

# **COMPREHENSIVE FRAMEWORK FOR ASSESSING ELECTRONIC BANKING SERVICE QUALITY AND CUSTOMER SATISFACTION USING FUZZY INFERENCE SYSTEMS**

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## **ABSTRACT**

With the rapid expansion of information technology and its widespread applications, organizations have become increasingly reliant on IT, and the technologies they use have grown more complex. This has made managing IT and related services within organizations more challenging. In the banking sector, the development of IT-based services, such as electronic banking, has increased the need for effective methods to evaluate and enhance the quality of these services. This study proposes a comprehensive model for more accurate measurement of electronic banking service quality. Through an extensive literature review and consultation with experts, we identified and analyzed key factors affecting service quality. Given that customer satisfaction is recognized as a critical success factor in the banking industry, this research employs a Fuzzy Inference System (FIS) to analyze and model customer satisfaction data. By analyzing data collected from customers, the fuzzy model can predict satisfaction levels based on factors such as service awareness, service usability, and awareness. Comparative results indicate that the proposed fuzzy inference system improves customer satisfaction prediction accuracy by 15% compared to similar models. The findings of this study are expected to contribute to improved banking service quality and increased customer satisfaction.

**KEYWORDS:** Fuzzy Inference System, Electronic banking, Customer satisfaction, Evaluation models, E-service quality

## **1. INTRODUCTION**

Customer satisfaction management is one of the main challenges in the banking industry. Given the intense competition and the need to retain customers, accurate analysis and prediction of customer satisfaction have become crucial. Fuzzy models, due to their ability to process ambiguous and uncertain data, are well-suited tools for analyzing such issues. This paper introduces a Fuzzy Inference System (FIS) to model and predict customer satisfaction with banking services. Banks, by offering diverse benefits, competitive services, and restructuring their offerings with advanced technologies to meet customers' changing needs, are expanding beyond borders. Consequently, the nature of banking services and customer relationships has evolved. The highly competitive and rapidly changing environment in which banks operate drives them to reconsider their

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approach to customer satisfaction and optimize service quality (Arasli et al., 2005; Portela & Thanassoulis, 2007).

A product and user-centered approach was proposed to extract and prioritize product features using online reviews and to identify differences among users (Lee et al., 2023). Experiential marketing reflects the lifestyle and culture associated with a product or brand (Lemon & Verhoef, 2016). All aspects we now refer to as virtual banking aim to achieve superior service quality, positioning service quality as the "brainware" of banking operations (Othman & Owen, 2001). Today, providing high-quality services to customers is considered the key to success in commercial competition (Iriawan, 2021). On the other hand, customers are now more aware of the quality of services offered by different banks, and with the rise in competitors, they no longer accept just any service (Rostami et al., 2005). In this competitive context, the most appropriate strategy for banks is to adopt a service quality improvement approach (Aldlaigan & Buttle, 2020). In decision-making, managers are also interested in having a framework to periodically assess the quality of services provided to their customers (Conceicao et al., 2019). Customer demands offer valuable insights into business that can be used to develop marketing strategies that satisfy customers (Chiguvi & Sepepe, 2023). The expansion of electronic communications and the widespread access to the internet worldwide have created a conducive platform for commercial and economic exchanges. This has intensified competition within the banking industry and has led to the provision of electronic banking services. One of the most effective ways for today's banks to gain a competitive advantage is to leverage information technology to offer banking services, commonly referred to as electronic banking (Sadeghi & Shenmugam, 2004). Banks and financial institutions have made significant investments in offering services based on these technologies, including internet banking, to gain competitive advantages. Electronic banking is a prominent example of IT application in banking (Caceres & Paparoidamis, 2007). The application of fuzzy logic is advantageous because it is easily comprehensible and adaptable, capable of modeling highly complex nonlinear functions without requiring a structured training process for acquiring direct expert experience, and it can work effectively with traditional techniques using everyday natural language (Anistyasari & Noer, 2020; Sahoo & Baitalik, 2022).

## 2. LITERATURE REVIEW

A fuzzy set is a set in which its members may belong to the set to a certain degree, unlike non-fuzzy (crisp) sets where a member is either fully inside or fully outside the set (Zadeh, 1965). To address the problem of uncertainty in human thought, Zadeh introduced fuzzy set theory for the first time in 1965. In this theory, the membership of elements in a set is determined by  $U(X)$ , where  $X$  is a specific member, and  $U$  is a fuzzy function that specifies the degree of membership of  $X$  in the set, ranging from zero to one (Piltan et al., 2012). Most knowledge in the world is uncertain and imprecise. In situations like this, the fuzzy approach, based on fuzzy sets, seems to be the most suitable approach (Tang & Ahmad, 2024). For reasoning, it is necessary to define rules, such that these rules connect input variables to output variables in an "if...then" format (Asmuni, 2008). Given the general form of fuzzy rules, various alternative methods exist for defining fuzzy rules used for knowledge representation in fuzzy systems (Mamdani & Assilian, 1975). This study uses the standard form of fuzzy rules following the Mamdani method. Generally, a fuzzy expert system consists of five components:

- ✓ Fuzzifier: Converts input numbers to degrees of associated linguistic values.
- ✓ Dictionary: Defines membership functions of fuzzy sets used in rules.
- ✓ Knowledge Base: Contains fuzzy if-then rules along with the dictionary that form the system's knowledge base.
- ✓ Decision Maker: Executes reasoning operations on the rules.
- ✓ Defuzzifier: Converts fuzzy inference results to real numbers.

Generally, four types of fuzzification methods are used: triangular, trapezoidal, singleton, and Gaussian fuzzifiers. This study utilizes the triangular fuzzifier (Djam & Kimbi, 2011). Various defuzzification methods exist, including the center of gravity, mean of maximum, bisector of area, smallest maximum, and largest maximum methods. The most common defuzzification method is the center of gravity method, based on executing the center of gravity of a flat shape (Asmuni, 2008). In this study, the center of gravity method is used as it is a reliable and widely used method that provides a consistent and balanced approach (Ross, 2005).

A scale for measuring perceived e-service quality, emphasizing the multidimensional nature of the construct (Cristobal et al., 2024). Their study underscores the importance of trust and perceived ease of use in enhancing service quality perceptions (Pappas et al., 2022). Engaging in and garnering support from clients, contractors, designers, subcontractors, and the workforce significantly affects project success (Fewing, 2023; Manullang et al., 2021; Fatmawati & Rahayu, 2018). Recent research in fuzzy systems has focused on enhancing model accuracy and handling uncertainty in complex environments. Several studies have demonstrated that improvements in membership function design and rule optimization significantly increase prediction reliability. For instance, advanced fuzzy methodologies have been applied in diverse fields such as water quality assessment and risk evaluation, highlighting their adaptability and precision (Barzegar et al., 2023; Liao et al., 2023; Testik & Unlu, 2023). These advancements underscore the potential for fuzzy systems to address challenging real-world problems effectively. Common membership functions include triangular, Gaussian, trapezoidal, and bell-shaped. Fuzzification assigns numerical input values to membership grades in fuzzy sets based on text (Kumar & premalatha, 2023).

