# A Fuzzy Inference System for Selecting Product Design Concept

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**Abstract.** The product design and development process involve several phases that are implemented systematically to ensure the product is successful and meets consumer needs. One of the important stages in this process is the selection of product design concepts, which aims to determine the most appropriate design concept. The purpose of this paper is to develop a design concept selection method using the Mamdani Fuzzy Inference System (Mamdani FIS) to overcome the ambiguity and uncertainty that often arise during the evaluation and assessment process. The method is applied to select the most appropriate rice seedling planter design concept for further development. Four rice seedling planter concepts were evaluated and selected based on a set of criteria. This study resulted in a rice seedling planter design concept with a suitability score of 7.32, which is the highest score among the other concepts, making it the best concept for further product development. Furthermore, based on the final score of each concept, one concept is categorized as fair, while the other three concepts are categorized as good. The impact of this research is that the use of Mamdani FIS enables designers to manage subjective and hard to measure data more effectively and efficiently, ultimately supporting more accurate and reliable decision making in the product design concept selection process.

**Keywords:** Fuzzy Inference Systems, Fuzzy Logic, Design Concept Selection

## 1 Introduction

In the product design and development process, the product concept selection is one of the most crucial steps because it has a significant impact on the success of the product being developed. The product concept selection step is usually part of the concept development phase and occurs before the system level design and detail design phases are carried out. Its objective is to select the concept that most satisfies a set of defined criteria. The selection criteria may include technical requirements, user preferences, and manufacturing cost. Product concept selection involves evaluating multiple competing concept design alternatives under conditions of uncertainty, imprecision, and subjectivity. Traditional concept selection methods, such as the Pugh Matrix and


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Weighted Scoring Models, have limitations in handling the vagueness of qualitative judgments. To overcome this, recent studies emphasize the integration of fuzzy set theory, which has been developed and adopted to support more informed, transparent, and rational decision-making.

Fuzzy theory is a branch of mathematical logic developed by Lotfi A. Zadeh. Unlike classical binary logic that only recognizes true or false values, 0 or 1, fuzzy theory allows a value to be between 0 and 1 and allows linguistic variables (e.g., high, medium, "low") to be represented and analysed mathematically. This makes fuzzy theory very suitable for representing uncertainty, ambiguity, and linguistic reasoning that often arise in real life.

One of the frameworks or systems that uses fuzzy theory is the Fuzzy Inference System (FIS). Based on the concept of fuzzy set theory, FIS uses linguistic variables and rule-based logic that is similar to human [1]. This advantage makes FIS very good at solving problems where assessment is difficult to measure formally, or where the behavior of the system is too complex or poorly understood to be modeled conventionally.

This study aims to implement FIS in the concept selection stage to enable a more objective and comprehensive evaluation of the selection process. As a case study, a structured of FIS was applied to the selection of rice seedling planter concept design to determine the most suitable concept for further development.

## 2 Literature Review

### 2.1 Product Concept Selection

Selecting a product concept is a crucial step in developing a new product, as it requires selecting the most promising concept from several alternatives. At the selection stage, all concepts must be carefully evaluated based on criteria, such as technical requirements, consumer needs, and manufacturing costs.

The evaluation process requires a systematic approach to ensure that the concept to be further developed is the best, thereby reducing the product development failure and investment losses. Various selection methods have been developed, ranging from traditional to non-traditional. One of the most widely applied traditional methods is the Pugh matrix, which can be used for selection by qualitatively comparing the strengths and weaknesses of concepts based on a set of criteria. As an example, for application, the Pugh matrix was used to evaluate surgical aid design solutions [2]. The more objective evaluation than the Pugh matrix is the weighted scoring method in which evaluation is conducted based on a set of criteria, and each criterion is given a weight or importance level [3].

Another widely used traditional method is the Analytic Hierarchy Process (AHP), which can be used to determine criteria weights and concept scores by first decomposing a complex problem into a hierarchical structure and conducting pairwise comparisons [4]. The Quality Function Deployment (QFD) method is also frequently applied. In QFD, customer needs are linked to technical requirements through the construction of a House of Quality matrix to select the concept that best aligns with customers' needs [5].

