Barge Capacity Plan Analysis for Coal Transhipment Process with Decomposition Forecasting and Fuzzy Logic

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Abstract

PT XYZ is a company in the supply chain of coal distribution activities from Jetty Loa Tebu to Muara Berau. The coal distribution fleet operated is a barge guided by tugs. PT XYZ must be able to plan the needs of effective coal distribution capacity to avoid uneven distribution, anticipate fluctu ations and increase demand for transhipment. This study aims to calculate the projected number of coal transhipment and distribution capacity needs by barges at PT XYZ in the next 5 years and determine the appropriate capacity planning strategy to be implemented in meeting the needs. The research method used is forecasting to project the number of coal transhipment from 10 years ago, the methods being compared are regression and decomposition which appropriate for long-term forecasting. The accuracy of the forecasting model is compared and shows that forecasting using decomposition has better results to apply because it has the smallest RMSE and MAPE values. Coal transhipment projection in 2027 is 1,008,638 MT and we build with Fuzzy Logic Mamdani Optimization model with some rules and parameter. Furthermore, based on forecasting and optimization result we need to add 8 barges to balance the transhipment projection in 2027, a cost analysis comparison is conducted for alternative lead, lag, and average capacity strategies. The calculation results show that the lead capacity strategy has the lowest cost value and is the best capacity planning strategy by investing in or adding sets of tugs and barges.

Keywords
Transhipment, Decomposition, Forecasting, Fuzzy Logic Mamdani and Capacity Strategy.

1. Introduction

The area of Indonesia is around 7.81 million km^2. Of the total area of Indonesia, 3.25 million km^2 is sea and 2.55 million km^2 is the Exclusive Economic Zone. The efficiency of maritime transportation and logistics is very important for developing the economy in Indonesia (Amin 2021). According to Shipping and Transport Maritime Management, Netherland Maritime Institute of Technology one of the businesses that depend on waters is the coal mining sector. According to Fatai (2004) Coal commodities in Indonesia have a strategic role in supporting energy security while at the same time supporting the country's economy, especially foreign exchange earnings from exports, with looking at the real contribution to Indonesia's development, the coal industry is considered potential and prospective for the long term. However, not all products can be exported due to limitations such as irregular ship schedules, high transportation and logistics costs, and lack of logistics assets in the loading area. (Tinastiti 2019). Therefore, a company that acts as a supply chain integrator is needed to increase the efficiency and effectiveness of coal delivery to customers through the assistance of information and communication technology systems. In Indonesia, Coal Logistics will be sent on Barge assisted by Tug and due to low waterways we need transshipment activity to transfer cargo from barge to vessel, which showing in Figure 1.

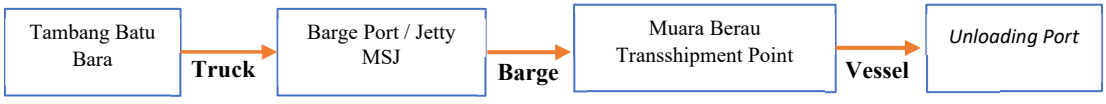

Figure 1. Flow of Coal Logistics in Indonesia

Based on below operational data from 2013-2022, the idle time for tugboats and barges at the Loa Tebu Jetty is very high. The demand for coal loading and unloading services using tugboats and barges is growing fluctuatively and tends to be slow. Planning the need for the number of tugboats and barges is required routinely every year which refers to the actual coal sales data from the Jetty to the Offshore Going Vessel (OGV).

