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Jurnal E-Komtek
Vol. 10, No. 1. (2026) pp. 291-304
https://jurnal.politeknik-kebumen.ac.id/index.php/E-KOMTEK
p-ISSN : 2580-3719 e-ISSN : 2622-3066

Integration of Sugeno Fuzzy & Tsukamoto Fuzzy for Readiness in Implementing Document-Based Banking Application QA Checklist

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https://doi.org/10.37339/e-komtek.v10i1.2946

Published by Politeknik Piksi Ganesha Indonesia

Artikel Info
Submitted:
29-12-2025
Revised:
20-06-2026
Accepted:
27-06-2026
Online first :
31-06-2026

Abstract

This study proposes a decision support expert system to evaluate production deployment readiness by integrating the Fuzzy Tsukamoto and Fuzzy Sugeno methods with a Quality Assurance (QA) checklist. The system addresses frequent production release failures caused by inconsistent testing procedures and reliance on QA personnel's subjective experience. Five assessment variables are considered: error handling, multi-platform testing, performance testing, defect handling, and User Acceptance Testing (UAT) results. Input variables are fuzzified into three linguistic categories (LOW, MEDIUM, and HIGH) using trapezoidal membership functions. The Tsukamoto method employs monotonic membership functions for inference, while the Sugeno method utilizes constant or linear output functions. An internal dataset consisting of 500 records (185 ready, 220 partially ready, and 95 not ready) was used for evaluation. Numerical mapping of fuzzy categories [0.30, 0.60, 0.90] with a weighting factor (λ) of 0.70 achieved an accuracy of 83.8%. The proposed system provides consistent deployment recommendations and conservative safeguards before production release.

Keywords*:* Logika Fuzzy, Quality Assurance, Deployement Perbankan, Readiness Deployment.

Abstrak

Penelitian ini mengusulkan sistem pakar pendukung keputusan untuk menentukan kesiapan deployment aplikasi ke lingkungan produksi dengan mengintegrasikan metode Fuzzy Tsukamoto dan Fuzzy Sugeno berdasarkan checklist Quality Assurance (QA). Penelitian ini penting karena kegagalan deployment masih sering terjadi akibat pengujian yang tidak konsisten serta ketergantungan pada pengalaman subjektif QA. Sistem mengevaluasi lima variabel, yaitu penanganan error, pengujian multi-platform, pengujian performa, penanganan defect, dan hasil User Acceptance Testing (UAT). Proses fuzzifikasi menggunakan tiga kategori linguistik, yaitu LOW, MEDIUM, dan HIGH, dengan fungsi keanggotaan trapesium. Metode Tsukamoto menghasilkan inferensi melalui fungsi keanggotaan monoton, sedangkan Sugeno menggunakan keluaran berupa konstanta atau fungsi linier. Evaluasi dilakukan menggunakan dataset internal sebanyak 500 data yang terdiri atas 185 data siap, 220 data cukup siap, dan 95 data tidak siap. Pemetaan numerik kategori fuzzy [0,30; 0,60; 0,90] dengan bobot λ sebesar 0,70 menghasilkan akurasi 83,8%. Sistem ini memberikan rekomendasi deployment yang konsisten serta meningkatkan keamanan sebelum proses rilis ke produksi..

Keywords: Logika Fuzzy, Quality Assurance, Deployement perbankan, Readiness Deployment

1. Introduction

The software application development cycle needs to be ensured to run smoothly in the production environment, which is a challenge frequently encountered. In reality, many applications deployed to production still experience issues such as functions not working as expected, unstable performance, or even bugs that affect the user or end-user experience. This often requires swift action such as an immediate fix (hotfix) or rollback, which can lead to operational disruptions and, in the worst case, decrease end users' trust in the product being used and developed. This is closely related to the QA team's experience in conducting testing and the time required, so a decision support mechanism that is consistent, adaptive, and able to account for uncertainty is needed. Fuzzy logic has advantages in linguistic assessment (LOW/MEDIUM/HIGH) and can combine them through a rule base to produce traceable crisp recommendations. Integrating Sugeno Fuzzy in the form of direct scores, constants & linear, as well as Tsukamoto Fuzzy rules in the form of monotonous outputs (increasing or decreasing curves), with weighted average defuzzification. This study presents a hybrid expert system to assess the readiness of deploying banking applications based on a QA checklist.