To overcome uncertainty and ambiguity during the evaluation and assessment processes, recent research has applied fuzzy logic and MCDM methods, for instance is the research that combines Fuzzy Logic and AHP [6]. Another example is the research which integrating Fuzzy Analytic Network (Fuzzy ANP) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) [7] for the assessment and selection of design concepts.

### 2.2 Fuzzy Inference System (FIS)

FIS has been developed as an effective approach for processing ambiguous and uncertain information. FIS has been applied in various fields such as control systems, healthcare, energy and stock market modelling [8-11].

In product design and development fields, FIS integrated with AHP was used for evaluating new product design alternatives [12]. García et al. proposed FIS to model qualitative data such as delivery, price, and reliability relevant to concept feasibility assessment and supplier-related design decisions in product design [13]. FIS was applied to model individual differences in design perception in Kansei engineering contexts [14].Fuzzy inference was applied to translate physician opinion into prioritized design improvements, affecting design aspects such as user interface, reliability, and component integration in the redesign of a hip-replacement surgery aid device [15].

## 3 Method

### 3.1 Mamdani Fuzzy Inference System

A fuzzy inference system (FIS) applies fuzzy set theory to relate inputs to corresponding outputs. There are several types of Fuzzy Inference System (FIS) based on the inference mechanism used. Among those types of fuzzy inference systems, the Mamdani type FIS is one of the most commonly used, because Mamdani FIS have more intuitive and easier to understand rule bases, making they are suitable for expert system applications where the rules are created from the knowledge of human experts. Other types of FIS include Sugeno FIS and Tsukamoto FIS [16]. The Mamdani FIS process involves the 4 major steps: fuzzification, rule base, inference engine and defuzzification as shown in Fig. 1.

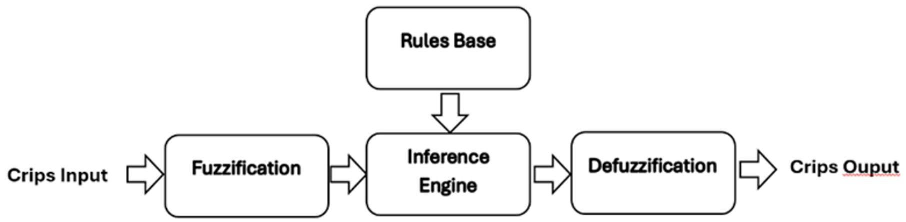


**Fig. 1.** Architecture of Mamdani FIS.

Fuzzification is the process of converting crisp numerical inputs into fuzzy sets. This is performed using membership functions that define the degree of membership of each input to linguistic labels (e.g., "Low," "Moderate," "High") [17]. Types of membership functions (MF) depending of the shapes of curve are: Triangular MF, Trapezoidal MF, Gaussian MF, Generalized Bell MF, Sigmoid MF, π-Shaped [18].

Triangular and trapezoidal fuzzy numbers are preferred because of their ease of use in operations. A fuzzy number A is a triangular fuzzy number (TFN) that has parameters (*l*, *m*, *u*) where *l, m, u* are the lower, middle and upper limit values respectively, if its membership function $\mu_A(x)$ has the following characteristics.

$$\mu_A(x) = \begin{cases} \frac{x-l}{m-l}, if\ l \le x < m \\ 1, if\ x = m \\ \frac{u-x}{u-m}, if\ m < x \le u \\ 0, if\ otherwise \end{cases} \quad (1)$$

The rule base consists of If–Then rules constructed using linguistic variables. Each rule describes a fuzzy relationship between input and output variables. These rules are expressed using fuzzy logic operators such as AND (min), OR (max), and NOT (complement) [19].The inference engine evaluates all applicable rules based on the fuzzified inputs. In Mamdani systems, the min operator is commonly used for AND operations, and max to aggregate the output of all rules.

