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MULTIMODAL INTEGRATION MODEL FOR REDUCING NATIONAL LOGISTICS COSTS

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Abstract: One way to minimize national logistics costs is to develop multimodal transportation. The steps for multimodal development are forming a linear model for each transportation mode, the simultaneous formation of a linear model, and forecasting and simulation of the minimum transportation costs. Area partition based on distance can be used as a solution for selecting transportation modes in multimodal with a certain distance. It can be useful in reducing transportation costs that only rely on unimodal, namely trucks. The estimation of reducing logistics costs is by forecasting goods that will pass through transportation modes in 2025 and making the simulation. Train or truck is used for short distances such as moving goods from factories or warehouses to transhipment points and from transhipment points to consumers or retailers. Trains, freighters and planes are used as the main routes as needed. The simulation results show that national logistics costs reduce by 17% when using the lowest-cost transportation mode in the area division.

1 Introduction

A country's logistics performance can be seen from the value of the logistics performance indicator (LPI). LPI is an index created by the World Bank to measure the logistics conditions of a country [1]. Table 1 shows that Indonesia's LPI rank is 46 out of 207 countries recorded by the World Bank in 2018. This ranking is below several ASEAN countries such as Singapore, Thailand, Vietnam, and Malaysia.

Table 1 LPI data for several ASEAN Region in 2018

Country	Score LPI	World Rank	ASEAN Rank
Singapore	4	7	1
Thailand	3.41	32	2
Vietnam	3.27	39	3
Malaysia	3.22	41	4
Indonesia	3.15	46	5

The poor performance of Indonesian logistics was due to the significant differences in product prices, which led to economic disparities between regions [2-6]. The high national logistics costs also show the lack of Indonesia's logistics performance. Indonesia's logistics costs currently reach 26% of the Gross Domestic Product (GDP). The logistics costs are significantly different when compared to developed countries' logistics costs i.e. Japan and the United States, which are 10.6% and 9.9% of GDP [7,8]. National logistic cost consists of transportation, administrative, and inventory costs of 12.04%, 4.52%, and 9.47% of GDP [9,10]. This cost is also higher when compared to some ASEAN countries. High logistics costs cause decreasing investors' income and move their investigation to other countries that have lower logistics costs [11].

The Indonesian government has taken various ways to minimize national logistics costs, such as minimizing dwelling time and balancing the imbalance of cargo. Nuyanto & Ngajian stated that dwelling time does not show a decrease in logistics costs. Instead, it has the potential to impose additional costs for entrusting containers to depots outside the port [12]. Priadi [13] stated that imbalanced cargo greatly impacts high logistics costs. Indonesian cargo has been getting more balanced in the last 2 years, but it does not have a significant impact on reducing national logistic cost. One alternative to reduce national logistic cost is to minimize logistics transportation costs.

Logistics transport plays a major role in improving the country's economy [14]. Logistics transportation also affects the price of a product [14]. The comparison of transportation modes in Indonesia is 90% road transportation, less than 1% air transportation, 8% sea transportation, and 1% rail transportation [15]. Indonesia's logistics transportation is currently still dominated by unimodal, namely trucks [16]. Instead of minimizing logistic transportation costs, it is also possible to develop transportation system models integrated with other multimodal transportation modes [17]. Multimodal can reduce logistics and administrative costs because it has a single national window concept.

2 Methodology

Data used in this analysis is the distance data (km) as the independent variable (*X*) and cost data (in Rupiah) as the dependent variable (*Y*) in 2021. The data analyzed is using one dry container (2TEUs). Transportation modes compared are trains, freighters, roll on roll off (RORO) ships, and trucks. The data of train, freighter and RORO are taken from State-Owned Companies and truck data are from Private Companies. The aeroplane is not used as one of the parameters due to the high cost and cannot much loading of goods much, so it is used as an exclusive alternative for sending small goods and fast time [18-20].

