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LB Lamp Production Planning Based on Fuzzy Logic Approach at PT XYZ

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A B S T R A C T

Increasingly tight competition in the industrial market encourages companies to optimize production planning to meet customer demand efficiently. Effective production planning is key in achieving this goal, as it guides entities towards achieving their goals appropriately. This research aims to develop a fuzzy method for production planning at PT XYZ, a lamp manufacturing company. This method is designed to assist PT XYZ The approach used in this research includes historical data analysis, forecasting techniques using the time series method, calculating raw material inventory, and applying fuzzy logic to determine optimal production quantities. Based on the results of fuzzy calculations, the production amount for the next period of 7,000 product units can be a suggestion for companies to avoid production shortages and excesses due to uncertainty in product demand.

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1. INTRODUCTION

Increasingly tight industrial competition requires companies to be able to meet customer demands in a timely and cost-efficient manner. One way to achieve this goal is to carry out proper production planning. Production planning is part of operations management that can help an entity achieve and direct the company to its expected goals. Implementing production planning in a company can help a company determine the required production capacity so that it can overcome fluctuations in demand and avoid excess or shortage of inventory capacity. PT XYZ is a lamp manufacturing company that produces various types of lamps. Production is carried out using the Make to Stock (MTS) and Make to Order (MTO) systems. The business unit that implements the Make to Stock (MTS) production system is the retail lighting business unit. The problems most often experienced in this business unit are related to excess or shortage of finished goods inventory. This is caused by inaccurate demand forecasting due to dynamic and fluctuating market demand. Apart from that, the safety stock implemented is still not optimal: the existing safety stock focuses more on finished good products, while the safety stock of raw materials is inadequate to meet market demand. Another problem is that production scheduling does not consider the availability of raw materials and finished goods stock in real-time. This problem results in financial losses due to high storage costs, potential product damage, and opportunity loss due to unfulfilled demand (Triawan, 2019). On the other hand, this problem results in customer dissatisfaction due to the company's inability to fulfill demand on time and the unavailability of the desired product. This also has an impact on low production efficiency due to the buildup of unsold products and shortages of needed products.

This research aims to develop a fuzzy method in determining production planning at PT XYZ. The fuzzy method can help PT XYZ to prepare production plans by considering several variables, such as market demand in the form of more accurate demand forecasting using the time series method (Gaspersz, 2008). Determining optimal safety stock of raw materials using the ROP (Reorder Point) method. As well as the availability of finished goods by conducting interviews with the production department to ensure product availability before production starts. The application of the fuzzy method in production planning is expected to provide benefits in the form of increasing production efficiency through reducing storage costs, increasing customer satisfaction by fulfilling demand on time and increasing the availability of desired products. This research combines fuzzy methods, forecasting using time series, safety stock optimization with ROP (Reorder Point), and real-time data integration for production planning. This combination is expected to produce a more accurate, adaptive, and efficient production planning model.

2. LITERATURE REVIEW

2.1 PDSA Cycle (Plan, Do, Study, Action)

Determining research priorities is carried out in several method stages. The research was carried out by preparing a research plan using the PDSA theory (Plan, Do, Study, Action). The PDSA concept is a continuous improvement cycle method consisting of four stages (Chen et al., 2021): (a) Plan. At this stage, problem identification, goal setting, and plan formulation are carried out to achieve these goals. (b) Do. Implement the plans made in the previous stage. (c) Evaluation (Study). Collect data and analyze implementation results to find out whether goals have been achieved. (d) Action. Based on the results of the analysis, take corrective actions to improve processes and achieve better goals.