The fuzzy outputs from each rule are combined into a single fuzzy set through aggregation**.** The aggregation process involves unifying the outputs of all fired rules into one fuzzy set on the output domain [19] Since Mamdani FIS generates a fuzzy set output, it needs to be converted into a crisp numerical value through defuzzification. Common defuzzification techniques include: Centroid Method (Center of Gravity)**,** bisector method, Mean of maximum, and Smallest/largest of maximum. [20].

# 4 Results and Discussion

## 4.1 Product Concepts

In this paper fuzzy inference system (FIS) is used for evaluating and selecting the product concepts of the rice seedling planter manual tool [21]. A rice seedling planter is a mechanical or manual tool used to plant rice seedlings in a field. It's designed to reduce the labour and time required compared to traditional hand planting, and to improve the uniformity and efficiency of planting rice. There are four alternatives product concepts to be evaluated: Concept 1, Concept 2, Concept 3 and Concept 4, that have to be evaluated and selected as shown in Fig. 2.

Based on a review of the literature and customer needs a set of selection criteria is developed for evaluating the concepts. Each concept is evaluated against each criterion to determine the suitability of the concept, whether the concept is very poor, poor, fair, good, or very good to proceed to the next development stage.

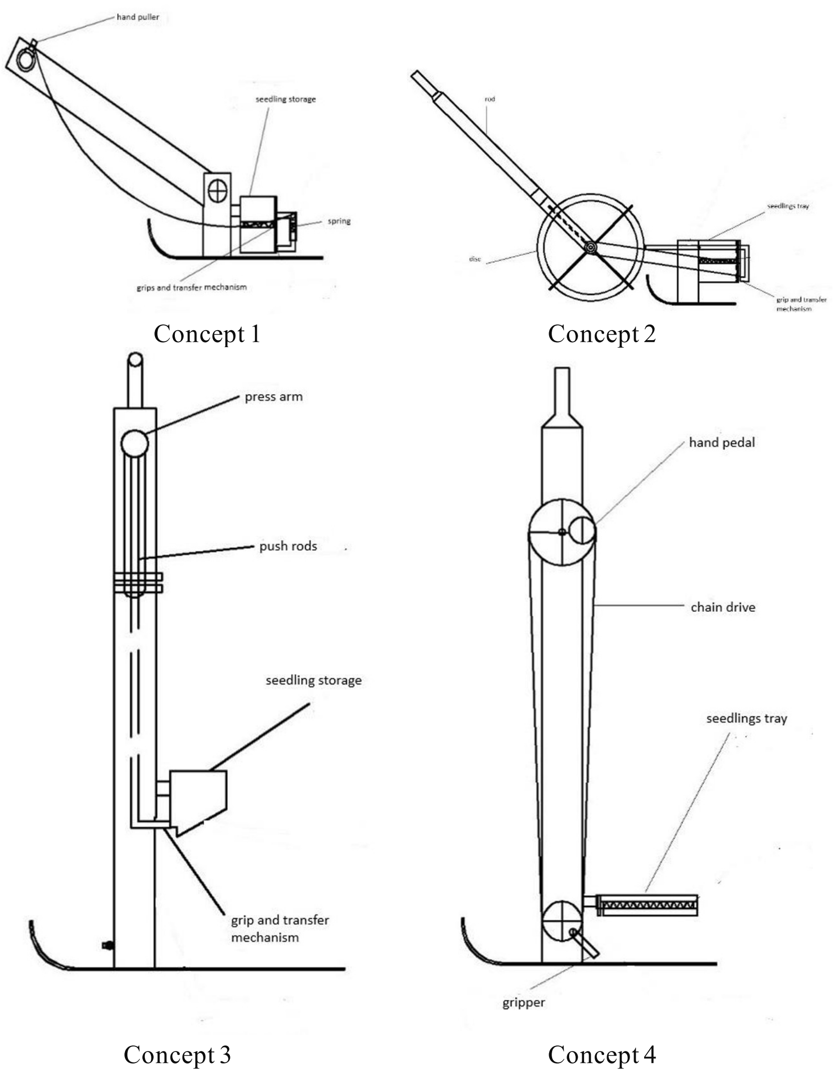


**Fig. 2.** Product concepts.

### 4.2 Develop a Mamdani Fuzzy Inference System

In developing the Mamdani FIS, the input and output variables were initially identified [22]. There are five input variables defined based on predetermined selection criteria and one output which is the rating of concepts. The input variables are ease of use, ease of handling, planting setting, ease of manufacture, and portability, while the output variable is the suitability of the concept.

