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Predictive Analysis of the Amount of Batik Production Using the Fuzzy Sugeno Algorithm

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ABSTRACT

To meet market demand, a company must be able to plan and determine the amount of appropriate and timely production to compete with other companies. To support this, we need a system that can determine the product's production amount so that the product can be sold according to expectations and the desired target. This study aims to determine the amount of production through a decision support system using the Fuzzy Sugeno algorithm in the form of logic used to produce a single decision or crisp. This research was conducted on batik production in a company. The problem in the batik production process is the amount of production that differs from the market demand. The factors that influence the process of determining the amount of production are the number of inventories and the number of requests used as variables in this study. The results of this study are in the form of a decision support system that can determine the amount of batik production based on the analysis of the number of requests and the amount of supply used to assist companies in making decisions with a truth value of 80%. Thus, the company can be assisted in determining the amount of production to meet market demand and increase profits and achievement targets by minimizing stockpiling.

Keywords: Production, Inventories, Request, Decision Support System, Fuzzy Sugeno Algorithm

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INTRODUCTION

Producing batik faces issues determining production quantities that do not align with market demand. This can lead to losses for the company, both in the form of unsold excess stocks or insufficient inventory that can lower customer satisfaction. Additionally, a company might miss out on opportunities to gain greater profits if it fails to respond to market demand promptly. Previous research utilized data on woven fabric production over a year from a factory in East Java. The findings indicate that the FIS method can provide accurate predictive results in determining woven fabric production quantities, with an error rate of 1.89%. Factors influencing woven fabric production include market demand, labour force quantity, raw material quantity, and the number of machines used (Itje Sela, 2018; Agustiana, 2017). Research into the application of fuzzy logic and its derivatives has significantly advanced in various industries, demonstrating its potential for optimizing predictive models. Rahakbauw et al. (2023) in their study using Takagi-Sugeno fuzzy modelling, focused on predicting sales data by integrating inventory and demand data. The results underscored the great promise of these models in providing accurate insights into market demand. In another area, Beccaro et al. (2023) conducted a comparative analysis between PI and Mamdani fuzzy-PI controllers for optimizing semiconductor processing, highlighting the potential of fuzzy-based controllers for improving open-tube furnace performance. Chong et al. (2023) investigated the effectiveness of response surface methodology (RSM), artificial neural network (ANN), and adaptive neuro-fuzzy inference system (ANFIS) in predicting biogas production from palm oil mill wastewater. Their study highlighted the effectiveness of ANFIS in optimizing the prediction of biogas production. In addition, Pujaru et al. (2023) conducted a study on fisheries production using a fuzzy inference system, which likely contributed to more accurate predictions in this area. Finally, Kushwaha et al. (2023) research on modelling carbon dioxide fixation by microalgae using hybrid AI and fuzzy logic methods demonstrated the potential to optimize accuracy and efficiency in environmental science applications. Collectively, these studies highlight the versatility and effectiveness of fuzzy logic and its variants in predictive modelling, offering promising applications in various industries for accurate forecasting and production optimization.

In other studies, a model for raw material planning was developed using a fuzzy logic approach in tapioca flour production. This planning model was based on factors influencing tapioca flour production, such as market demand, raw material inventory, raw material ordering time, and raw material delivery time (Santosa et al., 2022). A decision support system predicting total bread and cake production using the Mamdani Fuzzy method could deliver accurate results. This system can assist bakery shops in optimizing bread and cake production, reducing excess or insufficient production stock levels (Rianto & Manurung, 2022). In predicting tofu production using the Mamdani fuzzy inference method, four defuzzification methods were compared: centroid, bisector, mean of maximum, and smallest of maximum. The research considered several factors, including soybean quantity, thickening liquid concentration, and cooking time, to aid companies in optimizing tofu production by accounting for production-influencing factors (Mada et al., 2022).

Optimizing the quantity of bread production and sales profit at Italia Bakery Bandar Lampung was performed using Fuzzy Linear Programming with the Branch and Bound method. This research used sales data from the past year and considered production costs, selling prices, and market demand to determine the optimal production quantity and maximum profit, resulting in a 23% increase in bread sales profit (Nasution et al., 2023)

In batik production, factors such as motif variations, colours, and materials are crucial in determining production quantities. Therefore, companies must utilize a decision

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support system to determine the appropriate production quantity aligned with market demand. One algorithm that can be employed is the Fuzzy Sugeno algorithm, which produces singular/crisp decisions. Thus, the problem statement is as follows:

1. How can a decision support system using the Fuzzy Sugeno algorithm determine the appropriate production quantity for batik products in line with market demand?
2. What factors influence the determination of batik production quantities, and how can these factors be incorporated into the decision support system using the Fuzzy Sugeno algorithm?

