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A Sustainable Simulation Model Based on the Indonesia Sea Toll way

Muhammad Fakhruriza Pradana[1,2*], Sriram Praneeth Vinjamuri[1], Bernd Noche[1]

[1]*Institute of Transport Systems and Logistics, University of Duisburg-Essen, Forsthausweg 2, 47057 Duisburg, Germany*
[2]*Department of Civil Engineering, University of Sultan Ageng Tirtayasa, Jl. Jend Sudirman Km 3 Cilegon 42435, Indonesia*
**Corresponding author. Email: mfakhruriza@untirta.ac.id*

ABSTRACT
Indonesia being an island nation, is facing numerous issues with regards to connecting 17,000 odd islands. Due to the lack of connectivity between these islands, the people's price disparities and economic standards are being affected. It has resulted in the introduction of the Sea toll way program by the government of Indonesia in 2015. This article looks at two routes, T-3 and T-8 of 2017 because data availability is better than other routes. Tools of analysis is a simulation model, the use of slow steaming and extra steaming to make the model more sustainable. As part of sustainability, the environmental measures are taken care of constructing five different scenarios with five different ship speeds and analysing the impact of various factors: fuel consumption, EEOI (Energy Efficiency Operational Indicator), voyage time, fuel costs, etc. and total costs involved in each voyage. As a result, after the simulation and analysis, we found out that, for route T-3, scenario 5 is the best concerning both cost reduction and fuel reduction with $652,950 and 715.29 tons which is a reduction of 59.5 per cent and 72.73 per cent, respectively. Regarding route T-8, scenario 4 was the best, with a total cost of $1,121,490 and 490.51 tons of fuel consumption leading to a reduction of 17.19 per cent and 58.91 per cent, respectively.

Keywords: *Sea Toll way, Slow Steaming, Extra Steaming, EEOI*

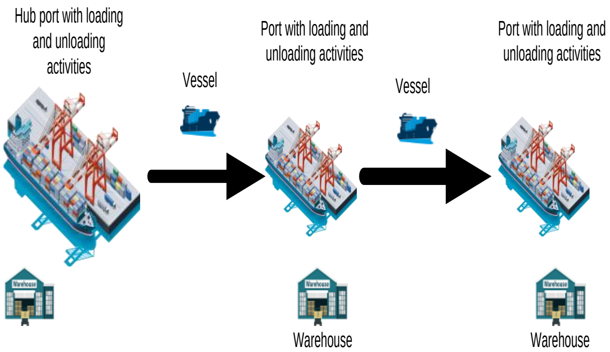
1. INTRODUCTION

The shipping trade has played a vital part in the dramatic enhancements in international living standards that have taken millions of individuals out of acute poverty in recent years [1]. This also draws our attention to the development of sustainable ship routing and networking, particularly in developing countries such as China, India, Indonesia, and other Southeast Asia, as they will be the future of maritime trade. Indonesia is the fourth populous country in the world and the fourteenth most prominent country in the world. This brings us many opportunities for maritime transport, not just for trade but also for connectivity purposes and overall economic growth. Many islands remain unconnected to their neighbours, and several benefit from only loose or intermittent contact. This lack of connectivity is much more significant in the outermost islands of Eastern Indonesia, such as Maluku and North Maluku. Over the years, Indonesia's port infrastructure has suffered from negligence and financial constraints by the government. Many ports are in poor condition, causing revenue losses, time lag, procedural delays, and inadequate port facilities to impede the country's internal and external maritime commerce. According to a World Bank report, shipping a container from Padang to Jakarta costs more than three times than shipping the same container from Jakarta to Singapore [2]. It is also reflected in regional imbalances in Gross Domestic Product (GDP) contribution, with Eastern Indonesia accounting for only 18% of total GDP (2014) [3].