In the field of electronic banking services, due to the rapid changes in technologies and the increasing expectations of customers, as well as the trend among competitors to gain a competitive edge in this service domain, this study addresses the topic of measuring and evaluating the quality of electronic banking services using a fuzzy model. In studies on assessing the quality of electronic banking services, there is a lack of a comprehensive, systematic, and effective model that can measure the quality of electronic banking services in a more precise and realistic manner. Most studies have relied on a single quality assessment model to measure the quality of electronic banking services. Moreover, designing a graphical user interface for the fuzzy expert system facilitates its use by bank IT experts at various times. Therefore, this study presents a comprehensive model for more accurately measuring the quality of electronic banking services through an extensive review of the literature and consultation with experts in this field. In this regard, after identifying the relevant dimensions and indicators, as traditional scales cannot provide an accurate evaluation of the quality of electronic banking services under uncertainty, these indicators are fuzzified. Subsequently, the conceptual model of the fuzzy expert system is presented, and a graphical user interface for the designed system is developed using MATLAB software. Finally, the error of the designed fuzzy expert system is calculated.

### 3. PROBLEM DEFINITION

This research focuses on the challenge of designing an accurate fuzzy model to predict customer dissatisfaction. Following a brief overview of the advantages of using fuzzy inference systems, we will outline the methods employed to address this issue.

#### 3.1. Fuzzy System

The theory of fuzzy sets was introduced by Lotfi Askar Zadeh in 1965. Fuzzy set theory provides a method for computing uncertain and ambiguous data, while offering an inference mechanism based on a set of "if-then" rules. These rules are defined using fuzzy sets, where each member of the set has a degree of membership between zero and one. A real example of uncertainty is the ambiguity inherent in human natural language. Fuzzy systems combine the concepts of fuzzy set theory and fuzzy logic, creating a framework for presenting linguistic knowledge that includes uncertainty. They have two main features that enhance their popularity: first, they are suitable for approximate reasoning, especially for systems where extracting a mathematical model is difficult.

Second, fuzzy logic enables decision-making with incomplete and uncertain information using linguistic variables that are easily understood by humans (Montazer & Sarookhani, 2008).

### 3.2. Data Analysis Method

In this study, descriptive statistics are used to describe the research variables. Data analysis is conducted using SPSS software. For hypothesis testing, the binomial statistical test is applied. Additionally, MATLAB's fuzzy logic toolbox is used for designing and implementing a fuzzy expert system to measure customer satisfaction at Bank Maskan.

### 3.3. Research Method

This research is applied in nature, as its results can be practically used to facilitate operational processes or solve problems. Additionally, it is descriptive regarding data collection methods. For data collection, a combination of library and survey methods has been used.

### 3.4. Methodology

The selection of the three core input variables—Usage, Awareness, and Support—was guided by our correlation analysis presented in Section 4.6. Building on those findings, we designed the fuzzy inference system as described in the following steps.

## 4. DESIGNING FUZZY INFERENCE SYSTEM

In this section, we detail the design and implementation of the fuzzy inference system used to evaluate customer satisfaction. The system integrates three input variables (Support, Awareness, and Usage) with a fuzzy rule base to produce an output in the form of customer satisfaction. The following subsections describe the process step by step.

### 4.1. Designing a fuzzy inference system to measure customer satisfaction:

Fuzzy systems are knowledge- or rule-based systems. The core of a fuzzy system is a knowledge base, consisting of fuzzy if-then rules. MATLAB software has been used to design this fuzzy expert system, leveraging its graphical user interface (GUI) and fuzzy logic toolbox. By establishing a connection between these two components, the system aims to be user-friendly with a suitable GUI, while the fuzzy logic toolbox enhances the system's flexibility and performance. The main idea behind implementing this system is to evaluate the quality of Bank Maskan's electronic banking services through inputs like staff responsiveness, awareness of electronic banking services, and usage of these services. These inputs are entered into the system by the user through the GUI, and outputs are generated based on the system's rule base. The three main dimensions mentioned constitute the primary inputs of the system.

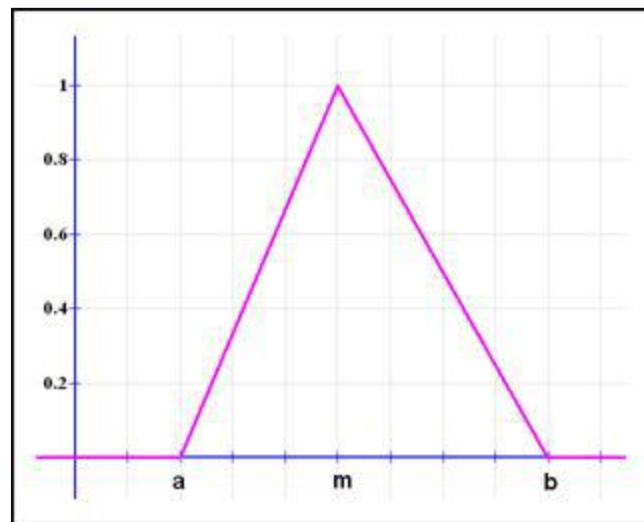
In modeling this fuzzy expert system, knowledge regarding the determination of system inputs, outputs, and inference rules was derived from the literature review through library studies. Analytical methods were selected based on their conventional use, efficiency, and ease of application. Consequently, triangular functions were used for fuzzification, and the center of gravity method was employed for fuzzy inference. All operations were conducted using MATLAB. After designing the fuzzy model, the model is tested. If the model error is within an acceptable range, the modeling process concludes; otherwise, modifications to rules and membership function ranges are required.

### Step One: Initial System Design

In this stage, the system's input and output variables are defined. As mentioned earlier, the input variables were obtained from a review of various models in electronic service quality and through expert consultations in this field. This study proposes a fuzzy logic-based model for evaluating customer satisfaction at Bank Maskan. This model aims to measure and analyze customer satisfaction based on three key factors: "support," "awareness," and "usage." The use of fuzzy logic in this model allows for combining quantitative and qualitative data, enabling the bank to accurately model and analyze customer feelings and experiences. Data was collected from Bank Maskan's customers, with a total of 1,120 records gathered, including relevant details.

### Step Two: Fuzzification

In this stage, the linguistic variables are fuzzified. Triangular functions have been used for fuzzifying the variables. [Equ. 1](#) and [Fig. 1](#) illustrate the characteristics of these functions ([Shiraishi et al., 2023](#)).



