Shipping cost optimization on the Indonesian sea tollway due to weather

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Abstract. Indonesian sea tollway main objective is to decrease price gap between the western and eastern part of Indonesia. Although, the price gap is still felt in eastern Indonesia, that means the objectives of this program has not yet reached its optimum mainly due to operational cost. This paper is trying to optimize shipping costs by reducing the speed with slow steaming due to weather. The method called Slow Steaming was added with the aim of optimizing the speed of the ship. In total, there are three scenarios created to achieve these research objectives. The first scenario used current operational data, while the second scenario use ship speed loss due to weather, and the last scenario used ship speed loss due to weather and slow steaming method. The results showed that reducing ship speed with scenarios two and three can optimize the total shipping cost. Decreasing the shipping speed due to weather and using 10% and 12% slow steaming method can reduce between 16.35% and 18.5% of total shipping costs depend on the route. It can be concluded that scenario III has the lowest shipping cost, but with a note that with different specific conditions of slow steaming for each route.

1. Introduction
Indonesia is one of the archipelagic nations with 17,504 islands. Sea transportation is significant for archipelagic nations since this is the best way to connect between locales from East to West Indonesia and it has a major job for economic activities [1]. Indonesia faces issues regarding sea transportation identified with port availability, delivering courses, costly coordination transportation costs, uneven distribution of logistics that does not reach the remote area. These factors affect the price gap between the western and eastern parts of Indonesia, which appeared by the number of Gross Domestic Product (GDP). The Eastern district delivered under 20 percent of GDP while the Western district contributes more than 80 percent [2].

To overcome this problem the Indonesian government through the Ministry of Transportation is implementing a sea tollway concept model. The Indonesian government began implementing this program in 2015, which began with 6 routes that developed in 2016 with the same number of routes but more ports were visited, in total 31 ports and in 2017 became 16 routes with 41 ports in implementing the sea tollway program, Indonesia faces numerous difficulties. In the first place, the backload brought from East to West was deficient. Second, the price gap is still felt in eastern Indonesia even though the
Objective of this program is to take care of this issue, but in reality, the effectiveness of this program has not yet reached its maximum. Third, the port performance, there are as yet numerous ports in Indonesia that must be upgraded again. Fourth is the utilization of data and technology in executing the sea tollway program [3]. Data sources for this program are as yet restricted and hard to access, in the future, it is hoped that these problems can be resolved and the effectiveness of this program can reach maximum potential.

Indonesia which is located geographically in the Pacific Circle has many natural events including hydrometeorological hazards including sea-level rise, flooding, and big waves. However, Indonesia consists of two-thirds of it from the sea and weather which factor plays a very important role in sea transportation. Weather at sea (wind and waves) affects the shipping process which directly impacts to ship performance. From Vessel Performance Optimisation home page stated that the shipping industry risks investing billions of dollars in ship optimization services that fail to deliver overall operational efficiency and performance due to a lack of understanding and appreciation of the weather, accounting for 80 percent of the impact on ship performance, warns shipping intelligence and Stratum Five insight specialists [4].

This ship performance optimization leads to shipping cost, which has several factors. The first one is wind; it has a big impact to ship speed. If the ship is in a headwind, it will lose speed and if it is in the following wind, it will gain speed. Wind also affects the height of the waves that can lead to speed reduction. Secondly, wave height is the second weather factor that influences ship performance. Waves can influence the boat's rolling and pitching movement. This movement will bring about diminished force from the boat's propeller and an expanded drag from the constant steering corrections. Wave height and direction impact to ship performance is similar to wind. The third factor is fuel quality. Fuel quality has an impact to ship machine, when the quality of fuel is poor it can damage the engine and cause speed reduction. The other factors are marine growth and current [5].