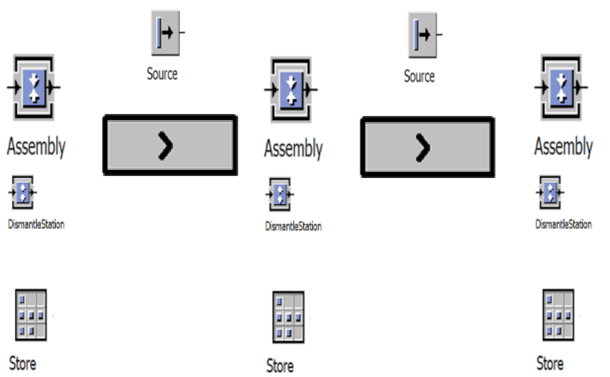
This led the Government of Indonesia to bring a comprehensive policy called the "Master Plan for the Acceleration and Expansion of Indonesia's Economic Development (MP3EI) 2011 – 2025" and the Global Maritime Fulcrum Policy in 2015. The latter focuses more on the maritime industry, and sea connectivity realized through the Sea tollway program or Tol Laut, as called locally in Indonesia. The main objective of the Sea tollway program is to implement and provide for a more effective and efficient delivery system from western Indonesia to the east to reduce economic disparities and prices. To address the price disparity problem resulting from higher logistics costs in Indonesia, they took the initiative to implement three routes in 2015, which continued to increase year on year, now summing up to 18 routes in 2018 [4]. Based on the above-described issues, this paper is to answer the main question that is "How can we optimize the existing system of the Sea Toll way program sustainably?"

2. METHODS

For this study, we are looking at two routes from the sea toll way program of 2017. The route T-3 and T-8 are used for our analysis because data availability is better than other routes. To replicate the same route, we have simulated our routes in software, and this model is used to get the data required for our analysis. This method helps us understand different scenarios and their effect on that model. We are using Siemens PLM Software, which is Tecnotrix Plant Simulation 14 software because of the capability to simulate discrete events and optimize logistics systems [10]. The prototype of the simulation can be seen in figure 1



(a) Maritime network



(b) Simulation model

Figure 1. A Prototype of simulation and maritime network.

2.1 Simulation Model

In our data Route, T-3 was initially scheduled for 11 voyages, but by the end of the year, it has completed only nine voyages. Out of these nine voyages, we only have sufficient data for six voyages for each simulation model is created. We conducted the simulation model for all six voyages. The route is divided into 14 legs with a total distance of 2150 nautical miles between them. The simulation model has been designed so that all the 14 legs of the routes are demarcated. When looking at the data, we can see that the cargo is being loaded at Tanjung Perak and the cargo is getting unloaded at five seaports, i.e., Larantuka, Lewoleba, Rote, Sabu, and Waingapu. The ship is then returning, passing the same ports covering the same distance. The ship used in our route is KM Caraka Jaya Niaga III-22, and its capacity is 135 TEU.

2.2 Calculation methodology

International Maritime Organization uses the bottom-up approach to estimate the emissions calculations because there could be many misinterpretations and loss of operational data when the emissions are estimated under the top-down approach. In this plan, IMO formulated various indices used to estimate energy efficiency at the operational level.

Energy efficiency is improved by Energy Efficiency Design Index (EEDI) and Energy Efficiency Operational Indicator (EEOI). While the former suggests the practical design of new upcoming ships and how to achieve minimum levels of greenhouse gases (GHG) emission, the latter is about reducing the GHG emissions of the existing ships. The formula of EEOI given by the IMO is as follows [11]:

$$EEOI = \frac{\Sigma_i FC_i * C_C}{\Sigma_i m_{c,i} * Di} \tag{1}$$

where:

FC_i = Fuel consumption (ton)

C_c = Constant carbon content in fuel

$m_{c,i}$ = Mass of the cargo transported in (TEU or cubic ton)

D_i = Distance travel (nautical mile or kilometer)