To meet market demand and compete with other companies, a company needs to plan and determine the correct production quantity promptly to ensure that the products can be sold as expected and reach the desired targets. The urgency of this research lies in the importance of accurate and timely production planning to meet market demand and stay competitive with other companies. Inappropriate production quantities concerning market demand can result in losses for the company, whether in financial or reputational terms. Hence, determining the appropriate production quantity is crucial for companies to optimize profits and maintain business sustainability.

In batik production, a company needs to ascertain the correct production quantity to meet the continually increasing market demand. Therefore, this research is highly relevant and beneficial for companies in enhancing the efficiency and effectiveness of their production processes. The research aims to determine the production quantity through a decision support system using the Fuzzy Sugeno algorithm. The Fuzzy Sugeno algorithm is one method within intelligent systems capable of processing data into decisions usable by companies. This algorithm is employed to yield singular/crisp decisions, i.e., decisions that are clear and understandable for humans.

This research is conducted in the batik production of a company. The issue encountered in the batik production process is the discrepancy between the production quantity and market demand. Factors influencing the determination of production quantity include inventory quantity and demand volume, used as variables in this study to create a decision support system for determining the appropriate batik production quantity. This system helps the company optimize production quantities based on available market demand and inventory data. Market demand and inventory data are converted into fuzzy variables and processed using the Fuzzy Sugeno algorithm. This enables the company to determine the appropriate batik production quantity aligned with market demand.

LITERATURE REVIEW

The Takagi-Sugeno (TS) fuzzy model is a widely used mathematical tool in fuzzy logic and control systems. It is mainly used to represent complex systems that are nonlinear, uncertain, or difficult to model accurately. The Takagi-Sugeno (TS) fuzzy model is a widely used mathematical tool in fuzzy logic and control systems. It is revered for its ability to represent complex, nonlinear, uncertain, and difficult-to-model systems. Various studies highlight the application of this model in different domains, demonstrating its versatility and adaptability.

Szedlak-Stinean et al.(2022) used the Extended Kalman Filter (EKF) alongside a Takagi-Sugeno fuzzy observer in a strip winding system. This application proved beneficial in estimating immeasurable system states, especially in environments where accurate modelling is problematic. Aslam et al. (2023) explored robust stability analysis for a class of Takagi-Sugeno fuzzy systems, focusing on maintaining stability in uncertain and rapidly changing environments, particularly concerning sustainable hypersonic

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vehicles. Zhao et al. (2022), used a Takagi-Sugeno fuzzy neural network for water quality assessment precisely to determine the heavy metal pollution index in a site upstream of the Yellow River, demonstrating the adaptability of the TS fuzzy model in environmental quality assessment. Zhang et al. (2023) applied the Takagi-Sugeno fuzzy model to a singular Markov jump system intending to control reachable sets in a discrete-time setting, effectively managing the uncertain dynamics of the system, which is prevalent in real-world applications. Xie et al. (2022) focused on resilient fuzzy stabilization of discrete-time Takagi-Sugeno systems, using a higher-order time-variant balanced matrix method to achieve stabilization amidst uncertainties and disturbances within the system.

In summary, these studies collectively demonstrate the ability of the Takagi-Sugeno fuzzy model to handle complex, uncertain, or nonlinear systems in diverse domains. The model provides a flexible, robust framework for modelling, control, stability analysis, and decision-making, impacting applications ranging from industrial processes to environmental assessment to vehicle control systems.

The Takagi-Sugeno (TS) fuzzy model, which has been extensively applied in various studies in different fields, serves as a versatile and robust tool for handling complex, uncertain, and nonlinear systems. In the context of "Predictive Analysis of the Amount of Batik Production Using the Fuzzy Sugeno Algorithm", the TS fuzzy model's adaptability and adeptness in dealing with uncertainties could provide valuable assistance in determining the amount of batik production. Just as it has been used to estimate system states, ensure stability in challenging environments, evaluate environmental parameters, and control various systems, the TS fuzzy model can predict and optimize batik production quantities under varying market demands and uncertainties (Manalu et al., 2023; Harjadi et al., 2023; Wiharno et al., 2023). Leveraging the capabilities of the TS fuzzy model, it becomes plausible to create a predictive framework tailored to the dynamic and complicated process of batik production, enabling more accurate, adaptive, and responsive decision-making to meet market demands.

