Erasmus University

Econometrics and Operations Research

Bachelor Thesis Quantitative Logistics

Service network design for liner shipping in Indonesia

Author:
Lisanne van Rijn

July 6, 2015

Abstract

In this thesis the designing of a service network for liner shipping is considered. The service network consists of a set of ship routes, the allocation of ships to the routes, the sailing speed of the ships on each route and the allocation of cargo over the routes. Two algorithms are proposed to construct a service network. The first algorithm uses pendulum routes in the route network and the second algorithm uses randomly generated routes. To determine how the aforementioned algorithms work in a real case, the algorithms are applied to a case study regarding Indonesia. The service network that achieves the highest profit uses randomly generated routes. The highest profit obtained is approximately 5.7 million USD per week.

Contents

1 Introduction **2**

2 Literature **3**
2.1 Fleet-design 3
2.2 Ship-scheduling 3
2.3 Cargo-routing 4
2.4 Combined Ship-scheduling and Cargo-routing 4

3 Data **5**
3.1 Ports 5
3.2 Fleet 5
3.3 Cargo Demand 6
3.4 Costs and Revenues 6

4 Methodology **7**
4.1 Fleet-design 7
4.2 Ship-scheduling 8
4.3 Combined Fleet-design and Ship-scheduling 8
4.4 Cargo-routing 10
4.4.1 Sets 11
4.4.2 Parameters 11
4.4.3 Decision variables 11
4.4.4 Linear programming formulation 12

5 Results **13**
5.1 Results Algorithm 1 13
5.2 Results Algorithm 2 16

6 Conclusion **18**

1 Introduction

United Nations Conference on Trade and Development reports that the liner shipping market held a market share of about 16% in the world's goods market in 2011 (UNCTAD, 2011). Furthermore, between 1990 and 2010 the container trade expanded at an average rate of 8.2% per year. Shipping is preferred above other forms of transport, such as truck, aircraft or train, due to for example the low costs, fast speeds and reliable schedules (Meng et al., 2014).

Three distinctions are made in the shipping market: tramp shipping, industrial shipping and liner shipping (Lawrence, 1972). The most common form of shipping in the container trade is liner shipping. In liner shipping, ships follow a fixed route adhering to fixed time schedules. In contrast, in tramp shipping the ships do not stick to a fixed schedule. Tramp ships are used to transport available cargoes so as to maximize revenue. In industrial shipping, the ships are controlled by the cargo owner, who seeks to transport the cargo at minimal cost.

This thesis considers the decision making in liner shipping. The objective is to develop a service network in liner shipping. The service network consists of a set of routes, the allocation of ships to the routes, the sailing speed of the ships on each route and the allocation of cargo over the routes. The decision making can be distinguished on three different planning levels: the strategic (3-5 years), the tactical (4-12 months) and the operational planning level (1-4 weeks) (Pesenti, 1995).

To start, decisions need to be made regarding the optimal-fleet design, which concerns the strategic planning level. Next, at the tactical level, the set of ship routes needs to be determined and ships have to be allocated to the routes. This is referred to as the ship-scheduling problem. Finally, the cargo-routing problem is considered, where the allocation of cargo over the routes is determined. This involves decision making on the operational level. Since the decisions made in earlier stages influence the decisions made in later stages it might be profitable to solve the problems simultaneously. To determine how the aforementioned methods work in a real case, the methods will be applied to a case study regarding Indonesia. This gives rise to the following research question: What does a service network for liner shipping look like for 6 ports in Indonesia?

To solve the fleet-design and ship-scheduling problem two algorithms are designed in this thesis. The algorithms describe a procedure to create routes and to determine which routes will be included in the route network. Furthermore, the algorithms describe how to adjust the sailing speed and the capacity of the ships. Next, the cargo-routing problem is solved using a multi-commodity flow linear programming formulation, proposed by Mulder and Dekker (2013). The algorithms differ in the procedure they use to determine the routes in the network. The first algorithm uses pendulum routes in the network and the second algorithm uses randomly generated routes.

The outline of the thesis is as follows. In Section 2 the relevant literature on the problems is discussed. In Section 3 the case study data is discussed. Section 4 explains the methods used in this thesis in more detail. The results are described in Section 5 and in Section 6 the main conclusions from this research are drawn.

2 Literature

As discussed before, designing a service network can be seperated in three different problems: fleet design, ship-scheduling and cargo-routing. This thesis examines the three problems simultaneously, but examining the problems seperately has been investigated as well. The relevant literature on this is discussed in the next sections. Section 2.1 discusses the literature on the fleet-design problem, Section 2.2 discusses the ship-scheduling problem, Section 2.3 the cargo-routing problem and finally Section 2.4 considers the literature on the combined ship-scheduling and cargo-routing problem.

2.1 Fleet-design

The goal of the fleet-design problem is to determine the number and the size of the ships needed in the fleet (Mulder and Dekker, 2013). Fagerholt (1999) uses a 3-step solution approach. In step 1 and 2, all feasible routes are generated and combined into multiple routes. The third step consists of solving a set partitioning problem to determine the optimal fleet and the coherent routes for the fleet. All the test problems were solved to optimality, within a few seconds.

2.2 Ship-scheduling

The ship-scheduling problem consists of designing a service network. This includes a set of ship routes and the allocation of the ships to the routes (Mulder and Dekker, 2013). Brønmo et al. (2007) present a multi-start local search heuristic to solve the ship-scheduling problem. To start, a large number of initial solutions are generated by an insertion heuristic. In addition, a quick and an extended local search method are used to improve on the initial solutions. The heuristic produces optimal or near-optimal and robust solutions. The objective of Christiansen and Fagerholt (2002) is to make robust schedules adhering to multiple time windows. Using a set partitioning approach, all the problem instances were solved to optimality. The results show that more robust solutions correspond with higher transportation costs, and vice versa.

In 2012, the Indonesian government introduced a nationwide freight transport programme, called Pendulum Nusantara. The goal of the programme is to reduce the cost of maritime logistics in Indonesia (Fau et al., 2014). The high logistic costs have been impeding the growth of the Indonesian economy. The World Bank (2014) determined that the logistic costs in Indonesia made up 25% of the GDP. In comparison, in Singapore and Malaysia this percentage is only 8% and 13% respectively. Figure 1 shows the proposed route in detail. The circles indicate the size of the domestic container volume in 2010. The route is a single ship route connecting the eastern and western regions of Indonesia.

