Evaluation of Innovative Chatbot Applications Using Fuzzy Decision Support Techniques

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Abstract: Chatbot agents represent an innovative field in delivering superior customer service through real-time live chat. These advanced chatbots have contributed exceptional services across various sectors. The infrastructure of these applications is designed to manage large volumes of information from various disciplines, enabling immediate responses during real-time conversations. Building on this capability, this study proposes a new framework that integrates fuzzy logic with decision-making techniques to identify the most important criteria for evaluating chatbots. Specifically, the approach combines triangular fuzzy numbers with the Analytic Hierarchical Process (AHP) method, considering several specific criteria. Six core criteria were considered in developing the chatbots. To establish their priority, the method uses a pairwise comparison of criteria. Following this analysis, statistical calculations such as the mean and standard deviation were performed based on the criteria weights measured in DM. As a result, the most important criterion identified was Natural Language Understanding (NLU), with a mean value of 0.294 and a ±SD of 0.148. In comparison, the conversation design (CD) criterion had the lowest value, with an average of 0.094 and a ±SD of 0.039. The other criteria showed varying values calculated accordingly. The study's contributions are demonstrated through the proposed framework, which offers an innovative model to assist researchers and developers in software engineering.

1 INTRODUCTION

Chatbots are considered an interesting application by users and were developed at the Massachusetts Institute of Technology (MIT) by scientist Joseph Weizenbaum in 1960, under the name ELISA. In simple terms, Chatbots are computer programs, algorithms, or artificial intelligence technologies that can communicate between humans and machines [1].

The goal of this application is to create a virtual environment that enables a conversation between the user and the machine as a real person over the internet. In the current century, interest in this field has increased, supported by advances in artificial intelligence, and various Chatbots have emerged, such as Siri (2010), Cortana, and Google Assistant [2].

In recent years, various Chatbot programs have been designed to provide services to users in education, medicine, marketing, entertainment, and more. Their main services include answering users' questions and problems, conducting scientific analyses, writing research, reformulating text, booking, and delivering orders using text and voice conversation agents [3].

These applications have become available to users due to their numerous advantages. They are instantly accessible and do not require installation like operating systems. These features facilitate the development process, support reliable communication, enable rapid and seamless development, and prevent version conflicts [4].

Multi-criteria decision-making techniques provide suitable solutions in various fields. These techniques rely on rules and strategies applied to complex domains to provide the necessary solutions. One of the most prominent of these techniques is the Analytic Hierarchy Process (AHP), which is based on pairwise comparisons [5]. Its fundamental principle lies in expert preferences, their analysis, and collective decision-making. In this study, fuzzy logic was integrated with the Analytic Hierarchy Process method to evaluate ChatBot criteria and improve the results [6].

2.1 Overview of the Developed Chatbot

In this section a comprehensive survey of all relevant literature related to the case study was conducted. Table 1 shows the most important criteria for evaluating Chatbots in this paper. The table includes the results of several studies that used these criteria to evaluate and develop innovative Chatbots. The percentages for each criterion were calculated according to the literature that was adopted, with conversation design receiving the highest percentage, while integration capabilities showed the lowest percentage.

Table 1: A survey Chabot features based literature.

References	Natural Language Understanding	Conversational Design	User Interactions	Adaptability and Learning	Integration Capabilities	Cross-Platform Compatibility
[7]	√	√	×	√	×	×
[8]	×	√	×	√	×	×
[9]	×	√	√	√	√	√
[10]	×	√	√	√	×	×
[11]	√	×	√	√	√	√
[12]	×	×	×	√	×	×
[13]	×	√	√	×	√	√
[14]	√	√	×	√	×	√
[15]	√	√	×	√	√	√
[16]	√	√	√	×	×	√
[17]	×	√	√	×	√	√
[18]	√	√	√	√	×	×
[19]	√	×	×	×	×	√
[20]	√	√	√	×	√	√
[21]	×	√	√	√	×	×
[22]	√	√	√	√	×	√
[23]	√	√	×	√	√	√
[24]	√	√	√	√	×	√
[25]	√	√	×	×	×	√
[26]	×	√	√	√	×	√
[27]	√	√	×	×	√	√
Total	60%	80%	55%	70%	35%	70%

2 LITERATURE REVIEW

In this section, a comprehensive literature review of the development of Chatbots across various areas of life is presented. The survey included all studies related to the case study based on a set of features to evaluate innovative Chatbots.

