Applying fuzzy Tsukamoto method to improve production efficiency in manufacturing industry

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Article Info

Article history:

Received Sep 23, 2024
Revised Jul 2, 2025
Accepted Aug 6, 2025

Keywords:

Decision support system
Demand and inventory management
Fuzzy Tsukamoto
Manufacturing industry
Production efficiency
Production planning
Uncertainty handling

ABSTRACT

Manufacturing can increase competitiveness and reduce costs by improving production efficiency. The study's goal is to develop a production prediction system using the fuzzy Tsukamoto technique. This method is used to model the uncertainty that occurs during the production process. Thus, production planning based on demand and inventory availability can be more accurate. After being tested on production data from a manufacturing company, the fuzzy Tsukamoto method showed the ability to make more efficient decisions than conventional methods. This system not only significantly reduces production costs but also improves overall operational efficiency, including resource management, waste reduction, and cycle time optimization. The adoption of this method provides added value to companies in facing increasing market competition while keeping production costs low without compromising quality.

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1. INTRODUCTION

Production efficacy is a critical factor in determining the success of a company in the manufacturing sector, inefficient processes can lead to wasted resources, increased costs, and decreased product quality [1]–[3]. As a result, many companies are looking for ways to improve the efficiency of their production processes [4], [5]. Uncertainty about market demand and raw material availability often leads to incorrect production planning, resulting in over- or under-production [6]. This is one of the major challenges faced in efforts to improve production efficiency. The fuzzy Tsukamoto method is one of many artificial intelligence (AI) approaches to address this problem [7]–[10].

The Tsukamoto fuzzy approach is one of the fuzzy system techniques that can deal with ambiguity in data. This method allows for modeling uncertain variables more flexibly, resulting in more accurate and adaptive decisions [11], [12]. The goal of this research is to use the Tsukamoto fuzzy approach to develop a production prediction system for the industrial sector. It is expected that this method can improve the efficiency of production planning.

The Tsukamoto method is one of the logic strategies that can handle ambiguous or uncertain data [13]–[15]. This method, in the context of production, has the ability to more accurately simulate the relationship between variables such as demand levels and availability [16]–[19]. As a result, this method is not only able to provide more accurate predictions, but also allows companies to adapt more quickly and efficiently to changing market conditions. It is hoped that this research will help improve production efficiency in the manufacturing sector by applying the fuzzy Tsukamoto method. It is anticipated that the fuzzy method's application in the decision support system will aid in determining how many things should be produced. Next, the Tsukamoto method will be employed by the decision support system to process the data in the input variables, and the output will indicate the quantity of products that require production [20].

2. PROPOSED METHOD

2.1. Research method

To plan, implement, and analyze research, these are some of the research methods used, namely:

- Literature study: the initial step involved a comprehensive literature review to gather theoretical knowledge about production efficiency and the fuzzy Tsukamoto inference system. Sources include peer-reviewed journals, technical books, prior research articles, and relevant case studies. This step established the theoretical foundation and guided the experimental design.
- Experimental method:
  1) Problem identification
     The study started by identifying inefficiencies in the manufacturing process through collaboration with a case study company. Data regarding demand variability and inventory availability were analyzed.
  2) System development
     a. Design phase
        The fuzzy Tsukamoto method was chosen for its capability to handle uncertainty in production processes. A flowchart as shown in Figure 1 outlines the system development process, which includes input, processing, and output stages.
     b. Implementation
        - The system interface was designed to allow users to input demand and inventory data.
        - A backend was built to calculate optimal production quantities using fuzzy Tsukamoto rules.
        - Results were displayed in a user-friendly interface, including visual charts for inference and output validation.
  3) Fuzzy logic application
     a. Fuzzification: crisp input variables (e.g., demand, inventory) were converted into linguistic variables using triangular membership functions.
     b. Rule establishment: rules such as "IF Demand is High AND Inventory is Low THEN Production Increases" were defined.
     c. Inference process: the system calculated the degree of rule activation (α-predicate) using the MIN implication function and determined outputs for each rule.
     d. Defuzzification: the output was transformed into a crisp production value using the weighted average method.
  4) System testing
     The developed system was tested on real production data, with demand ranging from 2,900 to 7,800 units and inventory ranging from 580 to 1,700 units. The output provided predictions for optimal production levels (4,140 to 8,460 units).