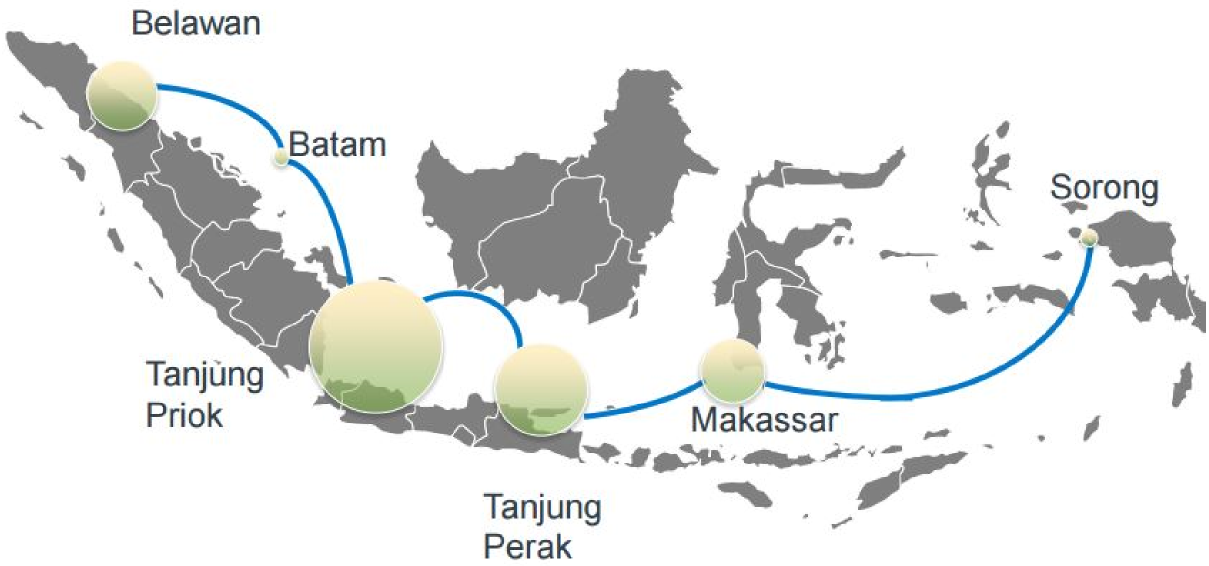

Figure 1: *Pendulum Nusantara*
SOURCE: ICP (2012)

2.3 Cargo-routing

The goal of cargo-routing is to decide which demands to accept and to establish which routes will be used to transport this demand from the origin to the destination point (Mulder and Dekker, 2013). Mulder and Dekker (2013) propose to formulate the cargo-routing problem as a multi-commodity flow problem, for which a linear programming formulation is developed. Song and Dong (2012) consider the problem of joint cargo routing and empty container repositioning. The problem can be solved with a two-stage shortest-path based integer programming method or with a two-stage heuristic-rules based integer programming method. Both methods seem to perform satisfactory, but the heuristic-rules based method seems preferable when considering large scale realistic systems.

2.4 Combined Ship-scheduling and Cargo-routing

Part of the literature focuses on solving the ship-scheduling and cargo-routing problems simultaneously. Agarwal and Ergun (2008) present a mixed-integer linear programming model to solve the combined ship-scheduling and cargo-routing problem. To solve the problem they develop a greedy heuristic, a column generation-based algorithm and an algorithm based on Benders decomposition. The authors report solutions with high utilization of ships' capacities. The solution method seems to perform well for a fleet composition up to 100 ships. Furthermore Álvarez (2009) discusses a mixed-integer programming model as well, for a homogeneous fleet composition. To solve the model Álvarez uses a two-tier solution approach with a tabu mechanism. Compared to an exact branch and bound algorithm the results indicate that solutions generated by the proposed algorithm are of good quality and can be obtained within a short amount of time.

The pendulum route proposed by the Indonesian government is used as a basis for the first algorithm. Different pendulum routes will be combined into route networks to test the effectiveness of pendulum routes. Fagerholt (1999) starts with generating all feasible routes, but for six ports the number of feasible routes is already very large. Therefore, instead of generating all feasible routes, a maximum number of routes is generated randomly to be used in Algorithm 2. Furthermore, in this thesis the multi-commodity flow formulation by Mulder and Dekker (2013) is used to solve the cargo-routing problem.

3 Data

As mentioned before, the methods will be applied to a case study on Indonesia. The ports are split up in 5 different regions: Sumatera, Java, Kaumantan, Sulawesi and the rest of Indonesia. In this section the following aspects of the data are discussed: the ports and distance between the ports, the available ships types and their characteristics, the cargo demand, and the relevant costs and revenues.

3.1 Ports

For each region, one port is investigated, with the exception of the region Java, where two ports are investigated. This is a total of 6 ports to be included in the service network. In Figure 2 a map of the ports is shown together with the distances between the ports. Hereafter, when discussing the routes, the ports will be referred to by the numbers shown in the figure.

In this case study, I make the following assumptions:

1. I assume that each port has unlimited capacity and that all the ships are able to berth at each port. So, there are no restrictions regarding capacity or ship size.

2. The time a ship spends in a port to unload the shipped cargo is assumed to be constant at 24 hours. This is due to the many uncertain factors that contribute to the port time, such as the number of cranes available and the number of containers that have to be (un)loaded (Mulder and Dekker, 2013). Furthermore, during the route generation the cargo allocation is not yet known. Thus, the time spend in the port can not yet be determined. Therefore, in order to calculate the duration of the route the time spend in the port must be assumed constant.

3.2 Fleet

There are 5 different ship types available. The specification of the ships is shown in Table 1. The different ship types are shown in the column Vessel Class. The ships can be distinguished on the following characteristics: capacity, fixed cost, speed (in nautical miles per hour), and fuel consumption. The capacity of the ship is shown in FFE. A Forty Foot Equivalent container is twice as large as a Twenty Feet Equivalent container. The bunker consumption of the ship is the fuel usage of the ship when sailing, given in tons per day. The idle consumption of ship is the fuel usage of the ship when it is berthed at the port and is given in tons per day as well.

