Erasmus University Rotterdam

Bachelor Thesis

Quantitative Logistics

Creating a Liner Shipping Network Design

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Contents

1 Introduction

In the shipping service sector one can distinguish between two main types of shipping: line – and tramp shipping. Line shipping is the type of cargo shipping which is most often used by shipping companies in the container sector. Other than in tramp shipping, vessels are sailing according to fixed routes and time-schedules. In tramp shipping, ships go to ports depending on cargo availability and demand. Tramp ships most often carry bulk cargo or liquids. In this thesis I will limit the scope to line shipping only.

More precisely, the aim of this thesis is to construct a shipping network for intra Indonesian container traffic. Currently, there is unbalance in trade between the more developed western region around the island Java, with the less developed eastern part of Indonesia. Java is connected to Europa via Singapore and therefore takes more economical benefit in comparison with the eastern part. As a result of this unbalance, the prices of goods in the eastern part are much higher and there is only little demand between the two regions. Therefore, the Indonesian government aims to develop an east-west shipping network in the container sector in order to re-establish the balance.

The decision making process for setting up a liner shipping service network consists of three different time-horizon levels. The strategic level has the longest horizon and it involves determining the optimal fleet. To do so, one has to decide the different types of ships to use. Ships may differ in capacity, sailing speed, (un)loading time, fuel consumption and fixed costs. Since vessels are often utilized for several years or even decades, in general, one cannot simply completely change the fleet on short term. Hence, the fleet composition will often remain more or less unchanged for a large time period.

The tactical planning level is done once in the several months and it involves constructing a set of routes which has to be sailed. Furthermore, a ship schedule has to be made, which also includes the optimal sailing speed of each ship.

The shortest term decision level is the operational level. In liner shipping, the cargo routing problem is the main problem to focus on. In this problem, the optimal allocation of cargo (in our case, containers) to routes has to be found. Since multiple transhipment ports can be used to ship cargo from port A to port B, this can rapidly become a complex problem.

When not all demand has to be fulfilled, i.e., the objective is to gain optimal profit, one also has to determine which orders to accept and which to reject.

2 Research Purpose

The purpose of this thesis is to provide a method, applicable to different datasets, that determines the best solution for all three decision making levels, such that profit is maximized. I will use my found method to construct a shipping service network for intra Indonesian container traffic. That intention is, that the method can be used to find a (near-)optimal solution within an acceptable computation time.

3 Literature Study

The research on maritime transportation has increased significantly the last two or three decades. The focus of this research lies on different aspects of creating a network design. In the paper of Ronen [1983] a comparison is made with a network design of road trucks. The main difference between the two is that more or less every truck has the same capacity, whereas nearly every ship has a totally different capacity. Furthermore, not every port is capable of handling every type of ship, since ships may have drafts too large for the ports. Often, comparisons with the aircraft network design are being made and they seem to have more resemblances. However, aircrafts mainly transport passengers, which have other preferences [Fagerholt et al., 2004]. Thus, the network design for maritime transportation requires its own method for finding a solution.

A lot of research already has been done on designing the optimal composition of the fleet. In his literature study, Fagerholt et al. [2004] refers to multiple papers in which the optimal fleet is to be determined. He refers to the early work of Dantzig and Fulkerson [1954] in which the number of tankers needed is minimized. This problem is called the fleet sizing problem. Other studies worth noting are presented by Cho and Perakis [1996] in which both the optimal fleet and liner routes are generated. The problem is modelled as an LP-model, each column representing a feasible route. In his paper, he also refers to his own earlier work, Fagerholt

[1999]. A shipping schedule is created for the Norwegian coast and it is based on the Set Partitioning formulation (SP). This method is further extended in Fagerholt and Christansen [2000a] in which also different sailing speeds can be included.

Limited research is done on the containership routing problem. In the paper of Shintani et al. [2007] a method is presented for constructing a service network. It is formulated as a two-stage problem. A genetic algorithm-based heuristic is used, which is later checked with numerical experiments. Unlike most other papers, the repositioning of empty containers is also considered.