The data are formed into a linear model for each mode using ordinary least squares (OLS) [21]. The linear model function is (1)

$$Y_{nx1} = X_{nxk}\beta_{kx1} + \varepsilon_{nx1} \quad (1)$$

The linear model assumption is

$$E(\varepsilon) = 0, E(\varepsilon\varepsilon') = \sigma^2 I_n$$

Calculate the sum square of the error

$$\begin{aligned} e'e = \ & (Y - X\hat{\beta})'(Y - X\hat{\beta}) \\ & = Y'Y - \hat{\beta}'X'Y - Y'X\hat{\beta} + \hat{\beta}'X'X\hat{\beta} \\ & \Rightarrow e'e = Y'Y - 2\hat{\beta}'X'Y + \hat{\beta}'X'X\hat{\beta} \end{aligned}$$

with $\hat{\beta}$ is the estimator of β. The way to minimize $\hat{\beta}$ is make condition the first derivative of the sum square error $e'e$ to be zero

$$\frac{\partial}{\partial\hat{\beta}}(e'e) = 0 \Rightarrow -2X'Y + 2X'X\hat{\beta} = 0$$

$$\Rightarrow X'X\hat{\beta} = X'Y$$

OLS estimator of β (2)

$$\hat{\beta} = (X'X)^{-1}X'Y \quad (2)$$

The significant impact of the independent variable on the dependent variable can be seen if the regression p-value is less than 0.05 [22]. If the independent variable has been proven to affect the dependent variable, then it can be seen the amount of influence of the independent variable on the dependent variable by using $\boldsymbol{R^2}$. $\boldsymbol{R^2}$ is used as measure of model fit [23-25]. The function of $\boldsymbol{R^2}$ is (3)

$$R^2 = \frac{V_{n=1}^{N}\hat{y}_n}{V_{n=1}^{N}y_n} \quad (3)$$

where $V_{n=1}^{N}\hat{y}_n$ is residual variance and $V_{n=1}^{N}y_n = \frac{1}{N-1}\sum_{n=1}^{N}(y_n - \bar{y})^2$. R^2 which is more than 60% indicates that the independent variable has a dominant role in influencing the dependent variable. The rest is explained by other variables [26,27].

After the significant regression test, it is continued by forming the model simultaneously. Each mode of transportation model is formed in a linear line with abscissa axes in the form of a distance from 0 to 2200 km. This distance is the estimated length of the longest island (Sumatra) in Indonesia, which is 2194 km. Ordinate axes result from a linear model of each mode of transportation. The point of intersection is used as a boundary to divide the order of transportation modes that should be used.

The calculation of the cheapest route is done after getting a linear model. The cost of transportation with the cheapest mode of transportation is calculated by calculating the minimum transportation costs and the cost of moving goods [19]. The network model and mathematical formulation is (4):

$$\min Z = \sum_{i\in 1}\sum_{j\in A_{\bar{i}}}\sum_{k\in J} c_{ij}^{k}x_{ij}^{k} + \sum_{i\in v}\sum_{j\in A_{\bar{i}}}\sum_{k\in J} c_{i}^{kl}r_{i}^{kl} \quad (4)$$

where

c_{ij}^{k} = The transport cost from node *i* to node *j* by choosing *k* transport

$x_{ij}^{k} = \begin{cases} 1, & \text{From node } i \text{ to node } j \text{ select the } k \text{ transport mode} \\ 0, & \text{From node } i \text{ to node } j \text{ select another transport mode} \end{cases}$

c_{i}^{kl} = The conversion cost from the *k* transport mode to the *l* transport mode at node *i*

$r_{i}^{kl} = \begin{cases} 1, & \text{At node } i\text{, switch from the } k \text{ tran. m. to the } l \text{ tran. m.} \\ 0, & \text{No change of transport mode occurs at node } i. \end{cases}$

A_{i}^{-} =The set of nodes pointed by the arc starting from node *i* connected to node *i*

A_{i}^{+} = The set of nodes, at the end of the arc that is connected to node *i* and points to node *i*

V = The collection of all nodes in the network

0 = The starting node of the network

D = the termination node of the network

I = the collection of all intermediate nodes in the network
$\boldsymbol{J}$ = collection of all modes of transportation

The calculation of the cheapest route is carried out on the island of Java because the complete mode of transportation is on the island of Java. Calculations were carried out in 4 simulations, consisting of Cikarang Dry Port – Tanjung Mas Semarang, Cikarang Dry Port – Tanjung Perak Surabaya, Tanjung Priok Jakarta – Tanjung Perak Surabaya, and Tanjung Perak Surabaya – Tanjung Priok Jakarta.

