Container liner-shipping network design using a path formulation model for Indonesia

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Dedicated to Emin Hamza and Esma.

Contents

Summary

This thesis is conducted in order to improve the liner shipping network in the Indonesian ports region. The network design problem is modelled with the use of a Path Formulation Model, which is a MIP. The model is primarily focused on the tactical and operational level, namely determining the allocation of cargo through different paths in the network. Paths belong to a route and consists of an origin and a destination port on which containers can be transported. As prerequisite, on the strategic level, routes are generated which serve as input for the PFM. The optimal solution maximises the profit by determining the set of paths to operate and how much cargo each path transports. The solution consists of a set of routes to operate. This model is further extended with transhipment, heterogeneous fleet, and speed optimisation. The model is compared with a benchmark consisting of a network with six hub ports. The results with all extensions show an improvement of the base solution by 12%.

Chapter 1

Introduction

In Indonesia there is unbalance in the domestic shipping trade between east and west parts of the country. Most shipping trade activity is in the region around Java, since this region is more developed and most trade from outside Indonesia arrives there. While the outskirts (mainly east Indonesia) are less developed due to the large distance and low demand/supply from these regions.

As a result the Indonesian government aims to improve the trade flows between east and west Indonesia in order to improve the economic growth. Together with terminal operators (Indonesia Port Corporation I-V), shipping companies and stakeholders, the Indonesian government plans to improve the current situation. As a solution, pendulum routes are considered to be used to connect east with west Indonesia. The characteristic of this kind of route is that the same ports (not all) are visited twice by going back and forth.

An important goal in this thesis is to develop a container shipping line network that will accommodate balance in trade flows between east and west Indonesia. Certain aspects must be taken into account in determining such a network. Demand and supply of each port/region is different, which requires the determination of what volume to transported to which port and by what order. Also, the current accessibility of ports requires the determination of which type of ships to use. Further, the availability of data determines the limitations of the model. Therefore, the data is required with regard to ports and its characteristics, possible ship fleet, costs and revenues structures.

This thesis starts by first defining the problem, which results in a main question and its sub questions. Based on these questions the literature is reviewed in order to acquire knowledge in the relevant field of research. Subsequently, a model is proposed to use for answering the main question. Before implementing the model, the available data is analysed in conjunction with the model requirements. This results in making simplification and assumption to the model. Lastly, results are presented, conclusion are drawn, and future research and limitations are discussed.

Chapter 2

Problem definition

In Indonesia there are many different kinds of ports with regard to attractiveness. That is, some ports are more profitable to serve than others. This causes unbalance in the shipping trade across the country.

Our goal is to gain insight into the problem situation and conduct research whether the situation at hand can be improved. Therefore, the aim is to build a model for the situation at hand and design container shipping network for liner shipping that improves the current situation.

In designing such a network several issues must be taken into account. There are many low demand/supply ports in Indonesia which also have large distance from the central region (Java). This requires the determination of which ports to visit and in what order.

Also the determination of which type of ship to operate is required. Since each ship type has its own characteristics, e.g. capacity, speed and size.

Based on this problem the main question is formulated as follows:

"Determine the best liner shipping network for Indonesian ports using a mathematical model"

Based on the problem, the following research questions are formulated:

1. Which model can be used to design container shipping networks for liner shipping?

2. How can the model be adapted to the size of Indonesia ports region?

3. What data is needed and available to solve the model?

In order to determine which mathematical models can be used literature research is conducted in Chapter 3. Different models and relevant topics are discussed. In Chapter 4 a model is proposed and the construction is discussed. Based on the model the data is analysed and prepared in order to run the model and compare it to a benchmark.

Chapter 3

Literature

In the literature the global shipping industry is divided into three modes of operation: *industrial*, *tramp*, and *liner* (Lawrence [1972]). The aim in industrial shipping is to minimise the total shipping cost over the owned ships. Tramp shipping refers to carriers that carries bulk cargo between specified ports according to a contract, which means cargo must be delivered according to specified time frames. In liner shipping it must be decided which set of trips to serve and by what schedule by a carrier.

The relevant mode of operation for this research is liner shipping. Therefore, liner shipping is investigated further. In Meng et al. [2014] it is stated that the aim of liner container shipping network design is to determine which ports the ships should visit and in what order. For liner container shipping companies there are three decision-making levels: strategic, tactical, and operational (Pesenti [1995]). Long-term decisions are made at the strategic level such as ship fleet size and mix, alliance strategies, and network design. Every three to six months, based on the change in demand, decisions are made at the tactical level. Here, the liner shipping company needs to decide on the frequency of its services, allocation of ships to routes, the sailing speed of those ships, and design schedules. At the operational level, decisions are made about whether to accept or reject cargoes, how to route accepted cargoes, and how to reroute or reschedule ships to cope with unexpected incidents.

In Meng et al. [2014] an overview and summary is given of the three decision-making levels. Based on this, in the following sections, the literature review is divided into these three levels.

3.1 Strategic level

Strategic Alliance and Fleet design and Mix, as discussed in Meng et al. [2014], are decision making problems on the strategic level. However, these are assumed to be given a priori and are not discussed. While the Network design problem, also on the strategic level, is relevant for this research and is discussed in the next section (3.1.1).

3.1.1 Network design

The liner container shipping network design problem is NP-hard (Agarwal and Ergun [2008]). Generally research on this topic can be classified into the following four categories (Meng

et al. [2014]): 1) Feeder network design, 2) Ship routes without transhipment, 3) Hub-and-spoke network, and 4) General liner shipping network design. In the following sections each category is discussed in more detail.

3.1.2 Feeder network design

In this category a network divided into hub ports and feeder ports. Each feeder port either originates from or is destined to a hub port. There is also no transhipment within the feeder network.

In Fagerholt [1999] a set-partitioning model is proposed. In this model all possible routes are enumerated into single routes, i.e. routes that can be accomplished using the largest ship. Then, the single routes that are not being used to its maximum potential are combined into feasible new routes. These routes are being operated by smaller ships. Finally, the set-partitioning model is used to determine which routes to use. The set of routes consists of the single routes and the combined routes. Later this model is extended in Fagerholt [2004] to enable the model to choose between multiple ships, where each ship has its own cost structure, capacity, and sailing speed.

In Sambracos et al. [2004] a meta-heuristic method is used for the VRP in order to design a network with feeder ships and small containers from one depot port to 12 other ports. A List-Based Threshold Acceptance (LBTA) meta-heuristic method is used to minimise the total distance travelled and to determine the best sequence of ports to be visited. The LBTA is a stochastic method, which searches iteratively through the solution region.

3.1.3 Ship routes without transhipment

The aim in this category is to design one or a few liner service routes without container transhipment.

Boffey et al. [1979] developed an interactive computer program and a heuristic optimisation model for designing the ship route of a container ship. Each route was assigned a value which is obtained by maximising the total freight revenue by use of a LP model.

In Lane et al. [1987] an analytical model is proposed. This model aims to plan for liner container shipping routes. First enumerate all possible ship routes and then choose the optimal set of ship routes that satisfy the requirements by use of a set-partitioning model.

Rana and Vickson [1988] built a MINLP model for routing a single container ship. By enumerating all possible round trips the model is linearised. As a result a MILP model is created and this is then solved using Benders' decomposition technique. The model assumes that the ships port-calling sequence is determined beforehand.

In Shintani et al. [2007] the assumption of port calling precedence relations is relaxed to design a single ship route and empty container repositioning is considered. The problem was formulated as a bilevel model, where the upper level was a knapsack problem choosing the best set of calling ports, and given these ports the lower level identified the optimal calling sequence of ports. With a GA model problems were solved simultaneously. Chuang et al. [2010] proposed a fuzzy GA for designing a liner ship route by assuming that the container shipment demand was not a crisp number, but a fuzzy number.

3.1.4 Hub-and-spoke network

Imai et al. [2009] compared the efficiency of H&S networks and Multi Port Call (MPC) networks using a simple six-port example. In H&S one port in each service area is chosen as a hub, and the other four ports are connected by feeders. While in MPC, all six ports are visited sequentially. They found that MPC network to be superior to the H&S network in most scenarios. However, this might change based on the cost structure.

3.1.5 General liner shipping network design

In this category a network is designed which involves more ports in the network and allows for container transhipment operations.

For the liner shipping service network design problem with cargo routing, Agarwal and Ergun [2008] propose a multi commodity-based space-time network model. The model incorporates a heterogeneous fleet, a weekly service frequency, multiple ship routes, and cargo transhipment. A MILP formulation is used with an exponential number of decision variables indicating whether a ship route is used or not. A greedy heuristic, a column generation-based algorithm, and a two-phase Benders' decomposition-based algorithm is used. However, transhipment cost were not considered in the network design stage.

Alvarez extended the problem addressed by Agarwal and Ergun [2008] in two aspects. First, transhipment cost was explicitly incorporated into the network design. Secondly the different ship types had different speed. By use of a combined tabu search and column generation-based heuristic to design the network.

Reinhardt and Pisinger [2012] presented a model with butterfly ship routes. This is a route which contains a port that is visited twice and at which transhipment is allowed. Their model also incorporates heterogeneous fleet and transhipment costs. An exact B&C algorithm to solve the problem.

In Mulder and Dekker [2013] a composite solution approach is used in which a LP is used for the Cargo Routing Problem (CRP). First the ports are aggregated into clusters and initial networks are created heuristically. After the initial solution the algorithm iterates through CRP, speed optimisation, disaggration into feeder networks, and a GA to change networks until optimality is met. They are able to compute this for 58 ports.

In Brouer et al. [2014] the problem of Liner-Shipping Network Design (LSND) is discussed and they provide a general benchmark suite with data. They solve the benchmark suite with a MIP model based on Alvarez with the extension to handle certain rotations and frequencies. Further, a combined heuristic method is used with tabu search and heuristic column generation.