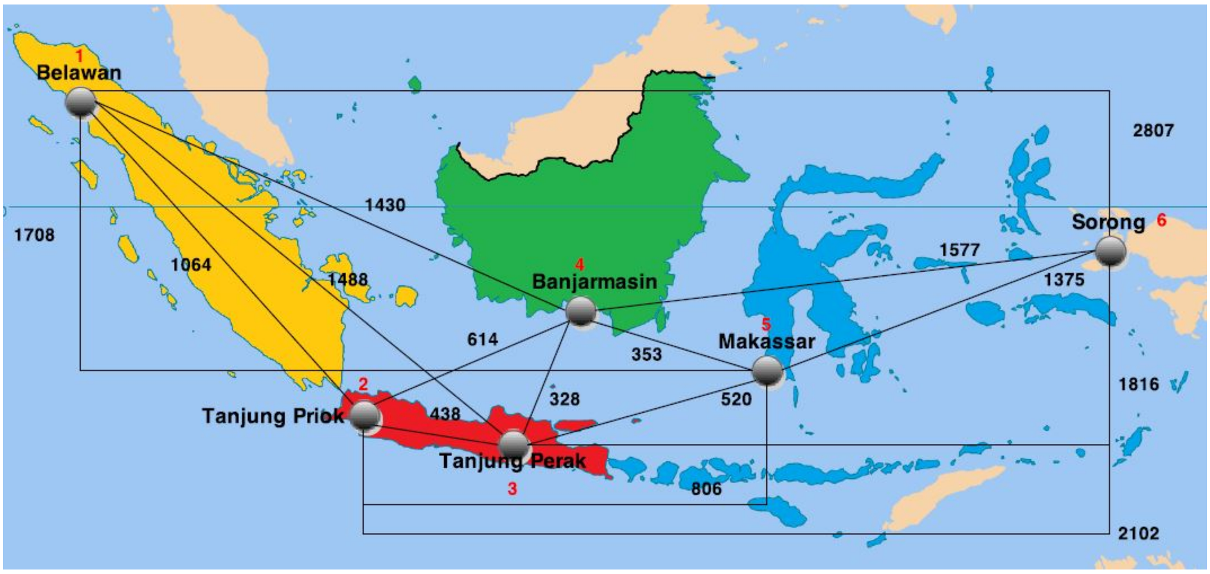

Figure 2: *Map of Indonesia showing the 6 ports and the distances between the ports*
SOURCE: Distances based on Wardana (2014)

Vessel Class	Capacity in FFE	TC rate per day	Min speed (in knots)	Max speed (in knots)	Design speed (in knots)	Bunker consumption in tons per day	Idle consumption in tons per day
1 Feeder_450	450	5000	10	14	12	18.8	2.4
2 Feeder_800	800	8000	10	17	14	23.7	2.5
3 Panamax_1200	1200	11000	12	19	18	52.5	4
4 Panamax_1750	1750	15000	12	20	18	55	4.5
5 Panamax_2400	2400	21000	12	22	16	57.4	5.3

Table 1: *Ship characteristics of the available ships*
SOURCE: Kalem (2015)

3.3 Cargo Demand

The cargo demand is shown in Table 2. The demand is shown in TEU per year. As indicated in the table, the largest amount of container flow is shipped to and from Java, more specifically from the ports Tanjung Priok and Tanjung Perak. The smallest demand and supply originates from Sorong.

3.4 Costs and Revenues

The relevant costs and revenues are shown in Table 3. The handling cost are paid twice when there is no transshipment, once when loading the containers and once when unloading the containers. When the containers are transshipped the handling cost are paid once more for each transshipment that occurs.

	Belawan	Tanjung Priok	Tanjung Perak	Banjar-masin	Makasar	Sorong	Total Supply
Belawan	-	348036	55016	4524	4212	1404	413192
Tanjung Priok	350480	-	99632	212784	145496	24128	832520
Tanjung Perak	53872	126724	-	197340	250640	113048	741624
Banjarmasin	4680	189124	181896	-	676	-	376376
Makasar	4732	182052	213668	3796	-	-	404248
Sorong	2028	34372	113048	-	-	-	149448
Total Demand	415792	880308	663260	418444	401024	138580	

Table 2: *Origin Destination demand matrix of the six ports in TEU per year*
SOURCE: Wardana (2014)

Revenue	215	per TEU transported from Origin to Destination
Handling cost	34	per container loaded, unloaded or transhipped
Port dues	628	per port visited per ship

Table 3: *Relevant costs and revenues in USD*
SOURCE: Kalem (2015)

The fuel cost differ depending on the ship type. To calculate the fuel cost a simplified version of the fuel cost function by Brouer et al. (2014) is used. The function is as follows:

$$F_s(v) = 600 \times (\frac{v}{v_s^*})^3 \times f_s \times \text{number of days sailing} \\ + 600 \times f_{idle} \times \text{number of days in port} \quad (1)$$

$F_s(v)$ denotes the fuel consumption per route for a ship type s that sails at speed v nautical miles per hour and has design speed v_s^*. f_s is the fuel usage in ton per day when the ship is sailing and f_{idle} denotes the fuel usage of the ship when stationary. The bunker price is 600 USD. The formula consists of two parts. The first part is the fuel usage of the ship when the ship is sailing. The second part is the fuel usage of the ship when it is berthed at the port. These cost will be incurred when the ship is loaded/unloaded at the port and when the ship has to wait at the port before he can start a route again.

4 Methodology

4.1 Fleet-design

The objective of the fleet-design problem is to determine both the number and the size of the ships in the fleet. The decision on the size of the ships is dependent on the fixed and variable costs associated with the ship type and the demand on the route that the ship will serve. Larger ships often have higher fixed cost than smaller ships, but in return have lower transportation cost per TEU. In order to solve the fleet-design problem the following assumptions are made:

3. There is no initial fleet. Thus, the company is able to choose the ships freely.

4. All the ships are available at the beginning of the planning period.

4.2 Ship-scheduling

A route network consists of a set of ship routes and the allocation of ships to the routes. A ship route describes the sequence of ports that a ship visits. A ship route must satisfy the following conditions. First, the ship route must be cyclic, that is the port where the route starts must equal the port where the ship will end. Second, the route must consist of a westbound trip and an eastbound trip. A port can be visited once on the westbound trip and once on the eastbound trip. A ship is allocated to each route and once a ship has been allocated to a route, the ship will serve this route for the remainder of the planning horizon. In this thesis, the route schedules required are weekly route schedules.

4.3 Combined Fleet-design and Ship-scheduling

To start, a number of service networks will be designed, using pendulum routes. Examples of these networks are a route network that includes one route that visits all the ports or only including routes that visit two neighbor ports. Algorithm 1 describes the procedure that is used to construct a service network.

The number of possible routes to be included in the route network is very large and examining the possible combinations of all these routes is too involved to be done in this thesis. Therefore, in Algorithm 1 I decided to focus on pendulum routes. I decided on pendulum routes, because the Indonesian government proposed a pendulum route, and second, because a pendulum route visits all the ports twice so it is easy to transport demand and supply to and from all the ports.