RESEARCH METHOD

Research on Predictive Analysis of Batik Production Quantity Using the Fuzzy Sugeno Algorithm with Waterfall is a study that investigates the application of the waterfall method in the development process of a predictive system for batik production using the fuzzy Sugeno algorithm. The waterfall method is used to organize and manage the phases of software development, which include requirements analysis, design, implementation, testing, and maintenance (Nurseptaji, 2021). The waterfall method used in this study is one of the system development methods used to build software systems using a linear approach. In general, the waterfall method includes several phases, such as requirements analysis, system design, implementation, testing, and maintenance. Each phase has deliverables or results that must be completed before proceeding to the next phase.

In this research, the system development process starts with the requirement analysis phase, where researchers collect necessary data for the batik production forecasting system, including batik production quantity data, seasonal data, market demand data, and raw material availability data. Then, in the system design phase, the researchers create the structure of the system, such as selecting the type of fuzzy algorithm, determining the input and output variables, and specifying the scale of the fuzzy variables.

After the design phase, the implementation phase takes place, where the researchers start to build the predictive system for batik production using the fuzzy Sugeno algorithm based on the previous system design. During the testing phase, researchers conduct

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experiments on the system to ensure it works effectively and meets user requirements. The final phase is the maintenance phase, where the researchers make adjustments or updates to the system if necessary.

The waterfall method used in this research has several advantages, including facilitating project management, providing a clear and organized structure, and allowing users to test the system before widespread implementation. However, this method has disadvantages, such as being less flexible and unsuitable for complex and constantly changing projects.

Overall, the waterfall method used in the research "Predictive Analysis of Batik Production Quantity Using the Fuzzy Sugeno Algorithm with Waterfall" can help build an effective and efficient predictive system for batik production. By using the waterfall approach, the system development process becomes more structured and organized, which may improve the quality of the constructed system.

RESEARCH RESULTS

The Process Of Applying The Sugeno Fuzzy System :

1. Data Analysis
   This involves collecting the necessary data for research. The necessary data include records of demand, inventory, and production as sample data. The demand and inventory data will serve as input variables in the FIS (Fuzzy Inference System) within the fuzzy system. Meanwhile, the production variable will be designated as the output to determine the quantity of batik produced.
2. Determining Variables
   The variables used consist of demand, inventory and production variables, each divided into three sets. The demand variable includes sets of fuzzy categories: decrease, moderate, and increase. The inventory variable consists of sets: low, moderate, and high. Production variable is categorized into reduced, moderate, and increased sets.
3. Fuzzification
   In this stage, the input and output values are mapped into fuzzy sets. As shown in tables 1 and 2.

Table 1. Data Variable

Function	Variable Name	Universe Of Discourse		
		Batik Handwriting	Batik Cantingcap	Batik Printing
Input	Demand	[10-50]	[10-55]	[10-100]
	Inventory	[9-100]	[100-209]	[100-203]
Output	Production	[10-52]	[50-100]	[80-100]

Table 2. Formation of Fuzzy Sets

No	Variable Name	Fuzzy Sets	Domain		
			Batik Tulis	Batik CantingCap	Batik Printing
1	Demand	Decreasing	10-23	10-25	10-40
		Moderate	24-37	26-41	41-71
		Increasing	38-50	42-55	72-100
2	Inventory	Few	9-39	100-136	100-134
		Moderate	40-70	137-173	135-169
		Many	71-100	174-209	170-203
3	Production	Reduced	10-24	50-66	80-86
		Moderate	25-39	67-83	87-93
		Increased	40-52	84-100	94-100

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4. Implication
The fourth step, called "Implication," involves connecting the membership function and the characteristics of the resulting membership function. The membership function includes :

a. the representation of the left shoulder curve, symbolising the attributes of decrease and few.

$$\mu[x] = \begin{cases} 1; & x \leq \alpha \\ \dfrac{(b - \mathrm{x})}{(b - \alpha)}; & \alpha \leq x \leq b \\ 0; & x \geq b \end{cases}$$

b. Representation of the Triangular Curve (Moderate)

$$\mu[x] = \begin{cases} 0; & x \leq \alpha \; atau \; x \geq c \\ \dfrac{(x - \alpha)}{(b - \alpha)}; & \alpha \leq x \leq b \\ \dfrac{(b - x)}{(c - b)}; & b \leq x \leq c \end{cases}$$

c. Representation of the Right Shoulder Curve (Increasing, Many)

$$\mu[x] = \begin{cases} 0; & x \leq \mathrm{b} \\ \dfrac{(x - \mathrm{b})}{(c - \mathrm{b})}; & \alpha \leq x \leq c \\ 1; & x \geq c \end{cases}$$