It can be concluded that ship speed has a big role to improve ship. Lowering speed means lowering fuel consumption, and this will lead to optimization of shipping costs. The changing prices of bunker fuel open the door for substantial cost savings by adjusting the sailing speed of ships. A large ship may be burning up to 100 000 USD of bunker fuel per day, which may constitute more than 75% of its operating costs [6]. One strategy to optimize shipping operation costs is to use slow steaming. Slow steaming corresponds to slower vessel speeds, has become popular to improve vessel fuel efficiency [7]. Shippers can benefit from moderate steaming through a reduced supply chain carbon footprint, but longer transit times will increase pipeline inventory costs. Although the operator has identified slow steaming as a solution for all stakeholders, the sender expressed concern[8]. In addition, although operators believe that slower vessels can improve schedule reliability and further reduce the need for safety stock, speed is often more important than reliability for sea shipping [9]. By reducing the current speed to 10% and 12 % it will decrease the fuel consumption by 19% and 23% [10]. Since fuel consumption is one of the main parameters in shipping cost, that means that speed variable has a big influence on shipping cost, that is why speed optimization can be used to optimize shipping costs. The objective of this research is to optimize shipping costs by reducing the speed with slow steaming due to weather.

2. Methodology
Indonesian Sea Tollway program has 13 routes. This research is using 3 routes out of 13 routes from (the 2017th) sea tollway program, which consists of routes T1, T2, and T13. These routes can be analyzed to obtain the actual distance from one port to the other port by using Google Earth by referring to the existing routes from the Indonesian Government. The next step is to collect Indonesian weather data between 2014-2017, the map was developed by EMD International A/S, Denmark and financed by the Environmental Support Programme 3 (ESP3) / Danida.

After the actual distance and weather data are found, we use them to get the weather data (wind speed) with actual distance using Google Earth. The acquired data is comprehensive on the weather variation at sea because this research aims to face the real situation. Furthermore, the wave height and
ship speed loss due to wind speed can be acquired by using the Beaufort Number Scale and referring to existing journals [11].

As stated in (1), maximum optimization can be obtained by adding, slow steaming. At a distance of 10% from the ship's departure from the port and a distance of 10% when they will reach the destination port, we will assume that the speed of the ship is 4 knots. So, in this study, the Slow Steaming process will be carried out at 90% of the total distance between the two ports [12] Once the vessel decreases its speed by 10 percent, the engine power will be reduced by 27 percent [13]. So, it can be assumed that at a 12% reduction in speed, the engine power will be reduced by 32.4 percent because the relation from the speed, distance, and time is linear.

In this research, there are three scenarios. The first scenario uses real data on the field. The second scenario uses ship speed loss, while the third Scenario uses ship speed loss and slow steaming.

- **Scenario I**
  - Use the real data on the field.

- **Scenario II**
  - Using the ship speed loss with Beaufort Number

- **Scenario III**
  - IIIa. Adding 10% slow steaming from current ship speed after ship speed loss due to wind and wave height
  - IIIb. Adding 12% slow steaming from current ship speed after ship speed loss due to wind and wave height

There are several assumptions for this research. The first assumption is there is 2 area process of shipping areas, which are process at Sea and process at Port. Be that as it may, the limit for this research is only using the process at Sea, one of the reasons is data limitations for the process at Port. Then, for time charter vessels with the daily charter is rated in Dollar per day (US$/day) After that, the total shipping time per voyage is the sum of the total hours shipping process at sea and port After the data from three scenarios is obtained, the shipping total cost can be determined. The shipping costs are the sum of charter time rates, fuel costs, port charges, and container handling costs [14]. The variable that is used to reach the objective of this research is ship speed that influences on shipping cost, while the other is assumed to be constant. The formula for shipping cost is shown below

\[
C_{st}^m = \sum_i \left[ \alpha_{it} + O_t W_i + F_{it} + D_{it}^m \left( \frac{O_t}{V_t} + \frac{F_{it}}{V_t} \right) \right] + \sum_i \sum_j \left[ (\beta_i + \frac{O_t}{R_i}) P_{ij} \right] 
\]