The goal is to make weekly schedules. When a route does not have a duration of an integer number of weeks it has to wait in the port until it can sail again. Therefore, the speed is chosen using the method as described in step 2, because this minimizes the time a ship spends at a port. In steps 4 & 6 the type of the ship is chosen. The algorithm starts with assigning the biggest ship type to all the routes. This is to ensure that the greatest possible amount of cargo-flow can be transported. However, if it turns out that some of the capacity is not used, a smaller ship type is assigned to the route. The speed needs to be adjusted, because there are different restrictions on sailing speed for different ship types.

Furthermore, the constraint that different ship types cannot sail on the same route is imposed, because this prevents that cargo waiting to be shipped has to be shipped on the next arriving ship, because the ship that has already arrived is too small. When a ship route is used more than once in the route network it is possible to assign a different ship type to this route.

Algorithm 1 *Designing a service network with pendulum routes*

1. Form routes using techniques such as connect neighboring ports, connect ports that have a large amount of cargo-flow, combine routes such that all ports are visited, focusing on pendulum routes. Combine these different routes in one network, such that all the ports are visited at least once.
2. For each route, calculate what the best speed is using the following technique. Choose the speed, such that the route duration (the time it takes to make a round tour) is an integer number of weeks or as close as possbile. The possible speeds are between 10 and 22 nautical miles per hour, with steps of 0.1.
3. Determine the number of ships needed on the route by using the general assumption that the number of ships needed on a ship route is at least equal to the number of weeks needed to complete a round tour (rounded above).
4. Assign the biggest ship type to all the routes.
5. Implement the route network in the cargo-routing model.
6. After the optimisation check if there are routes that can be assigned a smaller ship type, while adhering to the constraint that on the same route identical ship types must sail. Adjust the sailing speed of the ship as close as possible to the best speed determined in step 2.
7. Determine the profit per week by subtracting from the solution in step 5 the weekly fuel and fixed cost.

A second algorithm is designed to further investigate possible route networks. The algorithm is similar to Algorithm 1, but instead of creating routes by hand a number of random routes is generated. Algortihm 2 describes the steps to create a service network. In step 1 the generation of the routes is described. The assumption that a port is only visited once on a route is made, because this limits the number of possible routes. The number of possible routes, when this assumption is not made, is very large and too difficult to investigate. Step 6 creates a route network with routes of the same length. This allows for a systematic approach in making route networks, where longer routes can be switched for shorter routes.

Algorithm 2 *Designing a service network with randomly generated routes*

1. Generate a number of random routes, while adhering to the following assumptions:
   (a) The first port must be the same as the last port.
   (b) Ports are only visited once on a route, with the exception of the starting port.
2. For each route, calculate what the best speed is using the following technique. Choose the speed, such that the route duration (the time it takes to make a round tour) is an integer number of weeks or as close as possbile. The possible speeds are between 10 and 22 nautical miles per hour, with steps of 0.1.
3. Determine the number of ships needed on the route by using the general assumption that the number of ships needed on a ship route is at least equal to the number of weeks needed to complete a round tour (rounded above).
4. Assign the biggest ship type to all the routes.
5. For each route calculate the fuel cost, the fixed cost (port cost and ship charter cost) and the possible revenue on the route. The possible revenue is calculated as: capacity of the ship $\times$ (number of ports on the route $-$ 1) $\times$ 215. Sort the routes on (possible revenue $-$ fuel cost $-$ fixed cost), in decreasing order.
6. Create a route network using routes of the same length, starting with the upper most routes chosen from the list created in step 5. Implement the route network in the cargo-routing model. Add routes of the same length, untill all the ports are visited and all the demand is satisfied.
7. Check the solution of the cargo-routing model to see if there are routes where the capacity of the ship is not fully utilized. If this is the case, check if a smaller route can be used instead. If this network still satisfies the total demand switch the routes. Keep switching routes until no routes can be switched anymore.
8. After the optimisation check if there are routes that can be assigned a smaller ship type, while adhering to the constraint that on the same route identical ship types must sail. Adjust the sailing speed of the ship as close as possible to the best speed determined in step 3.
9. Determine the profit per week by subtracting from the solution in step 7 the weekly fuel and fixed cost.

4.4 Cargo-routing

The shipping company has to make two decisions, regarding the cargo-routing. The first is to decide which cargo demands to accept and the second is to decide on which route the demand is transported from the origin to the destination point. The objective is to maximize the profit. In this thesis only one shipping company is considered, so competition is not investigated. The transportation of cargo realizes revenue for the shipping company, but they incur a cost as well. The relevant costs and revenues are discussed in Section 3.4. To solve the cargo-routing problem the multi-commodity flow formulation by Mulder and Dekker (2013) is used. The following paragraphs will discuss the relevant sets, parameters, decision variables, and the linear programming formulation in detail.

4.4.1 Sets

- $h \in H$ Set of ports;
- $t \in T \subseteq H$ Set of transhipment ports;
- $s \in S$ Set of ship routes;
- $j \in J$ Indicator set denoting whether a ship passes both ports $h_1 \in H$ and $h_2 \in H$ on ship route $s \in S$, where $j = (h_1, h_2, s)$;
- $k \in K$ Indicator set denoting whether port $h_2 \in H$ is directly visited after port $h_1 \in H$ on ship route $s \in S$, where $k = (h_1, h_2, s)$.

4.4.2 Parameters

- r_{h_1,h_2} Revenue of transporting one TEU from port $h_1 \in H$ to port $h_2 \in H$;
- c^t_t Cost of transhipping one TEU in transhipment port $t \in T$;
- c^h_h Cost of (un)loading one TEU in origin or destination port $h \in H$;
- d_{h_1,h_2} Demand with origin port $h_1 \in H$ and destination port $h_2 \in H$;
- b_s capacity on ship route $s \in S$.
- $I^{path}_{h_1,h_2,h_3,h_4,s}$ 0/1 parameter that takes the value 1 if a ship passes consecutive ports $h_3 \in H$ and $h_4 \in H$ when sailing from port $h_1 \in H$ to port $h_2 \in H$ on ship route $s \in S$

4.4.3 Decision variables

- $x_{h_1,h_2,s}$ Cargo flow on ship route $s \in S$ between consecutive ports $h_1 \in H$ and $h_2 \in H$;
- $x^{od}_{h_1,h_2,s}$ Direct cargo flow on ship route $s \in S$ between ports $h_1 \in H$ and $h_2 \in H$;
- $x^{ot}_{h_1,t,h_2,s}$ Transhipment flow on ship route $s \in S$ between port $h_1 \in H$ and transhipment port $t \in T$ with destination port $h_2 \in H$;
- x^{td}_{t,h,s_1,s_2} Transhipment flow on ship route $s_2 \in S$ between transhipment port $t \in T$ and destination port $h \in H$, where flow to transhipment port $t \in T$ was transported on ship route $s_1 \in S$;
- $x^{tt}_{t_1,t_2,h,s_1,s_2}$ Transhipment flow on ship route $s_2 \in S$ between transhipment port $t_1 \in T$ and transhipment port $t_2 \in T$ with destination port $h \in H$, where the flow to transhipment port $t_1 \in T$ was transported on ship route $s_1 \in S$;
- $x^{tot}_{h_1,h_2,s}$ Total cargo flow on ship route $s \in S$ between ports $h_1 \in H$ and $h_2 \in H$.