The following is the researcher's data so that Tsukamoto fuzzy and Sugeno fuzzy are used for decision-making on deployment readiness:

a) Readiness deployment based on a QA checklist has a linguistic assessment (LOW, MEDIUM, HIGH) and is uncertain, so a method is needed that can process multi-criteria and produce a clear (crisp) value for the go/no-go decision.

b) Fuzzy Tsukamoto produces monotonic consequents where each rule generates a crisp value, making it suitable for decisions that need to be clear (READY / NOT READY). Fuzzy Tsukamoto also provides a conservative guardrail where if a critical variable (Performance or Defect) is LOW, the final score will drop significantly, making it suitable for high-security areas such as banking.

c) Sugeno Fuzzy provides outputs in the form of constants or linear functions that are easily integrated with CI/CD systems and quantitative analysis, as well as being responsive to variations in numerical scores (for example, giving a higher weight to Performance than to Multi-Platform), thus enabling weight optimization based on historical data (for instance, through grid search or machine learning).

d) Sugeno Fuzzy provides flexibility and score precision, while Tsukamoto Fuzzy maintains conservatism toward critical risks. The combination of both produces stable data (not overly optimistic when there is a high risk), adaptive (taking into account weights and data variations), and explainable (clear rules, results can be traced).

An example of a previously successful research literature project is: Rizky Nugraha Hidayat et al. (2025) conducted the study "A Comparative Analysis of Sugeno and Tsukamoto Fuzzy Logic for Temperature Stability in SCAMIS," which focuses on temperature control in an IoT smart incubator (SCAMIS), achieving target temperature with Sugeno accuracy: 98.40% and Tsukamoto: 96.93%, with the latter reaching the target faster (~1:3 of Sugeno's time). E. Nugraha et al. (2019) conducted research on "Implementation of the fuzzy Tsukamoto method in a decision support system for journal acceptance," regarding a decision support system for journal acceptance with an accuracy of 95% and an error rate of 5%, comparing manual decision-making and the Tsukamoto expert system.

Furizal et al. (2024) conducted a study "Analysis and Performance Comparison of Fuzzy Inference Systems in Handling Uncertainty: A Review," a comprehensive review of FIS (Mamdani, Sugeno, Tsukamoto) showing that Sugeno achieved an accuracy range of 81.48%–99% depending on membership and rule base optimization, while Tsukamoto also demonstrated a high impact on data variations and domain. Furizal et al. (2024) conducted a study "Analysis and Performance Comparison of Fuzzy Inference Systems in Handling Uncertainty: A Review," a comprehensive review of FIS (Mamdani, Sugeno, Tsukamoto) showing that Sugeno achieved an accuracy range of 81.48%–99% depending on membership and rule base optimization, while Tsukamoto also demonstrated a significant impact on data variations and domain.

Aep Saepullah, Romi Satria Wahono's research "Comparative Analysis of Mamdani, Sugeno and Tsukamoto Method of Fuzzy Inference System for Air Conditioner Energy Saving" focuses on AC energy, where the experimental results show that the best method in terms of reducing electricity consumption of the air conditioning system is the Tsukamoto method, achieving an average electricity efficiency of 74.2775%.

2. Methods

2.1 Fuzzy Logic.

Fuzzy Logic was first introduced in 1965 by Prof. Lotfi A. Zadeh, a researcher at the University of California, Berkeley in the field of computer science. Professor Zadeh believed that true-false logic could not represent all human thoughts, and thus fuzzy logic was developed to represent various states or human thoughts. The difference between crisp logic and fuzzy logic lies in the membership of elements within a set. In crisp logic, an element has two choices: either it is in the set, which is assigned a value of 1 meaning true, or it is not in the set, which is assigned a value of 0 meaning false. In fuzzy logic, however, an element's membership is in the interval [0,1]. Some reasons for using fuzzy logic are that the concept of fuzzy logic is easy to understand because it uses natural language that is already understood by humans (Nisa et al., 2020).

