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Analysis of Decision-Making Systems for Production Optimization Using the Fuzzy Logic-Based Mamdani Fuzzy Inference System Method: A MATLAB Application

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Abstract

Production system uncertainties often arise due to fluctuations in stock levels and unpredictable demand patterns. These challenges can be addressed using fuzzy logic through the Mamdani fuzzy inference system method. The fuzzy inference system algorithm consists of several key steps: analyzing input and output variables, defining input-output relationships, performing fuzzification to establish fuzzy sets, constructing rule bases, and executing defuzzification. This study implements the algorithm using MATLAB version 8. The centroid method is utilized to calculate daily production volumes, ensuring precision in decision-making. For instance, on a Wednesday, with an input variable of demand set at 4,000 packages and a current stock inventory of 400 units, the system determines an optimal production volume of 4,280 packages. By employing the Mamdani fuzzy logic method, uncertainties in demand and inventory can be effectively managed, resulting in a more reliable and adaptive production system.

Keywords: fuzzy logic, fuzzy inference system (FIS), Matlab8, Mamdani method, system uncertainty.

1. Introduction

Logic is the study of reasoning. In classical logic, statements are evaluated strictly as either true or false (Dermawan et al., 2022a). However, real-world scenarios often involve situations that cannot be definitively categorized as entirely true or false. Instead, such cases are better described using degrees of truth, such as “mostly true,” “partially true,” or “somewhat true (Dermawan et al., 2022b) (Kuo et al., 2020).” Fuzzy logic provides a framework to address this uncertainty by assigning values between true and false (Setiawan et al., 2023). This concept, introduced in the 1960s in the United States, has since become widely applied in various fields, particularly in advanced economies like Japan. Fuzzy logic has been implemented as a control mechanism for various devices, such as air conditioners and washing machines (Herpratiwi et al., 2022). It is highly practical due to its simplicity, flexibility, and cost-effectiveness. However, the application of fuzzy logic in industrial systems, particularly in production decision-making systems, remains limited due to several challenges (Nugraha and Ivannuri, 2022a). These include a lack of widespread understanding and the absence of standardized, systematic methods for its development.

Fuzzy logic is uniquely capable of handling uncertainty through the creation of fuzzy systems, which function as intelligent systems in uncertain environments (Ivannuri and Nugraha, 2022). The development of a fuzzy system involves several key stages: analyzing input and output variables, defining input-output relationships, establishing membership functions for fuzzy sets, formulating rule bases using expert knowledge, and implementing the fuzzy system (Arifuddin et al., 2024). Overall, fuzzy logic leverages simple mathematical concepts, is easy to understand, and tolerates imprecise or ambiguous data (Pangestu et al., 2024). It enables systems to incorporate expert knowledge directly without requiring extensive training, translating this expertise into reliable computational models for decision-making.

MATLAB (Matrix Laboratory) was initially introduced by the University of New Mexico and Stanford University in the 1970s as a tool for numerical analysis, linear algebra, and matrix theory (Magriza et al., 2021). Over time, its capabilities have expanded significantly, with the addition of advanced toolboxes that enhance its functionality. MATLAB is extensible, meaning users can write custom functions to supplement the built-in library when specific tasks cannot be performed using existing functions (Nugraha, 2024). For those familiar with programming languages like C, PASCAL, or FORTRAN, programming in MATLAB is relatively straightforward (Haque and Sriani, 2023). This versatility makes MATLAB an ideal platform for implementing fuzzy logic systems.

In this study, explore the application of fuzzy logic to optimize production decision-making at PT 'XYZ,' a company specializing in the sale of packaged snack products. The management faces challenges in determining the precise daily production volume due to fluctuating demand and inventory levels. This study seeks to address this issue using a fuzzy logic-based approach with the Mamdani fuzzy inference method.

The objective of this research is to estimate daily production volumes using fuzzy logic by considering the variables of demand and inventory levels. Additionally, the study aims to develop a fuzzy system model to support decision-making processes at PT 'XYZ.'.