Variable degrees are often described through subjective value judgments rather than precise numerical values. As a result, to incorporate the linguistic variables into a fuzzy system, they need to be represented using fuzzy subsets and corresponding membership functions [17].

Each input variable is divided into three categories: difficult, moderate and easy, while the output variable is divided into five categories: very poor, poor, fair, good, and very good. To define the fuzzy membership functions for inputs and output variables, the triangular membership functions are used. The triangular membership function of inputs and output can be seen in Tables 1 to 6. MatlabR2014 software display of triangular membership function for input variable ease of use is shown in Fig. 3.

**Table 1.** MF of ease of use and its categories.

| **Membership Function** | **Category of Ease of use** | **Meaning** |
|---|---|---|
| [1 1 2.5] | Difficult | Concept is complex and difficult to operate |
| [2 3 4] | Moderate | Concept require some learning and effort to operate |
| [3.5 5 5] | Easy | Concept is simple to learn and operate with minimal effort |

**Table 2.** MF of ease of handling and its categories.

| **Membership Function** | **Category of Ease of handling** | **Meaning** |
|---|---|---|
| [1 1 2.5] | Difficult | Concept is complex and difficult to handle |
| [2 3 4] | Moderate | Concept requires some learning and effort to handle |
| [3.5 5 5] | Easy | Concept is simple to learn and handle with minimal effort |

**Table 3.** MF of ease of planting setting and its categories.

| **Membership Function** | **Category of Scale of Planting setting** | **Meaning** |
|---|---|---|
| [1 1 2.5] | Difficult | Concept is complex and difficult to set |
| [2 3 4] | Moderate | Concept requires some learning and effort to set |
| [3.5 5 5] | Easy | Concept is simple to set with minimal effort |

**Table 4.** MF of Ease of ease of manufacture and its categories.

| Membership Function | Category of ease of manufacture | Meaning |
|---|---|---|
| [1 1 2.5] | Difficult | Concept is difficult to manufacture |
| [2 3 4] | Moderate | Concept is reasonable degree of effort to manufacture |
| [3.5 5 5] | Easy | Concept is easy to manufacture |

**Table 5.** MF of Ease of ease of manufacture and its categories.

| **Membership Function** | **Category of Ease of portability** | **Meaning** |
|---|---|---|
| [1 1 2.5] | Difficult | Concept requires effort or difficult to transfer |
| [2 3 4] | Moderate | Concept is reasonable degree of effort to transfer |
| [3.5 5 5] | Easy | Concept is easy to transfer |

**Table 6.** MF of ease of concept suitability and its categories.

| **Membership Function** | **Category of concept suitability** | **Meaning** |
|---|---|---|
| [1 1.5 3] | Very Poor | Concept has to be abandoned |
| [2.5 3.5 5] | Poor | Concept has many weaknesses |
| [4.5 5.5 6.5] | Fair | Concept has a few weaknesses |
| [6 7.5 8.5] | Good | Concept has a few minor weakness |
| [8 9.5 10] | Very good | Concept is desirable to develop |