Where:
\[
\alpha_{it} = \sum_t P_l_{it} + T_{0it} + L_{it} + B_{it} 
\]

**Where:**

- \( m \) : route
- \( i \) : port of origin on route \( m \)
- \( j \) : port of destination on route \( m \)
- \( t \) : type of ship
- \( \alpha_{it} \) : fixed portion of port \( i \) charge for a ship of type \( t \) (US$)
- \( O_t \) : average daily charter rate for a ship of type \( t \) (US$/day)
- \( W_i \) : time a ship spends on the arrival and departure process in port \( i \) (day)
- \( F_{it} \) : fuel cost in port \( i \) by a ship of type \( t \) (US$)
- \( D_{it}^m \) : shipping distance between port \( i \) and port \( i+1 \) on route \( m \) (nautical mile)
- \( V_t \) : service speed for a ship of type \( t \) (knot)
- \( F_t \) : fuel cost at sea for a ship of type \( t \) (US$)
- \( \beta_i \) : average handling fee per TEU in port \( i \) (US$ per TEU)
- \( R_i \) : average gross handling rate in port \( i \) (TEU per day)
\( P_{ij} \): the number of containers shipped between port i and port j on route m (TEU)

\( P_{lt} \): pilotage for a ship of type t (US$)

\( T_{ot} \): towage for a ship of type t (US$)

\( L_{it} \): anchoring fee for a ship of type t (US$)

\( B_{it} \): berth occupancy charge for a ship of type t (US$)

The objective of the proposed model is to minimize shipping costs. The fixed variable \( \Lambda^m_t \) and the variable shipping cost \( \Phi^m_t \) for ship type \( t \) on the route \( m \) can additionally be indicated by simplifying the variables as:

\[
\Lambda^m_t = \sum_i \left[ \alpha_{it} + O_t W_i + F_t + D^m_t \left( \frac{O_t}{V_t} + \frac{F_t}{V_t} \right) \right]
\]

\[
\Phi^m_t = \sum_i \sum_j \left[ (\beta_i + \frac{O_t}{R_t}) P_{ij} \right]
\]

Furthermore, the shipping cost equation can be simplified as

\[
C^m_s = \Lambda^m_t + \Phi^m_t
\]

The shipping cost function as denoted in equation (1) and simplified in equation (5) is a basic formula to calculate the total shipping costs in our excel sheet. Moreover, use unit cost \( C_{ij} \) as the variable cost of the one-unit container (TEU). Unit cost for every route within the arc (i, j) derived by dividing the total variable shipping cost \( \Phi^m_t \) by the number of containers carried from origin to destination \( P_{ij} \). While the fixed cost \( \Lambda^m_t \) reliant on the type of ship and route \( (X_{ij}) \). Thus, formulate the objective function (4) to determine the minimum shipping costs of distributing cargo on a certain route, as follows [10]:

\[
\text{Min} \sum_{i,j \in N, c \in D} \sum_{d \in D} P_{ij} * C_{ij} + \sum_{i,j \in N} \Lambda^m_t * X_{ij}
\]

The objective function refers to equation (4) and substitute the number of sailing frequency (f), subject to:

Connectivity constraint:

\[
X_{ij} \in \{0,1\}
\]

\[
\sum_{i \in N} X_{ij} \geq 1 \ \forall \ j \in N
\]

\[
\sum_{j \in N} X_{ij} \geq 1 \ \forall \ i \in N
\]

Cargo allocation constraint:

\[
\sum_{i \in N} P_{ij} = D_j \ \forall \ j \in N
\]

\[
\sum_{j \in N} P_{ij} = S_i \ \forall \ i \in N
\]

\( P_{ij} \geq 0 \text{ and integer} \ \forall \ i,j \in N\)
Ship capacity constraint:

\[
\sum_{i,j \in N} P_{ij} \leq \sum_{t \in T} U_t X_{ij}
\]