4.4.4 Linear programming formulation

$$\begin{aligned}
\max \quad & \sum_{h_1\in H}\sum_{h_2\in H}\sum_{s\in S} r_{h_1,h_2}(x^{od}_{h_1,h_2,s} + \sum_{t\in T} x^{ot}_{h_1,t,h_2,s}) \\
& - \sum_{h_1\in H} c^h_{h_1}(\sum_{t\in T}\sum_{h_2\in H}\sum_{s\in S}[x^{ot}_{h_1,h_2,s} + x^{ot}_{h_2,t,h_1,s}] + \sum_{h_2\in H}\sum_{s\in S}[z^{od}_{h_1,h_2,s} + x^{od}_{h_2,h_1,s}]) \\
& - \sum_{t_1\in T} c^t_{t_1}(\sum_{t_2\in T}\sum_{h_2\in H}\sum_{s_1\in S}\sum_{s_2\in S} x^{tt}_{t_1,t_2,h_2,s_1,s_2} + \sum_{h_2\in H}\sum_{s_1\in S}\sum_{s_2\in S} x^{td}_{t_1,h_2,s_1,s_2}) \quad (2)
\end{aligned}$$

$$\begin{aligned}
s.t. \quad & \sum_{t\in T}\sum_{s\in S} x^{ot}_{h_1,t,h_2,s} + \sum_{s\in S} x^{od}_{h_1,h_2,s} \leq d_{h_1,h_2} \quad h_1 \in H, h_2 \in H \quad (3) \\
& x_{h_1,h_2,s} \leq b_s \quad (h_1,h_2,s) \in K \quad (4)
\end{aligned}$$

$$\begin{aligned}
& \sum_{h_1\in H} x^{ot}_{h_1,t_1,h_2,s_1} + \sum_{t_2\in T}\sum_{s_2\in S} x^{tt}_{t_2,t_1,h_2,s_2,s_1} - \sum_{s_2\in S} x^{td}_{t_1,h_2,s_1,s_2} \\
& - \sum_{t_2\in T}\sum_{s_2\in S} x^{tt}_{t_1,t_2,h_2,s_1,s_2} = 0 \quad (t_1,h_2,s) \in J \quad (5)
\end{aligned}$$

$$x_{h_1,h_2,s} - \sum_{h_3\in H}\sum_{h_4\in H} x^{tot}_{h_3,h_4,s} I^{path}_{h_3,h_4,h_1,h_2,s} = 0 \quad (h_1,h_2,s) \in K \quad (6)$$

$$\begin{aligned}
& x^{tot}_{h_1,h_2,s_1} - x^{od}_{h_1,h_2,s_1} - \sum_{h_3\in H} x^{ot}_{h_1,h_2,h_3,s_1} - \sum_{s_2\in S} x^{td}_{h_1,h_2,s_2,s_1} \\
& - \sum_{h_3\in H}\sum_{s_2\in S} x^{tt}_{h_1,h_2,h_3,s_2,s_1} = 0 \quad h_1 \in H, \quad h_2 \in H, \quad s_1 \in S \quad (7)
\end{aligned}$$

$$\begin{aligned}
& x_{h_1,h_2,s} \geq 0 \quad (h_1,h_2,s) \in K \quad (8) \\
& x^{od}_{h_1,h_2,s} \geq 0 \quad h_1 \in H, \quad h_2 \in H, \quad s \in S \quad (9) \\
& x^{tt}_{t_1,t_2,h,s_1,s_2} \geq 0 \quad h \in H, \quad s_1 \in S, \quad (t_1,t_2,s_2) \in J \quad (10) \\
& x^{td}_{t,h,s_1,s_2} \geq 0 \quad s_1 \in S, \quad (t,h,s_2) \in J \quad (11) \\
& x^{ot}_{h_1,t,h_2,s} \geq 0 \quad h_2 \in H, \quad (h_1,t,s) \in J \quad (12)
\end{aligned}$$

The objective function (2) is the maximization of the profit, more precisely revenue minus the costs. The costs considered in the model are the (un)loading cost and transshipment cost, because the remaining cost are fixed for the route network, and can therefore be substracted afterwards. Constraints (3) specify that the total cargo shipped between two ports does not exceed the demand between the two ports. Constraints (4) ensure that the capacity of a ship is not exceeded, on a certain route. Constraints (5) ensure that all the cargo flow that is unloaded to be transshipped is loaded on another route afterwards. Constraints (6) represent the amount of cargo flow between two consecutive ports and Constraints (7) represent the total flow between each port in the same cycle. Constraints (8) – (12) make sure that the cargo flow between two ports is nonnegative.

5 Results

5.1 Results Algorithm 1

The route network consists of multiple routes used to transport the cargo from the origin to the destination point. The routes used in the route networks are designed based on the route proposed by the Indonesian government, as described in Section 2.2. Furthermore, routes were chosen, because there exists a large amount of cargo flow between the ports or, because the ports are near each other. Some routes were designed to include ports in the route network that had not been included yet. The characteristics of the different routes used are shown in Table 4. The number of weeks needed for a round tour is based on the sailing speed that gives a route duration closest to an integer number of weeks.

Route number	Ports visited	Distance	Speed	Number of weeks for a round tour	Number of ships on the route
1	1-2-3-4-5-6-5-4-3-2-1	7116	16.5	4	4
2	1-2-1	2128	17.8	1	1
3	2-3-2	876	10	0.8	1
4	3-4-3	656	10	0.68	1
5	4-5-4	706	10	0.71	1
6	5-6-5	2750	10	1.92	2
7	3-5-3	1040	10	0.91	1
8	3-6-3	3632	12.7	1.99	2
9	1-2-3-2-1	3004	12.6	1.99	2
10	2-3-4-3-2	1532	21.3	1	1
11	3-4-5-4-3	1362	19	1	1
12	3-5-6-5-3	3790	15.8	2	2
13	2-3-4-5-4-3-2	2238	11.7	2	2
14	1-2-4-2-1	3356	14	2	2
15	1-2-3-4-5-4-3-2-1	4366	14	3	3

Table 4: *Route characteristics of the routes included in the different route networks, using Algorithm 1.*

The service networks shown in Table 5 are made with Algorithm 1. The service networks are numbered, as shown in the first column. The second column shows the route numbers that were included in the route network. The third column shows which ship type is sailing on each route shown in the previous column. Furthermore the table shows the sailing speed of each ship and the total demand that is transported on the route network.

