Multi-Depot Vehicle Routing Problem with Heterogeneous Fleet for Distribution of Fuel Products in The Eastern Region of Indonesia

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Abstract
Equitable use of fuel products must be carried out by the Indonesian government, especially for the eastern region of Indonesia where most of the natural conditions are in the form of the sea. Since consumer requests on the islands come in at different times, fuel product deliveries are made in response to local demand, and occasionally the cargo hauled is not entirely full. Another challenge in shipping by ship is crew costs and the increase of fuel prices, thus making the company try different operational strategies. In addition, the open water conditions around September to early March are in choppy conditions, making the company spend more fuel costs, and of course it will require more costs as well. The company that distributes fuel products to consumers has three depots, twenty consumers, and twenty vessels with different capacities. Under these conditions, the problem will be solved by using a multi-depot vehicle routing problem using a heterogeneous fleet and binary integer programming. At the initial stage, the solution to the routing problem is expected to get the smallest distance, determine the ship that will carry out the transportation and determine the customers to be served. The purpose of the study is to meet consumer demand with minimum transportation costs and calculate the number of emissions caused by the distribution of fuel based on routes and sea conditions. This study resulted in 13 of 20 vessels owned by the company assigned to the delivery of fuel. When sailing in choppy sea conditions, the transportation cost increase by 16.70 percent, and emissions CO_2 increase by an average 17.28 percent when compared with calm water conditions.

Keywords:
Heterogeneous Fleet, Multi-Depot Vehicle Routing Problem, Binary Integer Programming, Emissions.

1. Introduction
Transportation and distribution are components that greatly affect the competitive level of business processes run by a company. Meanwhile, transportation management is one of the components of supply chain management which has the aim of meeting customer demand, as a result of planning, implementing and controlling efficient movement activities involving goods, services and information (Soeanu, Ray, Berger, Boukhtouta and Debbabi, 2019).

Parkhi, Jagadeesh, and Kumar (2014) stated that a good route for logistics distribution can reduce transportation costs thereby increasing shipping efficiency. The efficiency of these routes will affect the improvement of the logistics system (moving load, delivery, speed, service quality and usage of facilities) and especially the reduction of shipping costs and savings in terms of energy use. Determination of the optimum route in the distribution and transportation system is related to the distribution flow starting from the starting point (depot) to various consumer locations until ending back to the starting point (depot), as well as considering the balance between the routes formed.

PT. ABC is a company engaged in the distribution of fuel oil (BBM) shipments through sea transportation facilities, which send fuel from the depot to the customer. Figure 1 shows the operational area of PT. ABC is located in the eastern region of Indonesia. PT. ABC has three depots and 20 vessels, each tasked with distributing products to a predetermined number of customers and shipping these products by ship. The use of ships exposes various challenges to be faced.

The research gap is that the company is facing a situation where rising fuel prices, increasing crew costs and sea conditions such as wind and waves that often change can make inaccuracies in the calculation of fuel use, and the government requires the use of environmentally friendly fuels in order to create emission reductions by implementing carbon tax.

In this study, the problem to be solved is how to meet consumer demand with minimum transportation costs and calculate the number of emissions caused by the distribution of fuel based on routes and sea conditions. The purpose of this study was to determine the required transportation costs and the number of emissions generated by ships by comparing the use of fuels of different types, namely Marine Diesel Oil (MDO), Biodiesel B30 and Low Sulfur Fuel Oil (LSFO) using tankers under conditions calm and choppy sea.

This research is expected to provide advice for companies to plan strategies on the implementation of ship operational activities by considering various sea conditions by obtaining minimum transportation costs and knowing the number of emissions produced related to the imposition of carbon taxes.