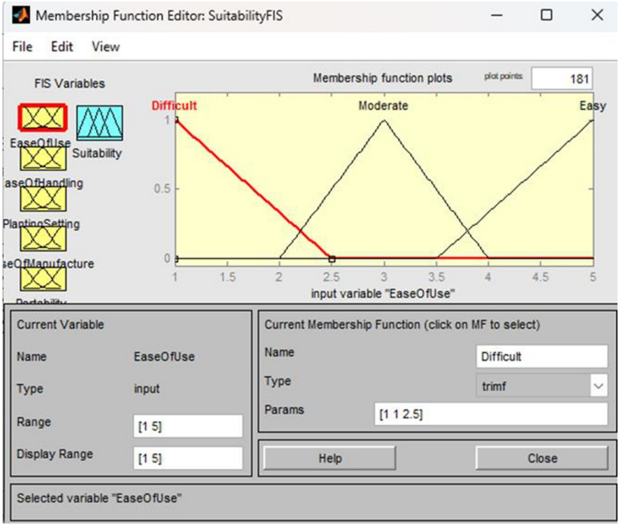


**Fig. 3.** Membership function for input variable ease of use.

**Table 7.** The judgments of the decision maker.

| Concept | Selection Criteria | | | | |
|---|---|---|---|---|---|
| | **Ease of use** | **Ease of handling** | **Planting setting** | **Ease of manufacture** | **Portability** |
| 1 | 3 | 3 | 3 | 3 | 4 |
| 2 | 2 | 5 | 3.5 | 2.5 | 2 |
| 3 | 3 | 4.5 | 3 | 4.5 | 4.5 |
| 4 | 4.5 | 4 | 3 | 3 | 3 |

Once the fuzzy membership functions were established for each criterion, the next step involved defining the If-Then rules for the inference system. In the selection concepts of rice seedling planter, 35 If-Then rules are formulated and applied. Some of the rules are as follows:

1. If (Ease of Use is Difficult) and (Ease of Handling is Difficult) and (Planting Setting is Difficult) and (Ease of Manufacture is Difficult) and (Portability is Difficult) then (Suitability is Very Poor)
2. If (Ease of Use is Moderate) and (Ease of Handling is Moderate) and (Planting Setting is Moderate) and (Ease of Manufacture is Moderate) and (Portability is Moderate) then (Suitability is Fair)
3. If (Ease of Use is Easy) and (Ease of Handling is Easy) and (Planting Setting is Easy) and (Ease of Manufacture is Easy) and (Portability is Easy) then (Suitability is Very Good)

The formation of rules is made with the help of MATLAB software and the results are shown in Fig. 4.

The rule viewers that show the values of the inputs and the corresponding computed output are presented in Fig. 4.

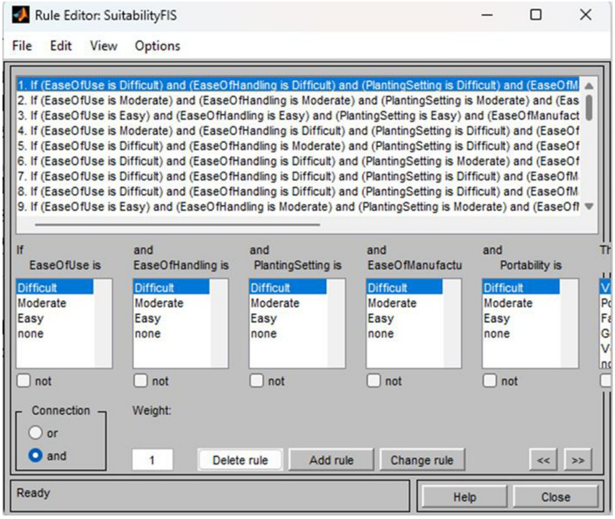


**Fig. 4.** Rules for FIS.

From the rule viewers, concept 3 received the highest suitability score among the other concepts and is categorized as good. This indicates that concept 3's development will proceed to the next phase of the product design and development process (see Fig. 5). Table 8 shows the suitability scores for each concept and its suitability category.