2.2 ABC Analysis

There are three classes in product grouping using ABC analysis. ABC analysis in inventory control is a method of classifying goods based on their value and importance. Items are grouped into classes A, B, and C. Items in class A have a large value and impact on inventory costs, so they require greater control and attention. Goods in class B have moderate value and impact, while goods in class C have low value and impact. ABC analysis is based on the Pareto principle which states that 80% of the effects come from 20% of the causes. In the context of inventory, this is interpreted as 20% of goods in class A (a small number) contributing to 80% of the company's total inventory value. Items in class A have the highest value (around 70-80% of the total inventory value) even though the number of items is small (20%). Goods in class B have a medium inventory value (around 15-25%) and a greater number of items than class A. Goods in class C have the lowest inventory value (around 5%) but the number of items is the highest.

2.3 Forecasting

Forecasting is done to determine future product demand. Forecasting is only carried out for independent products, namely products that are not directly related to the BoM (Bill of Materials) or final product. Meanwhile, for dependent products, material requirements need to be calculated first. One forecasting technique that can be used is the time series technique. The time series method can be used for data that repeats itself over time or changes over time (Gaspersz, 2008). Several time series methods are used, namely:

a. Exponential Smoothing

The Exponential Smoothing Method is a time series forecasting method that uses weighting and recording past data. This method is suitable for repetitive data with trend, cyclical, fluctuating and unstable patterns. The following is the equation for the Exponential Smoothing method (Reicita, 2019).

$$Ft = Ft\text{-}1 + \alpha\ (At\text{-}1 - Ft\text{-}1)$$

Information:

- Ft: Predicted value for period t

- Ft-1: Predicted value for the previous period (t-1)
- α: Smoothing constant (0 < α < 1)
- At-1: Actual value for previous period (t-1)

The α value is determined based on the data pattern (Martono, 2018):

- Stable data: α = 0,1 - 0,3 (the more stable it is, the smaller it is α)
- Trend data (up/down): α = 0,3 - 0,5
- Trend data with small fluctuations: α = 0,6 - 0,8

b. Moving Average

The Moving Average method is a forecasting method that uses past data to calculate a moving average. This average value is then used as a prediction value for the next period. The following is the equation of the moving average method (Gaspersz, 2008).

St+1 = (Xt + Xt-1 + …Xt-n +1) / n

Information:

- St+1: Predicted value for the period t+1
- Xt: Period data t
- n: Moving average timeframe (number of periods)

The calculation results were tested using the calculation of the smallest error value with the MAD, MSE and MAPE indicators. The following is the explanation:

a. MAD (Mean Absolute Deviation)

MAD is a measure of forecasting error that shows the average absolute difference between predicted values and actual values. MAD is calculated by adding up the absolute values of these differences and dividing them by the number of periods (Martono, 2018).

Formula MAD:

$$\text{MAD} = \sum \frac{(\text{Predicted Value} - \text{Actual Value})}{\text{Number of Periods}}$$

b. MSE (Mean Square Error)

MSE is a measure of forecasting error that shows the average squared difference between the predicted value and the actual value. MSE is calculated by adding the squares of these differences and dividing by the number of periods.

Formula MSE:

$$\text{MSE} = \sum \frac{(\text{Predicted Value} - \text{Actual Value})2}{\text{Number of Periods}}$$

c. MAPE (Mean Absolute Percentage Error)

MAPE is a measure of forecasting error that shows the average absolute percentage difference between predicted values and actual values. MAPE is calculated by adding up the absolute value of the percentage differences and dividing it by the number of periods. The MAPE formula is as follows with the MAPE criteria can be seen in Table 1 (Martono, 2018).

$$\text{MAPE} = \sum \frac{\frac{\text{Absolute Value of Deviation}}{\text{Sales}}}{\text{Number of Periods}} \times 100\%$$

Table 1. Criteria of MAPE

Criteria	Percentage MAPE
Very good	<10%
Good	10% - 20%
Enough	20% - 50%
Not accurate	>50%

2.4 Safety Stock and ROP (Reorder Point)

a. Safety Stock

Safety stock is a safety stock to anticipate shortages of raw materials due to demand or other unexpected events. Safety stock can help companies determine the ideal amount of raw materials that need to be prepared to handle fluctuating demand (Alfi et al., 2022) and (Rachmawati & Lentari, 2022).