3.1.6 Route generation

Fagerholt [2004] uses an algorithm to generate routes. It is an iterative algorithm which starts with small number of ports and extends by adding ports if the capacity constraints are not exceeded. In case the constraint is met, a TSP is solved to find the optimal visiting port sequence for the new route.

3.2 Tactical level

Meng et al. [2014] discuss the following studies in this category which are relevant for our research, namely frequency determination, fleet deployment, ship sailing speed optimisation, and schedule design. Schedule design has a lower priority and therefore is neglected in this thesis. In the following sections the other three topics are discussed separately.

3.2.1 Frequency determination

The time (in days) between two consecutive ships on a route visiting a port is called the service frequency. Generally in the literature, a weekly frequency is used in order to maintain a steady service by liner shipping (Meng et al. [2014]). The distance travelled by a ship on a route and its speed determines the number of ships required on a route.

3.2.2 Fleet deployment

Fleet deployment is about optimisation of assigning ships to routes. One of the relevant topics in here is the calculation of the required ships on a route. In order to calculate how many ships are required for a route, frequency of service and port waiting time are required. Wardana [2014] uses the following expression to calculate the number of ships required on a route with weekly service frequency.

$$n_s = \lceil (\frac{d}{s} + n_p)/7 \rceil \tag{3.1}$$

Where n_s number of ships required d is distance in nautical miles, s the speed in knots, and n_p the number of port visits. Note that for each port visit a port stay time of 24 hours is assumed. Also, distance denotes the total distance travelled by a ship on the route. Further, since an integer number is required, this number gets rounded up.

3.2.3 Ship sailing speed optimisation

Given the weekly service interval and the calculation of the number of ships, the speed of the ship travelling can be altered in order to reduce the number of ships used by travelling faster, alternatively reduce the fuel cost by travelling slower.
Based on Branch and Stopford [2013] and Alderton [2010] there is a general agreement that bunker consumption can be estimated by the following function:

$$F(s) = (s/v_*^F)^3 f_*^F \tag{3.2}$$

Where, s is any speed between min speed s_{min}^F and max speed s_{max}^F of the vessel F, v_*^F is the design speed, and f_*^F is the fuel consumption at design speed.

3.3 Operational level

In Meng et al. [2014] a number of operational-level decision problems in liner shipping is discussed, such as cargo booking, cargo routing ship rescheduling, and crew scheduling. In this thesis only cargo routing is considered relevant, therefore this is discussed next.

3.3.1 Cargo routing

Container routing problems are generally formulated as LP models where the number of containers is treated as a continuous decision variable. Some studies have modelled container routing using O-D-based link flow formulations (e.g., Agarwal and Ergun [2008], Brouer et al. [2011]), origin-based link flow formulations (e.g., Alvarez, Wang and Meng [2012]), or segment-based formulations, where a segment is a sequence of consecutive links (e.g., Bell et al. [2011], Meng and Wang [2011]). Some studies use path-based formulations (e.g., Agarwal and Ergun [2008], Brouer et al. [2011], Mulder [2015]).

In Bell et al. [2011] a frequency-based transit assignment model is applied to minimise sailing time with the addition of container dwell time at the origin port and any transhipment port. The assumption is made that the ship arrive at ports randomly, and that the dwell time at the origin port is equal to half the average headway.

Brouer et al. [2011] investigate the cargo allocation problem, taking into consideration the repositioning of empty containers. The aim is to maximise the profit from transporting cargos in a network, subject to the cost and availability of empty containers. Solving the LP-relaxed path-flow model with delayed column generation was very successful compared with solving the arc-flow model with the CPLEX barrier solver.

In Song and Dong [2012] the problem of joint cargo routing and empty container repositioning at the operational level is considered. The network consists of multiple service routes, multiple deployed vessels, and multiple regular voyages. A two-stage shortest-path-based IP model and a heuristic methods is proposed.

Mulder [2015] developed an LP formulation based on paths rather than routes as variables, which is called the Path Formulation Model (PFM). The model is defined as follows:

$$\min \sum_{p \in P} \tilde{c}_p x_p + \sum_{od} \hat{c}_{od} L_{od} \tag{3.3}$$

$$\text{s.t.} \ L_{od} + \sum_{p \ni od} x_p = d_{od} \qquad \forall od \tag{3.4}$$

$$\sum_{l \in p} x_p \leq Q_l = \sum_{s} q_r y_{rs} \qquad \forall l, r \tag{3.5}$$

$$x_p, L_o d \geq 0 \qquad \forall p, od \tag{3.6}$$

$$\tag{3.7}$$

Where p contains all legs l from origin port of the demand to the destination port. Leg l consists of two consecutive ports and the route on which these ports are visited. x_p is the amount of containers shipped using path p. $p \ni od$ means that path p starts in origin port o and ends at destination port d. $\tilde{c}_p$ is the cost of a path, this includes loading cost at the origin port, unloading cost at the destination port, possible transshipment costs at transshipment ports and the revenue of satisfying the demand (the revenue is subtracted from the costs). L_{od} is the amount of demand of od-pair od that is not fulfilled, each container that is not delivered has a penalty of $\hat{c}_{od}$. Finally, Q_l is the total capacity at leg l and can be found by adding the capacities of the different ship types that are allocated to the route (y_{rs} denotes

the number of ships of type s that are allocated to route r).

In this model the ship allocation is assumed to be fixed, such that route costs do not need to be included in the objective. The model can be extended to include the allocation of ships by letting y_{rs} be an integer variable and including route costs in the objective.

3.4   Cost estimations

Cost calculations derived from Veldman et al. [2011] are presented by Blancas and El-Hifnawi [2013] with the estimation of the parameters based on 2008 data from Lloyd's/Fairplay. Price of a container ship is calculated based on ship size, vessel speed, and fuel consumption.

The elasticity between waiting time at ports and vessel size is estimated in Veldman et al. [2011]. Here, a elasticity value of 0.43 is estimated as port time with respect to ship size. Meaning, that elasticity of cargo handling speed per ship equals $1 - 0.43 = 0.57$.

Further there are three types of charter cost for a ship, these are bareboat charter, time charter and voyage charter. In this thesis, time charter is used since these costs can be used as a fixed costs in the model and covers all the expenses.

3.5   Conclusion

On the operational level cargo routing is an important aspect. The Path Formulation Model (PFM) from Mulder [2015] is used to develop a method. However, the model needs to be adapted in order to select optimal routes. Further, the frequency determination, fleet design, and speed design are relevant on the tactical level, since these alter the cargo routing problem. On the strategic level the route generation methods used by Rana and Vickson [1988] are useful for this thesis, due to its practicality. The enumeration of the possible routes is intuitive and, if solved, results in a global optimum. Further in order to structure costs to certain variables/parameters calculation the fuel cost calculation based on Branch and Stopford [2013] and Alderton [2010] is used. It is observed from the PFM that routes are treated as input to the model. Therefore, the problem is split into route generation and PFM solving.

Chapter 4

Solution approach

The model is explained in Section 4.1 including the extensions. In Section 4.2 methods used to generate favourable routes are explained which are used to feed into the path formulation model.

4.1 Mathematical model

The idea of the path formulation model is that instead of using routes in the model and choosing which routes are optimal, paths are used to choose from, in which routes are treated as given. However, for this thesis it is also required to determine which routes should be used. Therefore, the PFM model becomes a MIP and this is explained in Section 4.1.1. The model is then extended further by using different ships for each route, which is explained in Section 4.1.2.

4.1.1 Path Formulation Model (PFM) with routes

This formulation of the problem serves as the basis for the later extensions. The model is based on PFM (Mulder [2015]), with the addition of routes as variables. Due to this, the model is becomes a MIP instead of a LP. The properties of the model are:

Sets:

L : contains all legs l which are consecutive
JL : contains all legs including jump legs jl, i.e. legs that omit at least 1 consecutive port visit
P : contains all paths p
OD : contains all origin-destination pairs od
R : contains all routes r

The relations between R (set of all routes), JL, and P are:

- A route $r \in R$ consists of legs $l \in L$

- legs are a subset of jump legs, i.e. $L \subseteq JL$

- A path $p \in P$ consists of jump leg(s) $jl \in JL$

Namely, foreach $r \in R$ multiple legs are created (JL). This contains legs of two types, namely consecutive l and jumping jl. These types are in essence the same, however a distinction is made in order to construct valid constraints, which is explained later in Section 4.2.4. As an example, for route { 1, 2, 3, 1 }, the set L would contain the legs l_1, l_2 and l_3, with respective origin-destination's: 1-2, 2-3, and 3-1. While, the set of JL contains $l_1 = jl_1$, $l_2 = jl_2$, $l_3 = jl_3$, and also jl_4, jl_5, and jl_6 with respective origin-destination's 1-3, 2-1, and 3-2. The sequence of construction is: first generate all jump legs for a given route, and then select the consecutive legs.

Further, paths $p \in P$ are constructed based on $jl \in JL$ that are valid. Invalid jump legs are filtered, this is explained in Section 4.2.3 under path construction rules.

In Section 4.2 all of these relations are explained in more detail.

Parameters:

p : path containing all jump legs (if there is no transhipment in the path there is only 1 jump leg, while if there is transhipment there are 2 jump legs)

jl : jump leg containing two ports (origin and destination), the route on which these ports are visited, and the position indices of origin and destination on the route

l : consecutive leg has the same properties as a jump leg, except this comes from the subset L which only contains consecutive legs

$\tilde{c}_p$: cost of a path, this includes loading cost at the origin port, unloading cost at the destination port, possible transhipment costs at the transhipment port, and subtracting the revenue of a shipped container

$\hat{c}_{od}$: cost of a od-pair od that is not fulfilled. This value is equal to revenue per container (in TEU) r_c.