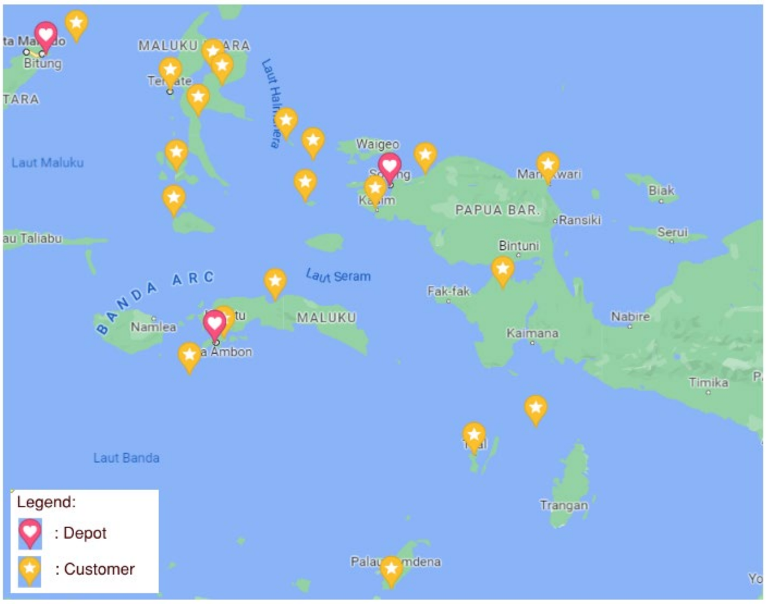

Figure 1. Operational area of PT. ABC in Eastern Indonesia

2. Literature Review

A product's distribution system, which calls for a means of transportation to supply a number of consumers, is directly tied to the VRP solution. When a business assigns a fleet of different vehicle types with a specific capacity to deliver or distribute a product from a factory, manufacturing site, depot, to a distribution point, or to a consumer, problems can occur. With the appropriate tactical and strategic judgments, optimal distribution system management can assist businesses in the economic rivalry (Lukman, et al. 2019). To fulfil the distribution system, the company identifies the distribution route to be traversed and the selection of the right vehicle so that logistics costs can be minimized (Bhattacharjee, et al., 2020). In VRP, besides aiming to minimize the total distance travelled or total transportation costs, it can also aim to minimize the number of vehicles used. Toth and Vigo, 2014 identified the characteristics of VRP and classified the problem based on (i) network structure (ii) type of transportation demand (iii) constraints affecting each route individually (iv) fleet composition and location (v) constraints between routes and (vi) optimization objectives.

The basic form of VRP assumes that all vehicle fleets owned by the company have the same capacity (homogeneous). In fact, it is possible for a company to have more than one depot that can be used as a product storage center, and companies do not always have a fleet with the same capacity. A company, whether large, medium or small, must have a fleet with their respective capacities (different capacities), so the basic VRP solution method is now difficult to implement (Mancini, 2006). Therefore, a VRP variant emerged which became known as the Multi Depot Heterogeneous Fleet Vehicle Routing Problem (MDHFVRP).

According to Siriruk and Tangmo (2017), HFVRP entails developing a number of vehicle routes for heterogeneous fleet utilization, each beginning and ending at the depot, serving a set of customers with known demand. According to Salhi et al. (2013), switching a multi-depot problem to a single-depot problem can be accomplished by allocating customers to the closest depot and then employing the suitable strategy for each single-depot problem by using mixed integer linear for MDHFVRP.

Consumers are divided up into different groups in this Multi Depot problem, and an approximation is made using the "cluster first, route second" kind (Giosa, Tansini, and Viera, 2002). A cluster is a collection of customers that one depot serves, and the number of clusters equals the number of existing depots (Viera and Tansini, 2004). Each cluster is utilized to compute the quickest path to be taken. When employing the cluster first, second route technique to solve the VRP problem, groups are first formed based on regions, and the trip route is subsequently determined using algorithms for assignments. Additionally, according to Siriruk and Tangmo (2017), consumer clusters are determined by nearby locales and transportation capability.

The fuel for ships assigned to serve customers-especially at the operational stage-must be calculated carefully. Fuel consumption can be calculated taking into account several factors. In addition to sailing speed and ship load, according to Yang, Chen, Zhao, and Rytter, (2020), weather, currents, waves, wind speed, engine efficiency and other factors can also affect the level of fuel consumption. Significant Wave Height, HS is the parameter most often used to describe the state of the sea. Historically, HS was defined as a time series of recorded wave heights taken during the prevalence of a particular sea condition (Muliati, 2020). Thus, the significant wave height can be reported as the prevailing wave height by visual observation (Weisse and Von Storch, 2010). In the world of shipping, ships must be able to sail in unfavorable weather conditions, but these conditions will be able to reduce the function of the ship's work system (Zaky, 2018). Overall assessment of seakeeping performance is difficult because of the many different sea conditions a ship may encounter and the different responses that may limit the ship's ability to perform its functions (Tupper, 1996).