formula Safety Stock:

$SS = \sigma d \times \sqrt{L}$

Information:

- SS: Safety stock
- σd: Standard deviation of demand
- L: Lead time

b. Reorder Point (ROP)

ROP is the point when raw material inventory needs to be reordered to avoid stock shortages. The ROP calculation considers average daily demand, purchase lead time, and safety stock (Sholehah et

al., 2021) and (Hilman Setiadi, 2020). Formula Reorder Point:
ROP = (D x L) + SS
Information:

- ROP: Reorder Point
- D: Average Daily demand
- L: purchase lead time
- SS: Safety stock

3. RESEARCH METHOD

Fuzzy logic is logic that has vague or vague values. This theory allows true and false values simultaneously. Fuzzy logic uses real values between 0 and 1 to indicate the truth of variables (Mudasir et al., 2021) and (Adedeji et al., 2023). Some terms used in fuzzy logic calculations include: (a) Membership functions are the essence of fuzzy logic. This function determines the level of membership of an element in the domain (parameter value) to the related fuzzy group. Membership functions have defined lower and upper bounds, so they always range [0,1] (Marimin et al., 2013). The commonly used forms of membership functions are triangular and trapezoidal. (b) Fuzzy VariablesFuzzy variables are variables that have uncertain or fuzzy values. In fuzzy logic, the value of a fuzzy variable is represented as a degree of membership. The degree of membership is a value between 0 and 1 which shows how much a value is included in a fuzzy set. (c) Universe of Conversations, the term "universe of speech" or "range" refers to the range of values that a variable can take in a specific domain. (d) Fuzzy Set Domain. A fuzzy set domain is a collection of values that can be taken by a variable in a fuzzy system. It refers to the range or domain assigned to a particular variable within the scope of a fuzzy system. (e) Fuzzy Set Operator. Fuzzy operators are operators applied in information processing using fuzzy logic. This function is used to combine or manage fuzzy sets or membership values to produce the expected output.

The stages used to determine fuzzy logic calculations include: (Basriati, M.Sc & Safitri, M.Mat, 2021): (a) Determination of Fuzzy Clusters. This stage determines the fuzzy groups that will be used in the fuzzy system. These groups are defined based on the values of the associated variables. (b) Application "IF-THEN" Rule.This stage creates rules that link input and output variables. This rule is made in the form of "IF-THEN", where "IF" is a condition and "THEN" is a consequence. (c) Inference Process Fuzzy. This stage uses the rules that have been created to produce fuzzy output. This fuzzy output is then converted into a definite value: (i) The universe of speech is the range of values that a variable may take. (ii) The domain of a fuzzy set is the set of values that a variable may take in a fuzzy system. (iii) Fuzzy set operators are used to combine or manipulate fuzzy sets. Defuzzification: Changes fuzzy output to crisp/firm values. The defuzzification method used is: Center of Area (CoA). Method of CoA used to calculate the defuzzification value. The CoA formula is as follows (Santosa et al., 2022).

$$x\,\mathrm{CoA} = \frac{\int \mu(x)\ x\ dx}{\int \mu(x)\ dx}$$

Information:

- μ(x): Membership function
- x: Output variable value
- dx: Differential elements
- ∫: Represents the integral over the entire domain of the output variable

4. RESULT AND DISCUSSION

4.1 Result of ABC Analysis

There are three classes in the grouping. Class A represents goods with the lowest number of units but provides the highest value, class B has a medium number of units with medium value, and class C has the largest number of units with the lowest value. The data required includes demand data for one year and product prices. By using ABC analysis, product priorities can be determined for further calculation processes to increase production efficiency. This process involves ranking product demand data based on its rupiah value, followed by cumulative calculations to determine the class of each product. The following LB products are included in class A in Table 2.