$\tilde{c}_r$: cost of route, this includes charter cost for the amount of ships required on this route, fuel cost, and port dues

d_{od} : demand between od-pair od

Q_l : total capacity at consecutive leg l

q : capacity of a ship

Decision variables:

x_p : amount of containers shipped using path p

L_{od} : amount of demand of od-pair od that is not fulfilled

y_r : number of times route r is operated

The MIP problem is defined as

$$\min \sum_{p \in P} \tilde{c}_p x_p + \sum_{od \in OD} \hat{c}_{od} L_{od} + \sum_{r \in R, s \in F} \tilde{c}_r y_{rs} \tag{4.1}$$

$$\text{s.t. } L_{od} + \sum_{p \ni od} x_p = d_{od} \qquad \forall od \in OD \tag{4.2}$$

$$\sum_{jl \in p} x_p \leq Q_l = q y_r \qquad \forall l \in L \tag{4.3}$$

$$x_p, L_{od} \geq 0 \qquad \forall p \in P, \forall od \in OD \tag{4.4}$$

$$y_{rs} \in \mathbb{N} \tag{4.5}$$

The objective (4.1) is to minimise the total costs. Costs is given by the cost of a paths that are selected and the costs of od-pairs that are not fulfilled. The cost of a path $\tilde{c}_p$ include the revenue of the path. Further, for each route r terms are added to the objective function with a coefficient of $\tilde{c}_r$

Constraints (4.2) ensure that all demand is either satisfied or penalised. Constraints (4.3) ensure that the maximum capacity of leg l is not exceeded by all paths travelling through this leg. The precise construction of these constraints is explained in Section 4.2.4. Further, constraints (4.4) and (4.5) ensures nonnegative shipment and unfulfillment.

The cost of a path $\tilde{c}_p$ is calculated as follows:

$$\tilde{c}_p = 2 \cdot c_h - r_c + I_t \cdot c_t \tag{4.6}$$

where c_h is the handling cost and r_c the revenue for transporting 1 TEU of container. If the path contains transhipment (denoted by I_t), for each transhipment a value of c_t is added. Note, that in this thesis a maximum of one transhipment is allowed.

The calculation of $\tilde{c}_r$ is as follows:

$$\tilde{c}_r = c_c + c_f + c_d \tag{4.7}$$

where c_c are the yearly ship charter cost, c_f the total yearly fuel cost, and c_d the yearly port dues.

Charter cost   Ship charter costs are calculated as:

$$c_c = n_s \cdot T_F \tag{4.8}$$

where n_s are the number of ships required on the route and T_F the yearly time charter rate of a ship. For calculating the number of ships, refer to Equation 3.1. Note that this number is rounded up in order to have integer value.

Fuel cost   Fuel cost is calculated by the following function:

$$c_f = (d \cdot c_{fs} + (n_p + w)c_{f0}) \cdot 52 \tag{4.9}$$

where d is the total distance of the route in nautical miles, c_{fs} the cost of fuel per nautical mile travelled at a certain speed s, n_p the number of port visits on the route, and c_{f0} the fuel cost per day for staying idle. w is the time in days the ship has waited, this value is the difference between number of weeks and rounding number of weeks up. Finally the whole term is multiplied by 52 to get the annual fuel cost. Note, that later on a Speed optimisation extension is proposed, in which the fuel cost are changed

Further, fuel cost per nautical mile travelled at design speed is calculated as:

$$c_{fs} = \frac{F(s) \cdot p_f}{24 \cdot s_*}$$

where $F(s)$ the fuel consumption at speed s and p_f the fuel price. Note, that $F(s)$ is shown in Equation 3.2.

The cost per day for staying idle is calculated as:

$$c_{f0} = f_0^F \cdot p_f$$

where f_0^F the fuel consumption per day for staying idle.

Port dues The last term associated with route cost are the yearly dues paid to the port. This is calculated as:

$$c_d = n_p \cdot p_d \cdot 52 \tag{4.10}$$

where n_p the number of ports visited on route and p_d the price paid to enter the port. This amount is assumed to be the same for all ports. Eventually the whole term is multiplied by 52 weeks in a year.

4.1.2   Extension 1: Multiple ships

In this section the PFM is extended with the option to choose between more than one ship type for a route. The model gets more complex since each route $r \in R$ is mapped to the number of ships in F. The properties of the model are as follows.
Additional sets:

F : Fleet: contains all ship types s

Additional parameters:

$\tilde{c}_{rs}$: cost of route using ship type s
q_s : capacity of ship type s

Additional decision variables:

y_{rs} : number of times route r, with allocated ship type s, is operated

The MIP problem is defined as

$$\min \sum_{p \in P} \tilde{c}_p x_p + \sum_{od \in OD} \hat{c}_{od} L_{od} + \sum_{r \in R} \tilde{c}_{rs} y_{rs} \tag{4.11}$$

$$\text{s.t. } L_{od} + \sum_{p \ni od} x_p = d_{od} \qquad\qquad \forall od \in OD \tag{4.12}$$

$$\sum_{jl \in p} x_p \le Q_l = \sum_s q_s y_{rs} \qquad\qquad \forall l \in L \tag{4.13}$$

$$x_p, L_o d \ge 0 \qquad\qquad \forall p \in P, \forall od \in OD \tag{4.14}$$

$$y_{rs} \in \mathbb{N} \tag{4.15}$$

Difference with the previous model is that the term $\tilde{c}_r$ is replaced by $\tilde{c}_{rs}$, which is the route cost using a specific ship type.

4.1.3 Extension 2: Speed optimisation

Speed optimisation refers to adapting the speed of the travelling ship in order to reduce costs. Since, weekly service rate is used, the sailing speed can be adapted to arrive exactly on the end of a week. For this, the ship can either travel slower or faster to arrive exactly on the end of a week. For example, if at design speed the ship takes 2.5 weeks, it could go faster in order to arrive in exactly 2 week, reducing the number of ships required on the route. Or, the ship can travel slower which reduces the fuel cost used. The bunker consumption depending on the speed change can be calculated using the function in Section 3.2. Using the speed optimisation is done using the following algorithm:

Algorithm 1 Constraint construction

1: $numberOfWeeks \leftarrow ((((totalDistance/designSpeed) + numberOfPorts \cdot 24)/24)/7)$
2: $speedLow \leftarrow totalDistance/(168 \cdot \lfloor numberOfWeeks \rfloor - 24 \cdot numberOfPorts)$
3: $speedHigh \leftarrow totalDistance/(168 \cdot \lceil numberOfWeeks \rceil - 24 \cdot numberOfPorts)$

4: $costLowSpeed \leftarrow calculateCostAtSpeed(Low)$
5: $costHighSpeed \leftarrow calculateCostAtSpeed(High)$
6: $costDesignSpeed \leftarrow calculateCostAtSpeed(Design)$

7: $optimalSpeedCost \leftarrow min(costLowSpeed, costHighSpeed, costDesignSpeed)$

4.2 Route generation

Main input of the model are the routes, and most of the variables in the model are created based on the routes. Therefore it is necessary to have a description of routes in the model which can be processed further.

Description of a route must be able to show the ports that are visited and the sequence in which they are visited. The following characteristics have been established to describe a route:

- Each port that is visited by a route is stated in the route.

- First port (beginning port) is equal to the last port (end port), since each route must return to its starting point.

- The sequence explains in which order the ports are visited.

To simplify the information ports have been replaced by an unique integer number. In Table 4.1 the Id of each port is given.

The following, r_1, is an example route (4.16), which starts at Belawan, travels to Tanjung Priok, Tanjung Perak, Banjarmasin, and back to Belawan.

$$r_1: \{1, 2, 3, 4, 1\} \tag{4.16}$$

The generation of routes starts by permuting over al possibilities, in which a port is allowed once in a route except for the beginning port. Although the model is capable of handling multiple visits of the same port in a route, due to high computation time for large number of

Id	Port name
1	Belawan
2	Tanjung Priok
3	Tanjung Perak
4	Banjarmasin
5	Makasar
6	Sorong

Table 4.1: Port name Ids

routes, this is limited to one port visit in a route. In Chapter 6, in the reference model from Wardana [2014], routes with multiple visits to the same ports are used. However in our own solution only routes with single port visits are used, since more routes are used in the model.

4.2.1 Path construction

Once the routes are generated, paths can be constructed. Basically, paths are described by an array that looks like $\{o, d, r, i_1, i_2\}$, where o is origin, d the destination, r the route the path belongs to, i_1 index of the paths origin in the route, and i_2 index of the paths destination or the route. In order to construct constraints it is required to know on which route the path is operating. Subsequently, in order to determine which paths overlap with each other (make use of the same leg), in constraint construction, the indices are required. Index 1 (i_1) shows on which position the origin port of the path is located on the route r. And index 2 (i_2) shows on which position the destination port of the path is located on the same route. Therefore, a path contains a beginning port, a destination port, route number, and the indices of the two ports in the route. Based on the example (4.16) the following paths are constructed:

$$p_1: \{1, 2, 0, 0, 1\} \tag{4.17}$$
$$p_2: \{1, 3, 0, 0, 2\} \tag{4.18}$$
$$p_3: \{1, 4, 0, 0, 3\} \tag{4.19}$$
$$p_4: \{2, 1, 0, 1, 4\} \tag{4.20}$$
$$p_5: \{2, 3, 0, 1, 2\} \tag{4.21}$$
$$p_6: \{2, 4, 0, 1, 3\} \tag{4.22}$$
$$p_7: \{3, 1, 0, 2, 4\} \tag{4.23}$$
$$p_8: \{3, 2, 0, 2, 5\} \tag{4.24}$$
$$p_9: \{3, 4, 0, 2, 3\} \tag{4.25}$$
$$p_{10}: \{4, 1, 0, 3, 4\} \tag{4.26}$$
$$p_{11}: \{4, 2, 0, 3, 5\} \tag{4.27}$$
$$p_{12}: \{4, 3, 0, 3, 6\} \tag{4.28}$$

These descriptions of paths are interpreted differently than the description of routes. A path description is summarised as:

1. Origin port ID

2. Destination port ID

3. Route ID

4. Index of origin port in route

5. index of destination port in route

Observe that routes are treated as circular routes, i.e. paths may be constructed with origin-port within the route description and destination-port after the route description. In more detail, take example (4.28). Although at first glance to the route there seems to be no connection from port 4 to port 3, there actually is. Since routes are circular, the journey continuous after the end-port is reached. Therefore, for p_{12} a ship travels from 4 to 1, to 2, and eventually to 3.