2.2. Flowchart

In the application development process, there are several stages to achieve maximum results as in Figure 1. The research flow used to develop a manufacturing production prediction system using the fuzzy Tsukamoto method is depicted in Figure 1. The flow of this system begins with a start then the next stage enters the dashboard page, on the dashboard page the user is asked to enter demand and supply to find the amount of production, and the data will be processed using the method of fuzzy Tsukamoto, and the results of the calculation will be recorded in the database. The results will be displayed on the results page, and a chart will be used to visualize the data. This flow is concluded with the completion of the process.

2.3. Fuzzy Tsukamoto

Fuzzy logic is a branch of computer science that investigates truth values that possess multiple values [21], [22]. In classical logic, truth values are either 0 (false) or 1 (true). However, fuzzy logic has actual truth values within the range of [0,1]. Fuzzy logic is based on the human cognitive process, which means that its values encompass not only 0 and 1, but also all potential values between 0 and 1 [23]. The concept of fuzzy logic enables us to address uncertainty in data and generate results that are more realistic and consistent with the conditions [24]. Fuzzy truth values may be classified as true, somewhat true, less true, not true, or very true [25].

The initial developer of fuzzy logic was Lotfi A. Zadeh, an Iranian-American scientist at the University of California. The Tsukamoto fuzzy method is one of the most popular approaches to using fuzzy logic to measure and improve production efficiency. However, Japanese practitioners created fuzzy logic. The triangular curve design is shown in Figure 2 [26].

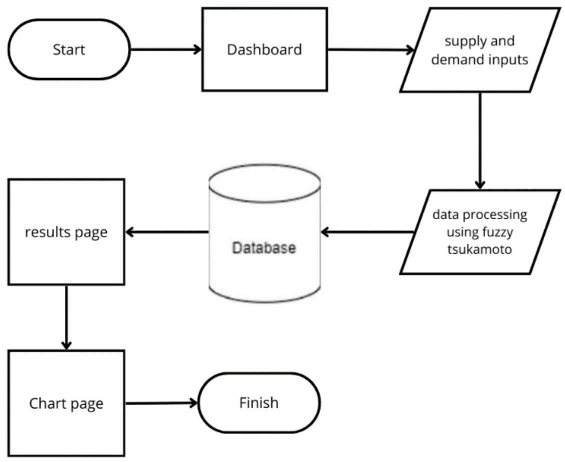


Figure 1. System flowchart

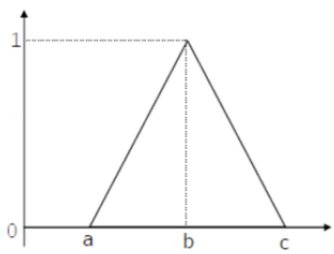


Figure 2. Triangular curve

Example formula for fuzzification [27]:

$$\mu[x] \begin{cases} 0; & x \leq a \; or \; x \geq c \\ (x-a)/(b-a); & a \leq x \leq b \\ (c-x)/(c-b); & b \leq x \leq c \end{cases}$$

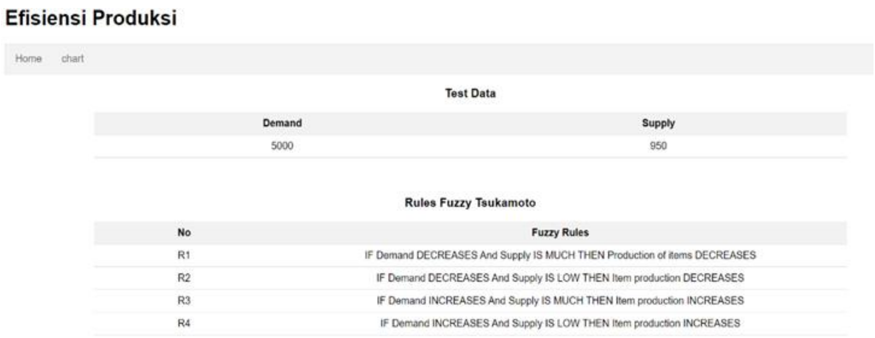
Fuzzy sets with monotone membership functions should be used to represent each outcome of the IF-THEN rules in the Tsukamoto fuzzy method. Tsukamoto fuzzy logic is chosen because it provides clear outputs from individual rules [28]-[30]. The inference results of each rule are explicitly (strictly) provided in accordance with the α-predicate (fire power), and the final result is subsequently determined by a weighted average. The operational phases of the Tsukamoto fuzzy:

a. Fuzzification is the process of converting system inputs with fixed values into linguistic variables by utilizing membership functions archived in a fuzzy knowledge base.
b. The establishment of an ambiguous knowledge base (Rule is IF THEN), that is typically employed in the Tsukamoto fuzzy model is IF (X IS A), (Y IS B), and (Z IS C), where A, B, and C are fuzzy sets, fuzzy rules in IF will connect more than one premise, and rules in THEN will connect more than one conclusion. They can use conjunction statements (AND) or disjunction statements (OR), or both [31].
c. The inference engine is a process that employs the MIN implication function to determine the α-predicate value for each Rule (α1, α2, α3, … αn) [24]. Next, the precise inference result for each Rule (z1, z2, z3, ... zn) is calculated using each α-predicate value.
d. Defuzzification, by using the average (weight average) with the formula: $z^* \frac{\alpha 1\, z1 + \alpha 2\, z2}{\alpha 1 + \alpha 2}$ and use the center area method with the formula: $Z^* \frac{\Sigma \alpha i * \text{zi}}{\Sigma \alpha i}$ [26].

3. RESULTS AND DISCUSSION

The application of the fuzzy Tsukamoto method in this study successfully demonstrated its capability to predict optimal production quantities in manufacturing, addressing uncertainties in demand and inventory data. The system calculated a production value of 6,118 units for specific inputs (demand: 5,000 units; inventory: 950 units), showcasing its adaptability and accuracy. These findings align with previous research emphasizing the advantages of fuzzy logic in managing ambiguity in production systems, leading to improved decision-making compared to conventional methods. The method enhances manufacturing efficiency by reducing costs, minimizing waste, and optimizing resources. However, its reliance on accurate input data and computational demands poses limitations that future research could address by incorporating additional variables or hybrid techniques to improve its performance in complex environments. Below is an example of the results of the research conducted.

Figure 3 shows the production value calculation system interface using the fuzzy Tsukamoto method. This shows an example where a user enters a demand value of 5,000 and an inventory value of 950. The system processes these inputs using fuzzy logic rules to predict optimal production quantities, demonstrating its ability to handle variability and provide accurate decision support for the manufacturing process.



Efisiensi Produksi

Home chart

Test Data

Demand	Supply
5000	950

Rules Fuzzy Tsukamoto

No	Fuzzy Rules
R1	IF Demand DECREASES And Supply IS MUCH THEN Production of items DECREASES
R2	IF Demand DECREASES And Supply IS LOW THEN Item production DECREASES
R3	IF Demand INCREASES And Supply IS MUCH THEN Item production INCREASES
R4	IF Demand INCREASES And Supply IS LOW THEN Item production INCREASES

Figure 3. System page for calculating data

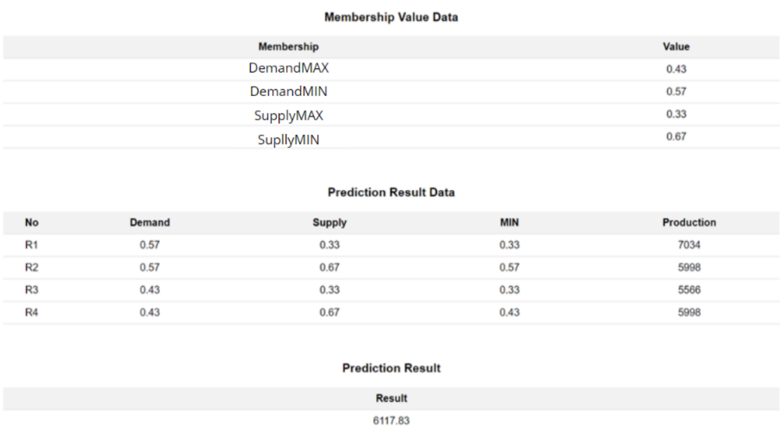
To calculate, it is necessary to calculate the largest demand (7800) and the smallest (2900), the largest inventory (1700) and the smallest (580), and the largest production (8460) and the smallest (4140). Then the membership data in Figure 4 is the result of the calculation using the fuzzy Tsukamoto formula using the following formula:

– Request MAX

  Figure 5 illustrates the Request MAX fuzzy membership function:

$$\mu requestMAX\ [5000] = (5000 - 2900)/4900\ = 0.43$$

Figure 5 depicts the membership function diagram for maximum requests (RequestMAX). The diagram represents the fuzzification process, where query values are converted into linguistic variables based on their degree of membership. This visualization helps in understanding how the fuzzy system categorizes different levels of demand, forming the basis for further inference and production prediction.