In relation to ship operations, cost and emission requirements must also be taken into account. Classification of transportation costs in the shipping sector is used in calculating the costs incurred as a result of operating the ship (Wijnolst and Wergeland, 1997). In the shipping sector, there is no standard cost classification used internationally, so the calculation uses a general approach that is in the field. Meanwhile, according to the Encyclopaedia Britannica, air pollution is the release of gases, finely divided solids or liquid aerosols into the atmosphere so that many pollutants have an impact on the environment, and some of them are very dangerous, namely (i) Carbon Monoxide, (ii) Sulfur Oxide (iii) Nitrogen Oxide (iv) Carbon Dioxide (v) Ammonia and (vi) Particulate matter.

1. Problem definition and mathematical Model

The company has three depots and 20 vessels of different capacities. Each vehicle operated has different characteristics in terms of speed, capacity and nature of fuel consumption based on the load transported (Jandaghi, et al., 2018). Operations manager believes that the use of the right type of fuel and ship speed, will optimize fuel consumption, minimize costs and produce less emissions. When the sea conditions are calm, the ship will sail at its service speed with a relatively short distance and time. However, if there are waves, the ship will not be able to sail according to its service speed and requires a longer travel time. This situation will result in the use of more fuel than the initial calculation, which so far, the calculation of fuel on a route is the same when the sea conditions are calm, and the sea is choppy. These choppy sea conditions usually occur around September to early March. To anticipate this, an analysis of determining the route to be passed by the ship is needed, the best ship speed in calm or choppy sea conditions. With this situation, this study proposes a VRP variant, namely Multi Depot Heterogeneous Fleet Vehicle Routing Problem (MDHFVRP) which is used to solve routing problems. The mathematical model will be solved by the binary integer programming method with the aim of getting the shortest distance and determining the ship that will send BBM products. According to Jabir et al, 2017, the problem of routing multi-depot vehicles has challenges such as the allocation of consumers to the depot, assigning customers to routes and the order of customer service and determining ships according to their capacity. In this study, the researcher adopted and developed a mathematical model of MDHFVRP based on the model proposed by Salhi, et. al, 2013. This model is a binary integer programming model with the aim of finding the best route in the distribution of BBM products. The basic assumption of this formulation is that the depot is the starting point of all vehicles and the place where they load products so that the depot has no demand.

Indeks

i, j : index of node

k : index of vessels

d : index of depot

Data

n : number of customers; (1, …, n)
m : number of depots; (n+1), …, (n+m)
K : number of ships; (1, …, K)
qi : demand from node i; i = (1, …, (n+m)
Qk : ship capacity k; k=1, …, K
Qd : depot capacity d; d=(n+1), …, (n+m)
O_C : operational cost such as allowance per ship trip crew and port fees
Cfu : fuel price
FOC : fuel consumption
Ef : emission factor
C_{CO} : carbon tax rate
v : speed of ships
D_{ij} : the distance between nodes i dan j, where i, j = 1, …, (n+m). Therefore, D_{ij} represents the distance from the customer to the customer and from the depot to the customer.

Sets

[1, …, (n+m)]	:	set of nodes
[1, …, n]	:	set of customers
[(n+1), …, (n+m)]	:	set of depots
[1, …, K]	:	set of vessels

Decision Variable

X_{ijkd} : binary variable. If X_{ijkd} = 1, then ship k travels on arc (i,j) and from the chosen origin depot, otherwise X_{ijkd} = 0. Where k=1, …, K; i=1, …, n+m; j=1, …, n+m and depot d (d=n+1, …, n+m).

Y_{ij} : non-negative continuous variable representing the total load remaining in the ship before reaching node j during the journey along the arc (i,j) (i=1, …, n+m; j=1,…,n+m).

Objective Function

$$Minimize\ Z = \sum_{d=n+1}^{n+m}\sum_{k=1}^{K}\sum_{i=n+1}^{n+m}\sum_{j=1}^{n} O_C.X_{ijkd} + \sum_{d=n+1}^{n+m}\sum_{k=1}^{K}\sum_{i=1}^{n+m}\sum_{j=1}^{n+m}(\frac{D_{ij}}{v}.FOC).C_{fu}.X_{ijkd} + \sum_{d=n+1}^{n+m}\sum_{k=1}^{K}\sum_{i=1}^{n+m}\sum_{j=1}^{n+m}\left(\frac{D_{ij}}{v}.FOC\right).E_f.C_{CO}.X_{ijkd} \quad (1)$$

The aim is to obtain the minimum amount of transportation costs and the minimum amount of emissions associated with the imposition of a carbon tax on the distribution of fuel products from depots to consumers.