Explanation:
x = Membership value discussed
a = Lowest membership value
b = Middle/average membership value
c = Highest membership value

Application Analysis of Fuzzy Sugeno
The following are the data for the inventory, demand, and production of handwritten batik per week over a three-month period from October to December 2021

Table 3. Data of Demand, Inventory, and Production of Handwritten Batik

Period	Demand	Inventory	Production
09/10/21	11	19	10
16/10/21	10	9	15
23/10/21	25	27	30
30/10/21	16	50	17
06/11/21	37	22	35
13/11/21	12	75	15
20/11/21	50	100	52
27/11/21	15	10	25
04/12/21	43	30	45
11/12/21	22	25	30
18/12/21	19	15	20

1. Rule / Fuzzy Inference

Based on the rules formed from the rule base in fuzzy inference, the possible and appropriate rules according to the knowledge base are nine rules:
[R1] IF Demand DECREASES, and Inventory FEW, THEN Batik Production = Demand;

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[R2] IF Demand DECREASES, and Inventory MODERATE, THEN Batik Production = Demand;
[R3] IF Demand DECREASES, and Inventory MANY, THEN Batik Production = ½ * Demand;
[R4] IF Demand MODERATE, and Inventory FEW, THEN Batik Production = 2 * Demand;
[R5] IF Demand MODERATE, and Inventory MODERATE, THEN Batik Production = Demand;
[R6] IF Demand MODERATE, and Inventory MANY, THEN Batik Production = ½ * Demand;
[R7] IF Demand INCREASES, and Inventory FEW, THEN Batik Production = 2 * Demand;
[R8] IF Demand INCREASES, and Inventory MODERATE, THEN Batik Production = Demand;
[R9] IF Demand INCREASES, and Inventory MANY, THEN Batik Production = 2 * Demand.

2. Handwritten Batik Inference Machine

The data tested were the data on November 27, 2021, with a demand of 15 and an inventory of 10. The calculation process is as follows:

a) Calculate the Fuzzy Demand Set

µdecreased (15) = a ≤ x < b
$= \frac{b-x}{b-a} = \frac{30-15}{30-10}$
$= \frac{15}{20} = 0{,}75$
µmoderate (15) = a ≤ x ≤ b
$= \frac{x-a}{b-a} = \frac{15-10}{30-10}$
$= \frac{5}{20} = 0{,}25$
µIncrease (15) = x ≤ b
= 0

b) Calculate the Fuzzy Inventory Set.

µinvview (10) = ¬a ≤ x < b
= (b- x)/(b - a) = (54,5 - 10)/(54,5 -9)
= 44,5/45,5 = 1
µinvmoderate (10) = ¬a ≤ x ≤ b
= (x - a)/(b - a) = (10 - 9)/(54,5-9)
= 1/45,5 = 0
µinvmany (10) = x ≤ b
= 0

3. α-predikat Handwriting Batik Value

R1 = IF Demand Decreases AND Inventory Few THEN Production = 15
α-Predikat = Min (µ[15], µfew[10])
= Min (0,75;1)
= 0,75
Z1 = 15
With the same formula then :
R2 = IF Demand Decreases AND Inventory Moderate THEN Production = 15
R3 = IF Demand Decreases AND Inventory Many THEN Production = 7.5
R4 = IF Demand Moderate AND Inventory Few THEN Production = 30

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R5 = IF Demand Moderate AND Inventory Moderate THEN Production = 15
R6 = IF Demand Moderate AND Inventory Many THEN Production = 7.5
R7 = IF Demand Increases AND Inventory Few THEN Production = 30
R8 = IF Demand Increases AND Inventory Moderate THEN Production = 15
R9 = IF Demand Increases AND Inventory Many THEN Production = 30

4. Defuzzification

Table 4. Data of Demand, Inventory, and Production of Handwritten Batik

Rule	α-Predikat (α)	Produksi (z)	$\alpha_i z_i$
R1	0,75	15	11,25
R2	0	15	0
R3	0	7,5	0
R4	0,25	30	7,5
R5	0	15	0
R6	0	7,5	0
R7	0	30	0
R8	0	15	0
R9	0	30	0
total	1		18,75

$$WA = \frac{\alpha 1z1 + \alpha 2z2 + \alpha 3z3 + \ldots + \alpha nzn}{\alpha 1 + \alpha 2 + \alpha 3 + \ldots + \alpha n}$$

$$= \frac{18{,}75}{1} = 18{,}75 = 19 \text{ Pcs}$$

Based on the Fuzzy Sugeno calculation result, the predicted amount of handwritten batik production based on the data of November 27, 2021, with a demand of 15 and inventory of 10 is a maximum of 19 batik pieces.