Membership Value Data

Membership	Value
DemandMAX	0.43
DemandMIN	0.57
SupplyMAX	0.33
SupllyMIN	0.67

Prediction Result Data

No	Demand	Supply	MIN	Production
R1	0.57	0.33	0.33	7034
R2	0.57	0.67	0.57	5998
R3	0.43	0.33	0.33	5566
R4	0.43	0.67	0.43	5998

Prediction Result

Result
6117.83

Figure 4. System page for calculating data

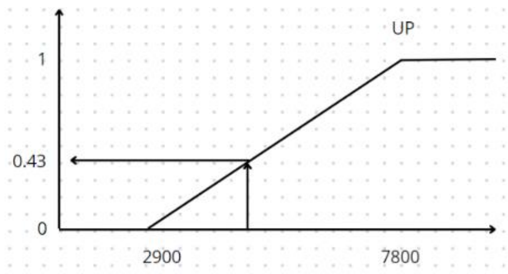


Figure 5. Diagram RequestMAX

– Request MIN

Figure 6 illustrates the Request MIN fuzzy membership function:

$$\mu requestMIN\ [5000] = (7800 - 5000)/4900\ = 0.57$$

Figure 6 illustrates the "Request MIN" diagram, which represents the membership function for the lowest request level in the Tsukamoto fuzzy method. This graph is important in determining the minimum demand membership degree, which directly affects the inference process used to calculate production values. By visualizing this data, the system can process input variables more accurately, ensuring production predictions are optimized even in low market demand scenarios.

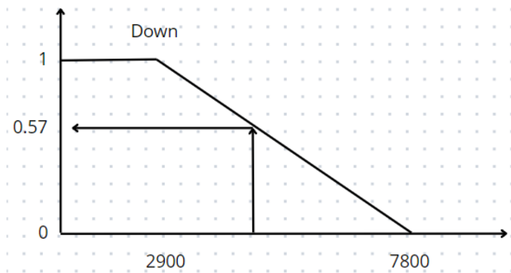


Figure 6. Diagram RequestMIN

– Supply MAX

Figure 7 illustrates the Supply MAX fuzzy membership function:

$$\mu Supply\ MAX\ [950] = (950 - 580)/1.120\ = 0.33$$

Figure 7 illustrates the "Supply MAX" membership function used in the fuzzy Tsukamoto method. This chart determines maximum supply levels based on input data, providing an important reference point for calculating production levels. By visualizing the maximum supply range, the image helps understand how the system processes supply data to make accurate and efficient production predictions.

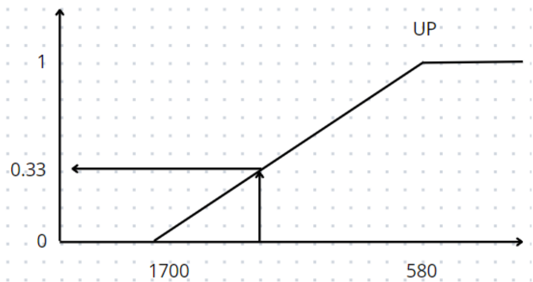


Figure 7. Diagram SupplyMAX

– Supply MIN

Figure 8 illustrates the Supply MIN fuzzy membership function:

$$\mu SupplyMIN\ [950] = (1700 - 950)/1.120\ = 0.67$$

Figure 8 illustrates the "Supply MIN" membership function used in the fuzzy Tsukamoto method. This graph represents the smallest inventory level and its membership degree, which is important for determining the level of correctness in fuzzy logic rules. The data obtained from this function contributes to the inference process, ensuring the calculation of correct production predictions based on limited supply conditions.

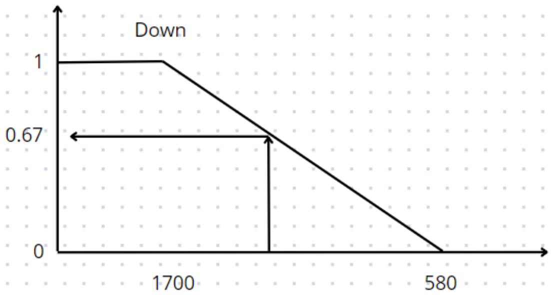


Figure 8. Diagram SupplayMIN

After finding the membership value, the next step is to find the inference from the production that matches the fuzzy Tsukamoto rule as follows.