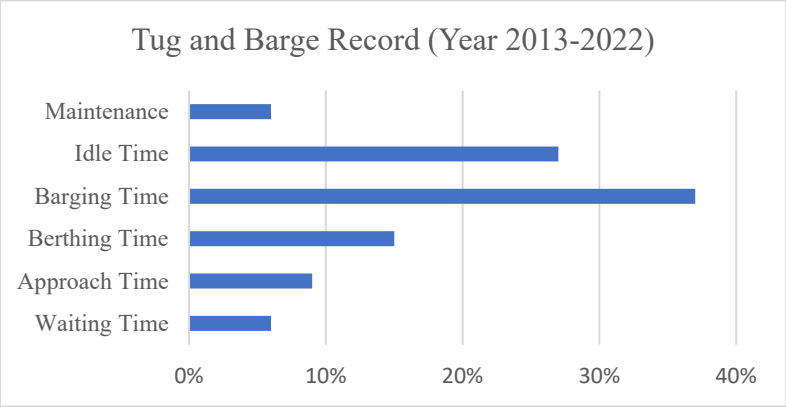

Figure 2. Operational Data Tug & Barge

When shipment coal up significantly, company had to cooperate with third parties to rent tugboats and barges on the spot basis in order to meet consumer demand, even though rental rates tended to increase. Based on company data, rental rates for barge and tugboat sets have increased by 7% from 2020 to 2021.

In the opposite condition, the number of requests that moves down will encourage increased costs arising from fleet management and losses for the company as a result of high operational costs. Therefore, setting the right number of fleets is very necessary to ensure the operational activities of distribution services to consumers can run safely, efficiently and effectively. The company's operational performance data shows that the total consumer needs of the company from 2013 to 2022 have experienced movements as shown in the following graph in Figure 3:

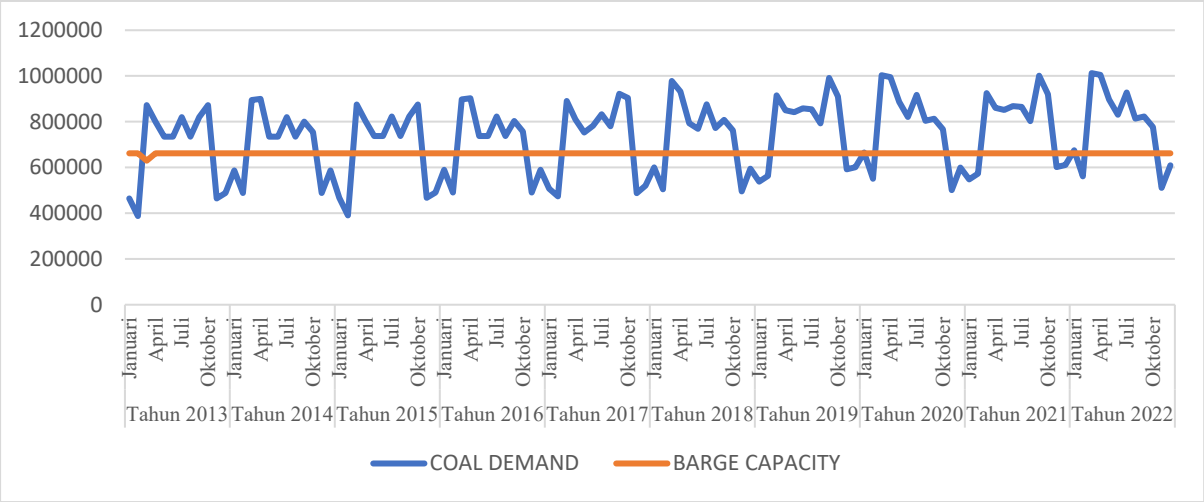

Figure 3. Comparison between Coal Demand and Barge Capacity

1.1 Objectives

Based on the changes in the trend above, to be able to determine the right corporate action in determining the strategy for planning the capacity of the barge fleet for the transhipment process, it is necessary to analyze the projection of the amount of coal transhipment using forecasting methods and calculating the cost components that affect the procurement of barge tugboat sets based on forecasting results for can determine the appropriate capacity strategy.Fulfillment of the demand for barges will depend on good long-term forecasting accuracy. The number of tugboats and barges operating at the Jetty Loa Tebu needs to have a coal distribution capacity that can meet coal demand from buyers through OGV.