Table 6 shows the revenue, the handling cost and the transshipment cost determined in the cargo-routing model. Furthermore, the fuel and fixed cost of the network and the profit are specified. The fixed cost of the network include the daily fixed cost of the ship and the fixed port dues per visited port. The profit is calculated by subtracting the handling, transshipment, fuel and fixed cost from the revenue.

Network number	Routes included	Ship Type	Sailing Speed in nautical miles per hour	Demand Satisfied per week in TEU
1	{1,1,1,1}	{5,5,5,5}	{16.5,16.5,16.5,16.5}	56,104
2	{1,1,1,1}	{5,5,4,4}	{16.5,16.5,16.5,16.5}	43,166
3	{2,2,3,4,5}	{5,5,5,5,2}	{17.8,17.8,12,12,10}	29,566
4	{2,2,3,4,7, 8,8}	{5,5,5,5,5, 3,3}	{17.8,17.8,12,12,12, 12.7,12.7}	43,253
5	{9,9,10,10, 11,11,12,12}	{5,5,5,5, 5,5,4,4}	{12.6,12.6,21.3,21.3, 19,19,15.8,15.8}	56,104
6	{9,9,12,12,13,13}	{5,5,5,5,5,5}	{12.6,12.6,15.8,15.8,12,12}	56,104
7	{12,12,13,13,14,14}	{5,5,5,5,5,5}	{15.8,15.8,12,12,14,14}	56,104
8	{8,8,13,13,14,14}	{4,4,5,5,5,5}	{12.7,12.7,12,12,14,14}	56,104
9	{12,12,15,15,15}	{5,5,5,5,5}	{15.8,15.8,14,14,14}	56,104

Table 5: *Route networks and the ship type and sailing speed on the route, using Algorithm 1.*

The first route network considered is a route network consisting of only route number 1, sailed by 4 ships. This is the route the Indonesian government proposed, only instead of visiting the port Batam, Banjarmasin is visited. This network satisfies the total demand. The second service network is the same as the first, but this time ship type 4 is used on 2 of the routes. This decreases the revenue, because not all the demand can be satisfied anymore. However, the fixed cost for ship type 4 are much lower and the ship has lower fuel consumption. From Table 6 can be seen that the profit is higher in this service network. The decrease in cost is larger than the decrease in revenue.

The third route network has the same stops as the first route network, but in this route network the ships sail between two ports instead of visiting all the ports in one route. To start, route number 6 was included as well in this route network , but the cargo-routing model did not include this route in the solution. The total demand is not satisfied, this is partially because it is not profitable to visit Sorong in this route network.

Network number	Revenue per week	Handling Cost per week	Transshipment Cost per week	Fuel Cost per week	Time Charter & Port Cost per week	Profit per week
1	12,062,360	3,815,072	0	2,842,498	2,377,120	3,027,670
2	11,430,690	3,615,288	0	2,388,934	2,041,120	3,385,348
3	6,356,690	2,010,488	149,634	611,489	650,280	2,934,799
4	9,299,395	2,941,204	168,096	927,076	1,051,792	4,211,227
5	12,062,360	3,815,072	266,526	1,710,302	1,616,096	4,654,364
6	12,062,360	3,815,072	130,492	1,279,788	2,369,584	4,467,424
7	12,062,360	3,815,072	119,782	1,512,044	2,369,584	4,245,878
8	12,062,360	3,815,072	232,696	1,039,319	1,611,072	5,364,201
9	12,062,360	3,815,072	40,494	1,808,802	2,957,584	3,440,408

Table 6: *Results for different service networks, using Algorithm 1.*

In an attempt to include Sorong in the network, it was checked between which city and Sorong the largest cargo flow exists. This is Tanjung Perak. Since there is no cargo flow between Makassar and Sorong, this route is replaced with the route Tanjung Perak - Sorong. Furthermore, the cargo-flow between Banjarmasin and Makassar is very small. It therefore might make more sense to replace the route Banjarmasin-Makassar with the route Tanjung Perak - Makassar. This is service network 4. The next step is to try and extend the routes. Since service network 4 seems to perform the best, the routes on this network are extended by adding an extra port to the route at the end. This network is service network 5. This network satisfies the total demand and the profit increases in comparision with service network 4.

Since service network 5 is highest in profit compared to the other service networks, a slight change is made in this route network. It might be profitable to combine 10 and 11 in one route. Therefore route 10 and 11 are switched for route 13. This is service network 6. However, switching the routes decreases the profit.

A route that seems to work well to include Sorong in the network is route number 12. The remaining ports are connected using route 14. Route 13 is added to satisfy the remaining demand. All the demand is satisfied using network 7. Route network 8 is similar to route network 7, only a smaller route is used to connect Sorong to the route network. This network satisfies all the demand and has a higher profit than the previous networks.

To investigate if a longer route is profitable route 15 is created and used in combination with route 12. This service network satisfies the total demand, but has very high fuel cost and fixed cost. Therefore, this service network has a low profit.

Service network 1 is the most similar to Pendulum Nusantara. However, the profit generated with this service network is the lowest of all the networks investigated. Furthermore, on 31 of the 40 legs, the full capacity of the ship is not utilized. Moreover, on 7 of the 31 legs the ship is empty. Hence, considering the profit and the utilized capacity, the route proposed in the Pendulum Nusantara programme does not seem to be the optimal route. Service network 8 achieves the highest profit. On 12 of the 24 legs the full capacity of the ship is not utilized. On 1 leg the ship is empty.

All the instances of the problem were solved with Aimms within a maximum of 0.11 seconds. The number of constraints was between 471–643 and the number of variables was between 785 –4421.

5.2 Results Algorithm 2

The routes in Table 7 were created using Algorithm 2. 100 routes were generated using the algorithm, because then there is a sufficient amount of routes to choose from without creating a lot of similar routes. The routes were chosen based on the list created in step 5 of Algorithm 2. Routes higher in the list were included first in the route network. The routes were chosen such that no double routes were in the route network and all the ports are visited. Some routes were included in the route network to replace similar and longer routes in the network. The characteristics of the different routes used are shown in Table 7. The number of weeks needed for a round tour is based on the sailing speed that gives a route duration closest to an integer number of weeks.