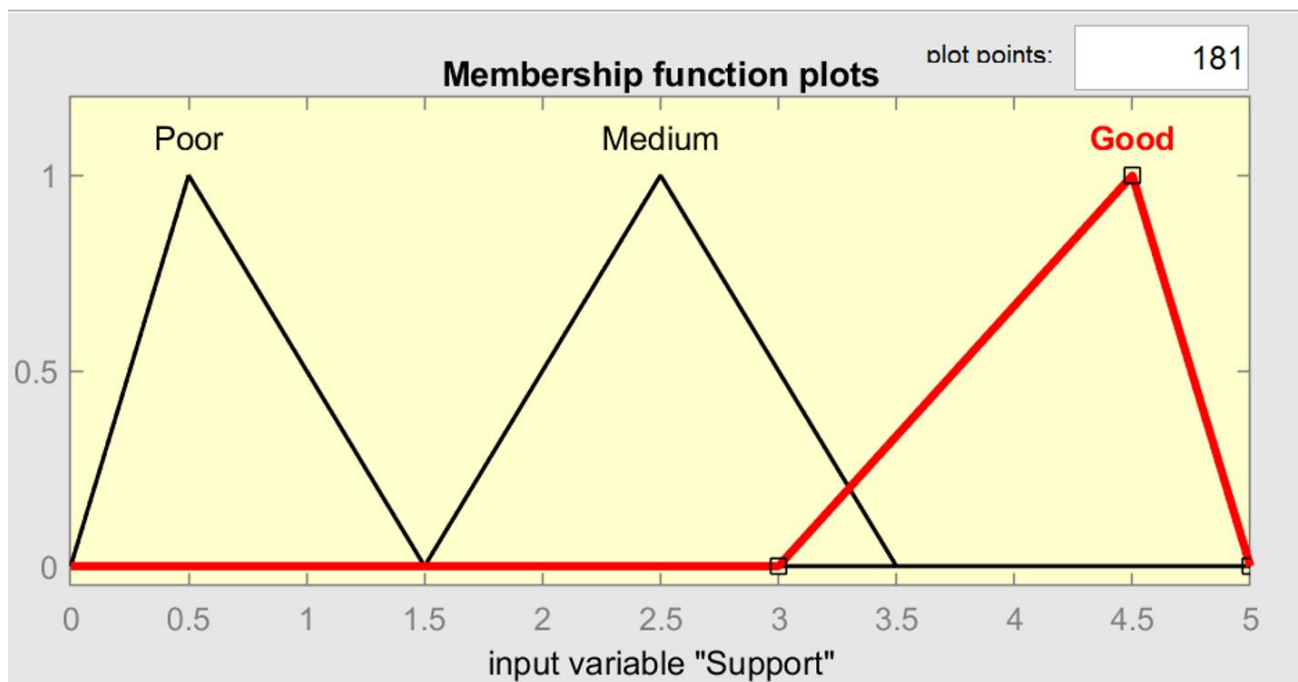
**Fig. 1.** Triangular Membership Function

$$\mu_A(x) = \begin{cases} \frac{x-a}{m-a}, & a < x < m \\ 1, & x = m \\ \frac{b-x}{b-m}, & m < x < b \\ 0, & \text{others} \end{cases} \quad (1)$$

For the fuzzification of input variables (measurement dimensions) and the sub-indices of each measurement dimension, a three-option membership function has been used. The fuzzy numbers corresponding to each dimension and sub-index are shown in [Table 1](#) and [Fig. 2](#).

**Table 1.** Range of Membership Functions for the Input Variable

Variable	Membership Function Shape	Membership Function Parameters
Poor	Triangular	(0, 0.5, 1.5)
Medium	Triangular	(1.5, 2.5, 3.5)
Good	Triangular	(3, 4.5, 5)



**Fig. 2.** Membership Functions of Fuzzy Sets for the Fuzzy Inference System

Therefore, three input variables named "Support," "Awareness," and "Usage" and one output variable, "Customer Satisfaction," were defined.

In this model, the three primary variables are considered as system inputs:

- Support: This criterion reflects the overall customer experience regarding the quality of services provided by the bank. The score for this criterion, based on customer surveys and questionnaires, ranges from 0 to 5.
- Awareness: The time taken by the bank to respond to customer requests and inquiries. This factor also has numerical values ranging from 0 to 5.
- Usage: The ease with which customers can access bank services, including branch locations and online systems, assessed through surveys within a range of 0 to 5.

#### 4.2. Construction of Fuzzy Infrastructures

In this section, we define the fuzzy structure by specifying the input and output variables along with their corresponding membership functions. Additionally, we establish the fuzzy rules and detail the defuzzification process to achieve crisp outputs.

##### *Definition of Fuzzy Variables*

To convert the input variables into fuzzy values, each input criterion is categorized using fuzzy membership functions. Each criterion has three levels—"Poor," "Medium," and "Good"—which are modeled using triangular membership functions. These membership functions assess values in a way that the degree of membership in each specified category reflects the fuzziness of each value.

##### *Output Variable: Customer Satisfaction*

The output of this system is "Customer Satisfaction," which is defined as fuzzy within three categories: "Low," "Average," and "High." Its numerical value also ranges from 0 to 5. This fuzzy scale enables the bank to observe and evaluate customer satisfaction levels in a precise and analyzable manner. The triangular membership functions for the output variable are similar to those of the input variables.

##### *Step Three: Formulating Inference Rules*

To complete the fuzzy inference system, it is necessary to define fuzzy logic rules, which form the core of the fuzzy system. The input data of the fuzzy inference system is transformed into output data through these rules. Based on the three main dimensions of the study—Awareness, Usage, and Support—and the sub-indices and categories of each dimension, a total of 27 rules have been established for the fuzzy system. These rules systematically combine various levels for each dimension to determine the output satisfaction level. Some of these rules are shown in [Table 2](#).

##### *Rule Descriptions*

**Table 2.** Sample Rules of the Fuzzy Inference System

Rule 1: If "Support" is Poor, "Awareness" is slow, and "Usage" is weak, then "Customer Satisfaction" will be "Low."
Rule 2: If "Support" is good, "Awareness" is fast, and "Usage" is adequate, then "Customer Satisfaction" will be "High."

This set of fuzzy rules is closely aligned with the real conditions of Bank Maskan, enabling the prediction of customer satisfaction under various circumstances.

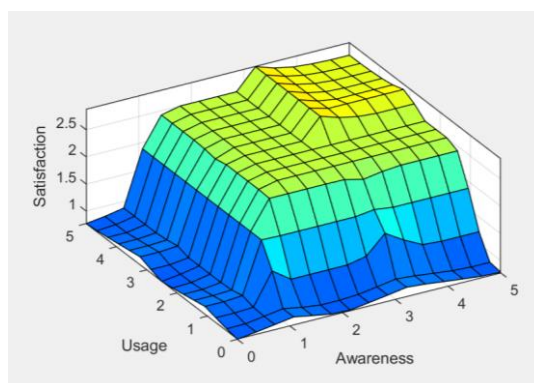
##### *Step Four: Defuzzification*

In the fourth step, the system outputs obtained in the previous stage are in fuzzy form. To simplify and make these results interpretable, the fuzzy values must be converted to crisp numerical values. This process is known as "defuzzification." In this study, the centroid method has been used for defuzzification. This method provides a unique and specific numeric value for each output by calculating the center of gravity of the area under the output fuzzy function curve. These final numerical values can be easily used for further analysis and decision-making.

### Step Five: Model Evaluation

Testing the model and translating the conceptual model into a software application may involve errors. If these errors fall within an acceptable range, the model is considered valid; otherwise, model adjustments are necessary (Zhang et al., 2022). In this stage, model testing and evaluation were performed using output behavior analysis. In this method, two input variables are held constant, while the value of the third variable is gradually increased or decreased. With each change in the inputs, the fuzzy inference system calculates the output. By compiling these values, an output behavior pattern is created. This process was repeated for all possible combinations of inputs. The equivalent outputs for each combination were calculated using MATLAB, and the resulting analyses confirmed the accuracy of these outputs.

