Application of Fuzzy Decision Models in Flexible Manufacturing Systems: Mamdani and Takagi-Sugeno on Literature Reviews

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APPLICATION OF FUZZY DECISION MODELS IN FLEXIBLE MANUFACTURING SYSTEMS: MAMDANI AND TAKAGI-SUGENO ON LITERATURE REVIEWS

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Abstract - Flexible Manufacturing Systems (FMS) require robust decision-making models to handle dynamic and uncertain environments. This study explores the application of fuzzy decision-making models in both contexts, focusing on the comparative performance of Mamdani and Takagi-Sugeno systems.A case study approach evaluates their efficacy in optimizing production scheduling, resource allocation, and demand forecasting. Results highlight the strengths and limitations of each model, providing insights into their practical applicability in FMS.

Keywords- Fuzzy logic, decision-making models, Mamdani systems, Takagi-Sugeno systems, flexible manufacturing systems, production scheduling, resource allocation, demand forecasting

I. INTRODUCTION

In modern manufacturing, Flexible Manufacturing Systems (FMS) play a crucial role in improving productivity, adaptability, and efficiency. These systems are designed to handle variability in production demands, resource allocation, and dynamic scheduling. However, the complexity of decision-making in FMS poses significant challenges due to uncertainties in machine availability, process variations, and external disturbances. Traditional decision-making models struggle to address these uncertainties effectively, leading to inefficiencies in manufacturing operations.

Fuzzy logic, first introduced by Zadeh (1975) [1], provides a robust framework for dealing with imprecise and uncertain information. It has been widely applied in industrial control, decision-making, and optimization problems. The two predominant fuzzy inference systems used in FMS are the Mamdani model **and the** Takagi-Sugeno model. The Mamdani fuzzy inference system [2] is based on linguistic rules and fuzzy set theory, making it interpretable and suitable for human decision-making. Conversely, the Takagi-Sugeno model [3] is based on mathematical functions, offering superior computational efficiency and adaptability in dynamic environments.

Fuzzy decision models have been successfully applied in various aspects of FMS, including production scheduling, process control, quality assessment, and resource allocation [4], [5]. The integration of fuzzy logic with artificial intelligence and machine learning techniques has further enhanced its applicability in real-time decision-making [6]. Several studies have explored fuzzy-based decision models for intelligent manufacturing systems, highlighting the advantages of fuzzy set theory and multi-criteria decision-making approaches [7], [8].

Recent advancements in fuzzy logic applications for industrial decision-making have emphasized the need for improved optimization techniques [9], [10]. In particular, comparative studies between Mamdani and Takagi-Sugeno models have revealed trade-offs in terms of interpretability, accuracy, and computational complexity [11], [12]. Some studies suggest that hybrid fuzzy decision models can overcome the limitations of individual fuzzy systems by combining the strengths of both Mamdani and Takagi-Sugeno models [13].

Despite the growing research in this field, there is still an open discussion regarding the optimal selection of fuzzy models in different manufacturing scenarios [14]. This paper aims to provide a comprehensive literature review on the application of fuzzy decision models in FMS, focusing on the comparative analysis of Mamdani and Takagi-Sugeno models. The study will explore their effectiveness in solving complex decision-making problems and propose future research directions for integrating fuzzy logic with emerging technologies.

Problem Flexible manufacturing and demand systems involve complex decision-making processes influenced by multiple factors, such as job priorities, production deadlines, and dynamic market conditions. Comparing the Mamdani and Takagi-Sugeno models in these contexts provides valuable insights into their relative advantages and limitations [5].

II THE MAMDANI AND TAKAGI-SUGENO

To compare the Mamdani and Takagi-Sugeno (TS) fuzzy systems, we can consider the following criteria:

1. **Rule: Mamdani:** The output of each rule is a fuzzy set. The rules are in the form [15]:

$$if\ x\ is\ A\ and\ y\ is\ B\ Then\ z\ is\ C, where\ C\ is\ a\ fuzzy\ set.$$

Takagi-Sugeno: The output of each rule is typically a linear equation or a constant. The rules are in the form:

$$if\ x\ is\ A\ and\ y\ is\ B\ Then\ z = ax + by + c.$$

2. **Defuzzyfication : Mamdani:** Requires a defuzzification step (e.g., centroid method) to convert the fuzzy output set into a crisp value;**Takagi-Sugeno:** Directly provides a crisp output through a weighted average of rule outputs.