Constrain:

$$\sum_{d=n+1}^{n+m}\sum_{k=1}^{K}\sum_{i=1}^{n+m} X_{ijkd} = 1 \qquad j = 1,\dots,n \quad (2)$$

$$\sum_{d=n+1}^{n+m}\sum_{k=1}^{K}\sum_{j=1}^{n+m} X_{ijkd} = 1 \qquad i = 1,\dots,n \quad (3)$$

Constraints (2) and (3) ensure that each customer is visited once with one ship on a predetermined route.

$$\sum_{i=1}^{n+m} X_{ijkd} = \sum_{i=1}^{n+m} X_{jikd} \qquad k = 1,\dots,K;\ j = 1,\dots,n+m;\ d = n+1,\dots,n+m \quad (4)$$

Constraints (4) ensures conservation of flow, when ship k with depot of origin d serves the customer, when it is finished, the ship must leave the location of the customer.

$$\sum_{i=n+1}^{n+m}\sum_{j=1}^{n+m} Y_{ij} = \sum_{j=1}^{n} q_j \quad (5)$$

Constraint (5) ensures that the total amount of product capacity leaving the depot is equal to the number of customer requests to be served.

$$\sum_{i=1}^{n+m} Y_{ij} - \sum_{i=1}^{n+m} Y_{ji} = q_j \qquad j = 1, \dots, n \tag{6}$$

Constraint (6) ensures that the remaining product capacity after visiting customer j, is equal to the capacity before visiting this customer minus its demand capacity.

$$Y_{ij} = \sum_{d=n+1}^{n+m} \sum_{k=1}^{K} (Q_k - q_i) X_{ijkd} \qquad i = 1, \dots, n+m; j = 1, \dots, n \tag{7}$$

Constraint (7) states that the capacity of the ship in any arc after the vehicle has delivered to customer i, in arc (i,j) is the remaining capacity.

$$Y_{ij} \geq \sum_{d=n+1}^{n+m} \sum_{k=1}^{K} q_j X_{ijkd} \qquad i,j = 1, \dots, n \tag{8}$$

Constraint (8) guarantees that there is at least sufficient quantity remaining to serve node j when traveling to node j on arc (i,j). Constraints (7) and (8) indicate that if the remaining capacity is greater than the demand of customer j, the ship will sail to customer j, if it is less than demand, the ship will return to the depot.

$$Q_d \geq \sum_{i=1}^{n} q_i \tag{9}$$

Constraint (9) ensures the depot capacity is sufficient to deliver products to customers.

$$X_{d1ikd2} = 0 \qquad i = 1, \dots, n; \; k = 1, \dots, K; \; d_1 \neq d_2 = n+1, \dots, n+m \tag{4.10}$$

Constraints (10) and (11) ensure that vehicles leaving the depot or returning to the depot, are not linked to another depot.

$$X_{id1kd2} = 0 \qquad i = 1, \dots, n; \; k = 1, \dots, K; \; d_1 \neq d_2 = n+1, \dots, n+m \tag{11}$$

Constraints (9), (10) and (11) can be said that if the capacity of the depot (d1) is not sufficient to meet the customers, it can take products from other depots (d2 or d3).

$$X_{ijkd} \in \{0,1\} \qquad i,j = 1, \dots, n+m; \; k = 1, \dots, K; \; d = n+1, \dots, n+m \tag{12}$$

$$Y_{ij} \geq 0 \qquad i,j = 1, \dots, n+m; \tag{13}$$

Constraints (12) and (13) refer to the binary and non-negative of the decision variables, respectively.

3. Data and Collections

There are 20 vessels owned by the company, each with a different capacity, as shown in Table 1. The vessels used are tankers that can transport fuel products. And data related to the customers served are presented in Table 2. Each customer has a request that will be sent at a certain time.

The distance between the depots, depots to consumers, and between consumers is then estimated using the list of consumer names from Table 2. The consumer's position and the depot's location have both been indicated with a dot so that a connecting line can be used to estimate the distance between them. A total of 23 points must be measured, with 20 points for customers and 3 points for depots. Google Maps was used to measure the distance, and the kilometres it yielded were translated to nautical miles to make the following calculation easier. By counting all the points in pairs, the distance between each point is calculated.

Table 1. Data Related to Ships and Their Capacities

Ship's Name	Capacities (m3)	Capacities (ton)	Ship's Name	Capacities (m3)	Capacities (ton)
K1	1204,4	1060	K11	1299,5	1144
K2	827,6	728	K12	1355,8	1193
K3	345,56	304	K13	317	279
K4	1678	1477	K14	1349,9	1188
K5	670,5	590	K15	1195,32	1052
K6	519,9	458	K16	1350	1188
K7	395,1	348	K17	1339,8	1179
K8	346,82	305	K18	1252,8	1102
K9	346,2	305	K19	1310,44	1153
K10	762	671	K20	1184,79	1043

Table 2. Data related to customers and their demand.