– R1 = IF RequestMIN and SupplyMAX THEN production DECREASES

Predikat$_1$ $= \mu\text{Request}MIN\ \cap SupplyMAX$
$= MIN(\mu\text{Request}MIN[5000], \mu SupplyMAX[950])$
$= MIN(0.57; 0.33)$
$= 0.33$
$= (8460 - z)/4320 = 0.33 -> z_1 = 7034$

– R2 = IF RequestMIN and SupplyMIN THEN production DECREASES

Predikat$_2$ $= \mu\text{Request}MIN\ \cap SupplyMIN$
$= MIN(\mu\text{Request}MIN[5000], \mu SupplyMIN[950])$
$= MIN\ (0.57; 0.67)$
$= 0.57$
$= (8460 - z)/4320 = 0.57 -> z_2 = 5998$

– R3 = IF RequestMAX and SupplyMAX THEN production INCREASES

Predikat$_3$ $= \mu RequestMAX\ \cap SupplyMAX$
$= MIN(\mu RequestMAX[5000], \mu SupplyMAX[950])$
$= MIN(0.43;\ 0.33)$
$= 0.33$
$= (z - 4140)/4320 = 0.33 -> z_3 = 5566$

– R4 = IF RequestMAX and SupplyMIN THEN production INCREASES

Predikat$_4$ $= \mu\text{Request}MAX\ \cap SupplyMIN$
$= MIN(\mu\text{Request}MAX[5000], \mu SupplyMAX[950])$
$= MIN\ (0.43;\ 0.67)$
$= 0.43$
$= (z - 4140)/4320 = 0.43 -> z_3 = 5998$

The next step is defuzzification to find the predicted production value, using the following formula [28]:

$$Z = \frac{\alpha pred_1 * z_1 + \alpha pred_2 * z_2 + \alpha pred_3 * z_3 + \alpha pred_4 * z_4}{\alpha pred_1 + \alpha pred_2 + \alpha pred_3 + \alpha pred_4}$$

or if the value is rounded: 6118

$$Z = \frac{0.33*7034+0.57*5998+0.33*5566+0.43*5998}{0.33+0.57+0.33+0.43} = \frac{10156}{1.66} = 6117.83$$

4. CONCLUSION

This study successfully developed a production prediction system using the fuzzy Tsukamoto method to enhance production efficiency in the manufacturing industry. The method effectively handles uncertainties in the production process by modeling variables such as demand and inventory availability more flexibly. Testing results demonstrate that this system can generate more accurate and efficient decisions compared to conventional methods, achieving cost reduction, improved resource management, waste minimization, and production cycle optimization. The adoption of the fuzzy Tsukamoto method adds significant value to companies facing increasing market competition by maintaining low production costs without compromising product quality. This system is expected to serve as a decision-making tool for companies to plan production more effectively and efficiently.

ACKNOWLEDGEMENTS

This research is made possible by the support of the Informatics Department of Sultan Agung Islamic University, which is headed by our research supervisor. We are grateful for their assistance. During our periods of perplexity, we are also appreciative of the support of all the researchers and acquaintances who have helped us.

FUNDING INFORMATION

This research was funded by Universitas Islam Sultan Agung, Semarang, Indonesia. The authors gratefully acknowledge the financial support provided by the university in conducting and completing this study.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Muhammad Qomaruddin	✓	✓	✓		✓	✓	✓		✓	✓	✓			
Muhammad Sholahuddin	✓	✓			✓				✓					

C : **C**onceptualization
M : **M**ethodology
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E : Writing - Review & **E**diting
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Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no known conflicts of interest, either financial or non-financial, that could have influenced the results of this research. This study was conducted independently, and all findings have been presented objectively based on the data and analysis carried out by the research team.

DATA AVAILABILITY

The data supporting the findings of this study are not publicly available due to company confidentiality and research restrictions. However, the data can be obtained from the corresponding author upon reasonable request. This policy ensures transparency and reproducibility of the research while maintaining compliance with organizational agreements and privacy considerations.

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