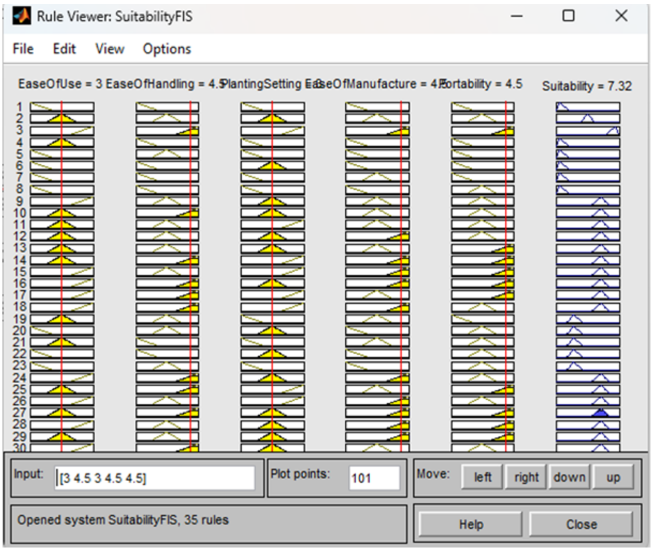


**Fig. 5.** Rules for FIS.

**Table 8.** The judgments of the decision maker.

| Concept | Suitability score | Suitability |
|---|---|---|
| 1 | 7.29 | Good |
| 2 | 5.5 | Fair |
| 3 | 7.32 | Good (develop) |
| 4 | 7.29 | Good |

From Table 8, it can be seen that concept 3 obtained a score of 7.32, concepts 1 and 4 each obtained a score of 7.29, while concept 2 obtained a score of 5.5. Referring to Table 6 as a reference, it can also be seen from Table 8 that the suitability of concepts 1, 3, and 4 is included in the good category, while concept 2 is included in the fair category.

## 5 Conclusion

A Mamdani Fuzzy Inference System (FIS) method was applied in this study for selecting the most suitable design concept. FIS has the ability to effectively manage the uncertainty, imprecision, and subjectivity of input that commonly occur in the design concept selection process. Moreover, in FIS the expert preferences can be integrated into the decision-making process when designing membership functions for variables. Compared with traditional methods that require precise input data, FIS is also more efficient in the evaluation process by using If-Then rules to determine the best design concept.

In this study Mamdani Fuzzy Inference System was implemented in the process of selecting the concept of rice seedling planter to determine the most suitable design concept to develop further. The FIS-based approach to concept selection demonstrated in this study is not restricted to the design of rice seedling planters and can be effectively applied to concept selection in fields beyond agriculture. In the design of agricultural tools, where uncertainty significantly influences the system's behavior, integrating expert knowledge into FIS can help manage incomplete information and minimize the risk of making inaccurate decisions when determining the most suitable design concept.

This study utilized five equally weighted selection criteria to evaluate the concept. Future research could consider incorporating additional selection criteria, such as durability and manufacturing cost. Moreover, to assign the weights of the selection criteria, future studies could explore integrating FIS with multicriteria decision-making methods like the Best-Worst Method (BWM) and the Analytic Hierarchy Process (AHP).

## References

1. Cao, J., Zhou, T., Zhi, S., Lam, S., Ren, G., Zhang, Y., Cai, J.: Fuzzy inference system with interpretable fuzzy rules: Advancing explainable artificial intelligence for disease diagnosis—A comprehensive review. Informative Science. **662**, 120212 (2024).