After the simulation is done by getting the cheapest route, then the right transportation mode is obtained as the main haul in multimodal. The multimodal transportation system in Indonesia is expected to be realized in 2025 based on the presidential decree [4]. Therefore, an estimation of the amount of movement of goods in Java will be carried out in 2025.

Forecasting methods used are simple moving average (SMA) and double exponential smoothing (DES). SMA indicator is by calculating the average historical data. SMA indicator at the t-th time step with a historical data size of m can be formulated as (5)

$$SMA_m^t = \frac{\sum_{u=1}^{m} p_{t-u+1}}{m} \tag{5}$$

with $\boldsymbol{p_u}$ is the data of the u-th time step [28]. The results of the fitting will be used as a basis for forecasting the following year.

DES is a time series forecasting method if there is a trend in data patterns [29, 30]. The modelling algorithm is (6):

(i) Determine $S'_t = \theta P_t + (1-\theta)P'_{t-1}$
(ii) Determine $S''_t = \theta P_t + (1-\theta)P''_{t-1}$
(iii) Determine $\gamma_t = 2S't - S''_t$
(iv) Determine $\varphi_t = \frac{\gamma_t}{1-\gamma_t}(S'_t - S''_t)$
(v) Then $S_{t+z} = \gamma_t + \varphi_t z$ (6)

The best model comparison between SMA and DES is by comparing the smallest mean absolute percentage error (MAPE), mean absolute deviation (MAD), and mean square deviation (MSD) [31]. The functions of MAPE, MAD, and MSD are (7), (8), (9)

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} \frac{|P_t - \hat{P}_t|}{P_t} \tag{7}$$
$$MAD = \frac{1}{n}\sum_{t=1}^{n} |P_t - \hat{P}_t| \tag{8}$$
$$MSD = \frac{1}{n}\sum_{t=1}^{n} (P_t - \hat{P}_t)^2 \tag{9}$$

The last step is the estimation of national logistics costs through the multimodal model to see the reduction in logistics costs after the multimodal model is applied.

3 Result and discussion

The data is presented descriptively in the form of a scatter plot, as shown in Figure 1. Figure 1 shows that the distance data forms a linear pattern of costs for each mode of transportation. Figure 1 shows that there are very few train lines in Indonesia. There are only six destination stations for cargo trains in Indonesia. After a linear pattern is seen, a linear model is formed using ordinary least squares (OLS).
Linear model of RORO is (10)

$$Y_{\text{roro}} = 10828600 + 11457X_{\text{roro}} \tag{10}$$

Linear model of freighter is (11)

$$Y_{\text{freighter}} = 2617045 + 1828X_{\text{freighter}} \tag{11}$$

Linear model of train is (12)

$$Y_{train} = 702216 + 3253X_{train} \tag{12}$$

Linear model of truck is (13)

$$Y_{truck} = 1448726 + 16368X_{truck} \tag{13}$$

P-value and coefficient of determination R^2 for each mode of transportation are shown in Table 2. The p-value for each mode is less than 0.05. The p-value indicates that the distance of each transportation mode has a significant effect on costs. The magnitude of the effect of distance on costs can be seen using the coefficient of determination R^2. R^2 for each transportation, mode is above 60%. P-value and R^2 shows that distance affects the cost of each mode of transportation significantly. Furthermore, a linear model is formed with the abscissa axes (X) in the form of a distance from 0 to 2200 to create a model simultaneously.

Table 2 P-value and R^2 for each transportation mode

Indicator	Transportation Mode			
	Truck	Train	Roro	Freighter
p-value	0.000	0.010	0.000	0.000
R^2	95.51%	81.60%	77.66%	70.15%

Figure 2 shows that there are 3 points of intersection on the abscissa axes (80, 1344, and 1910). The third intersection point is not used as a parameter because it is at a high-cost coordinate. The area is divided into three areas, according to Figure 2. Area 1 is a transportation distance of less than 80 km ($X \leq 80$). Area 2 is a transportation distance between 80 km and 1344 km ($80 < X \leq 1344$). Area 3 is a transportation distance above of 1344 km ($X > 1344$).