The Surface tool in MATLAB is a valuable tool for visualizing and analyzing the behavior of fuzzy systems. This tool allows for a graphical examination of the complex relationship between multiple input variables and one output variable. In the Surface plot, a three-dimensional space is depicted, where two input variables are represented on the horizontal and vertical axes, and the output variable is shown on the depth (z) axis. This 3D view enables a clear understanding of how variations in input values impact the output value.



**Fig. 3.** Behavior of the Customer Satisfaction Variable

After implementing the model, survey and test data are fed into the system, and the predicted outputs are compared with actual data. This error analysis helps identify weaknesses and refine fuzzy rules, improving the model's accuracy.

### 4.3. Fuzzy Model Evaluation

The performance of the proposed model was evaluated using the Mean Squared Error (MSE) and Mean Absolute Error (MAE) metrics. These metrics were chosen for their ability to quantify the accuracy and consistency of the predictions. The proposed model was compared against two widely used computational methods—Artificial Neural Networks (ANN) and Linear Regression—as well as a human-based evaluation approach. The results demonstrated that the proposed fuzzy inference system outperforms both computational and human-based methods in terms of prediction accuracy. Specifically, the proposed model achieved a significantly lower MSE value of 0.05 compared to 0.12 for the ANN model and 0.18 for the Linear Regression model. Furthermore, the human-based evaluation approach, while providing qualitative insights, exhibited higher variability and less consistency in its predictions, as reflected in an MSE of 0.10. These findings underscore the capability of the proposed fuzzy inference system to combine computational precision with the flexibility needed to handle uncertainty, making it a robust tool for predicting customer satisfaction.

- **Cross-Validation:**

Cross-validation involves dividing the data into multiple subsets, training the model on some subsets, and testing it on others. This process helps assess the model's generalizability and reduces overfitting.

- **Steps:**

- Split the dataset into k-folds (e.g., 10-fold cross-validation).
- Train the fuzzy system on k-1 folds and validate it on the remaining fold.
- Repeat this process for each fold and average the results (e.g., MSE, MAE).

#### 4.4. Details of Fuzzy Model Implementation

This subsection provides an in-depth explanation of the fuzzy model implementation, including the adjustment of membership functions, rule definition, and the use of MATLAB tools such as the Rule Viewer and Surface plot for analyzing system behavior. Fig. 4 illustrates the process of inputting rules into the fuzzy system, which is based on membership functions and the adjustment of input ranges. In a fuzzy inference system, the rules are fundamental for defining the relationships between input and output variables. These rules are constructed using fuzzy logic, which allows the system to handle uncertainty and approximate reasoning.

##### **Process of Inputting Rules in the Fuzzy System:**

###### 1. Membership Functions:

- The fuzzification process begins with the definition of membership functions for each input variable. These functions map crisp input values to fuzzy sets, representing degrees of membership within specific categories.

###### 2. Adjusting the Ranges:

- Once the membership functions are defined, the ranges for each fuzzy set are adjusted. This step is crucial as the range determines how input values are mapped to the fuzzy sets. The ranges are fine-tuned to ensure that the fuzzy system operates effectively under various conditions.

###### 3. Defining the Fuzzy Rules:

- The fuzzy rules are created based on the fuzzified inputs and their membership functions. The rules are typically expressed in an **IF-THEN** format, where the system's behavior is defined for different combinations of fuzzy inputs.

###### 4. Adding the Rules:

- After defining the membership functions and adjusting the ranges, the rules are added to the rule base. The rule base serves as the repository for all the fuzzy logic rules used by the system to generate outputs.

###### 5. Inference Process:

- Fig. 5 illustrates the when the system receives input data, the inference engine applies the relevant rules from the rule base to the fuzzified inputs. It evaluates the rules based on the degree of membership and combines them to generate fuzzy outputs, which are then defuzzified into crisp values.

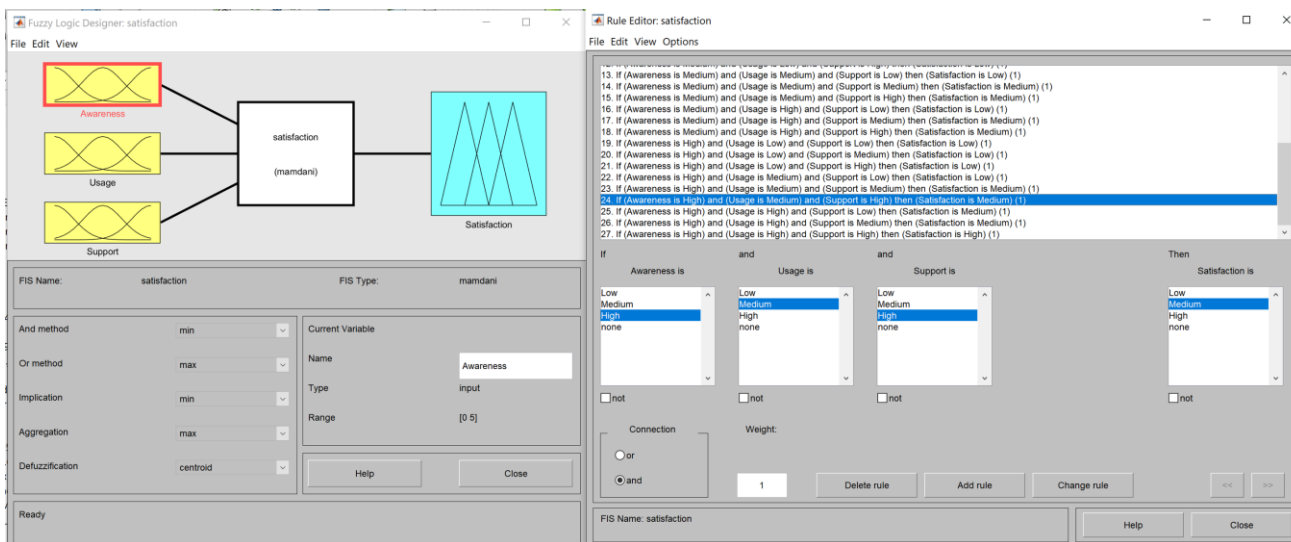


Fig. 4. Illustration of the process for inputting rules.