Muhammad, Aliv Faizal, et al. [9] developed a Chatbot for the English language based on artificial intelligence techniques integrated with the Dialogflow platform as an artificial intelligence search engine. The accuracy of users' responses was verified using experts' opinions to evaluate the developed Chatbot. The results showed that all answers achieved 100% accuracy based on the users' response indicators. Therefore, it is expected that this program may help students improve their language skills by conducting conversations through this application.

Mittal, Mamta, et al. [18] proposed a framework for developing a Chatbot based on web technologies. Machine learning techniques were used to integrate a robot engine based on the Gradient Descent (GD) algorithm into Natural Language Processing (NLP). The GD algorithm was applied by dividing the training data into miniword batches, each containing small speeches, using a sequential approach within each mini-batch. The applied methodology relied on converting words to their stems in text using NLP, which makes the text less readable. The proposed robot helped users and hospital workers communicate to extract medical data and reduce congestion.

Vanichvasin, P. [19] developed an educational Chatbot to increase students' research knowledge by administering a questionnaire and an evaluation form to test the program on a sample of 36 Thai university students. The data were analyzed and evaluated by calculating the mean, standard deviation, and performing a t-test. The results showed that the automated Chatbot was efficient at a high level (M = 4.67, SD = 0.08), with a recommendation to add educational content grounded in research and interactive learning. Therefore, the evaluation of the target group of students showed that this technology is easy to use and understand, enjoyable to learn, and allows immediate answers without waiting for responses.

Sari, Azani Cempaka, et al [11] proposed a Chatbot for use in customer service, designed to assist customers and provide up-to-date business information. Two methods were used to develop the Chatbot: a comprehensive literature survey and a questionnaire about the program. The study focused on features that support the development of Chatbots suitable for business environments. The results included feedback on service delivery for customers using the Chatbot and evaluation of program features, with recommendations to scale up implementation.

3 METHODOLOGIES

In this study, fuzzy logic is integrated with the Analytical Hierarchy Process (AHP) method to evaluate innovative Chatbots. The decision matrix evaluates Chatbots based on the chosen six criteria. The criteria weights are calculated using the pair-wise principle. The validity of the initial results for the criteria weights is verified using the consistency index. At this stage, fuzzy logic, utilizing triangular fuzzy numbers (TFN), which represent uncertainty using three values (lower, middle, upper), is incorporated to calculate the final weights of the criteria.

3.1 Chatbot Development Framework

This section proposes a framework for developing innovative Chatbots using selected criteria. A review of Chatbot literature identifies the criteria that most influence the development process. Prioritizing and ranking these criteria is crucial for developing an effective approach. Using a fuzzy-AHP algorithm, the criteria are weighted to determine their importance. Figure 1 shows the implementation of the proposed Chatbot framework [28].

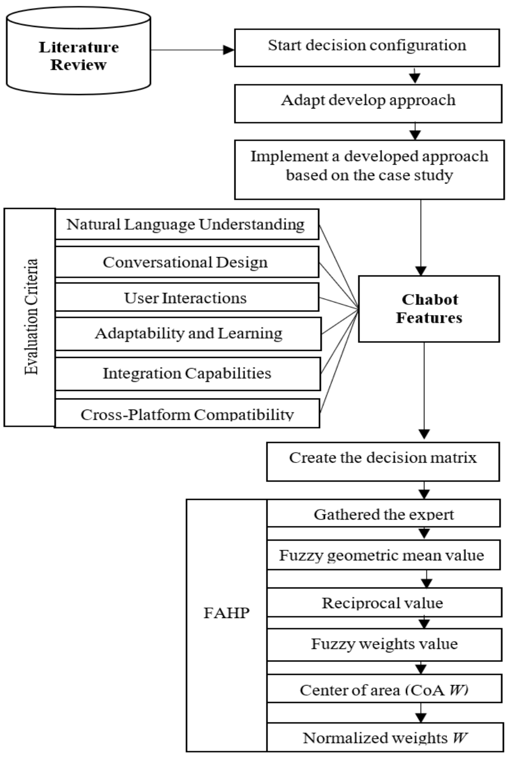

Figure 1: Architecture of the Chatbot development framework.