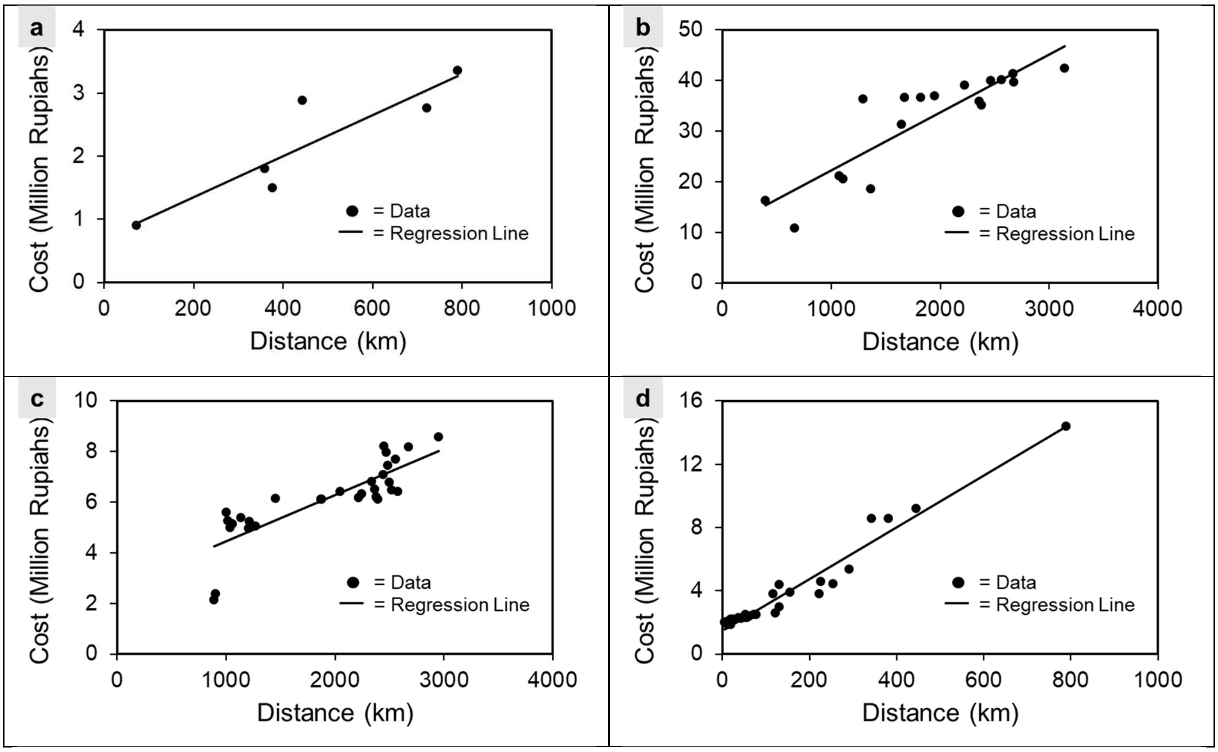

Figure 1 Scatter plot between distance vs cost in transportation modes (a) Train, (b) Roro, (c) Freighter, and (d) Truck

Area 1 shows that the train is the cheapest mode of transportation, so the train is the first alternative for the main transportation. However, not all areas have access to trains. The construction of railway lines and the procurement of trains take a long time and have high costs. So in Area 1, trucks can be used as an alternative to trains. Freighter and Roro cannot be recommended because of the high cost of short-distance transportation.

The cheapest mode of transportation for Area 2 is the train. The intermediate distance in Area 2 is between 80 km and 1344 km. The train can be used as a main haul for transportation within the island at medium distances. The second cheapest mode of transportation for Area 2 is the freighter. Freighter can be used as another alternative solution for inter-island transportation modes with medium distances.