Customer Name	Demand (m3)	Demand (ton)	Customer Name	Demand (m3)	Demand (ton)
B1	450	396	B11	620	546
B2	560	493	B12	190	167
B3	620	546	B13	250	220
B4	675	594	B14	230	202
B5	170	150	B15	120	106
B6	220	194	B16	220	194
B7	560	493	B17	390	343
B8	620	546	B18	250	220
B9	900	792	B19	205	180
B10	120	106	B20	550	484

4. Results and Discussions

Based on the closest distance between the consumer and the depot, the results of the clustering of consumers are generated after creating a program using the Matlab software. It is also decided which ship would deliver petroleum items to these users with the proviso that a depot serves a number of consumers. Out of the 20 ships held by the corporation, 13 units are allocated to supply fuel goods, and the remaining 7 vessels are awaiting assignment from the company for another task. Figure 2 depicts the paths taken by ships serving consumers, while Table 3 lists the depots and ships that serve consumers.

Ships that sail in one trip to send fuel products to consumers, from the depot to the consumer to the depot again through various water conditions. The time it takes the ship to sail is the distance travelled divided by the speed of the ship. In this study, two sea conditions were compared, namely calm sea conditions and choppy sea conditions. The speed of the ship is constant whether carrying cargo or not carrying cargo (returning to the depot).

After obtaining the route, then validation is carried out. Validation is a process to check the suitability of the model made with real conditions in the field. In this study, validation is done by looking at the output of the program. The outputs generated from the program are in the form of ships used, consumers served, routes taken, transportation costs and the resulting emissions. With this route all consumers have been served. And the model made does not violate all existing restrictions in the form of the capacity of the ship and the cargo that is transported and sent to the consumer, and after completing the delivery, the ship returns to the depot. Table 3 also shows the match between ship capacity, cargo carried and customer's demand.