4.2.2 Path construction with transhipment

The description of a path changes if this is a path with transhipment. Let the example (4.29) be another valid route in the model.

$$r_2 \colon \{3, 5, 3\} \tag{4.29}$$

If transhipment is allowed, more paths are constructed with transhipment from one route to another. As an example, when r_1 and r_2 are considered, the following is a path that is constructed.

$$p_{13} \colon \{1, 3, 0, 0, 2\}\{3, 5, 1, 0, 1\} \tag{4.30}$$

In order to construct a path with transhipment, two routes are required. These routes must have a port in common at which the transhipment can take place.
Example (4.30) shows that a container travelling on a ship starting at port 1 along route r_1 is transhipped in port 3 to another ship travelling along route r_2. The container eventually arrives at port 5. This is a path for the origin-destination pair 1-5, which was not available at route r_1.

4.2.3 Filtering

Both with the generation of routes and paths, the number of variables created grows rapidly. Therefore, some routes and paths are left out due to invalidity. And a filter is applied to routes with regard to distance.

In route generation the following rules are used to filter:

- Validity: a certain order of port visits is not allowed more than once. E.g. route { 1, 2, 3, 1 } is the same route as route { 2, 3, 1, 2 }.

- Filter: the total distance of a route must not exceed the maximal allowed distance.

For path construction the following rules are used:

- Validity: The origin-destination demand must exist. No paths are constructed for which there is no demand.

- Validity: Per route, only one path with the same origin-destination is allowed. In case there are more than one, the shortest is chosen.

- Validity: The starting index (4th index in a path description) of a path must not be larger than the number of ports in the concerning route. This is in order to stop infinite circulation.

4.2.4 Contraint construction

The constraints in (4.3) and (4.13) have the same algorithm with regard to selecting paths that overlap a certain leg (consecutive leg l). The following algorithms are used in the model.

Algorithm 2 Constraint construction

1: **for all** l in L **do**
2:     $expression \leftarrow empty$
3:     **for all** p in P **do**
4:         **if** $l.origin = p.origin$ **AND** $l.destination = p.destination$ **then**
5:             $expression \leftarrow expression + p$
6:             **goto** next p
7:         **for all** jl in p **do**
8:             **if** $JumpLegOverlapsL(jl)$ **then**
9:                 $expression \leftarrow expression + p$
10:                 **goto** next p
11:     $model \leftarrow expression$

Algorithm 2 explains the procedure to add constraints. For each consecutive leg l all paths in P are checked whether it overlaps with this leg. The reason for iterating through all legs in p (row 7) is due to paths with transhipment. Since these could have more than 1 leg.

Algorithm 3 is a procedure that returns true or false based on whether l and $jl \in p$ overlap. This is the reason indices of origin and destination ports are recorded in the description of a path. Namely every port in a route is numbered according to the sequence, i.e. beginning port has index 1, next port to be visited has index 2, etc. This is used in order to determine whether paths travelling along a certain leg in route overlap with each other or not.
Basically the algorithm checks certain properties and returns true if any of the statements are hit, otherwise by default false is returned. Statement on row 2 checks whether both legs are on the same route. Statements on rows 3 and 4 simply check whether legs use the same ports. The remaining statements are explained by an example. Note that the first number in the bracket represent the index of origin port and the second number the index of destination port.

1. row 5: [1,4] [2,3] - jl falls between l

2. row 6: [2,3] [1,4] - jl starts before l and ends after l

Algorithm 3 Finding overlapping legs

1: **procedure** JUMPLEGOVERLAPSL(JL)
2:     **if** $l.route \neq jl.route$ **then return** false
3:     **if** $l.originIndex = jl.destinationIndex$ **then return** true
4:     **if** $l.destinationIndex = jl.originIndex$ **then return** true
5:     **if** $l.originIndex < jl.originIndex$ **AND** $l.destinationIndex > jl.originIndex$ **then return** true
6:     **if** $jl.originIndex < l.originIndex$ **AND** $jl.destinationIndex > jl.originIndex$ **then return** true
7:     **if** $l.originIndex < jl.originIndex$ **AND** $l.destinationIndex > jl.originIndex$ **AND** $l.destinationIndex < jl.destinationIndex$ **then return** true
8:     Reverse statements and check again
9:     **return** $false$
---

3. row 7: [1,3] [2,4] - jl starts between l and ends after l

Further the statements (row 5, 6, and 7) are checked again after reversing the statement. Since these situations can also occur and must be checked as well. Lastly if non of the statements hit, the function returns false.

Chapter 5

Data

In this chapter the data available is evaluated according to the requirements defined in Section 5.2. Due to incompleteness of data, modifications and simplifications are applied if necessary. This is summarised in Section 5.3.

5.1 Sources

There are two main sources from which data is acquired, these are data from Indonesia Port Corporation I-IV via Wardana [2014] and from Maersk shipping line via LINERLIB (Brouer [2015]). For location data, publicly available sources are used.

Data Wardana [2014] Via the Port Corporation I-IV data is available about, demand between ports (see Table 9.2), costs and revenues for the ports in Indonesia. Based on this data, in Wardana [2014] some assumptions and simplifications were made.

Data LINERLIB There is data available via Brouer [2015] about Maersk Shipping line which is used for the article published by Brouer et al. [2014]. In the following sections, this source of information is denoted by LINERLIB. This source contains data about fleets (Table 5.5) and, a subset of the ports (Table 9.3).

5.2 Requirements

In order to apply the Benchmark Liner Shipping model from Brouer et al. [2014], certain data is required. This is summarised Table 5.1.

Port list P	Fleet list V	Cargo demand list C	Distance
Port α^P	Vessel class v^F	Origin port α^C	Origin port α^D
Name n^P	Capacity c^F	Destination port β^C	Destination port β^D
Country o^P	TC rate T^F	Quantity q^C	Draft δ^P
Cabotage a^P	Draft δ^P	Freight rate f^C	Distance d^D
Region r^P	Min speed s^F_{min}	Max transit time t^C	
Latitude x^P	Max speed s^F_{max}		
Longitude y^P	Design speed v^F_*		
Draft δ^P	Fuel consumption f^F_*, design speed		
Move cost m^P	Fuel consumption f^F_0, idle		
transhipment cost t^P	Quantity of vessels q^F		
Fixed port call cost f^P			
Variable port call cost v^P			

Table 5.1: Data requirements based on Benchmark Liner Shipping Brouer et al. [2014]

5.2.1 Port list

Ports A subset of 17 major ports in Indonesia are considered in Wardana [2014] through 5 regions. For each region, a port called "others" is created which is an aggregation of all the remaining minor ports of that region. From LINERLIB there are 3 ports which coincide with the ports used in Wardana [2014], these are Tanjung Priok (Jakarta), Tanjung Emas (Semarang), and Tanjung Perak (Surabaya).

Location The Langitude and Longitude of each of the 12 ports (excluding the "others") are gathered through publicly available sources (Ports.com [2014], [publisher]).

Draft size There were three sources of information about these data, namely through Wardana [2014], LINERLIB, and publicly available. This is summarised in Table 5.2.

Port name	LINERLIB	Wardana [2014]	Public
Tanjung Priok (Jakarta)	8	14	
Tanjung Emas (Semarang)	9.5	9	
Tanjung Perak (Surabaya)	9.5	12	
Belawan		10	15.2
Pekanbaru			
Batam			
Pontianak		6	10
Banjarmasin		7	9.1
Makassar		12	
Bitung		12	23.2
Ambon		10	23.2
Sorong		20	23.2

Table 5.2: Draft data in meters according to various sources. Empty denotes there were no data available.

Port costs The data about Move, Transhipment, Port call fixed, and Port call variable costs is incomplete. This is due to that in LINERLIB only 3 of the 12 ports available, and due to the fact that in Wardana [2014] cost were averaged and simplifications were made with regard to data. The cost parameters used by LINERLIB and in Wardana [2014] are presented respectively in Tables 5.4 and 5.3.

Port name	Move cost	Transhipment cost	Port Call Cost Fixed	Port Call Cost Per FFE
Tanjung Priok (Jakarta)	135.00	62.00	2999.00	7.00
Tanjung Emas (Semarang)	134.00	81.00	2926.00	10.00
Tanjung Perak (Surabaya)	185.00	3.00	884.00	5.00

Table 5.3: Cost data in dollars based on LINERLIB

Revenue	215	Per TEU transported
Ship Charter Cost	3,296,680	Per ship in a year
Fuel Cost	78	Per nautical mile
Port Dues	628	Per port visited
Handling Cost	34	Per container handled

Table 5.4: Cost data in dollars based on Wardana [2014]

5.2.2   Fleets

The information about fleets is based on the data from Maersk through LINERLIB, which is summarised in Table 5.5.