Table 2. Product LB A class

Product (LB)	% Value	% Cumulative	Class
7	11%	11%	A
6	10%	21%	
9	9%	30%	
10	9%	40%	
5	8%	48%	
2	8%	55%	
4	7%	62%	
3	7%	69%	

Based on Table 2, LB7 products have the largest value in class A, so this product will be the focus of research.

4.2 Forecasting Calculations

Forecasting or forecasting aims to project the number of goods that will be demanded in the future. PT XYZ the data used is demand data for LB7 products for one year. The available data has a fluctuating pattern so the method used uses a quantitative method with time series (Gaspersz, 2008). The following is data on demand for LB7 products for one year in Figure 1.

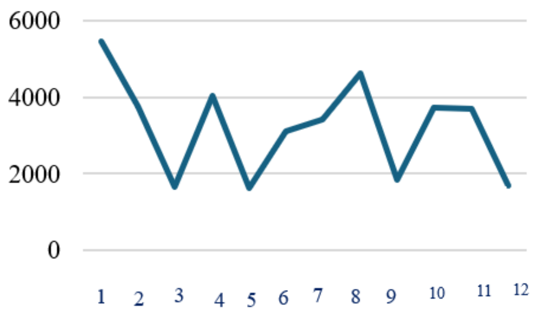

Figure 1. LB demand for one year

Data patterns that change over time and do not form a trend line can use moving average and exponential smoothing methods (Gaspersz, 2008). The moving average applied looks at the average sales for two, three and four quarters. Meanwhile, according to the book (Martono, 2018) the alpha (α) value in exponential smoothing calculations with quite fluctuating data patterns can use α, namely 0.2; 0.3; 0.4; and 0.5. Calculations are carried out using POMQM software to get accurate results. The data used to carry out calculations is the result of aggregation from each quarter, so that 4 quarters are obtained as a basis for forecasting calculations for the next quarter. The following are the results of calculations using POMQM which can be seen in Table 3.

Table 3. Result of forecasting with POMQM

Method	MAD	MSE	MAPE	T5
MA (2)	135,5	22.204,3	1%	9.494,0
MA (3)	719	516.961	8%	9.241,7
MA (4)	719	516.961	8%	9.649,3
ES (α= 0,2)	1.307,87	2.124.007	2%	10.087,3
ES (α= 0,3)	1.167,98	1.904.775	13%	9.820,8
ES (α= 0,4)	1.042,33	1.767.910	12%	9.621,2
ES (α= 0,5)	979,92	169.945	11%	9.475,6

Based on Table 3, the lowest error value obtained with the MAPE indicator is 1% with the forecasting method in the form of a two-quarter moving average. The resulting forecast for the next period is 9.494 product units. This forecasting value will be input to the fuzzy logic calculation.

4.3 Safety Stock and Reorder Point (ROP)

a. Safety Stock

Safety stock and Reorder Point (ROP) calculations are used to anticipate product shortages and excesses. PT XYZ has a fluctuating demand value with a lead time that tends to be constant. Factors that influence safety stock calculations include demand, lead time, and the service level value expected by the Company. This service level value is represented in the form of a Z score in the normal distribution table. PT The average daily product demand is 155 products, so a standard deviation demand value of 66 products is obtained. The lead time required to order raw materials is 90 days or 3 months.

$$SS = Z \text{ x } Sd \text{ x } \sqrt{LT}$$
$$SS = 1{,}65 \text{ x } 66 \text{ x } \sqrt{90}$$
$$SS = 1.036$$

From the calculations made, the amount of raw material safety stock required in the fifth quarter for LB7 products is 1,036 product sets, in accordance with the service level desired by the company.

b. Reorder Point (ROP)

The ROP calculation is used to see the minimum inventory point so that the company needs to reorder. The reorder point (ROP) calculation is carried out by considering the average daily demand for the product. Average demand is calculated from the total demand each month, then divided by the number of working days in that month for 21 days. The daily demand value is multiplied by the waiting time for purchasing raw materials, which is 90 days. The calculation results show that the ROP value for LB7 products is 14,976. This ROP number will be used as input in the fuzzy calculation process.