Where:
- \( P_{ij} \): binary variable
  - \( 1 \) = if ship sails from port \( i \) to port \( j \) using ship of type \( t \)
  - \( 0 \) = otherwise
- \( N \): all nodes on route \( m \)
- \( D_j \): total demand of the container (TEU) at port \( j \)
- \( S_i \): total supply of the container (TEU) from port \( i \)
- \( U_t \): maximum TEU capacity of ship type \( t \) per voyage

Construct three constraints to gain the objective of this study. Firstly, develop connectivity constraint, equation (9) depicts that ship sails from port \( i \) to port \( j \) (1) or not (0). Equations (10) and (11) indicate that the sum of traveling routes should be equal or more than 1 since this multi-port-calling model is used to capture the shipping costs in the implementation of the Sea Tollway program of 2016 and 2017 where a vessel is allowed to visit port more than once in one route (pendulum service) [14].

3. Result and Discussion

In this research, there are 3 out of 13 routes that have been chosen. The data is provided by the Ministry of Transportation of the Republic of Indonesia. These 3 routes are chosen on the grounds that these routes have the most comprehensive data regarding ship and voyage information. These routes have the biggest hub (Tanjung Perak Port) in eastern Indonesia. The 3 routes have a different type of ship and destination port. The sea tollway routes can be seen in Figure 1.

![Figure 1. Route information for Indonesian sea tollway program](image)

3.1. Data

As mentioned above, 3 routes have been chosen. The routes are Tanjung Perak- Wanci-Namlea (T1), Tanjung Perak-Kalabahi-Saumlaki-Moa (T2), and Tanjung Perak- Fak-Fak-Kaimana-Timika (T13). For
route T1, the ship utilized is KM. Nusantara Pelangi 101 that has 21 voyage targets and completed voyage only 9 in 2017. A Cargo ship, KM. Mentari Prakarsa is used for route T2 and has 17 voyage targets in 2017. The completed voyage by the route in 2017 is 7. The last route, T13 is using KM. Mentari Freedom that has completed 5 voyages in 2017 and 14 target voyages. Table 1 below summarizes these routes details used in this research.

| Route | Port | Type of Ship | Target Voyage (2017) | Completed Voyage (2017) | Total Distance |
|-------|------|--------------|----------------------|------------------------|----------------|
| T1    | Tanjung Perak-Wanci-Namlea | KM Nusantara Pelangi 101 | 21 | 9 | 958 |
| T2    | Tanjung Perak-Kalabahi-Moa | KM Mentari Prakarsa | 17 | 7 | 1158 |
| T13   | Tanjung Perak-Fak-Fak-Kaimana-Timika | KM Mentari Freedom | 14 | 5 | 1604 |

3.2. Weather and ship speed loss
As stated in (2), the wave height and ship speed loss due to wind speed can be acquired by using the Beaufort Number Scale and referring to existing journals and research [11]. By using Google Earth, we can get the distance between each port. From this distance, weather data that was developed by EMD International A/S, Denmark is used and combined with real distance. From these data, the wind speed can be acquired and decide which Beaufort number is it. Then, take data from a journal that has ship speed loss due to Beaufort number. Since the wind speed data from contour is with range, not exact value and the Beaufort number is divided into the two limit, high breaking point, and low cutoff. From this limit, the average value of ship speed loss is taken and can be seen in Table 4. Refer to Table 4, the data from each port for Beaufort number, and the mean ship speed loss is shown.

| Beaufort Number | Wind speed (kts) | Wave Height (m) | Ship Speed Loss |
|-----------------|------------------|-----------------|-----------------|
| 0               | <1               | 0.0             | 0.1922          |
| 1               | 1-3              | 0.1             | 0.2094          |
| 2               | 4-6              | 0.4             | 0.2610          |
| 3               | 7-10             | 0.8             | 0.3297          |
| 4               | 11-16            | 1.5             | 0.4501          |
| 5               | 17-21            | 2               | 0.5360          |
| 6               | 22-27            | 3               | 0.7079          |
| 7               | 28-33            | 4               | 0.9658          |