Table 1. Tug & Barge Spesification

Total	10 Sets

TUGS	***Year Built***	2004
	Class	RINA
	Engine	Yanmar 6RY 17D-GV / 1000 PSx2 / 1500 rpm
BARGES	***Year Built***	2004
	Class	RINA
	LOA	300 ft
	Gross Tonnage	7500 ft3
Economic Age		20 Tahun
Coal Transport Capacity		7500
Utility		0,83
Efficiency		0,94

In this study we will focus to 10 sets of tug and barges which sailing from Jetty Loa Tebu to Muara Berau transshipment anchorage. We will try to optimize the number of sets to reach higher profit and minimize the idle, the number sets will calculated with capacity strategy such as lead capacity, lag capacity and average capacity.

2. Literature Review

2.1 Forecasting

Heizer dan Render (2015:113) defining forecasting is the art and science of predicting future events. Forecasting will involve taking historical data (last year's sales) and projecting it into the future with a mathematical model. Companies are always required to estimate or predict the amount of customer demand for their products. According to Russell dan Taylor (2011:497), product demand forecasting determines how much inventory is needed, how much product must be made and how much material must be purchased from suppliers to meet the forecasted customer needs. Without proper forecasting, inventory in large quantities and costs must be prepared to anticipate the uncertainty of demand by customers. As we can see on the figure 3, the data is seasonal trend so in this study we are using regression and decomposition, at the end we will compare the errors between these methods.

2.1.1 Regression

Regression forecasting model (linear) using independent variables (bound) in response, to predict the dependent variable (independent) or variable control. According to (Putri et al., 2019), the steps for calculating linear regression are as follows Identify the dependent (y) and independent variables (x), then prepare the data that will be used as a variable x and y, calculate the value of x2, xy, as well as respectively the total value, then calculate the value of a and b using formulas (2) and (3). The form of the linear regression equation model using formula (1). Regression (simple linear) is useful when there is a linear relationship nor non-linear between the dependent and independent variables, as in the following mathematical agreement :

$Y = a + bX$ (1)

where :

Y = predicted value; a = intercept coefficient (intercept); b = slope coefficient (slope); X = time period.

2.1.2 Decomposition

The decomposition forecasting model performs forecasting by separating different components of the archetype of a number of data series. Component These include trend factors, cyclical factors, and seasonal factors. The trend factor shows the behavior of the data in the long term, the cycle factor indicates both the decline of a particular industry, and seasonal factors have associated with periodic fluctuations of fixed or constant length, ie influenced by factors such as temperature and weather. Basically, the decomposition model assumes that the data series is available is a combination of periodic data components as follows:

Data = Pattern + Irregular (Random) (2)

The random element assumes the difference between the combined effects of the 3 (three) components (trend, cycle, and seasonality) of the data series with data that is Actually.

2.1.3 MSE & MAPE

MSE calculation is done with adding up all forecasting errorsin each period and then squared and divided by the number of periods forecasting (Astuti et al., 2019). MSE formulated as follows (Kumila et al.,2019):

$MSE = \sum(Xt-Ft)2\ n$ (3)

MAPE represents the percentage of error from forecasting results to real data oncertain period, where the results of this MAPE will provide information about error percentage too high or low (Astuti et al., 2019). MAPE formulated as follows (Kumila et al.,2019) :

$MAPE = (100n)\sum |Xt - FtXt|$ (4)

Where :

Xt = actual data for a certain period (t).

Ft = forecasting value in certain period (t).

n = amount of dataforecasting model ability can is said to work well if it increases low MAPE value generated.

According to (Maricar, 2019) value calculation MAPE has a range of values that can be used as a benchmark for determine the ability of a calculation forecasting model.