Vessel class	Capacity FFE	TC rate daily (fixed Cost)	draft	Min Speed	Max Speed	Design Speed	Bunker ton per day at Design Speed	Idle Consumption ton/day
Feeder_450	450	5000	8	10	14	12	18.8	2.4
Feeder_800	800	8000	9.5	10	17	14	23.7	2.5
Panamax_1200	1200	11000	12	12	19	18	52.5	4
Panamax_2400	2400	21000	11	12	22	16	57.4	5.3
Post_panamax	4200	35000	13	12	23	16.5	82.2	7.4
Super_panamax	7500	55000	12.5	12	22	17	126.9	10

Table 5.5: Fleet data based on LINERLIB

5.2.3 Cargo demand

Quantity This data is gathered via Wardana [2014] and is summarised in Appendix Table 9.1.

Freight rate The only available information about the freight rate can be found via Wardana [2014], namely a rate of $215 per TEU transported.

Max transit time Based on Wardana [2014], average time spent in port is 24 hours. Maximum distance between ports is 2879 nautical miles between Belawan and Ambon. Based on an average speed of 18 knots per hour (Wardana [2014]), this implies a maximum travel time of about one week.

5.2.4 Distance

Distance information is based on public data and is summarised in Appendix Table 9.2. Draft size is decided based on the minimum between Origin port and Destination port. Suez traversal and Panama traversal is not applicable in this context, therefore these will be neglected.

5.3 Preprocessing

To be able to compare this model with a reference model, data and parameters are aligned in order to compare with the model from Wardana [2014].
One of the tasks to compare is to use the same demand matrix. Wardana [2014] transformed the original demand matrix (Appendix:Table 9.1) into a smaller set by aggregating the demand to a regional hub. The aggregation of ports into main ports is summarised in Table 5.6.

Main port	Added ports
Belawan	Pekanbaru, Batam, Others
Tanjung Priok	
Tanjung Perak	Tanjung Emas, Others
Banjarmasin	Pontianak, Others
Makasar	Bitung, Others
Sorong	Ambon, Others

Table 5.6: Port aggregation. Source: Wardana [2014]

With others, the remaining ports in each of the 6 major regions is meant (see Appendix:Table 9.1). Note that it is unclear from Wardana [2014] which ports are exactly meant with "others". However, it is assumed this is done correctly.

5.3.1 Port aggregation

The aggregation of the ports into 6 main ports including the demand data is summarised in Table 5.7.

	Belawan	T. Priok	T. Perak	Banjarmasin	Makasar	Sorong	Supply
Belawan	-	348036	55016	4524	4212	1404	413192
T. Priok	350480	-	99632	212784	145496	24128	832520
T. Perak	53872	126724	-	19734	250640	113048	741624
Banjarmasin	4680	189124	181896	-	676	-	376376
Makassar	4732	182052	213668	3796	-	-	404248
Sorong	2028	34372	113048	-	-	-	149448
Demand	415792	880308	663260	418444	401024	138580	2917408

Table 5.7: Yearly demand in TEU in case of port aggregation into 6 main ports. Source: Wardana [2014]

Both in supply and demand Belawan, T. Priok, and T. Perak have the most volume. It is expected that these ports will be visited the most. Belawan and Sorong have little demand and supply also there distance is the largest among the ports. Thus, this origin-destination pair is expected to have low or no volume.

5.4 Parameter setting / Assumptions

In this section, a summary is given with regard to which data is used from the various sources and what modifications/simplifications are applied. In the following sections, each subject is discussed separately. And the assumptions made for the PFM and Fleet Extension Model are also discussed separately.

Fleet In order to compare the model with the reference, only one ship type is used as it is done by Wardana [2014]. The characteristics of this ship is summarised in table 5.8. However, other ships are used as well, since there are ports in Indonesia that are capable of handling

each fleet. Therefore some of the fleets in the Table 5.5 are used. The exact fleet and its results are discussed in 6.2.3.

Vessel class	Capacity FFE	TC rate daily (fixed Cost)	draft	Min Speed	Max Speed	Design Speed	Bunker ton per day at Design Speed	Idle Consumption ton/day
Panamax_1750	1750	15000	8	12	18	20	55	4.5

Table 5.8: Ship used by Wardana [2014]

Draft size   The draft size is neglected in the model since only one type of ship is used, namely ship Panamax_1750 with a capacity of 3500 TEU. The ports are aggregated in such a way that there is always a port within the region which able to handle this ship size.

Port costs   In Wardana [2014] a move cost of $34 per container handled is used, while in this model this is multiplied by two for loading and unloading. Port dues are $628 per port visited and in line with Wardana [2014].

Fright rate   In line with Wardana [2014] a freight rate of $215 is used per transported container.

Maximum transit time   After experimenting with the model with regard to amount of routes versus computation time and route distance versus improvement, a maximum distance of 4500 (16 days sailing) seems both practical for the model and a reasonable sailing time for a ship. This information is used during the route generation in order to filter out exceeding routes.

5.5   Technique

The model is built using Java as a programming language with the use of IBM CPLEX 12.6.0.0 solver and Java Combinatorics 2.1 Paukov [2000–2004] as external libraries. The CPLEX solver is used in the model and the Combinatorics is used to generate routes by permutation.
A Mac operating system is used and the hardware consists of a processor of 2.5 GHz Intel Core i5 and a memory of 4 GB (1600 MHz DDR3).

Chapter 6

Results

In this Chapter the results are presented. First, the results from the reference model are discussed in Section 6.1. Secondly, the results are discussed using route generation in Section 6.2. In this section, all the extensions are discussed in separate. A base model is used to compare each extension. There are three extensions, these are transhipment, Multiple Ships, and Speed Optimisation. The extensions are used separately, i.e. only 1 extension is enabled while others are disabled. Later, the extensions are combined together and this is called ALL setting.

In advance, the fleet used in the following sections is summarised in 6.1. Note, that the Id is used to describe what type of ship is used in the following sections. Further, ship type 4 (Panamax_1750) is used whenever only 1 ship type is used. Since this is the only ship type used in the Reference model by (Wardana [2014]).

Id	Vessel class	Capacity FFE	TC rate daily	Min Speed	Max Speed	Design Speed	Bunker ton/day at designSpeed	Idle Cons. ton/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 6.1: Fleet used

6.1 Reference model

In order to compare and verify the PFM model, the model from Wardana [2014] is used. Table 6.2 summarises the results. Column Reference shows the result as reported by Wardana [2014]. While Reference* is the result of the PFM using the same set of routes as in Reference. The last column, Reference*(ALL), contains the results using the same routes as in Reference except that all settings/extensions are enabled. This is summarised in Table 6.4.

	Reference	Reference*	Reference*(ALL)
# routes (input)	4	4	4
# paths	-	60	146
# routes (output)	4	5	4
# ships	11	13	10
Weekly profit ($)	7,745,073	5,066,915	5,671,141
Increase		100%	112%
Comp. time (sec)	-	0.184	0.808
Cargo (TEU)	2,765,672	2,778,828	2,894,632
Satisfied demand	0.95	0.95	0.99
Revenue ($)	594,619,480	597,448,020	622,345,880
Trans. cost ($)	0	0	68,952
Handling cost ($)	94,032,848	188,960,304	196,834,976
Ship charter ($)	36,263,480	71,175,000	72,270,000
Fuel cost ($)	60,762,936	72,853,444	57,456,224
Port dues ($)	816,400	979,680	816,400
Total costs ($)	191,875,664	333,968,428	327,446,552
Profit ($)	402,743,816	263,479,592	294,899,328

Table 6.2: Results from Reference model(Wardana [2014]), the results of PFM using the same routes, and the results of PFM using same routes and all extensions and settings.

The first row, number of routes, shows the input size of the different models. The number of paths are generated based on the input, which is discussed in Section 4.2.1. The number of ships displays the amount of ships required for the solution. Weekly profit is calculated based on the Profit, which is based on a yearly basis. Computation time gives the amount of time it took to solve the model, the hardware specification are discussed in Section 5.5. Cargo shows the total amount of containers in TEU that are transported.
Revenue is based on a freight rate of $215. transhipment cost is based on the amount transhipment multiplied by the handling cost of $34. Handling cost is calculated by multiplying amount of Cargo with twice the handling cost cost $(2 \cdot \$34)$. Ship charter, Fuel cost, and Port dues are calculated based on the functions (4.8),(4.9), and (4.10) respectively.

6.1.1 Difference between PFM and Reference model

Although the Reference* setting of the PFM was meant to mirror the Reference model, there are some differing interpretations with regard to cost calculations.The differences between the two models are summarised as:

- Transported cargo: Satisfied demand is larger in the Reference* solution than in the Reference solution

- Handling cost: In Reference a handling cost of $34 is calculated once while in PFM this value is calculated twice, once for loading and once for unloading.

- Fuel cost: In PFM idle consumption per day per port visit is also included in the Fuel cost, while this is neglected in Reference.

- Charter cost: In calculating the amount of ships required to satisfy weekly service, the total duration is calculated based on total travel time and port (stay) time. In the Reference model the port time is ignored, while in PFM the port time is set to 24 hours per visit.

6.1.2 Reference* solution

The following table summarises the solution to the PFM using the Reference* setting.

Route	y_{rs}	Distance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{1 2 3 4 3 2 1}	2	7,320	1,682,356	6	4	32,850,000	32,594,467	391,872	18
{ 2 3 4 5 4 3 2}	2	4,476	728,676	4	4	21,900,000	20,256,167	391,872	18
{ 2 3 5 6 4 3 2}	1	4,676	367,796	3	4	16,425,000	20,002,811	195,936	18
Total	5	16,472	2,778,828	13		71,175,000	72,853,444	979,680	

Table 6.3: Solution: Reference* (PFM with the use of routes from Wardana [2014])

In the above table, Route displays the route based on the route description as discussed in Section 4.2. y_{rs} is the variable in the model indicating the amount of times the route is used (operated) per week. rs indicates a route r and a ship type s. Distance gives the total nautical miles travelled by a ship on the route. Number of ships displays the amount of ships required on the route to maintain weekly visits. Ship type shows the chosen ship that operates on the route. The id's are given in Section 6.2.3. Id 4 is the Panamax_1750 which is the same type as in Wardana [2014]. The Ship Charter, Fuel cost, and Port dues show the cost in dollars for each route in separate. Finally, Speed shows the speed in knots per hour.