The fuel consumption is based on the relationship between speed and fuel consumption. The fuel consumption is a cubic representation of ship speed (v) for many types of ship [12]:

$$f(v) = kv^3 \tag{2}$$

But here we are, leaving behind the factor of cargo weight. The weight from full to empty also affects speed and fuel consumption. Therefore, the formula for fuel consumption is [12]:

$$f(v,w) = k(p + v^q)(w + A)^{2/3} \quad (3)$$

where:

k, p, q = constant as such as k>0, p>= 0 and q>=3
v = speed (knots/kmph)
w = weight (TEU or ton)
A = lightweight ship

Most of the researchers assume p=0, q=3, and k equal to one over the fuel coefficient, which is used for fuel consumption calculations of most ships. The fuel coefficient depends on the type of engine the ship uses. There are two main types of engines: steam turbine machinery (F_c = 110,000) and diesel turbine machinery (F_c = 120,000). We would be using both equations (1) and (3) for our calculations to find EEOI and fuel consumption [13].

Typically, IMO suggests a decrease of 10 to 17% from the average speed to benefit from slow steaming, making it a profitable venture both economically and environmentally. But a study in 2013 continued experimenting with the decrease in speeds for slow steaming and found out that the costs and benefits of "extra slow steaming" under various volumes and fuel price. The study says a cost decrease by 20 per cent and carbon dioxide emissions by 43 per cent [14].

If reduced vessel speeds are modelled, used for slow steaming, the vessel extends its total voyage time or increases the requirement of additional ships for the same amount of cargo. While slow steaming reduces emissions, the increase in voyage time or additional ships increases the emissions. Hence tight modelling is done to manage and maintain both low emissions and a faster delivery period. Hence, we would be looking at five different scenarios.

i. Calculation of days of the voyage, fuel consumption, and EEOI concerning maximum speed.
ii. Calculation of days of the voyage, fuel consumption, and EEOI for Speed reduction by 10% of maximum speed.
iii. Calculation of days of the voyage, fuel consumption, and EEOI for Speed reduction by 20% of maximum speed.
iv. Calculation of voyage days, fuel consumption, and EEOI concerning Speed reduction by 30% of maximum speed.
v. Calculation of voyage days, fuel consumption, and EEOI to Speed reduction by 40% of maximum speed.
vi. Comparing cost estimates and environmental estimates of all the various scenarios for finding an optimal solution

3. RESULTS AND DISCUSSION

3.1 Simulation analysis

To understand how the simulation and calculation work, we would be considering the first voyage of route three as our example. The first figure deals with the model without running the simulation.

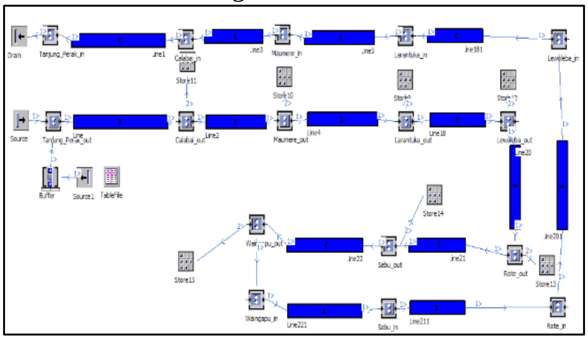


Figure 2. Simulation model of Route T-3.

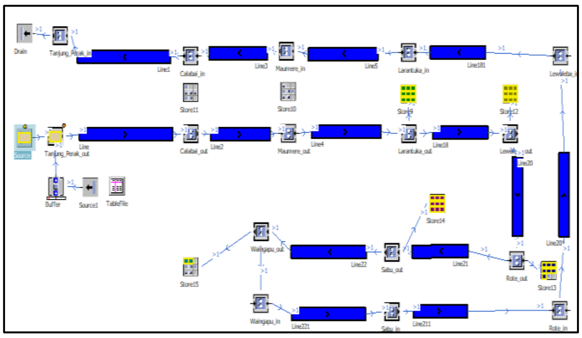


Figure 3. Route T-3 after running the simulation.