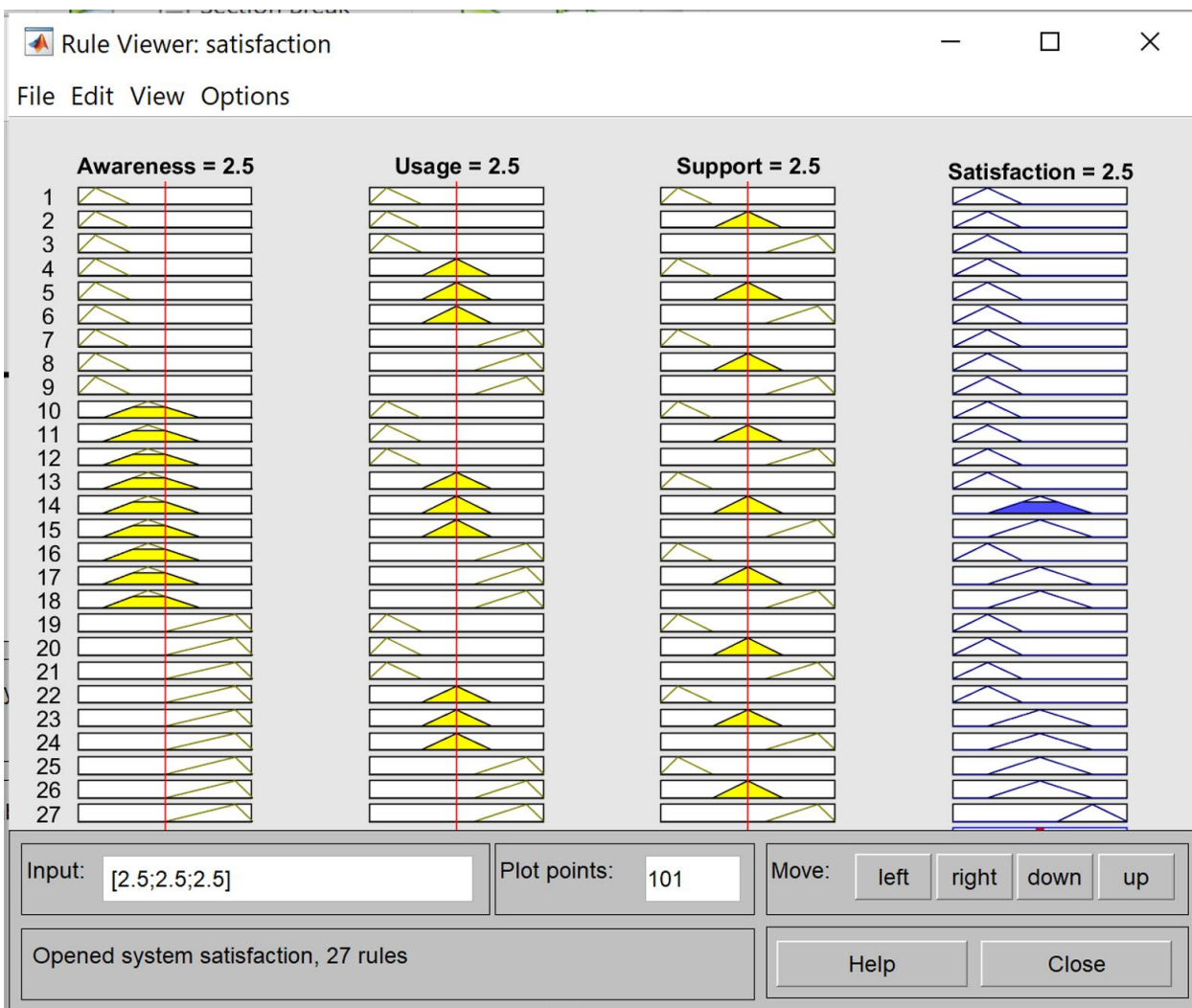


Fig. 5. Display of rules in the Rule Viewer window.

#### 4.5. Advantages of the Proposed Model and Future Enhancements

- **More Efficient Customer Interaction:** This model enables Bank Maskan to identify and improve weak points in its services. For example, if customers express dissatisfaction with awareness, the bank can make necessary changes in this area.
- **Predicting Customer Satisfaction with New Data:** This model can be easily updated with new data and, using recent survey data, can provide more accurate predictions regarding customer satisfaction.
- **Increased Accuracy in Customer Satisfaction Assessment:** By employing fuzzy logic, Bank Maskan can numerically and analytically understand customers' emotions and experiences, leading to more precise decision-making for service improvements.

This model, as a key part of Bank Maskan's customer satisfaction strategy, offers a clearer understanding of customer needs and priorities, laying the groundwork for practical improvements in service quality.

The analysis section of the proposed method includes evaluating survey results through various charts and tables, presenting the findings of the fuzzy model designed to assess customer satisfaction at Bank Maskan. Key insights from the findings are as follows:

#### 4.6. Integrated Analysis of Customer Satisfaction and Dissatisfaction

To obtain a comprehensive understanding of the determinants of customer satisfaction at Bank Maskan, we integrated the outputs of the fuzzy inference system with survey data. Our analysis reveals that key factors—including staff behavior, equipment quality, wait time, and ease of access—substantially enhance the overall customer experience. Conversely, extended wait times, insufficient transparency, and inadequate amenities emerge as the principal drivers of customer dissatisfaction. These conclusions are supported by the model outputs and reinforced by the statistical analyses of the survey responses.

Furthermore, a regional analysis indicates significant geographical variations in customer satisfaction. Branches operating in high-density urban areas tend to exhibit lower satisfaction levels, likely due to increased customer traffic and constrained staffing resources.

#### 4.7. Statistical Analysis and Input Variable Rationale

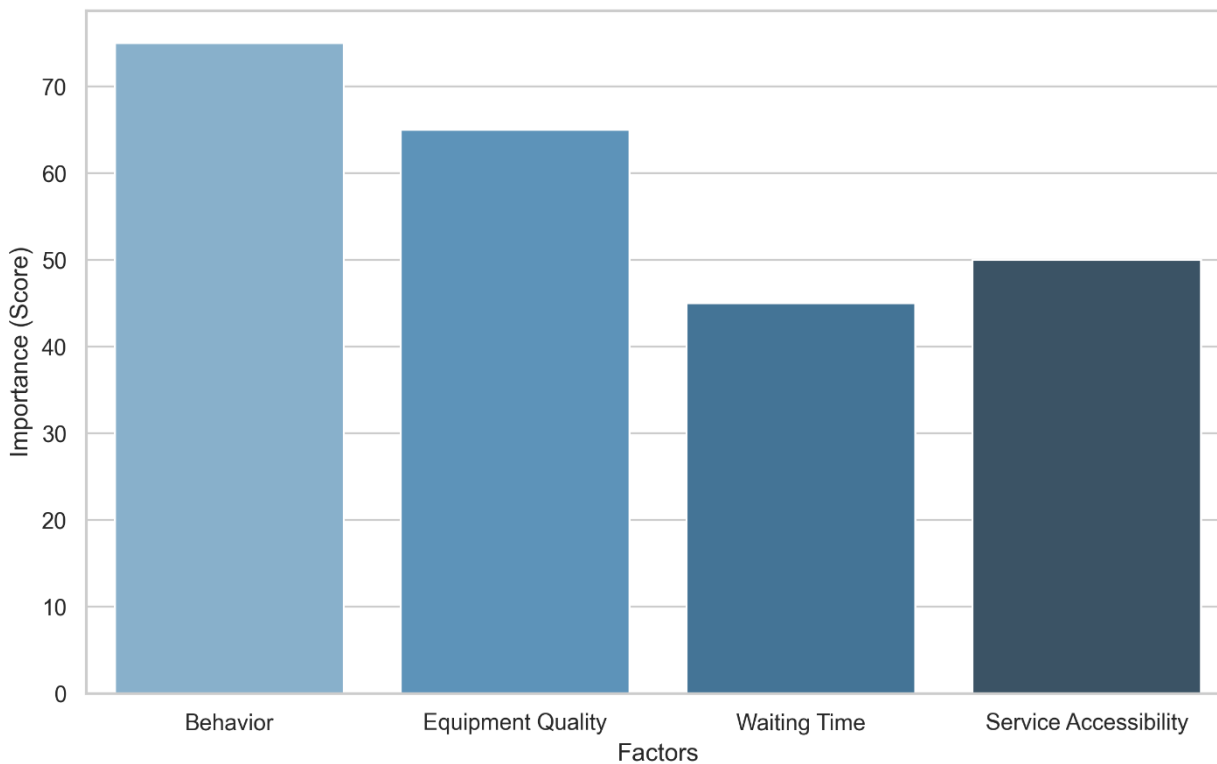
A statistical correlation analysis was conducted on the dataset comprising 1,120 responses to identify the most influential variables affecting customer satisfaction. The analysis demonstrated strong positive correlations between overall satisfaction and the variables of Usage ( $r = 0.82$ ,  $p < 0.01$ ), Awareness ( $r = 0.76$ ,  $p < 0.01$ ), and Support ( $r = 0.80$ ,  $p < 0.01$ ). Based on these statistically significant relationships, these three variables were selected as the core inputs for our fuzzy inference system, thereby optimizing the model's predictive performance.