6.1.3 Reference*(ALL) solution

Using the same model from Reference* and enabling transhipment, Multiple Ships, and Speed Optimisation has the following solution:

Route	y_{rs}	Distance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1 2 3 4 5 3 2 1 }	1	4,205	1,211,132	3	5	22,995,000	13,155,683	228,592	12.51
{ 1 2 3 4 5 3 2 1 }	1	4,205	1,211,132	3	5	22,995,000	13,155,683	228,592	12.51
{ 2 3 4 5 4 3 2 }	1	2,238	503,672	2	5	15,330,000	11,788,774	195,936	16.00
{ 2 3 5 6 4 3 2 }	1	4,676	499,200	3	5	22,995,000	15,364,047	195,936	12.99
Total	4	14,779	2,896,660	10		72,270,000	57,456,224	816,400	

Table 6.4: Solution: PFM with the use of routes from Wardana [2014]) and enabling transhipment, Multiple Ships, and Speed Optimisation

Compared to the solution of Reference*, the solution of Reference*(ALL) has better results. By using larger ships (ship type 5) more cargo can be transported. Although the Ship

Charter is more, due to the larger ships, making use of transhipment and Speed Optimisation results in 1 less ship. Ship type 4 is sailing faster in order to preventing the need for an extra ship (due to weekly service rates), and 2 out of 3 ships (ship type 5) sail slower in order to reduce fuel cost. Overall, with all the settings and extensions the solution improves with 12%.

The exact path flows for route { 1 2 3 4 5 3 2 1 } are given in the following table.

i	r	o	d	x_{p_i}	c_{p_i}	p_i^o	p_i^d	index(p_i^o)	index(p_i^d)
1	{ 1 2 3 4 5 3 2 1 }	1	2	190372	-147	1	2	0	1
2	{ 1 2 3 4 5 3 2 1 }	1	3	55016	-147	1	3	0	2
3	{ 1 2 3 4 5 3 2 1 }	1	5	4212	-147	1	5	0	4
4	{ 1 2 3 4 5 3 2 1 }	2	1	186316	-147	2	1	6	7
5	{ 1 2 3 4 5 3 2 1 }	2	3	99632	-147	2	3	1	2
6	{ 1 2 3 4 5 3 2 1 }	2	5	33072	-147	2	5	1	4
7	{ 1 2 3 4 5 3 2 1 }	3	1	53872	-147	3	1	5	7
8	{ 1 2 3 4 5 3 2 1 }	3	2	126724	-147	3	2	5	6
9	{ 1 2 3 4 5 3 2 1 }	3	4	19864	-147	3	4	2	3
10	{ 1 2 3 4 5 3 2 1 }	3	5	192452	-147	3	5	2	4
11	{ 1 2 3 4 5 3 2 1 }	4	1	4680	-147	4	1	3	7
12	{ 1 2 3 4 5 3 2 1 }	5	1	4732	-147	5	1	4	7
13	{ 1 2 3 4 5 3 2 1 }	5	2	26520	-147	5	2	4	6
14	{ 1 2 3 4 5 3 2 1 }	5	3	213668	-147	5	3	4	5

Table 6.5: Solution paths under Reference*(ALL) for route { 1 2 3 4 5 3 2 1 }.

Each row indicates a path and its characteristics are given in the columns. r denotes the route the path p_i belongs to. Note that, only the paths belonging to route { 1 2 3 4 5 3 2 1 } are given in this table. Each path has an origin p_i^o and a destination p_i^d, which must match a demand origin o and a demand destination d. x_{p_i} denotes the amount of cargo transported on path p_i, which is used in the model as one variable. The cost belonging to the path p_i is given by c_{p_i}.

Further, the indices of the origin and destination of paths with regard to route r are given. This is used in order to identify which paths are using the same leg. For example, for leg 1-2 the first three paths, p_1, p_2, and p_3 with the respective o-d's 1-2, 1-3, and 1-5, have a total cargo of 249,600 TEU. This is equal to the yearly capacity of ship type 5 (Panamax_2400). This means that the ship travelling from port 1 to 2, has a load/capacity ratio of 1. While for leg 2-3, which are used by paths: p_5, p_2, p_3, and p_6, a total of 191,932 TEU is transported. This results in a load ratio of 0.77.

6.2 Route generation

Here, the results from the model with the use of different settings are discussed. In all of the settings same set of generated routes are used (a total of 72 routes). Routes are generated as discussed in Section 4.2 and are filtered based on a maximum distance of 4500 nautical miles. In the following subsection the solution of each setting is discussed separately.

BASE setting indicates the basic model without any modification to the PFM model. Under transhipment the base model is modified to enable transhipment between routes. Multiple ships is the first extension and opt. is the second extension as discussed in Sections 4.1.2 and 4.1.3, respectively. Finally, the model is used using all settings together (ALL). The following table contains a summary of the different results.

	BASE	transhipment	Multiple ships	Speed opt	ALL
# routes (input)	72	72	360	72	360
# paths	500	16,976	500	500	16,976
# routes (output)	8	7	7	8	7
# ships	10	8	9	10	9
Weekly profit ($)	5,757,357	5,799,822	5,783,703	6,124,640	6,304,356
Increase	100%	101%	100%	106%	110%
Comp. time (sec)	1.264	83.987	5.512	0.958	7.267
Cargo (TEU)	2,904,980	2,764,372	2,890,363	2,904,980	2,917,408
Satisfied demand	0.99	0.95	0.99	0.99	1.00
Revenue ($)	624,570,700	594,339,980	621,429,120	624,570,700	627,242,720
Trans. cost ($)	-	2,781,064	-	-	3,334,448
Handling cost ($)	197,538,640	187,977,296	196,545,024	197,538,640	198,383,744
Ship charter ($)	54,750,000	43,800,000	58,035,000	54,750,000	53,655,000
Fuel cost ($)	72,213,736	57,570,392	65,508,719	53,082,375	43,422,556
Port dues ($)	685,776	620,464	587,808	718,432	620,464
Total costs ($)	325,188,152	292,749,216	320,676,551	306,089,447	299,416,212
Profit ($)	299,382,548	301,590,764	300,752,569	318,481,253	327,826,508

Table 6.6: Results under different settings

As it can be observed from the above table, each setting/extension results in a better result. However, the speed optimisation extension is by far the best extension contributing to improve the model. Although it uses more routes and more ships it manages to have more profit by increasing the cargo shipped and reducing its total fuel cost.
Enabling transhipment does not improve the BASE solution much, in the solution less ships are used in and less cargo is transported in order to reduce costs.
Further, note that the computation time in the transhipment setting is much more than the ALL setting even though there are the same amount of variables. We expected to have a larger computation time, however CPLEX managed to solve it quicker.
Multiple ship extension does not improve much, this could be due to the fact that the demand is already largely satisfied in the BASE solution. The amount of cargo transported is less, however the costs are less with regard to fuel costs and port dues.
It is noteworthy that when using all settings/extensions together (ALL) the increase (10%) in profit is better than the sum of the three individual improvements.
In the following sections, the solution of each setting/extension is discussed in separate.

6.2.1 BASE solution

This is the basic setting in which the model is kept as simple as possible. That is no extensions or extra settings are enabled and is meant to be a base result to compare the other settings and extensions.

The following table displays the characteristics of the BASE solution.

Route	y_{rs}	Dis-tance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	2	4,256	667,160	2	4	10,950,000	17,488,178	130,624	18
{ 2, 4, 3, 2 }	1	1,380	396,240	1	4	5,475,000	6,015,967	97,968	18
{ 1, 2, 3, 4, 1 }	1	3,260	429,208	2	4	10,950,000	13,855,544	130,624	18
{ 2, 5, 2 }	1	1,612	327,496	1	4	5,475,000	6,862,122	65,312	18
{ 3, 5, 3 }	1	1,040	364,000	1	4	5,475,000	4,775,911	65,312	18
{ 3, 5, 4, 3 }	1	1,201	367,120	1	4	5,475,000	5,363,114	97,968	18
{ 2, 6, 3, 2 }	1	4,356	353,756	2	4	10,950,000	17,852,900	97,968	18
Total	8	17,105	2,904,980	10		54,750,000	72,213,736	685,776	

Table 6.7: Solution: Base model

In comparison to the Reference* solution (Table 6.4) the routes selected have less ships and less travel distance. This enables to reduce fuel and ship charter costs while increasing the amount of cargo transported. Overall the BASE solution compared to Reference*, increased the profit by 13%.

6.2.2 Transhipment solution

As described in Section 4.2.2 the model is set to allow transhipment. This does not change the PFM, however the amount of variables increase vastly. This explains the extreme increase in the computation time. The solution of this setting is summarised in the following table.