2.2 Fuzzy Logic

Fuzzy is linguistically defined as blurry or vague which means something value can be true or false at the same time. In fuzzy known degrees membership which has a value range of 0-1. fuzzy logic is a logic that has a value of obscurity or ambiguity between true or false. In fuzzy logic theory a value can be true or false simultaneously. But how much truth and error depends on the weight of its membership. Fuzzy logic has degrees of membership in the range 0 to 1 and fuzzy logic shows how far a value is true and how far something is the value is wrong. Fuzzy logic is an appropriate way to map something input space into an output space and has a continuous value. Fuzzy expressed in degrees of membership and degrees of truth. Therefore something can be said to be partly right and partly wrong at the same time (Kusumadewi 2004).

2.3 Capacity Strategy

Capacity planning is the process of determining the potential needs of your project. The goal of capacity planning is to have the right resources available when you'll need them. Resources could mean individuals with the right skills, time available to add another project, or the necessary budget. 3 types of capacity strategy are Lead Capacity, Lag Capacity and Average Capacity. Lead capacity strategy, or lead strategy, is the process of increasing production capacity when you're in anticipation of a high demand. Lag strategy planning is the process of increasing production capacity when you're experiencing a real-time demand. Match strategy planning is a combination of lead capacity planning and lag strategy planning. The process of match strategy planning requires slowly increasing capacity in small increments until you reach the desired resource utilization.

3. Methods

This research uses a quantitative approach with extensive data collection gathered from various kinds of information sources such as demand coal, total transshipment, operational data and previous research. After that we start to pojecting the coal demand with regression-decomposition methods and start calculating how to get a fixed figure to add some assets as per below (Figure 4).

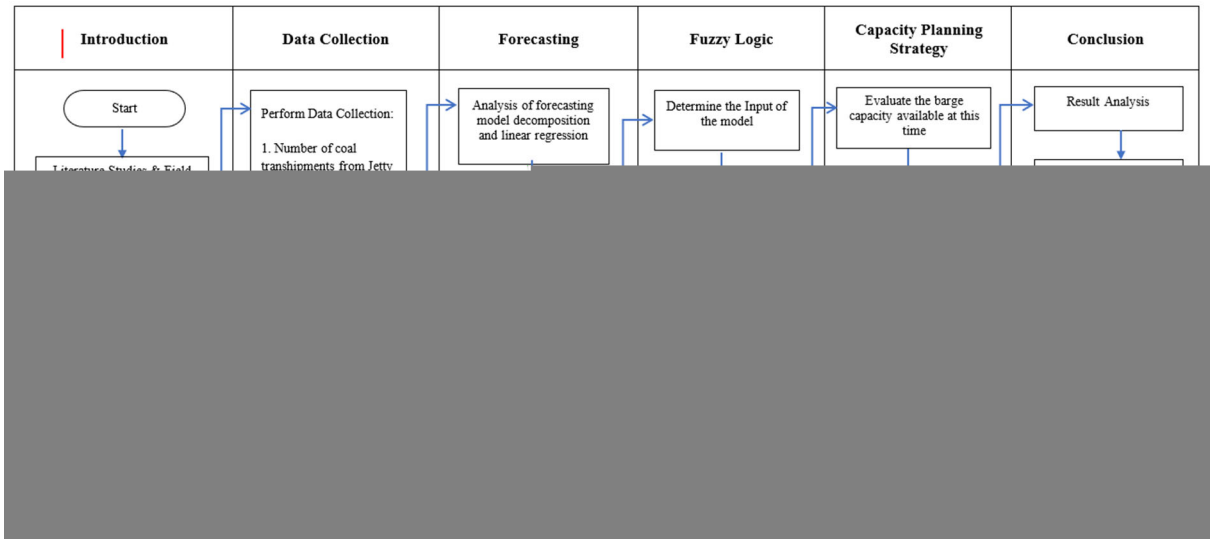

Figure 4. Research Methodology Flowchart

4. Data Collection

For forecasting process we need to have historical data from 10 years ago to projecting the demand for 7 year ahead which will calculated with regression and decomposition method (Table 2).

Table 2. Historical data from 2013-2022.