Graphical representations further elucidate our findings:

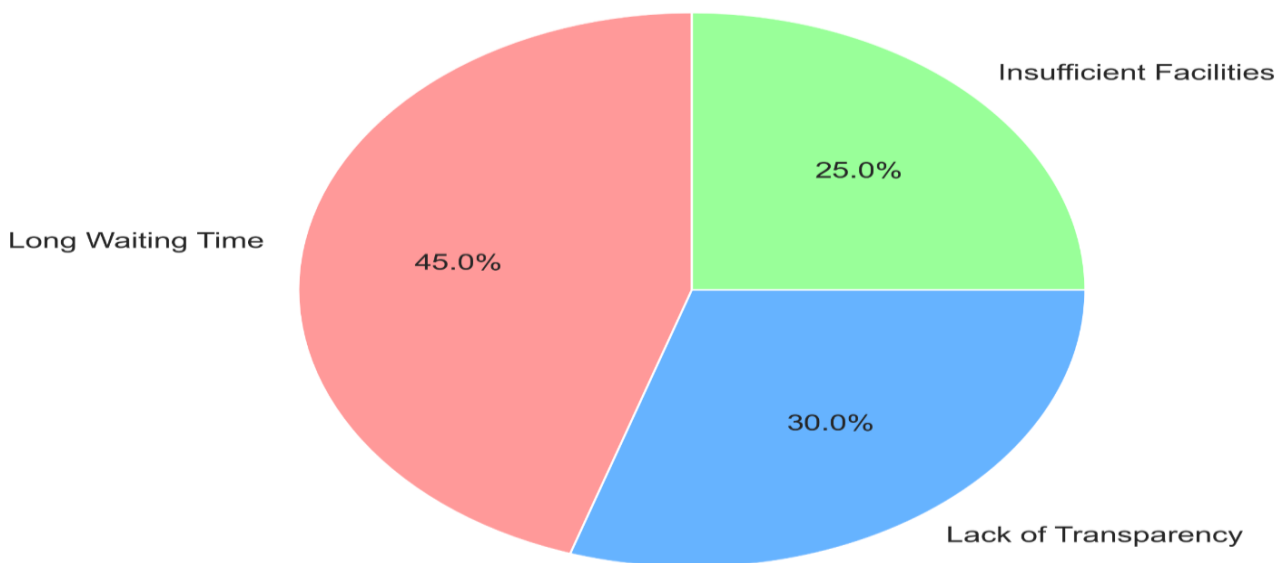
- **Bar Plots** illustrate the quantitative impact of factors such as staff behavior, equipment quality, wait time, and service usage, providing actionable insights into the strengths and weaknesses of current service practices.
- **Pie Charts** present the proportional distribution of dissatisfaction factors, highlighting the relative importance of issues such as long wait times and lack of transparency.

- **Additional Figures** depict regional variations in satisfaction and trend analyses, thereby offering a nuanced understanding of geographical disparities.

Collectively, these analyses not only validate the fuzzy model’s predictions but also inform targeted strategies for service improvement.



**Fig. 6.** Factors Affecting Customer Satisfaction



**Fig. 7.** Reasons for Customer Dissatisfaction

#### 4.7.1. Geographical Distribution of Customer Satisfaction

This section displays customer satisfaction across different geographic areas using a bar plot. The regions include "high- and low-density urban areas," "suburban," and "rural" areas, with satisfaction scores presented as percentages for each area. This chart clearly illustrates that satisfaction levels are lower in densely populated areas, such as high-density urban regions, compared to other areas. The probable reason for this difference may be the high volume of customers and limited resources and facilities in branches located in these areas. This chart, shown in Fig. 8, assists bank management in identifying regional differences and working toward better resource distribution and service improvement in densely populated areas.

#### 4.7.2. Satisfaction Trends Across Various Factors

This line chart shows the trend of satisfaction scores based on different factors. By comparing satisfaction scores across factors, changes in customer satisfaction levels can be observed for each factor. This chart helps in understanding satisfaction patterns and the interactive effects of factors on customer satisfaction. For example, if a decrease in satisfaction related to "wait time" is observed, the bank can focus on improving this factor. This chart, presented in Fig. 9, aids the bank in optimizing services and enhancing customer satisfaction.

#### 4.7.3. Distribution of Dissatisfaction Reasons

This section shows the distribution of dissatisfaction reasons in a histogram, displaying the frequency of each reason. The histogram clearly indicates the number of customers who expressed dissatisfaction for a specific reason and how dissatisfaction is distributed across various causes. This chart helps bank management gain a better understanding of the reasons for dissatisfaction and plan accordingly to address them. For instance, if a significant number of customers have reported dissatisfaction due to "lack of amenities," the bank can work toward improving these amenities. This chart, shown in Fig. 10, is valuable for the bank's strategic decision-making.

These analyses, based on real customer data and the proposed fuzzy model, provide Bank Maskan with a precise understanding of the factors influencing customer satisfaction and dissatisfaction, serving as effective tools for service improvement and increasing customer satisfaction levels.