ROP = (Average of Demand x Lead time) + safety stock
ROP = (155 x 90 days) + 1.036
ROP = 14.976 product units

Determining optimal production quantities uses safety stock and Reorder Point (ROP) values as key information in fuzzy calculations. Uncertain conditions in market demand can increase the possibility of stock outs. To overcome decision making amidst this uncertainty, fuzzy values can be considered by considering variables related to potential stock outs.

4.4 Calculation of Fuzzy Logic

The use of the fuzzy method in calculations involves three input variables and one output variable. The input variables considered are raw material inventory levels, demand, and finished goods stock. The desired output variable is the amount of production in the current period. All maximum and minimum values for each input and output variable over the past year were obtained from interviews with experts at the company. The following are the discussion universe values for each variable in Table 4.

Table 4. Universe of conversations

Function	Variabel	Universe of conversations
Input	Raw material	0 – 50.000
	Request	0 – 10.000
	FG Supplies	1000 – 21.000
Output	Production quantity	0 – 20.000

The first step is to determine the membership set model for each existing variable, followed by determining the membership set. Before determining the membership set value, it is necessary to identify the membership function that will be used. There are two types of membership functions, namely triangular membership functions and trapezoidal membership functions. Using a membership set with one highest value can form a triangular membership function, while with two highest values it can form a trapezoidal membership function. The following is an explanation for each existing input and output variable

a. Raw Materials (input)
   Domain parameters are created based on maximum and minimum values obtained from interviews with PPIC staff. There are three parameters for raw material input, including low, medium and large. Each parameter has one highest value thus forming a triangular membership function. The membership set formed can be seen in Figure 2.

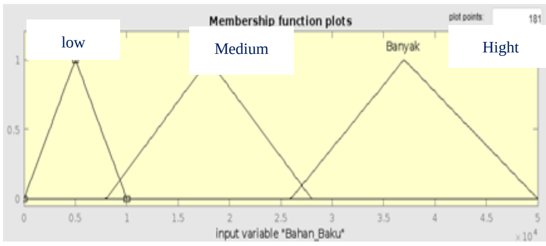

Figure 2. Membership set raw material input

   Determining the degree of membership requires input from the results of the Reorder Point (ROP) calculation to determine the amount of production in the following month. Based on calculations (ROP), the amount of stock that needs to be maintained for the next period to avoid running out of stock is 14.976 sets, which is included in the medium parameter category. From this value, we can calculate the degree of membership with a combination of medium parameter membership functions, namely 0,61.

b. Request (input)
   The use of membership functions for demand variables using a triangular form with the highest value for each parameter can be referred to in Table 5.

Table 5. Request parameter values

Parameter	Values of Parameter		
Low	0	1500	3000
Currently	2500	5000	7000
Tall	6000	10000	10000

The selection of the triangular membership function is based on the maximum value range for each parameter, where the low parameter has the highest value of 1.500, the medium parameter is 5.000, and the high parameter is 6.000. An illustration of set membership for raw material variables can be found in Figure 3.

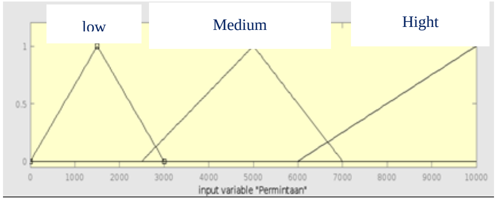

Figure 3. Membership set of demand

Based on forecasting results with using several methods, the smallest error value was found using the 2-quarter moving average method, namely 9,494 product units, which is included in the high parameter category. The results of calculating membership degrees using this input show a result of 0,87.

c. Supply of Finished Good (Input)
There are 3 parameters in the finished good inventory variable, namely low, medium, and high. The membership set value for this parameter can be seen in Figure 4.