YEAR	MONTH	COAL DEMAND	CAPACITY	SHIPPING	YEAR	MONTH	COAL DEMAND	CAPACITY	SHIPPING
2013	Januari	464520	600000	464520	2018	Januari	600244	662000	600244
	Februari	387884	630000	387884		Februari	504014	662000	504014
	Maret	872350	662000	654500		Maret	977919	662000	654500
	April	799635	662000	654500		April	931979	662000	654500
	Mei	734525	662000	647000		Mei	793242	662000	662000
	Juni	734525	662000	647000		Juni	768584	662000	662000
	Juli	819988	662000	654500		Juli	875722	662000	662000
	Agustus	734525	662000	654500		Agustus	772337	662000	654500
	September	819988	600000	585000		September	807670	662000	654500
	Oktober	872350	662000	647000		Oktober	761585	662000	662000
	November	464520	630000	464520		November	495455	662000	495455
	Desember	487884	662000	487884		Desember	594248	662000	594248
2014	Januari	586740	662000	586740	2019	Januari	537755	662000	537755
	Februari	487884	600000	487884		Februari	562938	662000	562938
	Maret	894700	662000	654500		Maret	914803	662000	654500
	April	899635	662000	654500		April	850204	662000	654500
	Mei	734525	630000	650000		Mei	841536	662000	662000
	Juni	734525	662000	650000		Juni	858065	662000	495455
	Juli	819988	600000	650000		Juli	854340	662000	594248
	Agustus	734525	630000	660000		Agustus	792564	662000	537755
	September	800123	662000	660000		September	991336	662000	562938
	Oktober	754000	662000	660000		Oktober	910120	662000	654500
	November	487884	630000	487884		November	591366	662000	591366
	Desember	586740	662000	586740		Desember	600708	662000	600708
2015	Januari	467063	662000	467063	2020	Januari	665184	662000	661000
	Februari	390400	662000	390400		Februari	550688	662000	550688
	Maret	874920	662000	661000		Maret	1002853	662000	654500
	April	802178	662000	661000		April	994875	662000	654500
	Mei	737039	662000	661000		Mei	886564	662000	662000
	Juni	737054	662000	660000		Juni	820321	662000	495455
	Juli	822525	662000	660000		Juli	917335	662000	594248
	Agustus	737073	662000	660000		Agustus	803797	662000	537755
	September	822507	662000	654500		September	812670	662000	562938
	Oktober	874895	662000	654500		Oktober	766585	662000	654500
	November	467091	662000	467091		November	500455	662000	500455
	Desember	490454	662000	490454		Desember	599248	662000	599248
	Januari	589260	662000	589260		Januari	547755	662000	547755

2016	Februari	490423	662000	490423	***2021***	Februari	572938	662000	572938
	Maret	897213	662000	661000		Maret	924803	662000	661000
	April	902204	662000	660000		April	860204	662000	661000
	Mei	737068	662000	660000		Mei	851536	662000	661000
	Juni	737123	662000	660000		Juni	868065	662000	660000
	Juli	822572	662000	654500		Juli	864340	662000	660000
	Agustus	737084	662000	654500		Agustus	802564	662000	660000
	September	802670	662000	654500		September	1001336	662000	654500
	Oktober	756585	662000	654500		Oktober	920120	662000	654500
	November	490455	662000	490455		November	601366	662000	601366
	Desember	589248	662000	589248		Desember	610708	662000	610708
2017	Januari	507111	662000	507111	***2022***	Januari	675184	662000	654500
	Februari	473292	662000	473292		Februari	560688	662000	560688
	Maret	890552	662000	662000		Maret	1012853	662000	654500
	April	810104	662000	662000		April	1004875	662000	654500
	Mei	752343	662000	654500		Mei	896564	662000	662000
	Juni	781877	662000	654500		Juni	830321	662000	662000
	Juli	832642	662000	662000		Juli	927335	662000	662000
	Agustus	780216	662000	662000		Agustus	813797	662000	654500
	September	922105	662000	662000		September	822670	662000	654500
	Oktober	903801	662000	662000		Oktober	776585	662000	654500
	November	487761	662000	487761		November	510455	662000	510455
	Desember	520457	662000	520457		Desember	609248	662000	609248

Besides the historical data, we need to calculate cost component and employee cost so we are able to know how much is needed when we add more barges (Table 3).