The simulation here is done at the shipping speed of 13.44 kmph, which is a speed reduction of 40% from the maximum speed. This simulation is modelled based on the data from the first voyage of route T-3, which can be seen below. Figure 3 illustrates the result after simulating with the specifications. After the simulation, we can see the material flow properties that the required cargoes have been placed in their respective stores with the correct number of volumes.

Table 1. Cargo present in each Store.

Object	Number of entries	Number of exits	Minimum contents	Maximum contents	Relative empty
Store 9	20	0	0	20	5,70%
Store12	40	0	0	40	6,54%
Store13	7	0	0	7	7,88%
Store14	41	0	0	41	8,92%
Store15	2	0	0	2	10,13%

Table 2. Simulation time of Route T-3.

Object	Name	Mean life time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	KM_caraka_jaya	20:08:35:42,8571	1	0	39,33%	60,67%	0,00%	39,33%	

The total time taken for the voyage with an addition of a day at the loading/unloading port and three days in Tanjung Perak because of the business of the port, the total time taken for the voyage with a 40% of reduction from the maximum speed is 20 days 8 hours and 35 minutes. The total transportation time was around 60.67%, and the ports' time was 39.33%.

3.2 Numerical calculation

The effect of slow steaming on fuel consumption could be looked at in the below figure. Each voyage has five scenarios, and the first scenario is when the vessel moves at the maximum speed, which is 11.9 knots or 22.4 kmph.

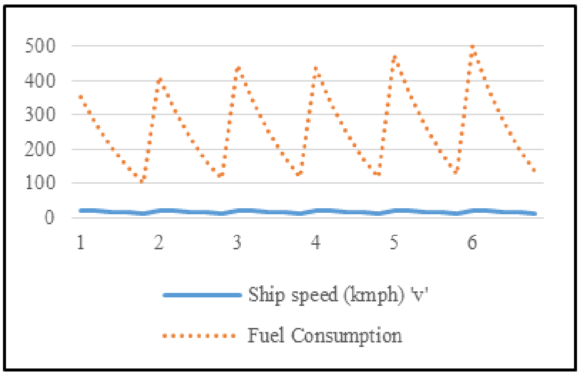


Figure 4. Ship speed v/s fuel consumption, Route T-3.

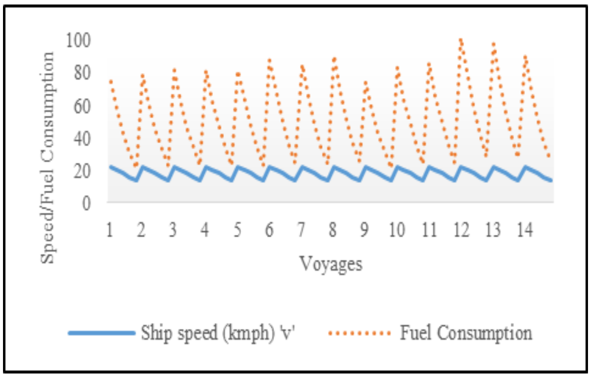


Figure 5. Ship speed v/s fuel consumption, Route T-8.

The second scenario is with a 10% reduction which is 20.16 kmph, and the third scenario is the speed reduction by 20%, which is 17.92 kmph, the fourth scenario is with a 30% speed reduction which comes to 15.68 kmph and the final fifth scenario is with a 40% speed reduction which is running the vessel at 13.44 kmph. When looked at all the voyages of both the routes, as seen in figures 4 and 5, there is a cumulative decrease of up to 78 per cent. This happened when the fuel consumption is achieved with a speed reduction of 40 per cent. With each scenario, the change in fuel consumption is reduced by around 20 percentage points, with a maximum of 31 percentage points for the last case.