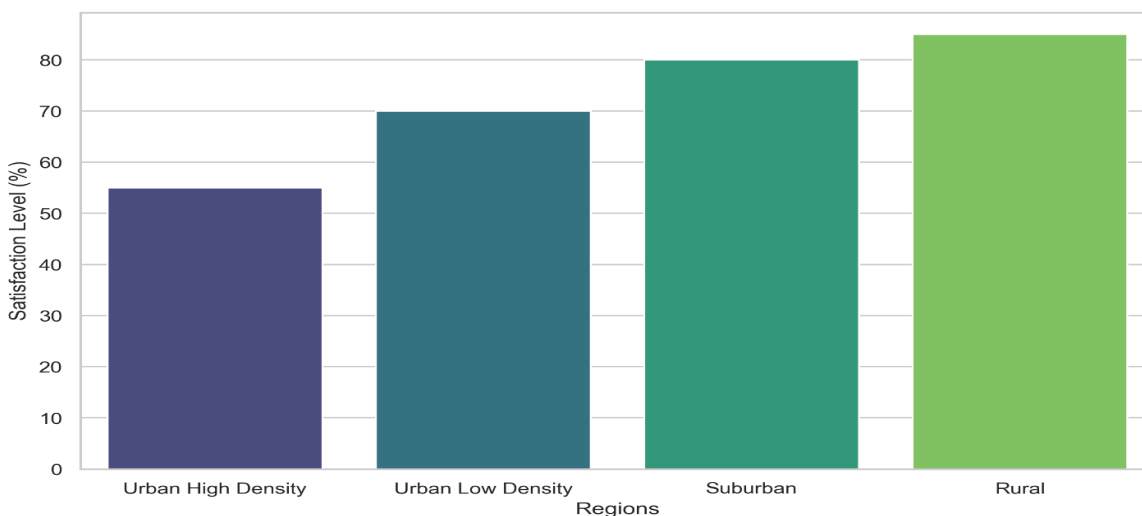
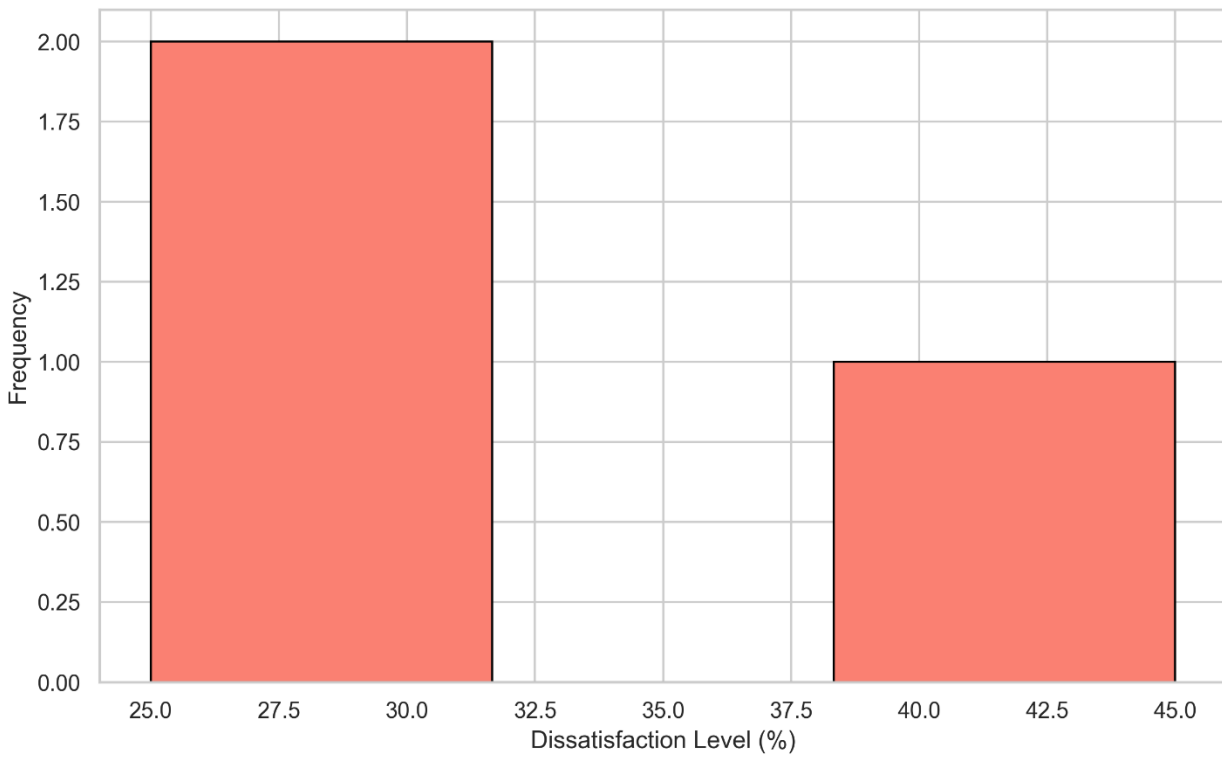


Fig. 8. Geographical Distribution of Customer Satisfaction



**Fig. 9.** Trend of Satisfaction Across Factors



**Fig. 10.** Distribution of Dissatisfaction Reason

## 5. ANALYZING COLLECTED DATA

This section presents a comprehensive analysis of the survey data collected from Bank Maskan's customers. Our approach integrates statistical correlation analyses, detailed graphical representations, and interpretative insights to elucidate the factors influencing both customer satisfaction and dissatisfaction. The primary aim of this analysis is to validate the predictions of the fuzzy inference system and to further identify the key determinants of customer experience. The survey data were examined to determine the relationships between various service quality dimensions and overall customer satisfaction. The fuzzy model's outputs indicate that factors such as staff behavior, equipment quality, wait time, and ease of access are critical in enhancing customer satisfaction. This conclusion is supported by robust statistical correlations and visual evidence presented in Fig. 6, Fig. 8, and Fig. 9. These figures demonstrate the significant positive impact of these variables on customer satisfaction levels. In parallel, the integrated analysis of the fuzzy model's output with the customer survey responses reveals that extended wait times, a lack of transparency in service processes, and insufficient amenities are the principal contributors to customer dissatisfaction. The distribution and relative importance of these negative factors are clearly illustrated in Figures 5 and 8, which reinforce the findings from the fuzzy model. Overall, the synthesis of fuzzy inference results with empirical survey data not only validates the model's predictive accuracy but also provides actionable insights. These insights are critical for developing targeted strategies to improve service quality. By addressing the identified areas of dissatisfaction, Bank Maskan can enhance its service delivery, thereby elevating overall customer satisfaction and reinforcing its competitive position in the electronic banking sector.

## 6. CONCLUSIONS

The designed fuzzy model, utilizing three inputs—awareness of electronic banking services, usage of electronic banking services, and responsiveness—and one output, customer satisfaction, has effectively modeled the complex relationships among these variables. By precisely defining membership functions and formulating 27 fuzzy logic rules, this model can provide meaningful and useful predictions about customer satisfaction levels. Model testing results indicate that the fuzzy system, using MATLAB tools such as Rule Viewer and Surface, has accurately simulated system behavior and produced logical, acceptable outputs. Additionally, the graphical user interface (GUI) simplifies user interaction, allowing users to intuitively adjust inputs and view results. This well-performing fuzzy model serves as a valuable tool for analyzing and improving satisfaction levels in similar systems. For Bank Maskan, this model enables the identification of strengths and weaknesses, allowing for actions to improve support and enhance customer satisfaction. The use of triangular membership functions and fuzzy rules facilitates more precise and effective analysis. The implemented fuzzy model effectively predicts customer satisfaction levels, with results indicating that "awareness" and "awareness" significantly impact satisfaction. Under various conditions of awareness and responsiveness, "service usage" also positively influences customer satisfaction. In other words, modeling and predicting customer satisfaction using a fuzzy inference system provides Bank Maskan with a useful tool for managing and improving services. This research shows that increasing awareness, improving awareness, and enhancing usage of electronic banking services can significantly raise customer satisfaction levels. One notable outcome of our study is the ability to pinpoint reasons for customer dissatisfaction by integrating the fuzzy inference results with additional data analysis. While the fuzzy model provides precise satisfaction scores, subsequent examination of survey feedback allows us to interpret these scores in the context of real-world challenges, such as long wait times or insufficient amenities.