Table 3. Cost Component

Purchase Cost		
Purchase Price of Tugboats	Rp 50.531.234.833	**Rp 111.766.055.833**
Purchase Price of Barges	Rp 60.754.000.000	
Tugboat Certification Fee	Rp 294.378.000	
Barge Certification Fee	Rp 186.443.000	
Operational Cost		
Maintenance Cost	Rp 477.956.686	**Rp 3.644.549.464**
Fuel Cost	Rp 1.641.785.543	
Port Services	Rp 838.385.548	
Insurance	Rp 686.421.687	
Rental Cost		
Tugboat Rent Cost	Rp 13.403.280.000	**Rp 62.052.720.024**
Barge Rent Cost	Rp 48.354.000.000	
Tugboat Insurance	Rp 77.847.024	
Barge Insurance	Rp 217.593.000	

Table 4. Employee Cost

Employee Cost							
Position	**Captain**	**Officer 1**	**Officer 2**	**Chief Engineer**	**Electrician**	**Chef**	**Waitre**
Annual Salary	Rp 170.256.177	Rp 129.844.170	Rp 93.473.208	Rp 144.339.399	Rp 71.949.546	Rp 40.729.824	Rp 38.837.853
Allowance	Rp 6.075.000	Rp 6.075.000	Rp 6.075.000	Rp 6.075.000	Rp 6.075.000	Rp 6.075.000	Rp 6.075.000
Health Cost	Rp 5.535.000	Rp 5.535.000	Rp 5.535.000	Rp 5.535.000	Rp 5.535.000	Rp 5.535.000	Rp 5.535.000
Insurance Cost	Rp 387.000	Rp 387.000	Rp 387.000	Rp 387.000	Rp 387.000	Rp 387.000	Rp 387.000
Meal Cost	Rp 9.450.000	Rp 9.450.000	Rp 9.450.000	Rp 9.450.000	Rp 9.450.000	Rp 9.450.000	Rp 9.450.000
Fresh Water Cost	Rp 972.000	Rp 972.000	Rp 972.000	Rp 972.000	Rp 972.000	Rp 972.000	Rp 972.000
Total Cost	**Rp 192.675.177**	**Rp 152.263.170**	**Rp 115.892.208**	**Rp 166.758.399**	**Rp 94.368.546**	**Rp 63.148.824**	**Rp 61.256.853**
Grand Total Cost	**Rp 846.363.177**						

Based on Table 4, it can be concluded many costs on Tug & Barge. Therefore, need a mature planning to add some barges to operate in this company. This study was designed to get an optimized number for add some additional barge to filled up the demand in the future.

5. Results and Discussion

5.1 Forecasting

5.1.1 Regression Method

In this study, the forecasting model used is the model regression forecasting where this model is appropriate for deep forecasting long term. The regression method is based on sales data patterns (transhipment) determine how demand increases or decreases over time. Model accuracy Regression forecasting will be analyzed using the Minitab 16, we got fitted regression equation as per below:
Demand = 674734 + 1041 Month