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2. Material and methods

2.1. Fuzzy Logic

Fuzzy logic is an effective method for mapping input spaces to output spaces, particularly for highly complex systems (Yunan and Ali, 2020). Traditional control systems are typically designed to manage single outputs derived from several independent inputs. Due to this lack of interdependence, adding new inputs to such systems complicates the control process and requires recalculating all associated functions (Damanik et al., 2024). Conversely, adding new inputs to a fuzzy system, which operates on the principles of fuzzy logic, merely requires the addition of new membership functions and the corresponding rules. This characteristic makes fuzzy systems inherently flexible and scalable (Nasution et al., 2024). Generally, fuzzy systems are well-suited for approximate reasoning, especially when addressing problems that are difficult to define mathematically (Amalia and Saputra, 2021). Another notable advantage of fuzzy systems is their reasoning capability, which closely resembles human reasoning. This capability allows fuzzy systems to respond effectively to qualitative, imprecise, and ambiguous information.

Fuzzy logic extends classical Boolean logic, which assigns binary values—true (1) or false (0) (Swastika and Andani, 2024). However, real-world problems often cannot be simply categorized as "black or white." Situations frequently involve shades of gray, where recognizing the nuances can help in making more intuitive and balanced decisions. Fundamentally, fuzzy sets are an extension of crisp sets, which divide a collection of individuals into two categories: members and non-members. In crisp sets, the membership value of an element xx in a set AA, typically represented as μA(x)μA(x), has only two possibilities:

- One (1), indicating that an item is a member of the set.
- Zero (0), indicating that an item is not a member of the set.

In contrast, fuzzy sets allow membership values to lie within the range of 0 to 1 (Hrehova et al., 2021). The universe of discourse refers to the entire set of permissible values for a fuzzy variable. It is typically a monotonic, ordered set of real numbers that can include both positive and negative values.

The domain of a fuzzy set represents all permissible values within the universe of discourse that can be operated upon in the context of a fuzzy set. A membership function is a curve that maps input data points to their respective membership values, which fall within the interval [0,1]. Membership values signify the degree of belonging of an element to a fuzzy set. One common method for obtaining membership values is by employing function-based approximations. Several types of membership functions are commonly used, including:

- Linear representations, such as triangular or trapezoidal functions.
- Curved representations, such as shoulder curves, S-curves, and bell-shaped curves.

2.1.1. Applications in Engineering Systems

The flexibility and adaptability of fuzzy logic make it highly applicable in engineering systems, particularly for addressing uncertainties in decision-making. For instance, in industrial process control, fuzzy logic is instrumental in managing complex variables such as demand fluctuations and inventory levels. These systems employ fuzzy inference mechanisms to process input variables, define output targets, and generate actionable insights. Membership functions play a critical role in defining the relationships between inputs and outputs, ensuring the system can operate effectively under uncertain conditions (Sakti, 2014).

In the context of production decision-making, fuzzy systems enable organizations to incorporate human-like reasoning into computational processes. By utilizing a range of membership functions and rules, fuzzy logic systems provide nuanced and reliable solutions, even when dealing with imprecise or incomplete data. For example, the Mamdani method of fuzzy inference is widely recognized for its robustness and has been implemented using tools like MATLAB (Mugirahayu et al., 2021). MATLAB's flexibility and extensive library of built-in functions make it a preferred choice for modeling and optimizing fuzzy systems in engineering research.

This study emphasizes the use of fuzzy logic as a decision-support tool for complex systems. By leveraging fuzzy membership functions and the Mamdani inference method, the proposed approach offers a scalable and practical solution for optimizing industrial production processes. Furthermore, MATLAB's extensibility enhances the accuracy and efficiency of implementing fuzzy models, ensuring their relevance for real-world engineering applications (Akgun et al., 2012).

2.2. Flowchart

The flowchart of the Mamdani fuzzy method, used as an algorithm for determining production based on the Fuzzy Inference System (FIS) method, is implemented in MATLAB and presented in the form of a flowchart, as shown in Figure 1.