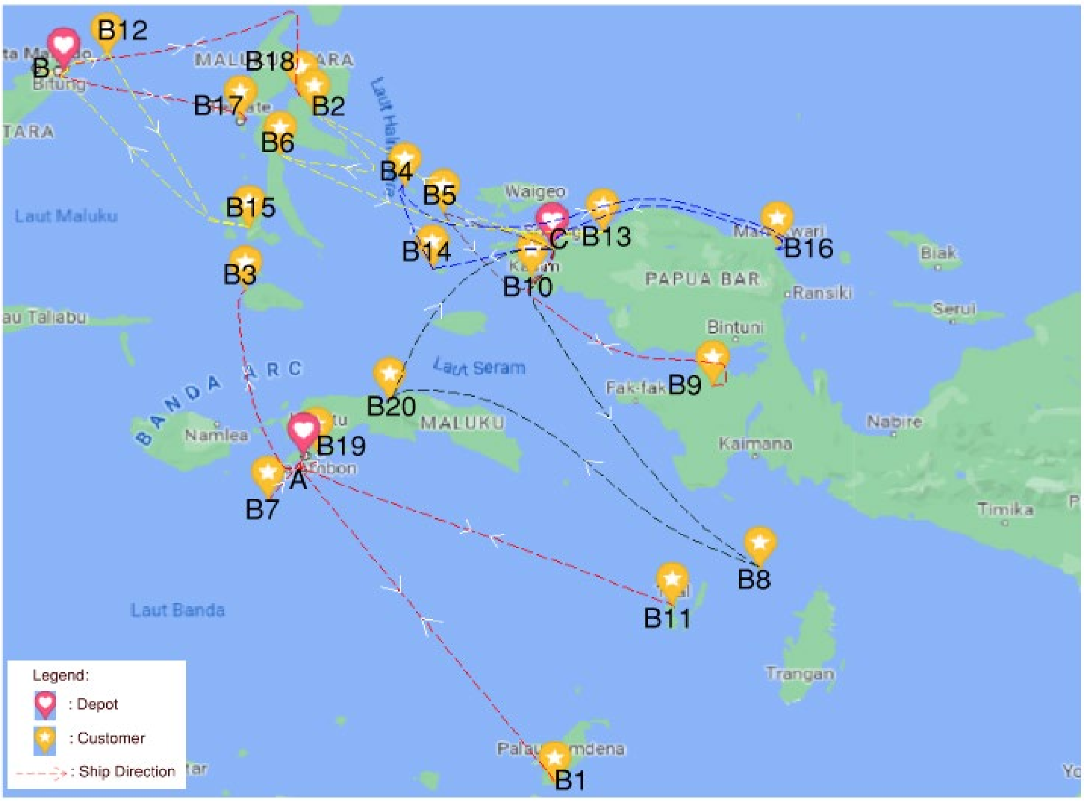

Figure 2. The route of the ship in charge of serving custome

Table 3. Shows the match Between Ship Capacity, Cargo Carried and Customers Demand.

Route	Ships	Ship Route to Customer	Ship's capacity (m3)	Distance (Nautical Mile)	Load Transported (m3)	Delivery to customers (m3)		
						1st	2nd	3rd
1	K2	A - B11 - A	827,6	620	620	620		
2	K5	A - B3 - A	670,5	330	620	620		
3	K6	A - B1 - A	519,9	664	450	450		
4	K9	A - B19 - A	346,2	66	205	205		
5	K10	A - B7 - A	762	86	560	560		
6	K3	B - B18 - B	345,6	498	250	250		
7	K7	B - B17 - B	395,1	286	390	390		
8	K13	B - B12 - B15 - B	317	405	310	190	120	
9	K1	C - B14 - B4 - B16 - C	1204,4	669	1125	230	675	220
10	K8	C - B10 - B5 - C	346,8	251	290	120	170	
11	K11	C - B9 - C	1299,5	456	900	900		
12	K15	C - B13 - B2 - B6 - C	1195,3	574	1030	250	560	220
13	K18	C - B20 - B8 - C	1252,8	822	1170	550	620	

The calculation of transportation costs and total emissions in this study was carried out by adding up the 13 ships used. Transportation costs are limited to the calculation of allowances per trip, port fees, carbon taxes and fuel usage costs. Calculations were carried out in calm sea conditions and choppy seas. Transportation costs and total emissions are carried out by comparing the use of various fuels. This is done to get the lowest cost and the lowest CO2 emissions. Table 4 represents the transportation costs borne by the company and Table 5. shown the amount of CO2 emission produced by the ships.

Table 4. Transportation Costs

Sea State	Transportation Costs if the ship uses Fuel:		
	MDO	B30	LSFO
Calm Water	Rp. 1,906,182,121	Rp. 1,828,171,223	Rp. 1,879,993,728
Choppy Seas	Rp. 2,224,854,218	Rp. 2,133,363,400	Rp. 2,194,140,650

Table 5. Amount of CO2 Emission Produced by the Ships.

Sea State	Amount of CO2 Emission (tonCO2e) if the ship uses Fuel:		
	MDO	B30	LSFO
Calm Water	286.93	172.80	279.44
Choppy Seas	336.60	202.68	327.73

The need for transportation costs when the sea conditions are choppy will increase by about 16.70% when compared to transportation costs when the sea conditions are calm. Ships sailing in choppy sea conditions will not reach their service speed, due to resistant from wind and waves, so ships will need a long time and more fuel which results in greater transportation costs incurred by the company. The difference in transportation costs is followed by changes in the amount of CO2 emissions produced by the ship. The amount of CO2 emissions will increase by an average of 17.28% when the sea is choppy compared to the number of emissions when the sea conditions are calm.

2. Sensitivity analysis

Sensitivity analysis is done by changing the parameter values that are considered to have a significant effect on the total transportation costs generated by the model, namely fuel prices, ship speed and fuel consumption.

a. Changes Fuel Prices
In real conditions in Indonesia, the price of fuel often increases in price, but it is very rare for the price to go down. The price of Pertamina's fuel circulating in Indonesia is still below the economic price, lower than the price sold by competitors. Changes in fuel prices are caused by many reasons, including the situation of oil producing countries which is sometimes unstable so that world oil prices continue to change. In this analysis, fuel prices will be increased by 2%, 4%, 6%, 8% and 10%, and the results are presented in Table 6. for transportation costs in calm water and Table 7 for transportation costs in choppy condition.