The service networks shown in Table 8 are made with Algorithm 2. The service networks are numbered, as shown in the first column. The second column shows the route numbers that were included in the route network. The third column shows which ship type is sailing on each route shown in the previous column. Furthermore the table shows the sailing speed of each ship and the total demand that is transported on the route network.

Table 9 shows the revenue, the handling cost and the transshipment cost determined in the cargo-routing model. Furthermore the fuel and fixed cost of the network and the profit are specified. The fixed cost of the network include the daily fixed cost of the ship and the fixed port dues per visited port. The profit is calculated by subtracting the handling, transshipment, fuel and fixed cost from the revenue.

Service network 10 consists of routes that visit 3 ports, before returning to the first port. Service network 11 is made by switching several longer routes for a shorter route. Route 23 and 24 were switched with routes that visit one port less, route 16 and 17 respectively. Next, route 21 was switched with a shorter route and after that deleted from the network. Finally, route number 19 was switched for route 18. The adjustments in the routes leads to an increase in profit of 210,592 USD per week.

Routes that visit 4 ports are included in service network 12. The profit for this network is lower, since these longer routes have a higher cost. Adjusting the routes in this network gives service network 13. 10 adjustments were tried, of which 6 were succesful. Only one

Route number	Ports visited	Distance	Speed	Number of weeks for a round tour	Number of ships on the route
16	1-2-1	2128	17.8	1.00	1
17	3-4-3	656	10	0.68	1
18	4-5-4	706	10	0.71	1
19	4-5-3-4	1201	12.6	1.00	1
20	3-4-2-3	1380	14.4	1.00	1
21	2-5-4-2	1773	18.5	1.00	1
22	2-1-3-2	2990	11.4	1.99	2
23	1-3-4-1	3246	12.3	2.00	2
24	6-5-4-6	3305	12.6	1.99	2
25	2-1-5-2	3578	13.6	1.99	2
26	6-5-3-6	3711	14.1	2.00	2
27	3-2-4-5-3	1925	10.0	1.72	2
28	5-1-2-4-5	3739	15.6	2.00	2
29	6-4-3-5-6	3800	15.9	1.99	2
30	1-5-3-4-1	3986	16.7	1.99	2
31	6-2-3-5-6	4435	18.5	2.00	2
32	4-2-6-5-4	4444	18.6	1.99	2
33	3-5-2-1-4-3	4148	19.3	1.99	2
34	6-2-5-3-4-6	5333	13.9	3.00	3
35	2-4-5-3-6-2	5405	14.1	3.00	3
36	6-1-3-4-5-6	6351	16.6	2.99	3
37	2-3-1-5-4-2	4601	21.4	1.99	2

Table 7: *Route characteristics of the routes included in the different route networks, using Algorithm 2.*

route of the original network is included. The other routes have been switched for shorter routes. The profit of service network 13 is 5,687,964, which is the highest profit so far. Figure 3 shows the network in more detail.

Including routes that visit 5 ports decreases the profit, as shown by service network 14. This network can be improved upon by deleting route 36 and switching route 35 for the shorter route 27. This is service network 15, which has an increased profit of 4,776,376 per week.

Creating and improving route networks with routes that visit 2 ports or 6 ports has been done as well, but this did not result in a higher profit, compared to service network 13. Especially, including routes that visit 6 ports is not profitable.

Service network 13 achieves the highest profit. On 7 of the 18 legs the full capacity

Network number	Routes included	Ship Type	Sailing Speed in nautical miles per hour	Demand Satisfied per week in TEU
10	{19,20,21,22, 23,24,25,26}	{5,5,5,5, 4,1,5,5}	{12.6,14.4,18.5,12, 12.3,12.6,13.6,14.1}	56,104
11	{16,17,18,20,22,25,26}	{5,5,4,5,5,5,5}	{17.8,12,12,14.4,12,13.6,14.1}	56,104
12	{27,28,29,30,31,32}	{5,5,5,5,5,5}	{12,15.6,15.9,16.7,18.5,18.6}	56,104
13	{16,19,20,21,22,31}	{5,5,5,5,5,5}	{17.8,12.6,14.4,18.5,12,18.5}	56,104
14	{33,34,35,36,37}	{5,5,5,5,5}	{19.3,13.9,14.1,16.6,21.4}	56,104
15	{27,33,34,37}	{5,5,5,5}	{12,19.3,13.9,21.4}	56,104

Table 8: *Route networks and the ship type and sailing speed on the route, using Algorithm 2.*

Network number	Revenue per week	Handling Cost per week	Transshipment Cost per week	Fuel Cost per week	TC & Port Cost per week	Profit per week
10	12,062,360	3,815,072	40,494	1,351,411	1,618,072	5,237,311
11	12,062,360	3,815,072	237,456	1,122,625	1,439,304	5,447,903
12	12,062,360	3,815,072	132,566	2,299,725	1,779,072	4,035,925
13	12,062,360	3,815,072	14,110	1,357,910	1,187,304	5,687,964
14	12,062,360	3,815,072	0	2,776,961	2,367,700	3,102,627
15	12,062,360	3,815,072	157,828	1,831,152	1,481,932	4,776,376

Table 9: *Results for different service networks using Algorithm 2*

of the ship is not utilized. Moreover, the ship is never empty.

The generation of the routes takes less than one second. All the instances of the cargo-routing problem were solved to optimality within a maximum of 0.13 seconds. The number of constraints was between 895–982 and the number of variables was between 1773–10,078. The maximum number of changes tried in a service network is 10. This means that the cargo-routing model was implemented 10 times. Using the maximum solving time, the total run time is 1.3 seconds.

6 Conclusion

Two algorithms have been proposed to create a service network. The service network consists of a set of ship routes, the allocation of ships to the routes, the sailing speed of the ships on each route and the allocation of cargo over the routes. The first algorithm creates route networks using pendulum routes. The second algorithm generates random routes and creates a route network by adding routes of the same length to the route

