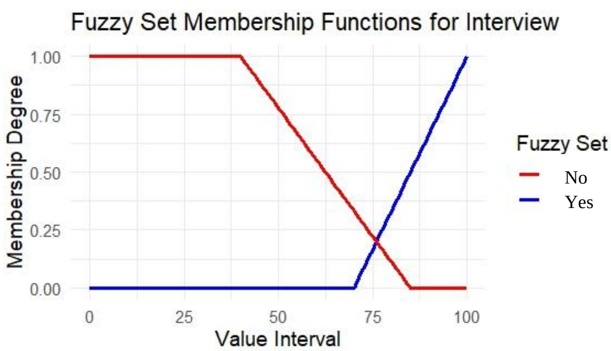

Figure 3. Membership Function of the Interview Variable

Table 2. Fuzzy Set Domains for Interview

Fuzzy Set	Value Interval
Yes	[70, 100]
No	[40, 85]

$$\mu_{Ya}[x]\begin{cases} 0, \ x \le 70 \\ \frac{x-70}{85-70}, \ 70 < x < 85 \\ 1, \ 85 \le x \le 100 \end{cases} \quad [20] [8]$$

$$\mu_{Tidak}[x]\begin{cases} 1, \ 40 < x \le 70 \\ \frac{75-x}{75-70}, \ 70 < x < 85 \\ 0, \ x \ge 85 \end{cases} \quad [21]$$

- Observation

During the data collection stage, observation is conducted directly at the school to assess student behavior, learning processes, and facility conditions. Table 3 presents the fuzzy set domains for the Observation variable, which are divided into three categories with specific value intervals. Meanwhile, Figure 4 illustrates the fuzzy membership functions for each category, where observation scores are mapped into degrees of membership to produce a more objective evaluation.

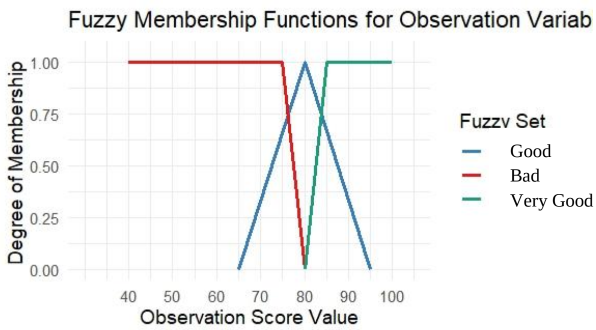

Figure 4. Membership Function of the Observation

Table 3. Fuzzy Membership Domains for the Observation Variable

Fuzzy Set	Value Interval
Very Good	[85, 100]
Good	[70, 90]
Bad	[40, 75]

$$\mu_{Sangat\ Baik}[x]\begin{cases} 0, & x \le 85 \\ \frac{x-85}{90-85}, & 85 < x < 9 \\ 1, & 90 \le x \le 100 \end{cases} \quad [6] [8]$$

$$\mu_{Baik}[x]\begin{cases} 0, \ x \le 70 \\ \frac{x-70}{80-70}, \ 70 < x < 80 \\ 1, \ x = 80 \\ \frac{90-x}{90-80}, \ 80 < x < 90 \\ 0, \ x \ge 90 \end{cases} \quad [22]$$

$$\mu_{Buruk}[x]\begin{cases} 1, \ x \le 70 \\ \frac{75-x}{75-70}, \ 70 < x < 75 \\ 0, \ x \ge 75 \end{cases} \quad [8]$$

- Output

The final results are determined through membership functions within a value range of 0 to 100. As shown in Table 4, achievement levels are classified into Buruk, Cukup, Baik, and Sangat Baik, each representing a score from 1 to 4.

Table 4. Output Fuzzy

Fuzzy Set	Interval Value	Class Rate
Very Good	91 - 100	4
Good	81 - 90	3
Fairly Good	71 - 80	2
Bad	61- 70	1

- Inference

Inference is a decision-making process based on fuzzy IF–THEN rules, in which the Tsukamoto method calculates the output as a weighted average of each rule's result, according to the degree of input matching [7], [23]. Table 5 presents the set of rules used in the fuzzy process to generate the final assessment decision.

Table 5. Fuzzy Inference Rules

No	Document Review	Interview	Observation	Output
R1	Very Good	Yes	Very Good	Very Good
R2	Very Good	Yes	Good	Good
R3	Very Good	No	Very Good	Good
R4	Good	Yes	Very Good	Good
R5	Good	Yes	Good	Good
R6	Very Good	No	Good	Fairly Good
R7	Very Good	Yes	Bad	Good
R8	Very Good	No	Bad	Fairly Good
R9	Good	Yes	Bad	Fairly Good
R10	Good	No	Very Good	Fairly Good
R11	Good	No	Good	Fairly Good
R12	Bad	Yes	Very Good	Good
R13	Good	No	Bad	Fairly Good
R14	Bad	Yes	Good	Fairly Good
R15	Bad	Yes	Bad	Fairly Good
R16	Bad	No	Very Good	Fairly Good
R17	Bad	No	Good	Fairly Good
R18	Bad	No	Bad	Fairly Good