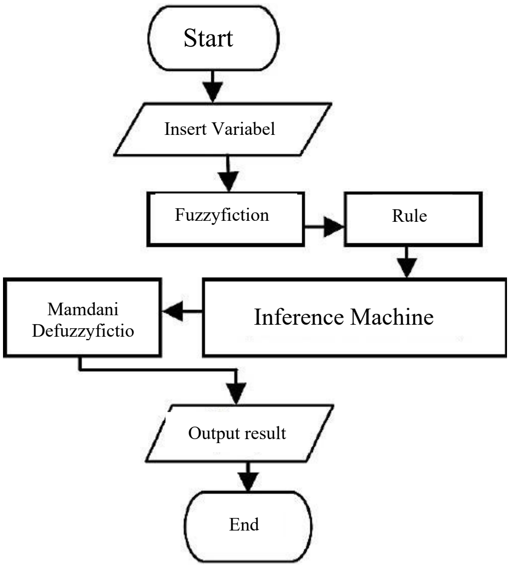

Figure 1. Mamdani flowchart

3. Results and discussion

3.1. Data Identification

The identification of data involves the precise determination of variables essential for conducting accurate calculations and problem analysis. In the context of production optimization and decision-making systems, the sales process is influenced by several interrelated factors. These include Demand Volume, Inventory Levels, and Production Quantity. In fuzzy logic systems, these variables serve as the foundational inputs for developing fuzzy membership functions and inference rules. By incorporating these factors, the system can evaluate various scenarios and generate precise recommendations for production adjustments. This approach not only addresses uncertainties in demand and inventory but also facilitates adaptive decision-making, which is particularly crucial in dynamic industrial environments.

3.2. Formation of fuzzy sets

In the Mamdani fuzzy inference method, both input and output variables are systematically divided into one or more fuzzy sets. This division is a critical step in constructing the fuzzy logic framework, as it allows for the representation of uncertainty and imprecision inherent in real-world systems. Input variables, such as demand, inventory levels, or temperature, are categorized into fuzzy sets that reflect linguistic terms like "low," "medium," or "high." Similarly, output variables, such as production quantity or control actions, are also partitioned into fuzzy sets to represent possible outcomes. This structured categorization enables the fuzzy system to process qualitative and ambiguous data efficiently.

The division into fuzzy sets enhances the adaptability of the Mamdani method to handle complex and nonlinear systems. For instance, in production optimization scenarios, this approach can effectively capture subtle variations in input parameters and translate them into precise and actionable output recommendations. By structuring the problem space into meaningful fuzzy categories, the Mamdani method ensures that the decision-making process is intuitive, robust, and closely aligned with practical engineering requirements.

3.3. Application of the implication function

In the Mamdani fuzzy inference method, the implication function employed for each rule is the minimum (min) function. This choice is central to how fuzzy logic systems handle the relationship between input conditions and their corresponding output actions, ensuring clarity and precision in the inference process.

The min function operates by truncating the membership degree of the input fuzzy set to the level determined by the rule’s antecedent. For example, if the antecedent of a rule has a degree of truth of 0.6, the membership degree of the output fuzzy set is scaled down to this value, effectively capping it. This process reflects the logical AND operation in fuzzy logic, preserving the integrity of the rule’s inference while considering the inherent uncertainty and imprecision of the system.

3.4. Defuzzy

The defuzzification process, a critical stage in fuzzy logic-based systems, is executed with the assistance of MATLAB, leveraging the advanced features provided by its Fuzzy Logic Toolbox. Defuzzification serves as the bridge between the fuzzy inference process and actionable outputs, converting fuzzy set representations into precise, quantitative results that are essential for decision-making and system control.

In MATLAB, the Fuzzy Logic Toolbox simplifies the implementation of defuzzification by offering built-in functions and graphical tools. The toolbox supports various defuzzification methods, including the centroid method (center of gravity), which is widely regarded for its balance between accuracy and computational efficiency. This method computes the crisp output by determining the center of the aggregated fuzzy set, ensuring that the result aligns with the system's modeled behavior.

3.5. Data Collection and Processing

The data utilized in this study originates from daily consumer demand, which fluctuates according to varying market requirements and the operational dynamics of PT. 'XYZ'. The inventory data reflects the production levels established by the manufacturing processes, which are adjusted to align with consumer demand patterns. This synchronization between demand and supply is critical to optimizing production efficiency and minimizing waste.

The specific data points, including consumer demand, inventory levels, and resulting production outputs, are systematically tabulated for analysis. These datasets serve as the foundation for developing a fuzzy logic-based decision-making model aimed at production optimization. The detailed information is presented in Table 1, offering a comprehensive overview of the input variables and their corresponding outcomes.

Table 1. Data on demand, stock and production quantities of goods

Day	Demand	stock	Production
monday	5.500	350	4.610
tuesday	1.000	350	3.330
wednesday	4.000	400	4.280
thursday	3.000	350	4.000
friday	5.000	700	3.910

Based on the data presented in Table 1, which covers a one-week period excluding Saturdays and Sundays (non-working days), the highest recorded consumer demand reached 5,500 packages per day, while the lowest demand was 1,000 packages per day. The inventory levels ranged from a maximum of 700 packages per day to a minimum of 100 packages per day. These fluctuations highlight the variability in both consumer demand and stock availability, emphasizing the need for a robust decision-making system to manage production effectively.