Since the speed of the ship is decreased, this automatically increases the time taken for each trip. While keeping a day at each port of operation and three days at Tanjung Perak port, the total days per trip of voyage one route T-3 took 15 days 10 hours at 22.4 kmph. This increased to 20 days 8 hours for the same distance while the ship travelled at 13.44 kmph. A 20 per cent speed reduction could lead to an increase in 11 per cent of initial voyage time. For example, if looked at the third voyage of route T-8 with a speed of 22.4 kmph, the time taken to complete the total voyage was nine days and 8 hours while the same route is taken ten days and 22 hours with a speed of 17.92 kmph, which is a 30% reduction of the actual maximum speed. This scenario reduces fuel consumption by 42.67% per cent with an additional percentage change of 11.95 per cent in the total time taken by each voyage. The relationship between speed v/s days of the voyage can be seen in Figures 6 and 7.

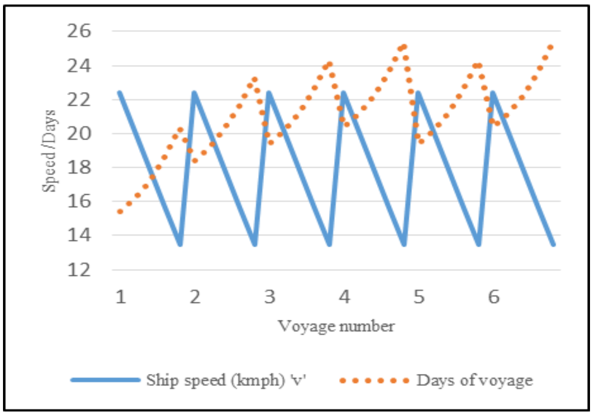


Figure 6. Ship speed v/s Voyage time.

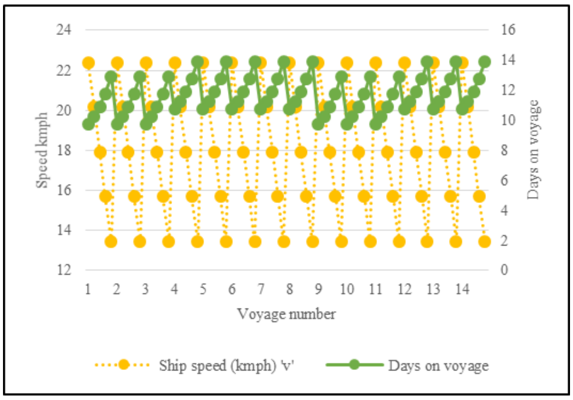


Figure 7. Ship speed v/s Voyage time, Route T-8.

As per our simulation, even with a speed reduction of 40 per cent, the time taken to complete one trip is just above 20 days which infers that the 15 trips for the next year could be made within 310 days giving us an idle window for around 50 days. Hence a reduction in 40 per cent of ships speed makes sense for our case. The Energy Efficiency Operational Indicator (EEOI) gives you the total carbon emissions per unit length, in our case, unit kilometre. This is one way of making sure the efficiency of the ship is checked for environmental emissions. Since the fuel consumption is reduced, with reduced speed, the EEOI is also reduced in effect. The relation between the speed of the ship with EEOI is given in below the graph. If we look at voyage 5 of route T-3, the EEOI is 2.787 x 10^{-3} tons of CO_2/tons km, while at the lowest speed in scenario five, the EEOI is 7.56 x 10^{-4}tons of CO_2/tons km, which is a reduction of 72.8 percentage. This is a vast improvement in operational efficiency.

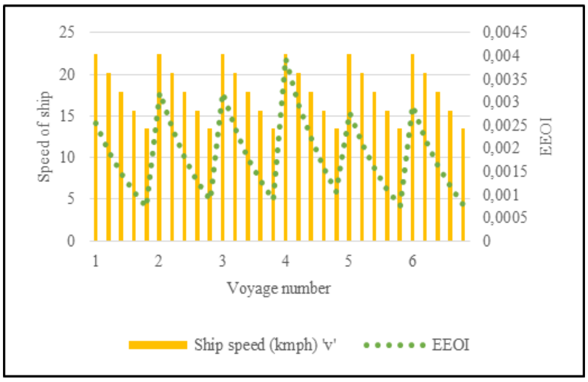


Figure 8. Ship speed v/s EEOI, Route T-3.