3.2 Triangular Fuzzy Numbers Approach

Fuzzy set theory is based on the concept of fuzzy variable probability distributions, developed by L. Zadeh [29]. This method uses fuzzy and flexible boundaries for the values represented by specific variables. A new approach based on the concept of fuzzy numbers, called fuzzy number theory, has been developed. This approach transforms linguistic variables into fuzzy triangular numbers for decision-making.

Triangular Fuzzy Numbers:

$$\tilde{a} = (a^l, a^m, a^u). \quad (1)$$

$$\mu\,\tilde{a}\,(x) = \begin{cases} (x - a_l)\,/\,(a_m - a_l) & \text{if } a_l \le x \le a_m \\ (a_u - x)\,/\,(a_u - a_m) & \text{if } a_m \le x \le a_u \\ 0, & \text{Otherwise.} \end{cases}$$

The triangular fuzzy number can be represented as in:
Where the lower number is in (a^l) the moderate number is in (a^m), and the upper number is in (a^u) respectively**.** Thus, the formula ($a^l \le a^m \le a^u$) , to be ($a^l = a^m = a^u$) and then the $\tilde{a}$ can be to as a crisp number.

3.3 AHP Method

The decision support approach includes several methods for prioritizing criteria. The Analytical Hierarchy Process (AHP) is a valuable method for calculating criterion weights, frequently applied across various fields and developed by T. Saaty [30]. According to the literature review, six core criteria were selected for Chatbot development. These criteria were evaluated based on expert preferences through a series of pairwise comparisons. Figure 2 illustrates the architecture of the proposed Analytical Hierarchy Process (AHP).

According to the AHP method, a DM is constructed for pairwise comparison of criteria based on expert preferences. This method relies on scales within a relative range of (1 to 9) as defined by Saaty. The values of the DM can be represented as:

$$A = (\dot{m} \times n).$$

The elements of the decision matrix (DM) are represented based on the triangular fuzzy number formula $\tilde{A} = (a^l, a^m, a^u)$.

$$\tilde{A} = (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}), \quad (2)$$

$$\tilde{A} = \left(\frac{1}{a_{ij}^{l}}, \frac{1}{a_{ij}^{m}}, \frac{1}{a_{ij}^{u}}\right), \quad (3)$$

where the i,j = 1,2,……, n

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}) & \cdots & (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}) \\ \left(\frac{1}{a_{ij}^{l}}, \frac{1}{a_{ij}^{m}}, \frac{1}{a_{ij}^{u}}\right) \vdots & (1,1,1) & \ddots & (a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}) \vdots \\ \left(\frac{1}{a_{ij}^{l}}, \frac{1}{a_{ij}^{m}}, \frac{1}{a_{ij}^{u}}\right) & \left(\frac{1}{a_{ij}^{l}}, \frac{1}{a_{ij}^{m}}, \frac{1}{a_{ij}^{u}}\right) & \cdots & (1,1,1) \end{bmatrix}. \quad (4)$$

Figure 3 shows the distribution of fuzzy values within the period (1 to 9) which represent the linguistic terms (equal, weak, strong, very strong, and excellent) respectively. This approach simplifies the calculation process by using the linguistic terms and converting them into triangular fuzzy numbers. Table 2 shows the conversion of values used in the decision matrix based on a five-point Likert scale for the TFN scales.

Where $0 < a_{ij}^{l} < a_{ij}^{m} < a_{ij}^{u}$, i,j = 1,2,….., n.