Table 6. Changes in Fuel Prices to Transportation Costs in Calm Water

Fuel Price increase	Transportation cost in calm water			Average increase (%)
	MDO	B30	LSFO	
0%	Rp. 1,906,182,121	Rp. 1,828,171,223	Rp. 1,879,993,728	0%
2%	Rp. 1,942,755,006	Rp. 1,863,354,573	Rp. 1,916,157,334	1.92%
4%	Rp. 1,979,626,853	Rp. 1,898,636,200	Rp. 1,952,419,478	3.85%
6%	Rp. 2,016,299,393	Rp. 1,933,819,550	Rp. 1,988,583,084	5.78%
8%	Rp. 2,053,071,586	Rp. 1,969,101,178	Rp. 2,024,746,690	7.70%
10%	Rp. 2,089,744,125	Rp. 2,004,284,527	Rp. 2,061,008,835	9.63%

Table 7. Changes in Fuel Prices to Transportation Costs in Choppy Condition

Fuel Price increase	Transportation cost in choppy condition			Average increase (%)
	MDO	B30	LSFO	
0%	Rp. 2,224,854,218	Rp. 2,133,363,400	Rp. 2,194,140,650	0%
2%	Rp. 2,267,746,683	Rp. 2,174,626,223	Rp. 2,236,553,114	1.93%
4%	Rp. 2,310,989,767	Rp. 2,216,004,306	Rp. 2,279,081,144	3.87%
6%	Rp. 2,353,999,106	Rp. 2,257,267,130	Rp. 2,321,493,608	5.81%
8%	Rp. 2,397,125,317	Rp. 2,298,645,212	Rp. 2,363,906,073	7.74%
10%	Rp. 2,440,134,655	Rp. 2,339,908,036	Rp. 2,406,434,103	9.68%

The Table 6 and Table 7 shows that changes in fuel prices will affect transportation costs. If the price of fuel increases by 2%, then transportation costs also increase by an average of 1.94% by using different types of fuel. However, price changes do not affect the amount of fuel needed, so the amount of emissions produced, and the amount of carbon tax borne by the company also does not change. So, it can be said that changes in fuel prices are directly proportional to the transportation costs needed.

b. Changes in ship speed and fuel consumption
The thing that often happens in the field is done by ship captains, namely reducing the speed of the ship in order to save fuel on the ship. By reducing the speed of the ship, the engine rpm will be smaller so that fuel consumption is also reduced. By reducing the speed, the sailing time of the ship becomes longer. This analysis is carried out under the condition that fuel prices do not change. The analysis is carried out on the value of the speed up and down by 5% and 10%, and for the value of fuel consumption it will increase and decrease by 7.5% and 15%. In calm sea conditions, changes in transportation costs can be seen in Table 8 and in choppy sea conditions can be seen in Table 9.

Table 8. Changes in ship speed and fuel consumption to Transportation Costs in Calm Water

Changes in ship speed and fuel consumption	Transportation cost in calm water			Average Changes (%)
	MDO	B30	LSFO	
-10% and -15%	Rp. 1,803,695,351	Rp. 1,729,981,145	Rp. 1,778,993,065	-5.37%
-5% and -7,5%	Rp. 1,857,658,563	Rp. 1,781,679,156	Rp. 1,832,121,355	-2.55%
0%	Rp. 1,906,182,121	Rp. 1,828,171,223	Rp. 1,879,993,728	0.00%
5% and 7,5%	Rp. 1,950,128,746	Rp. 1,870,224,302	Rp. 1,923,316,471	2.30%
10% and 15%	Rp. 1,990,019,051	Rp. 1,908,462,281	Rp. 1,962,636,361	4.40%

Table 9. Changes in ship speed and fuel consumption to Transportation Costs in in Choppy Condition

Changes in ship speed and fuel consumption	Transportation cost in choppy condition			Average Changes (%)
	MDO	B30	LSFO	
-10% and -15%	Rp. 2,104,658,298	Rp. 2,018,206,564	Rp. 2,075,687,616	-5.40%
-5% and -7,5%	Rp. 2,167,945,993	Rp. 2,078,837,721	Rp. 2,137,996,215	-2.56%
0%	Rp. 2,224,854,218	Rp. 2,133,363,400	Rp. 2,194,140,650	0.00%
5% and 7,5%	Rp. 2,276,395,190	Rp. 2,182,683,098	Rp. 2,244,949,309	2.31%
10% and 15%	Rp. 2,323,177,543	Rp. 2,227,528,192	Rp. 2,291,063,525	4.42%