The cheapest mode of transportation for Area 3 is the freighter. If the distance is within the island, then the train can be used as an alternative other than the freighter.

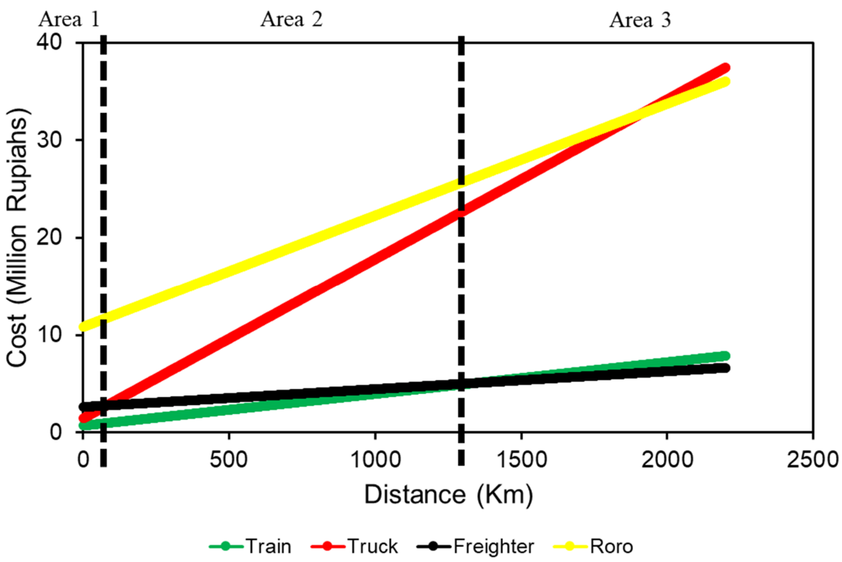

Figure 2 Linear model for simultaneous modes of transportation

The results of the combined linear models are summarized in Table 3. Each area has a choice of transportation costs from very low to very high. The cheapest mode of transportation for short distances is train and truck. The cheapest mode of transportation for medium distances is the train and freighter. The cheapest mode of transportation for long distances is freighter and train.

Table 3 Transportation cost options for each area

Transportation Cost	Area 1 ($X \leq 80$)	Area 2 ($80 < X \leq 1344$)	Area 3 ($X > 1344$)
Very Low	Train	Train	Freighter
Low	Truck	Freighter	Train
High	Freighter	Truck	Truck / Roro
Very High	Roro	Roro	

These results are in accordance with the results of other studies [19,32,33]. This is due to the lower operating costs of trains and trucks compared to freighters at short distances [31].

Train or truck is used for short distances such as moving goods from factories or warehouses to transhipment points and from transhipment points to consumers or retailers. Train, freighters, and aeroplanes are used as the main haul depending on needs.

The linear model simulation is carried out in Java because only Java has complete transportation. The distance to the island of Java is less than 1000 km (medium distance). Table 4 is a simulation result where the train is the cheapest mode of transportation, and the freighter is the alternative transportation. The train can be the main haul in multimodal, and freighter is the alternative mode. The result is in accordance with the results of the formation of a simultaneous linear model.