3.3. Shipping Cost
In this result, all scenarios are included in this calculation. From the results, can compare the value from each scenario and whether it answers the main objectives from this research or not. For route T1, all the data for each voyage is complete and can be seen from the graph that scenario 2 and scenario 3 have a lower amount of shipping costs. The voyage data for route T2 is not fully complete, the data for voyage 9 is not comprehensively. There are 2 sets of voyage data that are missing in route T13, they are voyage 5 and voyage 9. In route T2 and T13, the data for cargo volume (TEUs/Ton) for each port at a specified
voyage is missing. But it doesn’t have a big impact on total shipping cost since the only variable charter cost in port is missing. For route T2, the effect of missing voyage data to the total shipping cost only 0.01%-0.08%, and for the route T13, the effect is only 0.1%-0.6%. It can see from Figure 2, Figure 3, and Figure 4 that change one variable, which is speed can change the total shipping cost significantly.

Table 4. Mean ship speed loss due to wind and wave by using beaufort number

| Route Port | T1- Wanci | T1- Namlea | T2- Kalabahi | T2- Moa | T2- Saumlaki | T13- Fak-Fak | T13- Kaimana | T13- Timika |
|------------|-----------|------------|--------------|--------|-------------|--------------|--------------|-------------|
| Beaufort Number | 3-4 | 2-4 | 2-4 | 2-4 | 4 | 3-4 | 3-4 | 2-4 |
| Mean Ship Speed Loss (kts) | 0.3484 | 0.3416 | 0.3407 | 0.4176 | 0.5730 | 0.3933 | 0.3709 | 0.3222 |

Figure 2. Mean shipping cost for route T1

Figure 3. Mean shipping cost for route T2

Figure 4. Mean shipping cost for route T13

4. Conclusion, Limitation and Future Research
In this research there are four results for each route based on three scenarios in which the one result was acquired by scenario I that use real data on the field, the other one by scenario II that use ship speed loss due to weather with Beaufort number, and the other two results by scenario III that added slow steaming after ship speed loss due to weather. Each different route has a different number of voyages, route T1 has 15 voyages, route T2 has 11 voyages and route T13 has 10 voyages.
From figure 2, 3, and 4, it can be seen that the scenario I have the highest shipping cost for all routes. From closer observation from Figure 2, scenario III of the T1 route has the lowest shipping rate that reduces 16.35% of total shipping cost. For route T2, the result is similar to route T1, the lowest shipping cost is from scenario III that reduce 18.5% of total shipping cost, and it can be seen from Figure 3. The result from route T13 varies from Route T1 and Route T2, the lowest shipping cost is from Scenario III b, which added 12 % slow steaming from current speed to ship speed loss due to weather and it reduced 18.3% from the total shipping cost, it can be seen in Figure 4. It can be concluded that scenario III has the lowest shipping cost, but with a note that with different specific conditions of slow steaming for each route. These results answer the objectives of this research, which is to optimize shipping cost by reducing ship speed with slow steaming due to weather.

Although the objective of this research has already been accomplished, there is still a limitation of this research. The Beaufort Number with ship speed reduction from (3.2) is obtained by different ship models. The ship that is used as a reference is S175 and this data is compared to the existing method, Kwon’s Method that use the same type of ship. Thus, the accuracy of the calculation in this research is limited. The next limitation is the data availability for each voyage is not completed. Lastly, the scope of this research is limited. This research focuses only on 3 out of 13 routes. These 3 routes may not represent all the databases for the sea tollway program. Therefore, future research is needed. The increase of the data availability in future research may be needed to increase the accuracy for the parameter that is used. Furthermore, the research for Beaufort Number of specific ships maybe uses for specific others research.

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