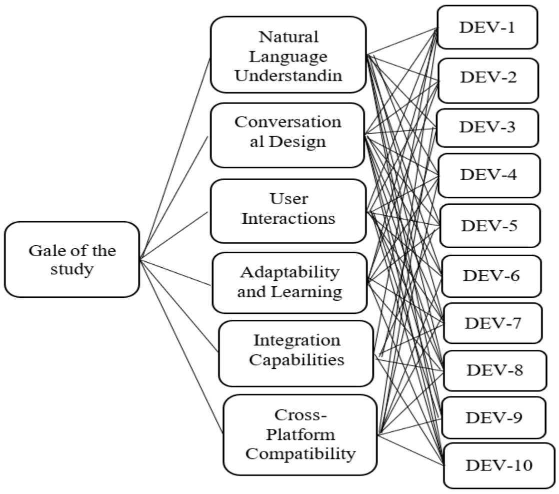

Figure 2: Analytical hierarchy process structure.

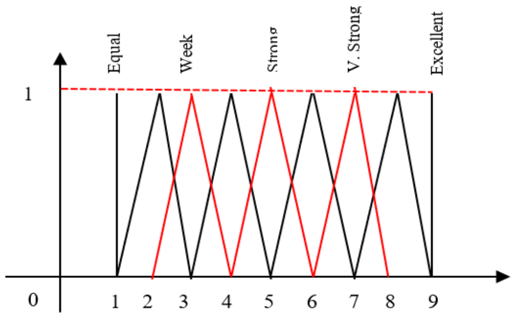

Figure 3: Measures of fuzzy linguistic numbers.

Table 2: Likert classifier for TFN scales.

Description	Scales of TFN
Equal importance	(1,1,1)
Week importance	(2,3,4)
Strong importance	(4,5,6)
Very strong importance	(6,7,8)
Excellent importance	(9,9,9)

3.4 Creating the Decision Matrix

The decision matrix creation phase is crucial and consists of four main stages. First, the matrix values based on expert opinion are normalized (transformed to a consistent scale). Second, the fuzzy geometric mean (a method for averaging uncertain values) is calculated for each criterion. In the third step, the inverse values of the criteria are used to calculate the fuzzy weights (relative importance of each criterion under uncertainty). Finally, the center of area or weighted normalization (a method for assigning final scores by balancing all factors) is used to calculate and validate the final weights of the criteria. Table 3 illustrates the steps for creating a decision matrix using the trigonometric fuzzy number (TFN) formula.

Table 3: Decision matrix for calculating the weights of the Chatbot.

Criteria	Fuzzy Geometric mean Values			Reciprocal value			CoA	Normalized weights
C1	\C1$\widetilde{G}1$	\C1$\widetilde{G}2$	\C1$\widetilde{G}3$	RV1\C1	RV2\C1	RV3\C1	Sum (W1/m)	W1 norm
C2	\C2$\widetilde{G}1$	\C2$\widetilde{G}2$	\C2$\widetilde{G}3$	RV1\C2	RV2\C2	RV3\C2	Sum (W2/m)	W2 norm
C3	\C3$\widetilde{G}1$	\C3$\widetilde{G}2$	\C3$\widetilde{G}3$	RV1\C3	RV2\C3	RV3\C3	Sum (W3/m)	W3 norm
C4	\C4$\widetilde{G}1$	\C4$\widetilde{G}2$	\C4$\widetilde{G}3$	RV1\C4	RV2\C4	RV3\C4	Sum (W4/m)	W4 norm
C5	\C5$\widetilde{G}1$	\C5$\widetilde{G}2$	\C5$\widetilde{G}3$	RV1\C5	RV2\C5	RV3\C5	Sum (W5/m)	W5 norm
C6	\C6$\widetilde{G}1$	\C6$\widetilde{G}2$	\C6$\widetilde{G}3$	RV1\C6	RV2\C6	RV3\C6	Sum (W6/m)	W6 norm

Table 4: Calculation weights of criteria based on expert judgment.