2. Zhu, T.L., Li, Y.J., Wu, C.J., Yue, H., Zhao, Y.Q.: Research on the design of surgical auxiliary equipment based on AHP, QFD, and PUGH decision matrix. Mathematical Problem in Engineering. **2022**(1), 4327390 (2022).
3. Ulrich, K. T., Eppinger, S. D., & Yang, M. C.: Product design and development. Vol. 384. McGraw-hill, New York (1995).
4. Ariff, H., Salit, M.S., Ismail, N., Nukman, Y.: Use of analytical hierarchy process (AHP) for selecting the best design concept. Jurnal Teknologi. (Sciences & Engineering) **49**, 1–18 (2008).
5. Shvetsova, O.A., Park, S.C., Lee, J.H.: Application of quality function deployment for product design concept selection. Applied Science **11**(6), 2681 (2021).
6. Olabanji, O.M., Mpofu, K.: Hybridized fuzzy analytic hierarchy process and fuzzy weighted average for identifying optimal design concept. Heliyon **6**(1) (2020).
7. Samanlioglu, F., Ayağ, Z.: Fuzzy ANP-based PROMETHEE II approach for evaluation of machine tool alternatives. Journal of Intelligent Fuzzy System **30**(4), 2223–2235 (2016).
8. Zhai, D., An, L., Dong, J., Zhang, Q.: Robust adaptive fuzzy control of a class of uncertain nonlinear systems with unstable dynamics and mismatched disturbances. IEEE Transaction on Cybern, **48**(11), 3105–3115 (2017).
9. Ghosh, G., Roy, S., Merdji, A.: A proposed health monitoring system using fuzzy inference system. Proceedings of the Institution of Mechanical Engineers, **234**(6), 562–569 (2020).
10. Suresh Kumar, K., Maheskumar, P., Girimurugan, R., Jayachandran, T., Chacko Jose, P., Basu Mallik, B.: Optimizing energy efficiency in smart grids using deep fuzzy nets: A comprehensive approach to power regulation and control. In: Applications of Fuzzy Logic in Decision Making and Management Science, pp. 61–87.Cham: Springer Nature (2025).
11. Chang, P.C., Liu, C.H.: A TSK type fuzzy rule based system for stock price prediction. Expert System With Application, **34**(1), 135–144 (2008).
12. Liu, W., Qi, J., Jin, Y., Zhou, Z., Zhang, X.: Application of fuzzy analytic hierarchy process–multi-layer fuzzy inference system in product design evaluation. Journal Intelligent & Fuzzy Systems, **45**(5), 7469–7492 (2023).
13. Garcia, N., Puente, J., Fernandez, I., Priore, P.: Suitability of a consensual fuzzy inference system to evaluate suppliers of strategic products. Symmetry **10**(1), 22 (2018).
14. Benaissa, B., Kobayashi, M., Kinoshita, K., Takenouchi, H.: A novel approach for individual design perception based on fuzzy inference system training with YUKI algorithm. Axioms **12**(10), 904 (2023).
15. Neira-Rodado, D., Ortíz-Barrios, M., De la Hoz-Escorcia, S., Paggetti, C., Noffrini, L., Fratea, N.: Smart product design process through the implementation of a fuzzy Kano-AHP-DEMATEL-QFD approach. Applied Science, **10**(5), 1792 (2020).
16. Pattiradjawane, V.E.: Comparative analysis of Mamdani, Sugeno and Tsukamoto fuzzy inference systems to support decisions on selecting outstanding employees. The Journal of Academic Science, **1**(1), 78–83 (2024).
17. Gorrin-Ortega, Y., Cardenas-Maciel, S.L., Lopez-Renteria, J.A., Cazarez-Castro, N.R.: Parameters determination via fuzzy inference systems for the logistic populations growth model. Axioms **14**(1), 36 (2025).
18. Hanumanthakari, S.: Comparative analysis of different types of membership functions for fuzzy logic controller in direct torque control of induction motor. In: Intelligent Computing in Control and Communication: Proceedings of the First International Conference on Intelligent Computing in Control and Communication (ICCC 2020), pp. 405–416. Springer, Singapore (2021).
19. Saatchi, R.: Fuzzy logic concepts, developments and implementation. Information **15**(10) (2024).

20. Lima, J.F., Patiño-León, A., Orellana, M., Zambrano-Martinez, J.L.: Evaluating the impact of membership functions and defuzzification methods in a fuzzy system: Case of air quality levels. Applied Science, **15**(4), 1934 (2025).
21. Rizaldi, T., Panggabean, S., Ayu, P.C., Jeremy, A.O.: Development of conceptual design and simulation of Dapog system rice seed seedling machine for production scale. In: IOP Conference Series: Earth and Environmental Science, 260(1), 012030. IOP Publishing (2019).
22. Ahmadi, M.H.E., Royaee, S.J., Tayyebi, S., Boozarjomehry, R.B.: A new insight into implementing Mamdani fuzzy inference system for dynamic process modeling: Application on flash separator fuzzy dynamic modeling. Engineering Application Artificial Intelligence **90**, 103485 (2020).