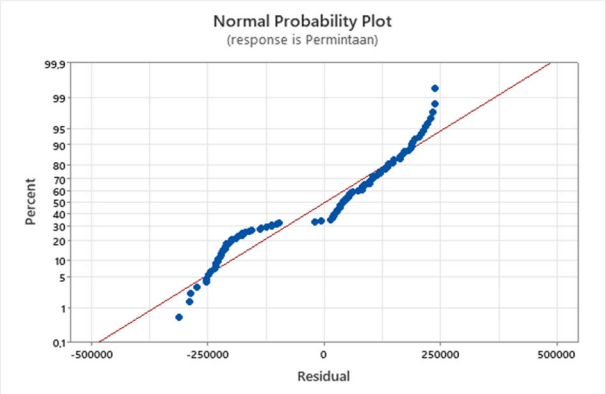

Figure 5. Data Plot for Regression Analysis

5.1.2 Decomposition Method

The forecasting model used next is the decomposition forecasting model, where this model is suitable for forecasting in the long term and in accordance with transshipment (sales) seasonal trend data patterns. The accuracy of the decomposition forecasting model will be analyzed using Minitab 16. Fitted Trend Equation and time series (Figure 6) decomposition plot as per below:
Demand = 667984 + 1167 Month

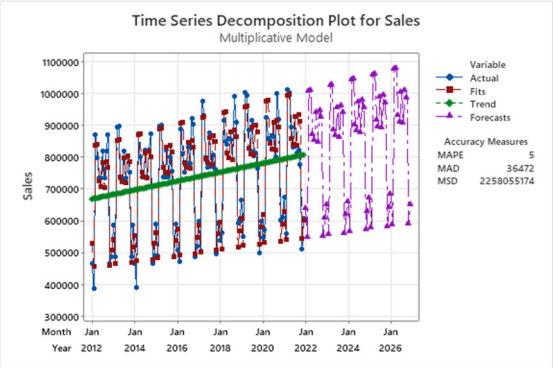

Figure 6. Data Plot for Decomposition Analysis

5.1.3 Comparison between Regression and Decomposition Method

A forecasting model can be said to be better if the error values (errors) in the form of RMSE and MAPE are getting smaller. From the Table 5, it can be analyzed that from a comparison of the regression and decomposition forecasting models, the smallest error of the forecasting method is shown by the decomposition method. The decomposition method will be used in research to predict the projected transhipment of coal for the next 2029 (seven) years.

Tabel 5. Comparison between Regression and Decomposition

Error	***Methods***	
	Regression	***Decomposition***
RMSE	156,991	123,416
MAPE	0,21	0,15

5.2 Fuzzy Logic

Furthermore, in designing the Fuzzy Logic model, in addition to input and output, rules or rules are also needed that bridge between input and output, based on the input and output that have been designed, then rules will be designed using the If Then rules (Table 6). After the If then rules are designed, the next stage is the defuzzification stage to convert the output into numbers.

Table 6. Input and Output Fuzzy Logic

Input		
Variable	***Linguistic***	***Range***
Demand	Low	[387884 778400]
	Average	[387884 778400 1012853]
	More	[778400 1012853]
Capacity	Low	[600000 630000]
	Average	[600000 630000 662000]
	More	[630000 662000]
Output		
Shipment	Low	[387884 556813]
	Average	[387884 556813 662000]
	More	[556813 662000]

After we build the input and output, we will get the rules as per below details in Table 7:

Table 7. Rules If Then Fuzzy Logic

Rule			
No	***Demand***	***Capacity***	***Shipment***
1	Low	Low	Low
2	Low	Average	Low
3	Low	More	Average
4	Average	Low	Average
5	Average	Average	Average
6	Average	More	Average
7	More	Low	More
8	More	Average	More
9	More	More	More

Referring to Setiawan (2016), the validation technique that will be used is the Extreme Combination Test. In this extreme combination test, each factor will be set under extreme conditions so that it can be seen whether the resulting output is in accordance with the conditions that have been set and whether it is in accordance with the actual conditions. The model to be tested is the procurement model. In this test will be tested in two extreme conditions.