Table 4 Delivery of goods simulation

Distance (Km)	Route	Track	Cost (Million Rupiahs)	Transportation
481	Cikarang Dry Port – Tanjung Mas Semarang	Cikarang Dry Port – Tanjung Mas Semarang	2.34	Train
		Cikarang Dry Port – Tanjung Priok Jakarta (transit) Tanjung Priok Jakarta – Tanjung Mas Semarang	3.78	Train (transit) Train
		Cikarang Dry Port – Tanjung Priok Jakarta (transit) Tanjung Priok Jakarta – Tanjung Mas Semarang	4.40	Train (transit) Freighter
753	Cikarang Dry Port – Tanjung Perak Surabaya	Cikarang Dry Port – Tanjung Perak Surabaya	2.76	Train
		Cikarang Dry Port – Tanjung Priok Jakarta (transit) Tanjung Priok Jakarta – Tanjung Perak Surabaya	4.26	Train (transit) Train
		Cikarang Dry Port – Tanjung Priok Jakarta (transit) Tanjung Priok Jakarta – Tanjung Perak Surabaya	4.96	Train (transit) Freighter
788	Tanjung Priok Jakarta – Tanjung Perak Surabaya	Tanjung Priok Jakarta – Tanjung Perak Surabaya	2.76	Train
		Tanjung Priok Jakarta – Tanjung Perak Surabaya	4.26	Freighter
		Cikarang Dry Port – Tanjung Priok Jakarta (transit) Tanjung Priok Jakarta – Tanjung Perak Surabaya	4.96	Train (transit) Train
	Tanjung Perak Surabaya – Tanjung Priok Jakarta	Tanjung Perak Surabaya – Tanjung Priok Jakarta	3.06	Train
		Tanjung Perak Surabaya – Tanjung Priok Jakarta	4.06	Freighter
		Tanjung Perak Surabaya – Tanjung Mas Semarang (Transit) Tanjung Priok Jakarta – Tanjung Perak Surabaya	4.41	Train (transit) Train

SMA (2) and DES prediction methods are used to predict the number of goods passing through all modes of transportation in 2025 based on data from the Central Statistics Agency from 2007 to 2021 [34]. The fitting results for data on the number of goods passing through transportation are shown in Figure 3. Figure 3 shows that fitting with the DES method produces a graph that is close to the original data. This prediction is reinforced by the smallest MAPE, MAD, and MSD values in the DES model, as shown in Table 5.

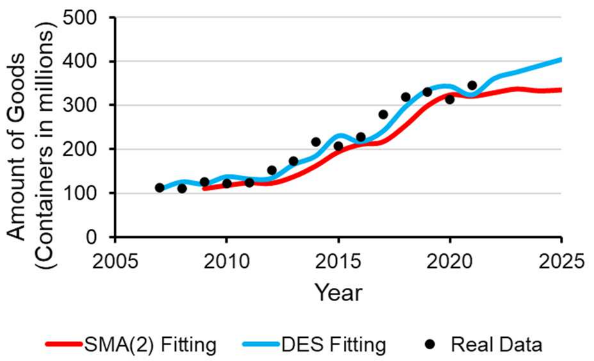

Figure 3 Data on the number of goods through transportation modes from 2007-2021 and fitting results from SMA (2) and DES prediction methods

Table 5 Measures of the accuracy of the fitted model

Measures of Accuracy	DES	SMA(2)
MAPE	8.36	9.75
MAD	1.71×10^{7}	2.25×10^{7}
MSD	4.06×10^{14}	9.63×10^{14}

The forecast results for the number of goods that pass through all modes of transportation using the DES method in 2025 are 404635322 containers.

The island of Java is the centre of the movement of goods in Indonesia, especially the Jakarta and East Java areas. Jakarta supplies western Indonesia, and East Java supplies eastern Indonesia [35, 36]. The transportation mode used from Jakarta to East Java or vice versa is dominated by unimodal, namely trucks [37]. The distance between Jakarta and East Java is about 800 km (medium distance). The number of goods in 2025 is divided into four conditions for travel from Jakarta to East Java. The result is that logistics costs decrease to 17% of GDP when using trains. It can be seen in Table 6.

Table 6 National logistic cost estimation

No	Condition	National Logistic Cost Estimation (%GDP)
1	90% truck, 4.5% freighter, 4.5% roro, and 1% train	73.96%
2	100% train	17.23%
3	100% freighter	21.99%
4	50% train, 40% freighter, and 10% truck	25.28%

4 Conclusions

The multimodal integration model in logistics transportation is an effective model for reducing national logistics costs. Transportation cost options are selected based on distance. Short distances are more efficient using trains and trucks as an alternative. Short distances are used for moving goods from factories or warehouses to transhipment points and from transhipment points to consumers or retailers. Medium distance is more efficient using train and freighter as an alternative. Long distances are more efficient using freighter and train as an alternative. Medium and long distances are used as the main haul in multimodal. The application of the unimodal to multimodal transportation model can reduce national logistics costs to 17% in 2025.

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Review process

Single-blind peer review process.