2.1.1 Sugeno Method

In reasoning, the Sugeno method is almost similar to Mamdani reasoning, except that the system output is not a fuzzy set, but rather a constant or a linear equation. This method was introduced by Takagi-Sugeno Kang in 1985. To obtain the output (result), 4 steps are required (Indonesia et al., 2009):

a. Formation of fuzzy sets

   Determine all variables involved in the process to be specified. In the Mamdani method, both input and output variables are divided into one or more fuzzy sets. 2. Application of the implication function.

   Compiling a rule base, which consists of rules in the form of fuzzy implications that express the relationship between input variables and output variables. In the Sugeno method, the implication function used is Min.

b. Rule composition

   If a system consists of several rules, then inference is obtained from the collection and correlation between rules. The method used in performing fuzzy system inference is: the Max (Maximum) Method.

c. Assertion

   Inference is a fuzzy set obtained from the composition of fuzzy rules, while the output produced is a definite real number. If the rule composition uses the Sugeno method, defuzzification is carried out by finding the weighted average.

2.1.2 Tsukamoto Method

In the Tsukamoto fuzzy method, each consequence in the IF-Then rules must be represented by a fuzzy set with a monotonic membership function as the result (fuzzification process). The inference output from each rule is given explicitly (crisp) based on the a-predicate. The final result is obtained using weighted average defuzzification (Ferdiansyah & Hidayat, 2018).

In its inference, the Tsukamoto Method uses the following stages (Indonesia et al., 2009):

1. Fuzzification

   It is the process of transforming system inputs that have precise values into linguistic variables using membership functions stored in the fuzzy output base.

2. Fuzzy set applications

   Compiling a rule base, which consists of rules in the form of fuzzy implications that express the relationship between output variables.

3. Rule Composition

   This process uses the MIN implication function to obtain the predicate value for each rule. Then each of these values is used to calculate the output value resulting from the inference explicitly.

4. Defuzzification

   By using the average method :

$$Z = \frac{\sum_i^n \propto izi}{\sum_i^n \propto i}$$

   With :

   Z = Output variable

   αi = α-predicate value

   zi = Output variable value

   Defuzzification is the final stage aimed at obtaining a precise value in the domain (Nurhidayah et al., 2022).

2.2 Data Collection

2.2.1 Observation

Observation was conducted by directly observing the application development process through both waterfall and agile methods at XYZ banking company. The purpose of this observation is to identify the challenges, opportunities, and needs encountered in improving understanding of the context of existing problems.

2.2.2 Interview

Interviews were conducted with the testing or quality assurance team at XYZ banking company to deeply explore the criteria and alternatives relevant in determining the most effective method for readiness deployment. The quality assurance team interviewed consisted of three professionals with experience in creating scenarios and determining readiness deployment at XYZ banking company.

2.2.3 Questioner

The quality assurance expert team in creating test cases and deployment readiness at XYZ banking company is asked to fill in error handling, multi-platform testing, performance testing, defect handling, and UAT results with low/medium/high values. They assess the importance of decision support in conducting deployment readiness, considering that QA experience and standards vary, as a second opinion in decision-making.

2.3 Fuzzy Process and Application Implementation

In this study, Fuzzy Tsukamoto and Fuzzy Sugeno were applied through the development of a prototype application. The framework used is based on Python programming for the implementation of fuzzy algorithms, including the processes of fuzzification, rule base, inference, and defuzzification. This application is designed to facilitate users in making deployment readiness decisions for applications using an expert system based on the Fuzzy Tsukamoto and Fuzzy Sugeno methods to provide a second opinion from QA before being uploaded to production. The following are the research workflow steps:

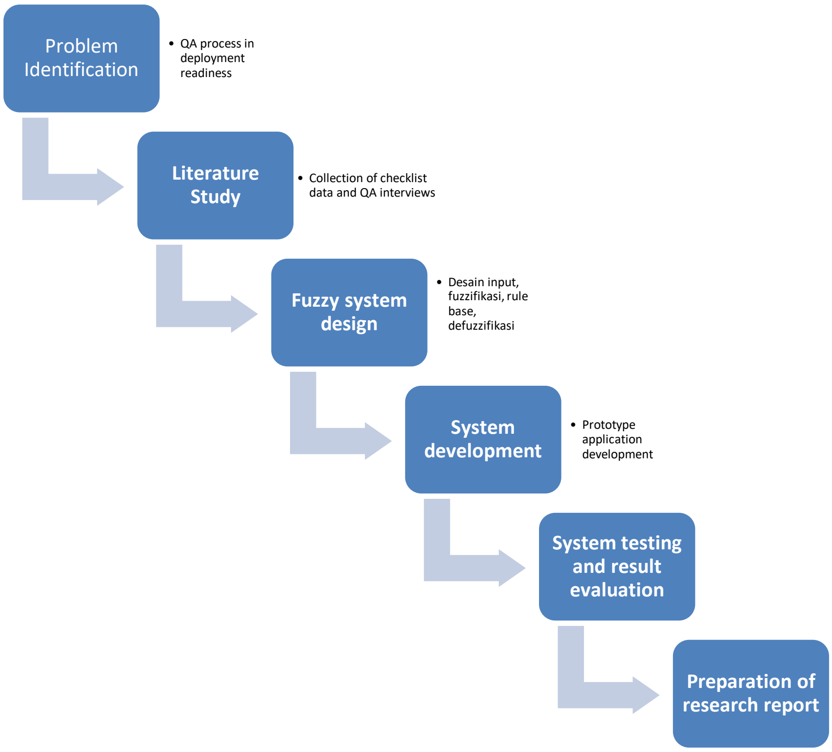

Figure 1. Research Flow

In designing a fuzzy system, the flowchart is as follows

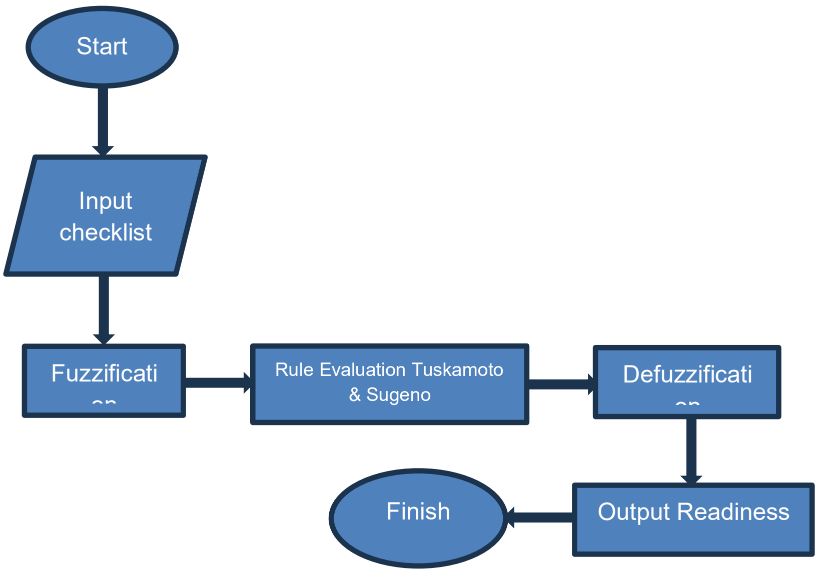

Figure 2. Flowchart of Fuzzy System Design

a. Start

This stage is the initial process of the expert system

b. Input Checklist

The system receives checklist data from QA (Quality Assurance) containing testing indicators such as:: Error Handling, Multi-Platform Testing, Performance Testing, Defect Handling, dan UAT Result. The data is in linguistic categories: LOW, MEDIUM, HIGH.