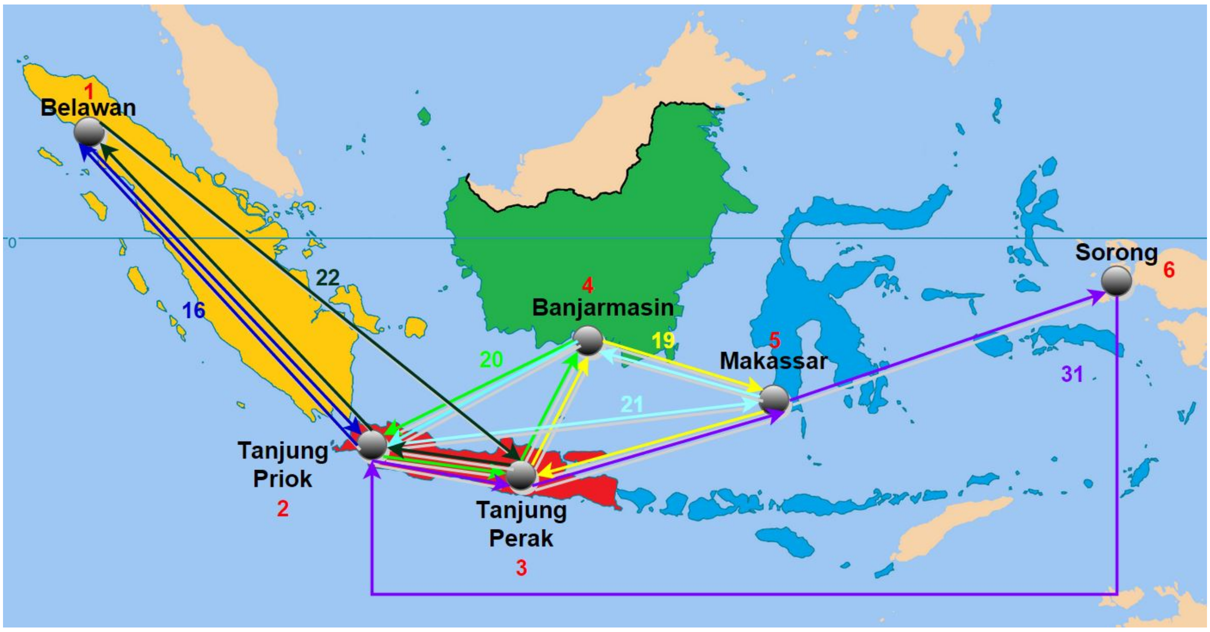

Figure 3: *Service network 13*

network. The route networks are improved upon by switching longer routes for shorter routes. The speed of the ship is chosen such that the duration of the route is closest to an integer number of weeks. The number of ships on the route is determined using the general assumption that the number of ships needed on a ship route is at least equal to the number of weeks needed to complete a round tour (rounded above). To start, the biggest ship type is assigned to each route. After implementing the route network, it is checked whether a ship with a smaller capacity can be assigned to the route.

Service network 1 is a pendulum route that visits all the ports on the eastbound trip and again on the westbound trip. The profit per week is equal to 3,027,670 USD per week. This can be improved by assigning a smaller ship type to half of the routes, but then the total demand is not satisfied anymore. The most profitable service network generated by Algorithm 1 is service network 8. The route network consists of three different pendulum routes that are all used twice. The profit per week is equal to 5,364,201 USD per week. Considering the utilization of the ship capacity, service network 8 has a higher utilization than service network 1.

With Algorithm 2 service networks were created that used routes that visit 2,3,4,5 or 6 ports. The results show that using routes that visit 5 or 6 ports is very expensive and therefore the profit of these service networks is low. Routes that only visit two ports are the cheapest, but a large amount of these routes is needed to satisfy the demand. Therefore, service networks containing only these routes are not the most profitable. The most profitable service network is network 13, created by improving upon the network that contained only routes that visit 4 ports. The profit of this network is 5,687,964 USD per week. Considering the utilization of the ship capacity, service network 13 has a higher utilization than service network 1 and 8.

All the instances of the cargo-routing problem were solved to optimality within a maximum of 0.13 seconds. The number of constraints was between 471–982 and the number of variables was between 785 – 10,078. Some of the implemented route networks that were generated with Algorithm 2 were bigger in size, compared to the route networks created with Algorithm 1. The solving time for these instances was 0.02 seconds longer. Algorithm 2 requires to run the cargo-routing model multiple times so this increases the solving time compared to Algorithm 1 as well.

In this thesis only a limited amount of routes and route networks were investigated. Possibilities for future research are therefore investigating routes that have not been researched yet in this thesis or to examine different combinations of the routes considered in this thesis. For example, when generating random routes, routes that visit ports multiple times can be included as well. Furthermore, a combination of pendulum routes and round tour routes can be examined, using the method that ports on a straight line will be visited using a pendulum route and ports on a circle will be visited using a round tour route.

References

R. Agarwal and Ö. Ergun. Ship scheduling and Network Design for Cargo Routing in Liner Shipping. *Transportation Science*, 42(2):175–196, 2008.

G. Brønmo, M. Christiansen, K. Fagerholt, and B. Nygreen. A multi-start local search heuristic for ship-scheduling – a computational study. *Computers & Operations Research*, 34:900–917, 2007.

B.D. Brouer, C.E.M. Alvarez, D. Plum, M.M. Pisinger, and Sigurd. A base integer programming model and benchmark suite for liner-shipping network design. *Transportation Science*, 48(2):281–312, 2014.

M. Christiansen and K. Fagerholt. Robust Ship Scheduling with Multiple Time Windows. *Naval Research Logistics*, 49:611–625, 2002.

K. Fagerholt. Optimal fleet design in a ship routing problem. *International transactions in operational research*, 6:453–464, 1999.

N. Fau, S. Khonthapane, and C. Taillard. Transnational Dynamics in Southeast Asia: The Greater Mekong Subregion and Malacca Straits Economic Corridors. *Institute of Southeast Asian Studies*, page 62, 2014.

H. Kalem. Liner-Shipping Network Design Indonesia. *Master's thesis. Erasmus University Rotterdam*, 2015.

S. Lawrence. International sea transport: The years ahead. *Lexington, Mass: Lexington Books*, 1972.

J.F. Álvarez. Joint routing and deployment of a fleet of container vessels. *Maritime Economics & Logistics*, 11:186–208, 2009.

Q. Meng, S. Wang, H. Andersson, and K. Thun. Containership Routing and Scheduling in Liner Shipping: Overview and Future Research Directions. *Transportation Science*, 48(2):265–280, 2014.

J. Mulder and R. Dekker. Methods for strategic liner shipping network design. *European Journal of Opertional Research*, 2013.

R. Pesenti. Hierarchical resource planning for shipping companies. *European Journal of Operational Research*, 86:91–102, 1995.

D.P. Song and J.X. Dong. Cargo routing and empty container repositioning in multiple shipping service routes. *Transportation Research Part B*, 46:1556–1575, 2012.

UNCTAD. Review of maritime transportation. 2011.

W. Wardana. Centre Gravity Model and Network Design to Determine Route of Liner Shipping: The Case of East-West Container Shipping Corridor in Indonesia. *Master's thesis. Erasmus University Rotterdam*, 2014.

World Bank. State of Logistics Indonesia. page 18, 2014.