	NLU	CD	UI	A&L	IC	CPC
DEV1	0.253	0.084	0.164	0.086	0.321	0.091
DEV2	0.040	0.168	0.049	0.332	0.093	0.318
DEV3	0.153	0.151	0.046	0.276	0.084	0.291
DEV4	0.166	0.107	0.199	0.177	0.146	0.206
DEV5	0.286	0.098	0.182	0.091	0.137	0.206
DEV6	0.307	0.097	0.179	0.091	0.138	0.189
DEV7	0.366	0.062	0.149	0.067	0.235	0.120
DEV8	0.476	0.054	0.129	0.035	0.203	0.104
DEV9	0.518	0.055	0.100	0.036	0.202	0.088
DEV10	0.372	0.065	0.117	0.042	0.234	0.170
Mean	0.294	0.094	0.131	0.123	0.179	0.178
±SD	0.148	0.039	0.054	0.105	0.074	0.081

4 RESULTS AND DISCUSSIONS

This section discusses the results obtained using the Fuzzy Analytical Hierarchy Process (FAHP). Weights for six criteria were calculated based on the preferences of ten software engineering experts, with their opinions converted into numerical values for the analysis. The AHP method ensures consistency and verifies the accuracy of these opinions, maintaining a p-value of no more than 0.1. Table 4 presents the final values for the criterion weights, reflecting the experts' preferences as determined using the FAHP methodology.

Table 5: Statistical calculations of criteria.

Criteria	Mean	±SD
NLU	0.294	0.148
CD	0.094	0.039
UI	0.131	0.054
A&L	0.123	0.105
IC	0.179	0.074
CPC	0.178	0.081

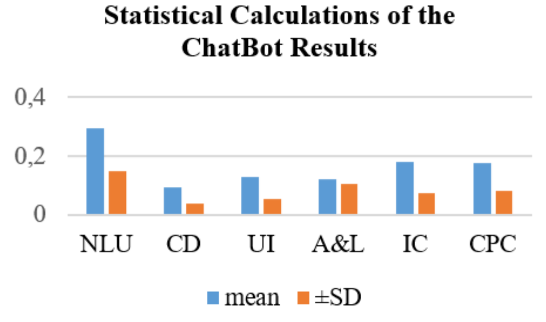

Figure 4: Statistical calculations of the ChatBot results.

In the final evaluation stage, the mean and standard deviation highlight the relative importance of each criterion in the decision matrix. The Natural Language Understanding (NLU) criterion emerged as the most significant, with a mean of 0.294 and a standard deviation of 0.148. Conversely, Conversational Design (CD) was the least important, with a mean of 0.094 and an SD of 0.039. Integration Capabilities (IC) (mean: 0.179, SD: 0.074), Cross-Platform Compatibility (CPC) (mean: 0.178, SD: 0.081), User Interactions (UI) (mean: 0.131, SD: 0.054), and Adaptability and Learning (A&L) (mean: 0.123, SD: 0.105) had intermediate significance. Table 5 presents these statistical calculations based on comparisons of software engineering experts' preferences, while Figure 4, further illustrates these findings.

5 CONCLUSIONS

Chatbots are considered one of the remarkable applications in the field of technology and software today. Many studies have focused on the most important criteria for developing Chatbots to deliver the best services to customers. according to the literature, six criteria were identified: natural language understanding (nlu), conversational design (cd), integration capabilities (ic), cross-platform compatibility (cpc), user interface (ui), and adaptability and learning (a&l). However, there are some limitations to the developed chatbots. Obtaining a dataset is currently difficult; therefore, surveys have been relied upon. In addition, evaluating the application with a specific number of experts is crucial. The paper introduced a new framework to assist researchers and developers in the field of software engineering during ChatBot development. The design of the proposed framework incorporated decision-making techniques combined with fuzzy logic. A significant challenge in this study was the conflict between standards. The FAHP method, which relies on pairwise comparisons between criteria, was used to prioritize them. Statistical calculations such as mean and standard deviation were applied based on the criteria weights measured using decision-making methods. The results showed that the most important criterion was natural language understanding (NIU), with a mean value of 0.294 and a ±SD of 0.148. The least important was conversation design (CD), with a mean value of 0.094 and a ±SD of 0.039. These criteria are essential for Chatbot developers. Therefore, the proposed framework is an innovative model that can be applied to other case studies in future projects.

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