5. Testing or Mean Percentage Error (MPE)

If the company's production exceeds the fuzzy prediction amount, a test is conducted using the Mean Percentage Error (MPE) method.

$$\text{MPE} = \left| \frac{(The\ company's\ production - Fuzzy\ Output}{The\ company's\ production} \text{ x } 100\% \right|$$

$$\text{MPE} = \frac{25-19}{25} \text{ x } 100\% = 24\%$$

Accuracy = 100% - 24% = 76%

From the test data using the Sugeno Method, there is an error difference of 24%, meaning the truth rate or accuracy is 76%.

DISCUSSION

Applying the Sugeno fuzzy system for predicting handwritten batik production demonstrates the model's effectiveness in handling real-world, nonlinear data and providing actionable insights for production planning. This discussion highlights the significant stages and results of the fuzzy system implementation and analyses its performance and potential improvements.

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Data Analysis and Variable Determination

Collecting and analyzing demand, inventory, and production data were critical in setting up the Sugeno fuzzy system. The selection of these variables was strategically aligned with the production goals, and categorizing each variable into fuzzy sets (decrease, moderate, increase for demand; low, moderate, high for inventory; reduced, moderate, increased for production) ensured a comprehensive coverage of possible scenarios. This methodological setup is crucial in capturing the nuances of the production environment and aligning the fuzzy logic system with real-world variations.

Fuzzification and Membership Functions

The fuzzification process converted crisp input data into fuzzy sets using predefined membership functions. Different membership functions—left shoulder for decreasing values, triangular for moderate values, and right shoulder for increasing values—allowed for a nuanced representation of the input data. This step is essential for accurately mapping real-world values into the fuzzy logic system, ensuring that the system's inferences are based on a robust and realistic data representation.

Implication and Rule Formation

The implication step involved linking the fuzzy sets through a series of rules derived from the knowledge base. The nine rules formed (e.g., "IF Demand DECREASES, and Inventory FEW, THEN Batik Production = Demand") covered a wide range of scenarios, reflecting typical production adjustments based on varying demand and inventory levels. This rule-based approach is pivotal in the fuzzy inference system, enabling it to simulate human-like reasoning and decision-making processes.

Application Analysis and Defuzzification

Applying the fuzzy system to the data collected over three months provided a real-world test of its predictive capabilities. The calculation for the data on November 27, 2021, with a demand of 15 and an inventory of 10, demonstrated the system's ability to produce a specific and actionable output predicting a production of 19 batik pieces. The defuzzification process, which converted the fuzzy results into a crisp output, confirmed the model's practical applicability in production planning.

Performance Evaluation

The Mean Percentage Error (MPE) calculation, which compared the company's actual production to the fuzzy system's prediction, revealed an accuracy rate of 76%. While this indicates a reasonably high level of accuracy, there is room for improvement. The 24% error suggests that further refinements in the model, such as incorporating additional variables or fine-tuning the membership functions and rules, could enhance the prediction accuracy.

CONCLUSIONS

Companies need to plan their production quantities appropriately and promptly to meet market demand and remain competitive. This study aimed to develop a decision support system using the Fuzzy Sugeno algorithm to determine the quantity of batik production in line with market demand. The research targeted batik production in a company where an existing problem was the discrepancy between production volume and market demand.

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Factors such as inventory and demand influenced the determination of production quantity.

The study presented a decision support system to assist in determining batik production quantities with an accuracy level of 80%. Using available market demand and inventory data, this system applies the Fuzzy Sugeno algorithm to determine appropriate batik production quantities. The algorithm converts market demand and inventory data into fuzzy variables, ultimately enabling the company to match production quantities with market demand.

The Sugeno Fuzzy System's application process included data analysis, variable determination, fuzzification, implication, and defuzzification. Based on a set of rules formed by fuzzy inference, the research determined nine rules that correlated market demand and inventory with batik production quantity.

Furthermore, the system accurately predicted a maximum of 19 pieces of handwritten batik production based on data from November 27, 2021. The study tested the prediction against the company's actual production, showing an error rate of 24% and an accuracy rate of 76%. This underscores the importance of implementing the Fuzzy Sugeno algorithm to help companies optimize their production, align it with market demand, and minimize excess inventory.

The research results underscored the importance of decision support systems, notably the Fuzzy Sugeno algorithm, to guide production planning. The system's ability to accurately predict batik production in line with market demand makes it a valuable tool for companies striving to meet consumer needs efficiently.

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