Despite these challenges, the company's current production capacity is limited to a maximum of 7,000 packages per day and a minimum of 2,000 packages per day. For instance, when consumer demand reaches 4,000 packages per day and the inventory available in the warehouse is 400 packages, the production system determines that 4,280 packages should be manufactured to meet the demand adequately while considering inventory constraints.

The calculation process, as reflected in these scenarios, illustrates the application of the fuzzy logic-based decision-making system. This method effectively bridges the gap between fluctuating consumer demand, dynamic inventory levels, and constrained production capacity. The use of the Mamdani Fuzzy Inference System (FIS) ensures that the system provides an adaptable and reliable output based on varying inputs.

Table 2 provides a detailed overview of the determination of variables and their corresponding universal sets. These universal sets define the boundaries for input and output variables within the fuzzy logic framework, facilitating a systematic approach to managing uncertainties in production planning.

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Table 2. Variabel and universal sets

Function	**Variabel Name**	**universal sets**	**explanation**
	Demand	[1.000-5.500]	Snack Demand
Input	Stock	[0-100-700]	Snack Stock
Output	Sales mount	[0-2000-7000]	Snack Production

The initial step in analyzing the system is the identification and definition of fuzzy variables to construct an effective model. For the production optimization case described, three primary fuzzy variables are determined to establish the framework for the fuzzy logic-based system. These variables, along with their corresponding fuzzy sets, are outlined as follows:

a. Demand Variable
This variable reflects fluctuations in consumer demand and is categorized into two fuzzy sets: decreasing and increasing.
b. Inventory Variable
Representing the current stock levels in the warehouse, this variable consists of two fuzzy sets: low and high.
c. Production Variable
This variable indicates the necessary adjustment to the production output and comprises two fuzzy sets: decreasing and increasing.

All these variables and their associated fuzzy sets are summarized in Table 3. This table provides a structured overview, ensuring clarity in the representation of variables for use in the fuzzy inference system.

Table 3. fuzzy set

Function	Variabel	Variabel fuzzy	Universe sets	Domain
Input	Demand	Down	[1-6000]	[0-0-100-5000]
Output	Stock	Up	[0-700]	[1000-5500-6000-7000]
	Production	Little	[0-8000]	[-24-0-100-700]
		Much		[100-700-800-900]
		decrese		[-2800-300-2000-7000]
		increase		[2000-7000-8000-9000]

3.6. Matlab

1. The 2 inputs to the FIS Editor are demand and inventory to produce goods production output.
2. To determine the membership function which consists of:
   a. The highest demand reaches 5500 packages/day
   b. The lowest demand reaches 1000 packages/day
   The membership line type becomes trapmf and
   c. The highest inventory reaches 700 packages/day
   d. The lowest inventory reaches 100 packages/day
   The membership line type becomes trapmf
   e. Just producing around 7000 packages/day
   f. It is hoped that the minimum production will reach at least 2000 packages/day
   g. Select a rule to determine the rules and implications of the antecedents and consequences

if the company's production process uses 4 fuzzy rules, namely:
[R1] IF Demand falls OR Supplies a lot Then Production of Goods decreases
[R2] IF Demand decreases OR Inventory decreases Then Production of Goods decreases
[R3] IF Demand increases OR Supplies a lot Then Production of Goods increases
[R4] IF Demand increases OR Supply decreases
THEN Production of Goods increases

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h. The function of the rule viewer is to display a membership graph of the entered values so as to produce an output value graph based on predetermined rules. It can be seen that with a demand of 4000, the supply is only 400. So the production of goods is 4280.

4. Conclusion

A decision-making model to estimate the daily number of product packages based on consumer demand and inventory levels at PT 'XYZ' has been successfully developed using MATLAB. This model applies the Mamdani Fuzzy Inference System (FIS), which integrates the MIN implication function for rule implication and the MAX method for rule aggregation.

In the specific scenario where the demand is 4,000 packages and the inventory level is 400 packages, the model computes the daily production output for Wednesday to be 4,280 packages. This estimation demonstrates the effectiveness of the fuzzy logic approach in addressing uncertainties related to fluctuating demand and inventory, providing a flexible and reliable framework for decision-making in production optimization.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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