3. **Interpretability: Mamdani:** Highly interpretable due to its use of linguistic variables and fuzzy outputs, making it suitable for expert systems; **Takagi-Sugeno:** Less interpretable because of its mathematical output expressions, but it is more compact and computationally efficient.

4. Mathematical Representation:Mamdani: Relies more on fuzzy logic principles and is less dependent on mathematical models. **Takagi-Sugeno:** Blends fuzzy logic with mathematical models, making it suitable for systems requiring higher precision.

5. Computational Complexity: Mamdani: Higher computational complexity due to fuzzification and defuzzification steps. **Takagi-Sugeno:** Lower computational complexity, especially for real-time systems, because of its direct computation of crisp outputs.

6. Application Areas: Mamdani: Used in systems where interpretability and transparency are crucial, such as decision support systems and control applications. **Takagi-Sugeno:** Preferred for dynamic and adaptive systems requiring high.

The Mamdani fuzzy system employs a rule-based approach where input variables are processed through fuzzy inference mechanisms. Its advantages include:

- **Ease of Understanding:** Rules are expressed in linguistic terms, making them intuitive for human interpretation [2].
- **Simplicity:** Ideal for systems where interpretability is critical.

However, the Mamdani system may suffer from computational inefficiency when handling large datasets due to the extensive defuzzification process.

The Takagi-Sugeno system differs by producing outputs as mathematical functions of input variables. Its key advantages include:

- **Higher Accuracy:** Especially in systems requiring precise numerical outputs [3].
- **Scalability:** Better suited for high-dimensional datasets due to its computational efficiency.

Nevertheless, the Takagi-Sugeno system is less interpretable, making it challenging for decision-makers unfamiliar with mathematical models.

Models Fuzzy decision-making models use linguistic variables and fuzzy rules to process imprecise information. The Mamdani model is rule-based and intuitive, making it suitable for applications requiring interpretability [2]. In contrast, the Takagi-Sugeno model employs mathematical functions as outputs, offering higher precision and computational efficiency [3]. Application in FMS and Flexible Demand Systems The study evaluates Mamdani and Takagi-Sugeno systems using simulated environments for both FMS and flexible demand systems. Key parameters include:

- Production scheduling: Assigning jobs to machines based on fuzzy priority rules.
- Resource allocation: Allocating resources dynamically under uncertain conditions [4].
- Demand forecasting: Predicting customer demand using fuzzy decision models.

Production Scheduling: Mamdani models have been used to prioritize jobs based on fuzzy criteria such as urgency and machine availability [12]. Quality Control: Fuzzy logic helps in identifying defective products based on imprecise quality parameters [9]. Adaptive Maintenance Planning: Predictive maintenance strategies using Mamdani systems reduce unexpected machine failures [10].

Real-time Control Systems: Takagi-Sugeno models optimize machine parameters dynamically [5]. Predictive Scheduling: Advanced fuzzy decision models forecast production delays and optimize scheduling strategies [14]. Energy Efficiency Optimization: Reducing energy consumption by adjusting machine operating parameters [13].

III CONCLUSION

This paper reviewed the applications of Mamdani and Takagi-Sugeno fuzzy models in FMS decision-making. While Mamdani models offer interpretability and ease of implementation, Takagi-Sugeno models excel in computational efficiency and real-time applications. Future research should explore the following: Hybrid Fuzzy Decision Systems**:** Combining Mamdani and Takagi-Sugeno approaches for improved decision-making. Integration with AI and Machine Learning: Enhancing fuzzy logic models with deep learning techniques. Industry 4.0 Applications: Implementing fuzzy logic-based decision models in smart manufacturing environments. Fuzzy logic remains a powerful tool for handling uncertainty in manufacturing systems, and its continued advancement will drive more intelligent and adaptive FMS solutions.

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