Route	y_{rs}	Cargo (TEU)	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	2	4,256	728000	2	4	10,950,000	17,488,178	130,624	18
{ 2, 3, 4, 2 }	1	1,380	479,596	1	4	5,475,000	6,015,966	97,968	18
{ 2, 4, 3, 2 }	1	1,380	538,876	1	4	5,475,000	6,015,966	97,968	18
{ 1, 2, 4, 3, 1 }	1	3,494	417,456	2	4	10,950,000	14,708,994	130,624	18
{ 2, 5, 2 }	1	1,612	364,000	1	4	5,475,000	6,862,122	65,312	18
{ 3, 5, 4, 3 }	1	1,201	371,020	1	4	5,475,000	5,363,114	97,968	18
{ 3, 4, 6, 5, 3 }	1	3,800	364,676	2	4	10,950,000	15,825,044	130,624	18
Total	7	13,629	2,846,168	8		43,800,000	57,570,392	620,464	

Table 6.8: Solution: Transhipment

Compared to the BASE solution (Table 6.7) this solutions requires 1 less route and 1 less ship. Less cargo is transported in order to reduce costs with regard to using ships. This is possible due to the ability to transport cargo through transhipment, which compensates for the smaller fleet size. Note that the total cargo transported in Table 6.8 is higher than in Table 6.6, due to double counting. In Table 6.8 shows the cargo transported per route

independently of other routes.
The following table describes the transhipments between the routes.

i	r_1	r_2	o	d	x_{p_i}	c_{p_i}	$p_{i_1}^o$ in r_1	$p_{i_1}^d$ in r_1	$p_{i_2}^o$ in r_2	$p_{i_2}^o$ in r_2
1	{ 1, 2, 1 }	{ 2, 3, 4, 2 }	1	3	15,964	-113	1	2	2	3
2	{ 2, 5, 2 }	{ 3, 5, 4, 3 }	2	4	17,680	-113	2	5	5	4
3	{ 2, 4, 3, 2 }	{ 1, 2, 1 }	3	1	13,520	-113	3	2	2	1
1	{ 2, 4, 3, 2 }	{ 2, 5, 2 }	3	5	18,824	-113	3	2	2	5
2	{ 3, 4, 6, 5, 3 }	{ 2, 4, 3, 2 }	6	2	15,808	-113	6	3	3	2

Table 6.9: Solution paths under the setting Transhipment

The table only shows the transshipment paths (i.e. paths with two jump legs) that are in the optimal solution. While, the model also contains normal paths which only have one leg in it. In the model each transhipment path is treated as a normal path, meaning it is represented by only one variable x_p with its own cost c_p. Each path p_i, in the table, consists of two jump legs: p_{i_1} and p_{i_2}. Further, each leg contains an origin and a destination belonging to a route. Note, that the routes of legs in a transhipment path cannot be on the same route. And, that some properties are left out of the table, such as origin and destination of paths, i.e. respectively p_o and p_d, which are the same as o and d.
In comparison to normal paths, as in Table 6.5, the cost are less negative. This is due to an extra handling cost of \$34.

6.2.3 Extension 1: Multiple ships solution

The model is extended as described in Section 4.1.2 in which there are 5 ship types. All of the ships described in Table 6.1 are used. The solutions are described in the following table.

Route	y_{rs}	Dis- tance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	1	2,128	364,000	1	4	5,475,000	8,744,089	65,312	18
{ 3, 4, 3 }	1	656	306,696	1	4	5,475,000	3,375,378	65,312	18
{ 2, 4, 3, 2 }	1	1,380	545,428	1	5	7,665,000	6,999,233	97,968	16
{ 1, 2, 3, 4, 1 }	1	3,260	519,480	2	5	15,330,000	16,115,028	130,624	16
{ 2, 5, 2 }	1	1,612	327,496	1	4	5,475,000	6,862,122	65,312	18
{ 3, 5, 3 }	1	1,040	463,268	1	5	7,665,000	5,559,970	65,312	16
{ 2, 3, 6, 2 }	1	4,356	364,000	2	4	10,950,000	17,852,900	97,968	18
Total	7	14,432	2,890,368	9		58,035,000	65,508,719	587,808	

Table 6.10: Solution: Multiple ships

Compared to the BASE solution the routes that entered the solution are: E1:{ 3, 4, 3 } and E2:{ 2, 3, 6, 2 }, while routes that left the solution are: L1:{ 3, 5, 4, 3 } and L2:{ 2, 6, 3, 2 }. It appears that E1 is switched with L1 and E2 with L2. Since more cargo can be transported, by using a larger ship (5), on E2 instead of L2, visit to port 2 in L1 becomes unnecessary.

6.2.4   Extension 2: Speed optimisation solution

The model is extended as discussed in Section 4.1.3. The impact of this extension is larger, since the evaluation of routes become different. That is, routes that were too expensive to operate become more profitable.

Route	y_{rs}	Dis-tance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	2	4,256	689,676	2	4	10,950,000	16,970,176	130,624	17.73
{ 2, 4, 3, 2 }	1	1,380	380,224	1	4	5,475,000	3,917,296	97,968	14.38
{ 1, 2, 3, 4, 1 }	1	3,260	421,356	2	4	10,950,000	7,935,867	130,624	13.58
{ 2, 5, 2 }	1	1,612	327,496	1	4	5,475,000	3,847,127	65,312	13.43
{ 3, 4, 5, 3 }	1	1,201	364,676	1	4	5,475,000	2,725,691	97,968	12.51
{ 3, 5, 4, 3 }	1	1,201	367,796	1	4	5,475,000	2,725,691	97,968	12.51
{ 2, 6, 3, 2 }	1	4,356	359,456	2	4	10,950,000	14,960,526	97,968	16.50
Total	8	17,266	2,904,980	10		54,750,000	53,082,375	718,432	

Table 6.11: Solution: Speed optimisation

From the BASE solution only three routes are left in the solution, namely { 1, 2, 1 }, {2, 4, 3, 1 }, and { 2, 5, 2 }. These routes have lower cost in this extension than in the BASE solution, due to more optimal use ships speed. The reason for this considerable change in the selection of routes is due to the fact that routes have become less expensive. Further, all the ships sail slower in order to reduce the fuel cost, this compensates for the extra ships. In total there is an extra route and an extra ship available.

6.2.5   All settings combined solution

In ALL, the previously mentioned settings and extensions are enabled. That is, transhipment is allowed, the allocation of ships to routes can be chosen from multiple ships, and speed optimisation is enabled to drive slower or faster in order to reduce costs. The resulting solution is shown in the following table.

Route	y_{rs}	Dis-tance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	1	2,128	496,600	1	5	7,665,000	12,521,954	65,312	17.73
{ 2, 3, 4, 2 }	1	1,380	479,804	1	4	5,475,000	3,917,296	97,968	14.38
{ 2, 4, 3, 2 }	1	1,380	490,100	1	4	5,475,000	3,917,296	97,968	14.38
{ 1, 2, 3, 4, 1 }	1	3,260	368,888	2	4	11,000,000	7,935,867	130,624	13.58
{ 2, 5, 2 }	1	1,612	358,852	1	4	5,475,000	3,847,127	65,312	13.43
{ 3, 5, 4, 3 }	1	1,201	533,208	1	5	7,665,000	3,920,459	97,968	12.51
{ 3, 6, 3 }	1	3,632	288,028	2	4	11,000,000	7,362,558	65,312	12.61
Total	7	14,593	3,015,480	9		53,755,000	43,422,556	620,464	

Table 6.12: Solution: Using Transhipment, Multiple ships and Speed optimisation

Since, Speed optimisation solution has the best profit, the ALL solution is compared to this. The differences are caused by transhipment possibilities and changing ships. Based on

the Speed optimisation solution only three routes have left the solution, namely: { 1, 5, 2, 1 }, { 3, 4, 5, 3 }, and { 2, 3, 6, 2 }. While, only { 2, 3, 4, 2 } and { 3, 6, 3 } entered the solution. In total, ALL solution requires 1 route and 2 ships less to satisfy more demand than Speed optimisation solution, namely all of the demand.

6.2.6 Custom input

Based on results from research by Wardana [2014] and Meijer [2015] on the same problem, two routes have been selected in order to add to the standard set of generated routes. These are the routes:

1. { 1, 2, 3, 4, 3, 2, 1 } Wardana [2014]

2. { 1, 2, 3, 4, 2, 1 } Meijer [2015]

Due the way routes are generated, i.e. ports are not allowed to be visited more than once in a route except for the starting port, these types are routes are not present in the generated routes set. The reason for this is that the enumeration of routes with multiple visits become too much to solve.
The following table summarises the results between the setting with all settings on (ALL) and the same setting with the above two routes added.

	ALL	Custom
# routes (input)	360	370
# paths	16,976	18,528
# routes (output)	7	6
# ships	9	8
Weekly profit ($)	6,304,356	6,325,460
	112%	113%
Comp. time (sec)	7.267	53.102
Cargo (TEU)	2,917,408	2,917,408
Satisfied demand	1.00	1.00
Revenue ($)	627,242,720	627,242,720
Trans. cost ($)	3,334,448	3,794,128
Handling cost ($)	198,383,744	198,383,744
Ship Charter ($)	53,655,000	50,370,000
Fuel cost ($)	43,422,556	45,215,795
Port dues ($)	620,464	555,152
Total costs ($)	299,416,212	298,318,819
Profit ($)	327,826,508	328,923,901

Table 6.13: Results between ALL and Custom setting

The above table shows that the two settings have similar results. However, the custom solution requires 1 route and 1 ships less in order to achieve the same amount of transportation. Also, the custom solution makes more (better) use of transhipment. Due to the lower

amount of ships in the custom solution, the ships travel more. Therefore the fuel cost are higher at Custom. However, due to having one less ship in custom solution, the ship charter costs and port dues compensate for more travelling. This results in a higher profit.

The solution of the custom setting is described in the following table.