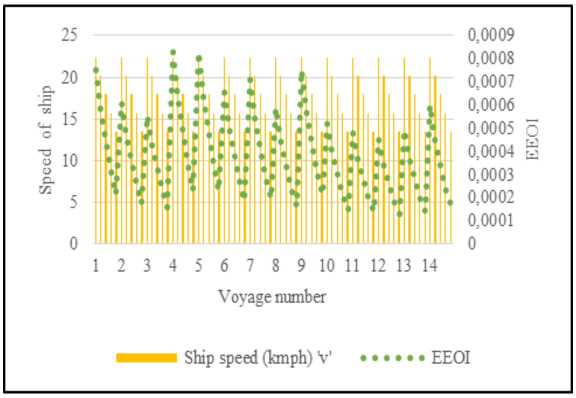


Figure 9. Ship speed v/s EEOI, Route T-8.

Similarly, even route T-8 has a very similar result. If looked at voyage 10 of route T-8, the reduction in EEOI is a staggering 71.38 percentage which reduced from 5.19 x 10^{-4} tons of CO_2/tons km to 1.49 x 10^{-4} tons of CO_2/tons km. The relation between the EEOI and ship speed can be looked at figure 8 and 9 for both routes.

While with every scenario, the fuel cost is reducing due to a reduction in fuel consumption. The voyage time also increases, respectively, leading to increased time charter costs [15]. When both the time charter costs and fuel costs are combined to get the total costs, concerning route T-3, the costs steadily decrease while the speed reduction is made to 40 per cent. This could be looked at in figure 10. When the percentage change between each scenario is looked at, a steady decline of about 20 per cent is evident with each scenario. For example, voyage 3 of route T-3 percentage decline in total costs is 20.15, 20.63, 20.62, and 19.62 per cent of 10, 20,30, and 40 per cent reduction in ship speed. Hence, both economically and environmentally, a reduction of 40 per cent on the maximum speed is a sustainable way to carry out short sea shipping.

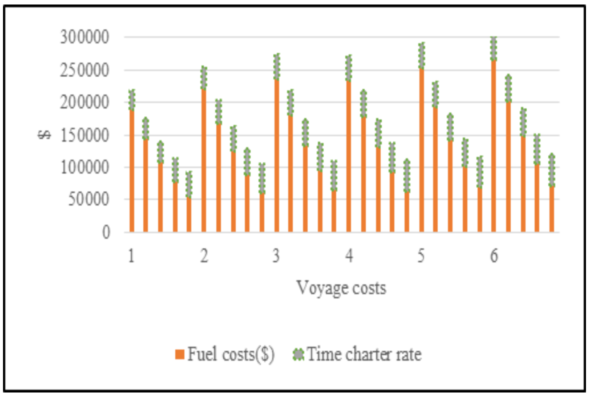


Figure 10. The total cost of Route T-3.

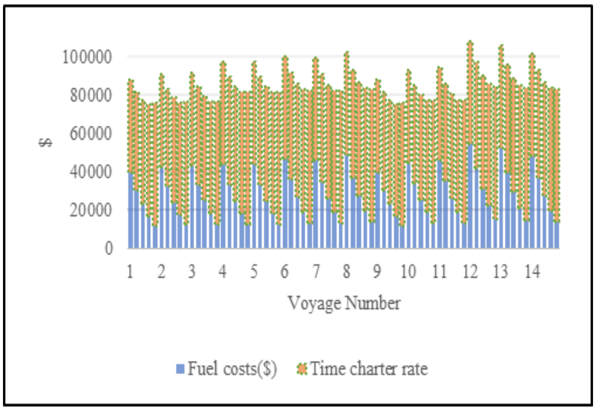


Figure 11. The total cost of Route T-8.