- Defuzzification

Defuzzification is the final stage aimed at converting fuzzy outputs into a crisp value Z [24]. As described in Equation (9), a_p represents the firing strength or alpha predicate of the rule, i denotes the number of fuzzy rules used, and z_i is the crisp value of each rule obtained using the Center Average Defuzzification method. The final result, Z is the overall weighted average of these values.

$$Z = \frac{\sum a\_p_i . z_i}{\sum a\_p_i} \quad (9)$$

B. Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER)

SMARTER is a multi-criteria decision-making method designed to simplify the process of criteria weighting [15]. This method employs the ROC approach, which assigns weights based on the priority ranking or relative importance of each criterion [21], [25].

- Rank Order Centroid (ROC)

The weight of each criterion (W_k) is determined based on its order of importance, starting from the highest-priority criterion to the least important. Here, W_k represents the weight of the k -th criterion, k is the total number of criteria, and i denotes the ranking position of the criterion (with 1 being the highest rank) [14]. The weight calculation is formulated as follows (10):

$$W_k = \frac{1}{k} \sum_{i=1}^{k} \left(\frac{1}{i}\right)$$ [10], [26], [27]

To calculate the final weight component in Equation (11):

$$U_s = \sum_{k=1}^{K} W_k \times U_s(X_{ks}) \quad [27], [28], [29]$$

In this case, U_s represents the final score obtained, W_k denotes the weight of the k-th criterion, and $U_s(X_{ks})$ refers to the utility value of the k -th criterion for the s -th alternative [30].

Table 6. Assessment Sub-Criteria

Criteria	Code Criteria	Sub- Criteria	Code Sub-Criteria	Weight Criteria
Defuzzification	K1	91-100	S1	0.521
		81-90	S2	0.271
		71-80	S3	0.146
		60-70	S4	0.063
Interview	K2	91-100	S5	0.521
		81-90	S6	0.271
		71-80	S7	0.146
		0-70	S8	0.063
Observation	K3	91-100	S9	0.521
		81-90	S10	0.271
		71-80	S11	0.146
		0-70	S12	0.063
Document Review	K4	91-100	S13	0.521
		81-90	S14	0.271
		71-80	S15	0.146
		0-70	S16	0.063

Table 7. Criteria Weights Based on the ROC Method

Criteria	Ranking	Weight Criteria
K1	1	0.611
K2 and K3	2	0.278
K4	3	0.111

Table 6 describes the assessment sub-criteria, which are divided into several score ranges with corresponding weights. In this system, higher scores are assigned greater weights, reflecting an emphasis on prioritizing higher quality. Table 7 then presents the weighting results among the main criteria based on the ROC method. The results show varying levels of importance, with one criterion established as the primary priority, two criteria sharing equal importance, and one serving as a supporting factor.

Table 8. Code Data Alternative

Alternative	**Description**
A1	Students demonstrate disciplined behaviour in various situations.
A2	Students demonstrate religious behaviour in activities at school/madrasah.
A3	Students demonstrate communication skills in line with 21st-century skills.
A4	Students demonstrate collaborative skills in line with 21st-century skills.
A5	Students demonstrate critical thinking and problem-solving skills in line with 21st-century characteristics.
A6	Students demonstrate creativity and innovation skills in line with the characteristics of 21st century skills.
A7	The learning process takes place actively by involving all students and developing higher-order thinking skills so that effective learning occurs in accordance with the learning objectives of the educational unit.
A8	Assessment of the learning process and outcomes is used as a basis for improvement and is carried out systematically.
A9	Teachers practise reading and writing literacy.
A10	The facilities and infrastructure available at schools/madrasahs are utilised optimally in the learning process.
A11	Teachers develop creative and innovative learning strategies, models, methods, techniques, and media.
A12	Schools/madrasahs develop, disseminate, implement, and evaluate the vision, mission, and objectives of the school/madrasah.
A13	Schools/madrasahs establish communication and interaction between school/madrasah members (students, teachers, principals/madrasah heads, educational staff), parents, and the community to achieve internal and external harmony within the school/madrasah.
A14	Schools/madrasahs instil habits of safety, orderliness, cleanliness and comfort to create a conducive school/madrasah environment.
A15	Schools/madrasahs manage facilities and infrastructure well to support quality learning processes.
A16	Schools/madrasahs provide student guidance and counselling services in personal, social, academic, further education and career matters to support achievement and development.

Table 8 presents the alternative data codes, consisting of 16 alternatives in total. These alternatives represent the different assessment units that will later be processed in the evaluation system to generate the final ranking results.

RESULT AND DISCUSSION

Table 9 presents the final weight calculation results for each criterion and sub-criterion. The final weights are obtained by multiplying the weight of each main criterion with the weight of its corresponding sub-criteria. The weighting process at both levels is carried out using the ROC method.