Table 1. Data used for input

Error Handing	Multi- Platform Testing	Performance Testing	Defect Handling	UAT
High	Low	Low	High	Medium

c. Fuzzification

The process of converting linguistic values into fuzzy membership degrees (values between 0–1).

1. Assigning values to each category: low : 0.30, medium: 0.60, and high: 0.9. Values are determined based on: linguistic distribution (LOW at the beginning, HIGH at the end), and consistency with the fuzzy membership function (LOW on the left shoulder, HIGH on the right shoulder).

Table 2. Input data conversion

Error Handing	Multi- Platform Testing	Performance Testing	Defect Handling	UAT
0.9	0.3	0.3	0.9	0.6

2. Calculating the fuzzy membership function (μ)

I use the formula for the function form (left shoulder, triangle, right shoulder) as follows:

Table 3. Fuzzy membership degree

Left Shoulder	Triangle Function	Right Shoulder
0.0 – 0.4	0.2-0.8	0.6-1.0

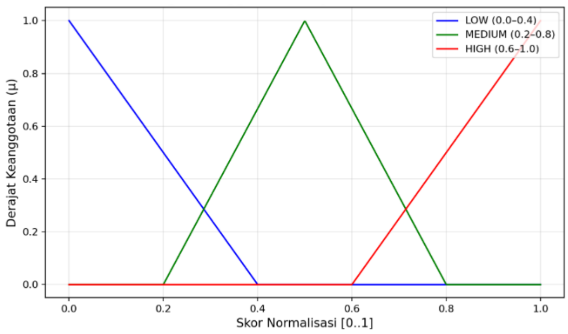

Figure 3. Fuzzy Membership Degree

Then calculate the fuzzy membership function (μ)

a. Low, left shoulder function (0.0-0.4)

$$\mu_{LOW}(x) = \begin{Bmatrix} 1 \\ \frac{0.4-x}{0.4-00} \\ 0 \end{Bmatrix} \quad (1)$$

b. Medium, triangle function (0.2-0.8, puncak 0.5)

$$\mu_{MEDIUM}(x) = \begin{Bmatrix} 0 \\ \frac{x-0.2}{0.5-0.2} \\ \frac{0.8-x}{0.8-0.5} \end{Bmatrix} \quad (2)$$

c. High, right shoulder function (0.6-1.0)

$$\mu_{HIGH}(x) = \begin{Bmatrix} 0 \\ \frac{x-0.6}{1.0-0.6} \\ 1 \end{Bmatrix} \quad (3)$$

Where μ represents fuzzy membership and x represents the conversion of input.

Table 4. Fungsi Keanggota Fuzzy (μ)

Error Handing	Multi- Platform Testing	Performance Testing	Defect Handling	UAT
0.75	0.25	0.25	0.75	0.67

d. Rule Evaluation (Tsukamoto dan Sugkeno)

Inference stage:

- Sugeno Fuzzy:

  Uses IF-THEN rules with an output in the form of a constant (0.95 for ready) or a linear function.

  Calculates α (firing strength) for each Sugeno rule

$$IF\ x\ adalah\ A\ AND\ y\ adalah\ B\ THEN\ z\ =\ f(x,y) \quad (4)$$

Where x and y = input variables ,

A and B = fuzzy sets F(x,y) = output function

R1: IF ErrorHandling HIGH AND Performance HIGH AND Defect HIGH AND UAT HIGH THEN z = 0.95

So it reaches up to R5 (rule)

- Combining with fuzzy operators

Min Method:

$$\alpha = \min\left(\mu_A(x), \min(\mu_B(y))\right) \quad (5)$$

Max Method:

$$\alpha = \min\left(\mu_A(x), \min(\mu_B(y))\right) \quad (6)$$

where

α_1 = min(0.75, 0 (because the performance is LOW), 0.75, 0 (UAT MEDIUM not HIGH)) = 0 → This rule is not active. So the data goes up to $\alpha 5$ dan z5=0.774

Table 5. Firing Strength (α)

$\alpha 1$	**$\alpha 2$**	**$\alpha 3$**	**$\alpha 4$**	**α 5**
0 (inactive)	0 (inactive)	0.25	0 (inactive)	0.75