Due to the high charter rate of route T-8, there is a bit of change in the costs evolved when compared to route T-8. Since the time charter rate for one day is $4969 per day, the reduction of fuel costs due to low fuel consumption is offset by the increasing time charter costs. If we look at figure 11, we can see that from the economic standpoint, there is no feasibility in total costs after reducing the shipping speed to 17.92 kmph, which is a 20 per cent reduction from the maximum speed. The percentage change for total costs is not as steep as route T-3, where the costs declined by over 20 per cent per scenario. Instead, the change is a bit moderate with a decline of 8.1 per cent, 5.8 per cent, 3.1 per cent, and finally, a mere 0.02 per cent for 10, 20, 30, and 40 per cent speed reduction, respectively were seen in voyage 4 of route T-8. In few cases, the total cost was increased in the last scenario by up to 0.65 per cent. This could be seen in voyage one, where the total costs at 15.68 kmph (30 per cent reduction of maximum speed) were $ 75,015.86 while at 13.44 kmph (40% reduction of maximum speed) was $ 75,508.25. This is an increase of 0.65 per cent.

4. CONCLUSION

Our study considered five scenarios related to speed reduction techniques or slow steaming to reduce environmental pollution. But this technique has its own set of problems; the first problem is that the voyage time is increased due to a decrease in ship speed, leading to increased charter costs. An unsustainable reduction of ship speed could lead to more damage to the program rather than helping it. Hence to get an optimal solution, each voyage has been simulated with five different ship speeds to find the best one suitable for both routes.

Scenario 1 is the fastest of the whole lot due to its high speed, but this is also the most expensive and polluting case, thus making it highly unsustainable for the government. Scenario 2 of route T-3 has reduced the average fuel consumption by 23.9 per cent and total costs by 20.13 per cent for all the voyages with a 10 per cent reduction in ship speed. When looking at route T-8 for scenario two, the total fuel consumption was down by 23.5 per cent, but the total costs were 8.5 per cent. The pattern continued for the next scene, scenario 3, with a 20 per cent speed reduction. With route T-8, fuel consumption dipped by 25.44 per cent from scenario two while the costs decreased by 6.24 per cent from the previous scenario. Route T-3 values came down by 26.1 per cent for fuel consumption and 20.6 per cent for the total costs compared to scenario 2. On similar lines, both scenario four and scenario 5 reduce the costs and fuel consumption to 20.53 per cent, 28.65 per cent, and 19.65 per cent, 32.04 per cent, respectively, making scenario five the best optimal solution for route T-3.

While scenario 5 is the best possible solution for route T-3, it is not the same for route T-8. In contrast, scenario 4 reduces the fuel consumption by 27.90 per cent and total costs by 3.46 per cent, and scenario 5 reduces the total costs by a mere 0.32 per cent, making it illogical to reduce the shipping speed by 40 per cent. This mainly occurred because extra slow steaming is mainly helpful for very short distances between the ports, and the other reason for the result is the high-cost difference in charter prices between both the ships of T-3 and T-8. Because of the high cost of the charter price, the ship costs have increased due to the rise in voyage time, offsetting the costs reduced due to fuel consumption. Thus, from our study, we can say that by using scenario 5 for route T-3, the average savings on total costs is by 59.53 per cent and fuel consumption by a staggering 72.73 per cent. Looking at route T-8, the average savings by using scenario 4 is 17.19 per cent on total costs and 58.92 per cent on fuel consumption.

Our study deals with the routes and data of 2017, and the program has evolved leaps and bounds in these three years, making further research possible in this area. The use of more integrated data sets and artificial intelligence, and machine learning for forecasting and predicting supply and demand can help develop next year's Sea tollway program. Artificial intelligence and machine learning can also help in environmental routing, which could help operational and tactical planning.

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