Table 9. Final Weight Calculation Results

Criteria	Weight Criteria	Code Sub-Criteria	Weight Sub-Criteria	Final Weight
K1	0.611	S1	0.521	0.318
		S2	0.271	0.166
		S3	0.146	0.089
		S4	0.063	0.038
K2	0.278	S5	0.521	0.145
		S6	0.271	0.075
		S7	0.146	0.041
		S8	0.063	0.018
K3		S9	0.521	0.145
		S10	0.271	0.075
		S11	0.146	0.041
		S12	0.063	0.018
K4	0.111	S13	0.521	0.058
		S14	0.271	0.030
		S15	0.146	0.016
		S16	0.063	0.007

Table 10. Alternative Assessment Results by Manual Assessor and Fuzzy System

Alternative	Score				Assessor	Fuzzy
	K1	K2	K3	K4		
A1	83	87	87	80	3	3
A2	100	100	100	90	4	4
A3	80	60	60	90	2	2
A4	90	87	100	67	3	3
A5	90	100	80	80	3	3
A6	88	100	90	87	3	3
A7	100	100	100	90	4	4
A8	100	100	100	90	4	4
A9	100	100	93	90	3	4
A10	100	100	90	100	4	4
A11	90	93	80	100	3	3
A12	86	87	80	84	3	3
A13	100	100	100	100	4	4
A14	90	92	80	100	3	3
A15	92	80	100	100	3	4
A16	85	100	85	95	3	3

Table 10 presents a comparison between the final decisions made manually by the assessor and the results calculated by the Fuzzy Logic system. Both approaches rely on the same three sources of input values interview scores (K2), observation scores (K3), and document review scores (K4) which together represent the total manual evaluation. In practice, the assessor determines the final decision by applying a triangulation of these three sources. In the table, the “Assessor” column shows the final outcome provided by the human evaluator, while the “Fuzzy” column displays the result computed by the system, with K1 representing the defuzzification value. Out of the 16 alternatives compared, the two methods show a high level of consistency at 87.5%, with only two cases differing in the final outcome. These findings demonstrate that the Fuzzy system is capable of replicating the assessor’s decision-making process with a high degree of accuracy.

Table 11. Final Ranking Results of Alternatives Using the SMARTER Method

Ranking	Alternative	Utility				Total K2-K4	Total Utility	Category
		K1	K2	K3	K4			
1	A13	0.318	0.145	0.145	0.058	300	0.666	Very Good
2	A2	0.318	0.145	0.145	0.03	290	0.638	Very Good
3	A7	0.318	0.145	0.145	0.03	290	0.638	Very Good
4	A8	0.318	0.145	0.145	0.03	290	0.638	Very Good
5	A9	0.318	0.145	0.145	0.03	283	0.638	Very Good
6	A10	0.318	0.145	0.075	0.058	290	0.596	Very Good
7	A15	0.318	0.041	0.145	0.058	280	0.562	Very Good
8	A16	0.166	0.145	0.075	0.058	280	0.444	Good
9	A6	0.166	0.145	0.075	0.03	277	0.416	Good
10	A11	0.166	0.145	0.041	0.058	273	0.409	Good
11	A14	0.166	0.145	0.041	0.058	272	0.409	Good
12	A4	0.166	0.075	0.145	0.007	253	0.393	Good
13	A5	0.166	0.145	0.041	0.016	260	0.367	Good
14	A1	0.166	0.075	0.075	0.016	253	0.332	Good
15	A12	0.166	0.075	0.041	0.03	251	0.312	Good
16	A3	0.089	0.018	0.018	0.03	210	0.154	Fairly Good

Table 11 presents the final ranking of 16 alternatives generated using the SMARTER method. The primary objective of this ranking is to provide clear recommendations to schools regarding which performance areas need improvement and which should be maintained. The ranking is derived from the Total Utility calculation based on the utility scores of four criteria (K1–K4). The "Total K2–K4" column summarizes the aggregated input scores obtained from criteria K2 to K4. The results show that A13, A2, A7, and A8 occupy the top positions, indicating that their performance in high-weighted criteria (particularly K1) should be prioritized for maintenance. Conversely, A3 is ranked at the bottom, suggesting that the areas evaluated in this alternative require immediate improvement. Thus, the SMARTER-based ranking serves as a roadmap for evaluation, guiding structured efforts in quality enhancement and performance strengthening.

CONCLUSION

This study develops a structured assessment model that integrates the Fuzzy Tsukamoto decision-making technique with the SMARTER method, aiming to provide schools with clear recommendations for quality improvement as well as a final evaluation of each alternative. During the validation stage, the Fuzzy Logic System proved effective in replicating manual assessor decisions, which were based on data triangulation, achieving a high similarity level of 87.5%. This percentage indicates that the automated model is capable of capturing the decision-making patterns of assessors with strong accuracy. Furthermore, the SMARTER-based ranking produced a focused priority list, where Alternatives A13, A2, A7, and A8 occupied the top positions and were identified as performance standards to be maintained, while A3 was identified as an area requiring immediate attention and improvement. Thus, the proposed model functions as a structured strategic guide to direct school quality enhancement efforts in an efficient and objective manner.

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