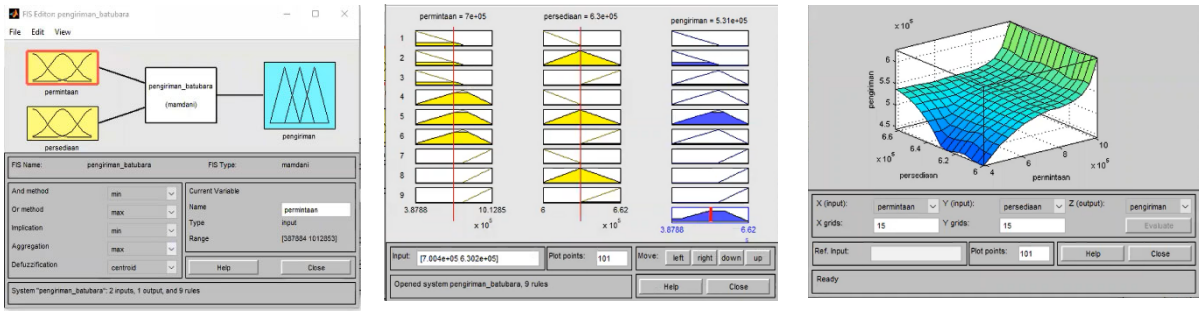

Figure 7. Data Input, Extreme Combination Test and Surface of Fuzzy Logic

The optimum results show that based on the projected demand for coal, the company needs 8 additional barges to meet demand and increase company profits.

5.1 Capacity Planning Strategies

5.1.1 Lead Capacity Strategy

The addition of barges with a lead capacity strategy is determined through an investment program or procurement of new tugboats and barges. The cost components that are taken into account in the lead capacity strategy analysis are the cost of purchasing new barges and tugboats in 2023, the operational and maintenance costs of the barges, as well as the salaries of skippers and crew members which are analyzed for 20 (twenty) years according to company policy. Based on the calculation results, the total cost required to implement this strategy is IDR 2,746,115,872,435.

5.1.2 Lag Capacity Strategy

The implementation of the lead capacity strategy includes the need for coal distribution capacity which is met after the current distribution capacity is equal to the level of demand. Therefore, the plan to implement tugboat and barge charters coupled with the lead capacity strategy will be carried out in January 2025 with the assumption that the additional distribution capacity will last until January 2044. Based on the calculation results, the total cost required to implement this strategy is IDR 3,873,281,668,489,94,-

5.1.3 Average Capacity Strategy

The implementation of this strategy includes the need for coal distribution capacity that is in a position that is less than or more than needed. The plan to implement the procurement of additional barges with the average capacity strategy will be carried out in January 2025. The additional sets of tugboats and barges are calculated for 5 (five)

years from January 2025 to December 2029, in which half of the required capacity of tugboats and barges with the holding of the investment will be carried out simultaneously with half the capacity requirement for the distribution of coal by chartering tugboats and barges. Based on the calculation results, the total cost required to implement this strategy is IDR 3,257,754,662,465,94.

5.1.4 Comparison between three Capacity Strategy

After conducting a cost analysis for each alternative barge capacity requirement planning strategy, it can be seen that the best strategy for procuring barges at the Separi Jetty to meet the needs for coal distribution capacity is to implement a lead capacity strategy in the form of adding 8 (eight) sets of 7,500 MT barges, with the result that the total cost of this strategy is the lowest cost IDR 2,746,115,872,435.00 (Table 8).

Table 8. Comparison between Lead, Lag and Average Capacity

Strategy Alternatives	***Price***
Lead Capacity Strategy	Rp 2.746.115.872.435
Lag Capacity Strategy	Rp 3.873.281.668.490
Average Capacity Strategy	Rp 3.257.754.662.466

6. Conclusion

Based on the results of calculations and analysis that has been done on the data processed, then it can be concluded as follows:

1. The accuracy of the forecasting model is compared and shows that forecasting using decomposition has better results to apply because it has the smallest RMSE and MAPE values. Coal transhipment projection in 2027 is 1,008,638 MT.
2. In line with the significant increase in coal export, we have to add assets in order to fulfill export needs. Based on forecasting and fuzzy logic calculation, the exact optimal number to increase the barge is 8.
3. Appropriate capacity planning strategy to implement in fulfillment of tugboats and barges at this company is the lead strategy capacity with the total cost IDR 2,746,115,872,435.00 for adding sets of tugboats and barges the lowest.

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