- Fuzzy Tsukamoto:

  Each rule has a monotonous consequence, producing a crisp value per rule..

$$z = f^{-1}(\alpha) \quad (7)$$

Where α= firing strength value, f^{-1}= inverse function of a fuzzy set.

$$z_{Low} = 0.0 + 0.4 \times \alpha$$

$$z_{Low} = 0.0 + 0.4 \times 0.25 = 0.10$$

$$z_{High} = 0.7 + 0.3 \times \alpha$$

$$z_{High} = 0.7 + 0.3 \times 0.75 = 0.925$$

Where Z is the weighted average.

e. Defuzzification

- Sugeno
  - The weighted average of the rule outputs (constant/linear function).

$$Output\ Sugeno = \frac{\sum(\alpha_i \times z_i)}{\sum \alpha_i} \quad (8)$$

Where: α is the rule, z_i is the weighted average.

- $Sugeno\ Result = \frac{(0.25 \times 0.25)+(0.75 \times 0.774)}{0.25+0.75} = 0.64$
- Final decision: READY_WITH_CONDITIONS because >0.60 but <0.85.

- Tsukamoto
  - weighted average of the rule values.

$$Output\ Sugeno = \frac{\sum(\alpha_i \times z_i)}{\sum \alpha_i}$$

Where: α is the rule, z_i is the weighted average.

  - Tsukamoto Results = $\frac{(0.25 \times 0.1)+(0.75 \times 0.925)}{0.25+0.75}$ = 0.72
  - Final decision: READY_WITH_CONDITIONS because >0.60 but <0.85
- Hybrid
  - a combination of Sugeno and Tsukamoto scores with a certain weight (λ)

$$Hybrid\ Score = \lambda\,.Sugeno + (1-\lambda).Tsukamoto \tag{9}$$

Where:

λ (lambda) = weight for Sugeno (0.70)

SugenoScore = defuzzification result of the Sugeno method (weighted average of Sugeno rules)

TsukamotoScore = defuzzification result of the Tsukamoto method (weighted average of Tsukamoto rules)

- $Hybrid\ Score = 0.7 \times 0.64 + 0.30 \times 0.72$=0.664
- Final decision: READY_WITH_CONDITIONS because >0.60 but <0.85

f. Output Readiness

The system produces a final decision in the form of: ready if the score ≥ 0.85, ready with conditions 0.6 – 0.85, and not ready ≤ 0.6 This decision was made based on the final scores and the limits that were already set..

g. Finish

The process has ended with a Decision outcome.

3. Results and Discussion

3.1 Result

The best configuration for the categories was obtained as LOW=0.30; MEDIUM=0.60; HIGH=0.90; λ=0.70; t_ready=0.85; t_cond=0.60. Accuracy: 83.8%. With a total learning dataset of 500 data points, the confusion matrix was: READY (165 correct), READY_WITH_CONDITIONS (176 correct), NOT_READY (78 correct).

Then retesting was conducted with 22 data entries, resulting in READY_WITH_CONDITIONS=16, NOT_READY=6, READY=0.

3.2 Discussion

The integration of Sugeno and Tsukamoto is effective and consistent for go/no-go decisions. The Sugeno weight used, λ=0.70, emphasizes the Sugeno score to align with historical patterns, while Tsukamoto restrains the score when Performance/Defect is low—according to the needs of the guardrail in the banking system. The absence of READY predictions in the test files indicates that there are still gaps in Performance/Defect/Multi-Platform; increasing test coverage and defect verification has the potential to elevate cases to READY.

4. Conclusion

This research introduces a hybrid fuzzy expert system to assess deployment readiness based on a QA checklist in the banking domain. With an accuracy of 83.8% and a conservative approach to critical risks, the application is able to improve consistency and speed in decision-making. Furthermore, I will enrich the rule base with security and compliance factors, continuously calibrate it using real deployment outcome data, and develop a web interface to manage Excel for integration within the QA team.

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