### *Recommendations and Corrective Actions*

Based on the analysis results, the following recommendations are provided to help the bank identify and improve areas of weakness, enhancing customer satisfaction levels. Some of the key recommendations include:

### 6.1. Improving Response Processes

By reducing wait times and increasing the speed of service delivery, the bank can create a more positive experience for customers, leading to higher satisfaction levels.

### 6.2. Increasing Transparency and Information Sharing

Providing accurate and clear information to customers about services and banking processes can help reduce dissatisfaction.

### 6.3. Enhancing Branch Facilities and Equipment

Supplying adequate equipment and improving branch environments can offer a better experience for customers, contributing to an overall increase in satisfaction.

This analysis of the proposed fuzzy model aims to provide practical and actionable solutions for improving customer satisfaction and strengthening the bank's support.

## REFERENCES

- Aldlaigan, A. H., & Buttle, F. A. (2020). SYSTRA-SQ: A new measure of bank service quality. *International Journal of Service Industry Management*, 13(4), 362-381.
- Anistyasari, Y., & Noer, R. M. (2020). Logika fuzzy untuk sistem rekomendasi peminatan siswa. *Indonesian Journal of Engineering and Technology (INAJET)*, 2(2), 66-71.
- Arasli, H., Mehtap-Smadi, S., & Katircioglu, S. T. (2005). Customer service quality in the Greek Cypriot banking industry. *Managing Service Quality*, 15(1), 41-56.
- Asmuni, H. B. (2008). Fuzzy methodologies for automated university timetabling solution construction and evaluation (Doctoral dissertation, University of Nottingham).
- Barzegar, Y., Gorelova, I., Bellini, F., & D'Ascenzo, F. (2023). Drinking water quality assessment using a fuzzy inference system method: A case study of Rome (Italy). *International Journal of Environmental Research and Public Health*, 20, 6522.
- Caceres, R. C., & Paparoidamis, N. G. (2007). Service quality, relationship satisfaction, trust, commitment, and business-to-business loyalty. *European Journal of Marketing*, 41(7/8), 836-867.
- Chiguvi, D., & Sepepe, T. (2023). Emergent marketing strategies and their influence on the Customer Value Proposition of Fast-Moving Consumer Goods (FMCG) businesses during Covid 19 Pandemic in Botswana. *International Journal of Research in Business and Social Science (2147- 4478)*, 12(2), 40-53.
- Da Conceição, V. P., Mendes, J. B., Teodoro, M. F., & Dahlman, J. (2019). Validation of a behavioral marker system for rating cadet's non-technical skills. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 13(1).
- Djam, X. Y., & Kimbi, Y. H. (2011). A decision support system for tuberculosis diagnosis. *The Pacific Journal of Science and Technology*, 12(2), 410-425.
- Fatmawati, R. D., & Rahayu, Y. S. (2018). Analisis pengaruh experiential marketing terhadap loyalitas melalui kepuasan nasabah sebagai variabel intervening (studi pada PT BRI Syariah cabang Malang).
- Iriawan, H. (2021). Manajemen merek & kepuasan pelanggan. Penerbit NEM.
- Kumar, G. S., & Premalatha, K. (2023). STIF: Intuitionistic fuzzy Gaussian membership function with statistical transformation weight of evidence and information value for private information preservation. *Distributed and Parallel Databases*, 41, 233-266.
- Lee, J., Jeong, B., Yoon, J., & Song, C. H. (2023). Context-aware customer needs identification by linguistic pattern mining based on online product reviews. *IEEE Access*, 11, 71859-71872.
- Lemon, K. N., & Verhoef, P. C. (2016). Understanding customer experience throughout the customer journey. *Journal of marketing*, 80(6), 69-96.
- Liao, D., Jin, Y., & Zhang, X. (2023). Environmental health risk assessment of urban water sources based on fuzzy set theory. *Open Geosciences*, 15(1), 20220565.
- Mamdani, E. H., & Assilian, S. (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, 7(1), 1-13.

- Manullang, G. G., Mangunsong, S. D., Simatupang, S. D., & Yulinda, R. (2021). Pendekatan teknik fuzzy Tsukamoto untuk mengukur kepuasan pelanggan (Studi kasus Mari Photo Studio). *Jurnal Teknologi dan Ilmu Komputer Prima*, 4(2), 586-587.
- Othman, A. Q., & Owen, L. (2001). Adopting and measuring customer service quality (SQ) in Islamic banks: A case study in Kuwait Finance House. *International Journal of Islamic Financial Services*, 3(1), 1-26.
- Piltan, M., Mehmanchi, E., & Ghaderi, S. F. (2012). Proposing a decision-making model using analytical hierarchy process and fuzzy expert system for prioritizing industries in installation of combined heat and power systems. *Expert Systems with Applications*, 39, 1124–1133.
- Portela, M. C. A. S., & Thanassoulis, E. (2007). Comparative efficiency analysis of Portuguese bank branches. *European Journal of Operational Research*, 177(2), 1275-1288.
- Ross, T. J. (2005). *Fuzzy logic with engineering applications*. John Wiley & Sons.
- Sadeghi, S., & Shenmugam, A. (2004). Investigating the amount of customer complaints about the banking system. *Islamic Banking Magazine*, 65-86.
- Sahoo, A., & Baitalik, S. (2022). Fuzzy Logic, Artificial Neural Network, and Adaptive Neuro-Fuzzy Inference Methodology for Soft Computation and Modeling of Ion Sensing Data of a Terpyridyl-Imidazole Based Bifunctional Receptor. *Frontiers in chemistry*, 10, 864363.
- Shiraishi, H., Hayamizu, Y., & Hashiyama, T. (2023, July). Fuzzy-UCS revisited: self-adaptation of rule representations in Michigan-style learning fuzzy-classifier systems. In *Proceedings of the Genetic and Evolutionary Computation Conference* (pp. 548-557).
- Tang, H. H., & Ahmad, N. S. (2024). Fuzzy logic approach for controlling uncertain and nonlinear systems: a comprehensive review of applications and advances. *Systems Science & Control Engineering*, 12(1).
- Testik, O. M., & Unlu, E. T. (2023). Fuzzy FMEA in risk assessment for test and calibration laboratories. *Quality and Reliability Engineering International*, 39, 575-589.
- Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353.
- Zhang, T., Ma, F., Peng, C., Yu, Y., Yue, D., Dou, C., & O'Hare, G. M. (2022). A very-short-term online PV power prediction model based on RAN with secondary dynamic adjustment. *IEEE Transactions on Artificial Intelligence*, 4(5), 1214-1224.