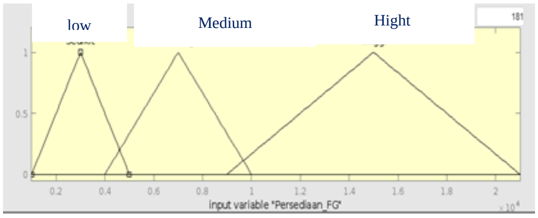

Figure 4. Membership set of finished good

The image above shows that there is one highest value for each parameter, thus forming a triangular membership function. Next, determine the membership degree value using input from the results of interviews with the production department and obtain finished good inventory in the previous period, namely 9,000 product units. The results of calculating the degree of membership obtained a value of 0.33.

d. Production Amount (output)
The output variable includes total production planned for the current period.

Based on discussions with the head of production, the value domain for each parameter is determined based on the maximum and minimum values. Details of these parameter values are in Table 6.

Table 6. Parameter value production quantity

Parameter	Values of Parameter		
A little	0	2500	5000
Currently	4000	7000	10000
Lots	8000	14000	20000

Based on the table above, the membership set formed can be seen in Figure 5. The membership set formed is triangular, with one maximum value for each parameter.

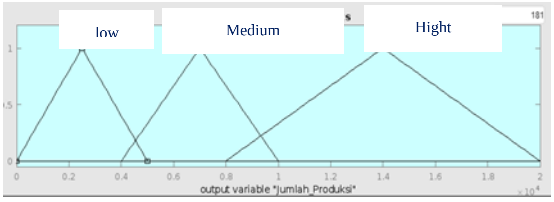

Figure 5. Membership set of output

The next step is to determine the fuzzy rules (rule base). Determination of fuzzy rules is based on the results of interviews with experts. It was found that there were 27 rule bases formed which can be seen in Table 7.

Table 7. Rule Base Fuzzy

No.	Raw Materials	Demand	Supply FG	Amount Production
1	A little	Low	A little	A little
2	A little	Low	Currently	A little
3	A little	Low	Tall	A little
4	A little	Currently	A little	A little
5	A little	Currently	Currently	A little
6	A little	Currently	Tall	A little
7	A little	Tall	A little	A little
8	A little	Tall	Currently	A little
9	A little	Tall	Tall	A little
10	Currently	Low	A little	A little
11	Currently	Low	Currently	A little
12	Currently	Low	Tall	A little
13	Currently	Currently	A little	Currently
14	Currently	Currently	Currently	Currently
15	Currently	Currently	Tall	A little
16	Currently	Tall	A little	Currently
17	Currently	Tall	Currently	Currently
18	Currently	Tall	Tall	Currently
19	Lots	Low	A little	A little
20	Lots	Low	Currently	A little
21	Lots	Low	Tall	A little
22	Lots	Currently	A little	Lots
23	Lots	Currently	Currently	Currently
24	Lots	Currently	Tall	A little
25	Lots	Tall	A little	Lots
26	Lots	Tall	Currently	Lots
27	Lots	Tall	Tall	Currently

Next is determining the output variable implication function that best suits the rule base formed, namely No.17. Followed by determining the fuzzy operator using the MIN rule which is obtained from the smallest value of membership degree, namely 0.33. This value is used to determine the magnitude of the x1 and x2 values of the output variable implication function with the following results:

$$0{,}33 = \frac{\text{x1} - 4.000}{7.000 - 4.000}$$
$$\text{x1} = 5.000$$

$$0{,}33 = \frac{10.000 - \text{x2}}{10.000 - 7.000}$$
$$\text{x2} = 9.000$$

After knowing the values of x1 and x2, the next step is to determine the defuzzification value to change the vague value to a clear value (crisp). Defuzzification is determined by preparing the output function as follows:

$$\text{f (a, b, c)} = \begin{cases} 0 & ; \quad \text{x} \le 0 \\ \dfrac{\text{x} - 4.000}{7.000 - 4.000} & ; \quad 4.000 \le \text{x} \le 5.000 \\ 0{,}33 & ; \quad 5.000 \le \text{x} \le 9.000 \\ \dfrac{10.000 - \text{x}}{10.000 - 7.000} & ; \quad 9.000 \le \text{x} \le 10.000 \\ 0 & ; \quad \text{x} \ge 10.000 \end{cases}$$