Route	y_{rs}	Dis-tance	Cargo (TEU)	# of ships	Ship type	Ship charter	Fuel cost	Port dues	Sp.
{ 1, 2, 1 }	1	2,128	329,784	1	4	5,475,000	8,485,088	65,312	17.73
{ 2, 4, 3, 2 }	1	1,380	501,696	1	4	5,475,000	3,917,296	97,968	14.38
{ 2, 5, 2 }	1	1,612	360,776	1	4	5,475,000	3,847,127	65,312	13.43
{ 3, 5, 4, 3 }	1	1,201	535,132	1	5	7,665,000	3,920,459	97,968	12.51
{ 3, 6, 3 }	1	3,632	288,028	2	4	11,000,000	7,362,558	65,312	12.61
{ 1, 2, 3, 4, 2, 1 }	1	3,508	1,013,584	2	5	15,300,000	17,683,267	163,280	16.24
Total	6	13461	3,029,000	8		50,390,000	45,215,795	555,152	

Table 6.14: Solution: Using ALL settings and two custom routes

In comparison to the solution of ALL setting (Table 6.12), routes { 2, 3, 4, 2 } and { 1, 2, 3, 4, 1 } have been replaced by the new introduced custom route { 1, 2, 3, 4, 2, 1 }. A bigger ship is used on the custom route and the amount of cargo transported on the custom route is more than the two replaced routes combined. Also, note that the first introduced custom route has not been used. Therefore, there is not enough evidence to conclude that these types of routes (multiple visits) always have better results.

6.3   Conclusion

A reference model is obtained from Wardana [2014] and a Reference* setting is created, which is the PFM model based on the same parameters, however with different (more stringent) cost calculations. This model, due to difference in cost calculation, performed worse as expected. However, using the same cost calculation as in Reference, Reference* performs better.

Then a BASE solution is solved, based on a set of 72 routes, which are generated by enumerating through six ports and filtering based on a maximum distance of 4500 mi.

This model is then extended with enabling transhipment. This did not improve BASE solution as much as expected, however this is due to having little room for improvement. Since the BASE solution already satisfied considerable amount of demand.

Multiple ship extension improved the BASE solution only slightly. The improvement is due to being able to transport more on a larger ship.

Speed optimisation improved the BASE solution the most, and also has a more different solution then Transhipment setting and Multiple ship extension. The reason for this is due to change in route costs. Routes that were too expensive have become less expensive.

In the ALL solution, all settings and extensions are enabled. As expected, the combination of the different extension improved the solution.

Finally, in Section 6.2.6, based on the contextual situation, two custom routes are added to the set of routes. This resulted in choosing one of the two added routes in the optimal solution, improving the total profit.

Chapter 7

Conclusion

The thesis is conducted to improve the liner-shipping network in Indonesia. The goal was to determine the best liner shipping network for Indonesian ports using a mathematical model. In order to obtain this, first an appropriate model is found through a literature review. The model used in this thesis is the Path Formulation Model (PFM) based on Mulder [2015] (Section 4.1.1). This model is then extended such that it is able to choose which ship to use on a route (Section 4.1.2) from a set of ships and altering the speed in order to reduce costs associated with a route. The last extension meant sailing slower in order to reduce fuel cost or sailing faster in order to meet weekly service times.

Next to finding a mathematical model, a method has been implemented to generate routes, which serve as input for the PFM. The routes were generated based on six hub ports. The six ports were enumerated through all possibilities, and then filtered based on similarity and distance.

Next, in Chapter 5 the context of Indonesian ports have been investigated and the model is adapted to fit the situation. That means, creating hub-ports to decrease the amount of ports and aggregating demand. Further simplifications/assumptions were made with regard to ship size, costs, and fleets due to inconsistency in data.

In Chapter 6 the results have been discussed. This includes results from the reference solution as well as the different settings and extensions. The Reference solution had some less stringent cost calculations, which were different from the PFM model. This caused discrepancy between the PFM and Reference solution. However, the Reference model did help to verify the PFM model.

The results from the different settings were compared to a BASE solution. Each extension/setting improved the BASE solution. Namely, enabling transhipment in the model improved the profit with 1%, extending the model to choose from multiple ships did not improve much, and extending the model with speed optimisation improved it by 6%. In the ALL setting, with all the three settings/extensions enabled, resulted in an improvement of 12% with regard to the BASE solution and 24% with regard to the Reference* solution. This resulted in a weekly profit of $ 6,304,356 using the following routes: { Belawan, T. Priok, Belawan }, { T. Priok, T. Perak, Banjarmasin, T. Priok }, { T. Priok, Banjarmasin, T. Perak, T. Priok

}, { Belawan, T. Priok, T. Perak, Banjarmasin, Belawan }, { T. Priok, Makassar, T. Priok }, { T. Perak, Makassar, Banjarmasin, T. Perak }, and { T. Perak, Sorong, T. Perak }.

Chapter 8

Discussion

Although the model has reasonable performance, both in speed and in the optimal solution, there are still some limitations to the model. In the Section 6.2.6 custom routes are added which are of a different type of than the generated routes in this thesis. Namely, the generated routes have single port visit, while the custom route is a pendulum route with multiple visits to the same route. One of the two custom routes is also selected in the optimal solution. Therefore, pendulum routes might have a better solution. However, enumeration of pendulum routes results in too many routes to solve.

Further, due to incompleteness of data many simplifications were made about the data. Therefore, a more realistic solution could be obtained once the data becomes more complete. For instance the cost for all paths are assumed the same. This could be differentiated based on distance. Further, a differentiation could be made based on ports. Namely, all ports are assumed to have same port dues and handling cost. The computation time is not expected to increase much due to these kind of changes.

Although in the ALL solution all of the demand was satisfied, this does not necessarily have to be the case. Due profit maximisation some ports could be ignored due to high costs. In order to improve overall profitability and economic growth of the region, the balance can be altered using government funding and sanctioning. This could be accomplished in the model by increasing or lowering the lost sales cost ($\hat{c}_{od}$) assigned to unsatisfied demand (L_{od}).

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Chapter 9

Appendix

	BLW	PKB	BTM	O	TPR	TPE	TEM	O	PTK	BJM	O	MKS	BTG	O	AMB	SRG	O	Total
BLW					4135	1030				23		57						5245
PKB					738													738
BTM					661	28				64		24				27		804
O					1159													1159
TPR	4263	681	774	1022		1275		641	1221	1690	1181	2487	243	6	67	353	44	15948
TPE	989		47		1532				5	1599	2191	1773	1146	1901	472	292	1410	13357
TEM																		0
O					905													905
PTK					1330	7				59		34	28					1458
BJM	16		74		1218	1599			21				13					2941
O					1089	1892												2981
MKS	57		34		2638	1279			37				195					4240
BTG					859	929			23	13		155						1979
O					4	1901												1905
AMB					67	462												529
SRG			39		255	281												575
O					339	1431												1770
Total	5325	681	968	1022	16929	12114	0	641	1307	3448	3372	4530	1625	1907	539	672	1454	

Table 9.1: Demand data in TEU (Wardana [2014]) Sumatra: Belawan BLW, Pekanbaru PKB, Batam BTM, Others O Java:Tanjung Priok TPR,Tanjung Perak TPE, Tanjung Emas TEM, O Kalimantan: Pontianak PTK, Banjarmasin BJM, O Sulawesi: Makassar MKS, Bitung BTG, O Rest of Indonesia: Ambon AMB, Sorong SRG, O

Table 9.2:

	BLW	PKB	BTM	O	TPR	TPE	TEM	O	PTK	BJM	O	MKS	BTG	O	AMB	SRG	O
BLW		453	518	486	1064	1488	1271	1274	874	1430	1152	1708	2347	2028	2879	2807	2843
PKB	453		132	293	712	1137	920	923	523	1079	801	1356	1995	1676	2528	2455	2492
BTM	518	132		325	591	1016	799	802	392	958	675	1235	1874	1555	2399	2327	2363
O	486	293	325		789	1214	997	1000	596	1156	876	1433	2072	1753	2602	2530	2566
TPR	1064	712	591	789		438	210	324	491	614	553	806	1517	1162	2068	2102	2085
TPE	1488	1137	1016	1214	438		284	154	654	328	491	520	1231	876	1782	1816	1799
TEM	1271	920	799	997	210	284		165	461	479	470	671	1382	1027	1933	1967	1950
O	1274	923	802	1000	324	154	165		535	474	505	666	1377	1021	1928	1962	1945
PTK	874	523	392	596	491	654	461	535		593	473	873	1512	1193	2063	2077	2070
BJM	1430	1079	958	1156	614	328	479	474	593		473	353	992	673	1543	1577	1560
O	1152	801	675	876	553	491	470	505	473	473		613	1252	933	1803	1827	1815
MKS	1708	1356	1235	1433	806	520	671	666	873	353	613		790	610	1341	1375	1358
BTG	2347	1995	1874	2072	1517	1231	1382	1377	1512	992	1252	790		545	551	585	568
O	2028	1676	1555	1753	1162	876	1027	1021	1193	673	933	610	545		946	980	963
AMB	2879	2528	2399	2602	2068	1782	1933	1928	2063	1543	1803	1341	551	946		494	454
SRG	2807	2455	2327	2530	2102	1816	1967	1962	2077	1577	1827	1375	585	980	494		402
O	2843	2492	2363	2566	2085	1799	1950	1945	2070	1560	1815	1358	568	963	454	402	

Table 9.2: Distance data in miles (Wardana [2014])

UNLocode	name	Country	Cabotage_Region	D_Region	Longitude	Latitude	Draft	CostPerFULL	CostPerFULLTrnsf	PortCallCost
IDJKT	Jakarta	Indonesia	Indonesia	Singapore	106.8	-61.667	8	135.00	62.00	2999.00
IDSRG	Semarang	Indonesia	Indonesia	Singapore	110.423.953	-6.974.997	9.5	134.00	81.00	2926.00
IDSUB	Surabaya	Indonesia	Indonesia	Singapore	112.75	-7.25	9.5	185.00	3.00	884.00

Table 9.3: Relevant Port data LINERLIB