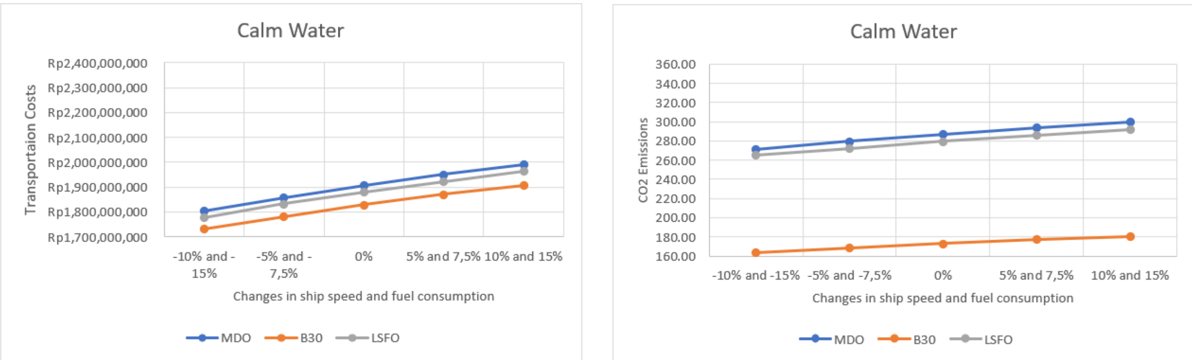

Figure 3. Changes of transportation costs and CO2 Emission in calm water

From Table 8 and Table 9, and Fig. 3 and Fig. 4 shows that changes in ship speed and fuel consumption will affect transportation costs, as well as the amount of CO2 emissions produced. Overall transportation costs and CO2 emissions increase when speed and fuel consumption increase, and vice versa. So, it can be said that changes in ship speed and fuel consumption are directly proportional to transportation costs and the amount of CO2 emissions produced. Changes in some of these parameters are more interesting for further research to find the optimum point because in the objective function formula (equation 1), ship speed is inversely proportional to transportation costs, the faster the ship the smaller the transportation costs.

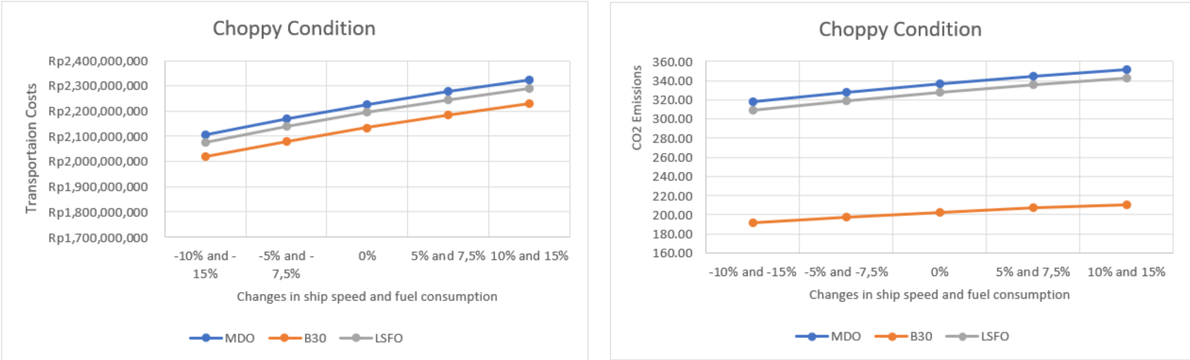

Figure 4. Changes of transportation costs and CO2 Emission in Choppy Condition

3. Conclusion

A mathematical model has been developed using the Multi Depot Heterogeneous Fleet Vehicle Routing Problem (MDHFVRP) and the results obtained are to deliver fuel products to 20 consumers, which was originally carried out using 20 ships, after arrangements were made, 13 ships were proposed to make the delivery. The need for transportation costs for all ships on one calm sea voyage is Rp. 1,906,182,121 if using MDO, Rp.1,828,171,223 if using B30 and Rp. 1,879,993,728 when using LSFO, and transportation costs will increase by 16.70% if sea conditions are choppy, and CO_2 emissions produced are 286.93 tonsCO_2e when using MDO, 172.8 tonsCO_2e when using B30 and 279.44 tonsCO_2e when using LSFO and will increase by an average of 17.28%. Under these conditions, the company can choose the use of fuel for its operations.

This research can be developed for consumers who are not fixed and unscheduled in ordering BBM products. Other research developments are calculating fuel requirements due to wind and waves coming from the front and side of the ship, paying attention to the real conditions of using engines related to fuel consumption and calculating ship maintenance costs for each ship, as well as setting up the ship's fleet if there are ships that are running. perform routine maintenance (docking).

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