The method used is Center of Area (CoA) by determining the moment value and area for each output function. Based on the existing rule base, the focus of defuzzification calculations is carried out in medium areas. There are 3 regions formed including two right triangles and one rectangle. The results of calculating the area for the three flat shapes are as follows:

Area 1 = ½ base x height
= ½x(5.000–4.000)x (0,33)
= 166,67
Area 2 = Length x Width
= (9.000 – 5.000) x 0,33
= 1.333,3
Area 3 = ½ base x height
= ½ x (10.000 – 9.000) x (0,33)
= 166,67
Total Area = Area 1 + Area 2 + Area 3
= 1.666, 67

Next, determine the moment value by carrying out integral calculations on each composition of the output function which is formed as follows:

Moment Calculation 1:

$$Momen\ 1 = \int_{4000}^{5000} (0{,}0003x - 1{,}33)\, x\, dx$$
$$Momen\ 1 = \left[\int_{4000}^{5000} 0{,}0003x^2 - 1{,}33\, x\right]$$
$$Momen\ 1 = \left[\int_{4000}^{5000} 0{,}00011x^3 - 0{,}66667x^2\right]$$
$$Momen\ 1 = (-2.777.777.777{,}78) - (-3.555.555{,}6)$$
$$Momen\ 1 = 777.777{,}8$$

Moment Calculation 2:

$$Momen\ 2 = \int_{5000}^{9000} (0{,}33)\, x\, dx$$
$$Momen\ 2 = \left[\int_{5000}^{9000} 0{,}16667x^2\right]$$
$$Momen\ 2 = (13.500.000 - 4.166.666{,}67)$$
$$Momen\ 2 = 9.333.333$$

Moment Calculation 3:

$$Momen\ 3 = \int_{9.000}^{10.000} (3{,}33 - 0{,}0003x)\, x\, dx$$
$$Momen\ 3 = \left[\int_{9.000}^{10.000} 3{,}33x \quad - 0{,}0003\, x^2\right]$$
$$Momen\ 3 = \left[\int_{9.000}^{10.000} 1{,}6667x^2 - 0{,}000111111x^3\right]$$
$$Momen\ 3 = (55.555.555{,}56) - (54.000.000)$$
$$Momen\ 3 = 1.555.555{,}56$$

$$\sum \quad Momen = 11.666.666{,}7$$

The results of the moment and area calculations are used to calculate the defuzzification value. This value is the output used as the recommended production quantity value:

$$\text{Defuzzification} = \frac{11.666.666{,}7}{166{,}67}$$
$$\text{Defuzzification} = 7.000$$

From the calculations that have been carried out, it was found that the total production for the next quarter is 7,000 product units, with the aim of avoiding stock outs or excess stock. The calculation results were then compared with the results obtained using MATLAB software with the same results which can be seen in Figure 6.

Figure 6. Calculation results with mathlab

5. CONCLUSION

The research results show that combining fuzzy methods, forecasting using time series, optimizing safety stock with Reorder Points, and real-time data integration has resulted in more timely and efficient production planning. ABC analysis identified the LB7 product as the focus of the research, while the forecasting method using a two-quarter moving average gave the best results with accurate forecasting values. Thus, this research makes a significant contribution in improving the production planning process at PT XYZ, as well as providing a basis for further research in developing more sophisticated and integrated production planning methods. It is hoped that these findings can provide valuable guidance for the manufacturing industry in improving operational efficiency and responding to the challenges of increasingly fierce competition in the global market.

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