Rana and Vickson [1988] also discuss optimal routing for a fleet of containerships. The fleet is assumed to be already existing and therefore it is not optimized. The profit is maximized and therefore for each port it is decided whether to visit it or not. The problem is formulated as a mixed integer non-linear programing model and solved by making use of Langrangian relaxation.

In the paper of Mulder and Dekker [2013] all three levels of decision making are of interest. In this approach, they start off with the available fleet instead of creating an optimal fleet from scratch. First, routes are generated at random. Then, the generated routes are checked for feasibility, by checking certain conditions. A ship is allocated to the feasible routes, at random. The constructed network is then used as input for the cargo routing model, which is formulated as a multi-commodity flow problem, an LP-problem. They make use of a generic algorithm in order to improve the network.

4 Data

This section summarizes all necessary data. The demand between all port combinations are required. Furthermore, information about the available vessels is needed. In order to calculate fuel costs and the duration of every route, the distances between all ports are given in Section 4.2. The main source of data used in this is the Indonesia Port Corporation I-IV via MSc thesis Wardana [2014].

4.1 Ports

The dataset of Indonesia Port Corporation I-IV contains information on 14 ports located on different islands in Indonesia:

- Belawan
- Panjang
- Palembang
- Tanjung Priok
- Tanjung Emas
- Tanjung Perak
- Pontianak
- Samarinda
- Palaran
- Banjarmasin
- Makasar
- Sorong
- Ambon
- Jayapura

Since making use of 14 ports already results in an enormous number of possible routes, aggregation of ports is required. Aggregation of ports can be based on throughput and geographical position. Wardana [2014] has already done aggregation on the 14 ports, based on those two criteria, which resulted in six hub-ports, island or region in brackets:

1. Belawan (Sumatera)
2. Tanjung Priok (Java)
3. Tanjung Perak (Java)
4. Banjarmasin (Kalimantan)
5. Makasar (Sulawesi)
6. Sorong (New Guinea)

For convenience, for the remainder of the text, I will refer to the ports as numbers as presented above.

4.2 Distances

The distances in nautical miles are presented in Table 1. This data is obtained from www.SeaRates.com [2015].

Distance	Belawan	Priok	Perak	Banjar-Masin	Makasar	Sorong
Belawan	-	1,064	1,488	1,430	1,708	2,807
Tanjung Priok	1,064	-	438	614	806	2,102
Tanjung Perak	1,488	438	-	328	520	1,816
Banjar-masin	1,430	614	328	-	353	1,577
Makassar	1,708	806	520	353	-	1,375
Sorong	2,807	2,102	1,816	1,577	1,375	0

Table 1: Distances between ports in Nautical Miles

4.3 Demand

For all combinations of ports, the demand is given by Wardana [2014]. The weekly demand is given in TEU, which stands for twenty-foot equivalent unit, the capacity of one 20-foot container.

Demand	Belawan	Priok	Perak	BanjarM.	Makasar	Sorong	Supply
Belawan	0	6,693	1,058	87	81	27	7,946
Tanjung Priok	6,740	0	1,916	4,092	2,798	464	16,010
Tanjung Perak	1,036	2,437	0	3,795	4,820	2,174	14,262
Banjar-masin	90	3,637	3,498	0	13	0	7,238
Makassar	91	3,501	4,109	73	0	0	7,774
Sorong	39	661	2,174	0	0	0	2,874
Demand	7,996	16,929	12,755	8,047	7,712	2,665	56,104

Table 2: OriginDestination Matrix in TEU

4.4 Costs and Revenue

In this thesis, I assume that the revenue for shipping one TEU from one port to another is fixed and equals $215 for all TEU [Wardana, 2014]. Hence, we do not distinguish between different types of cargo. The costs for loading or unloading one TEU are $34, so the costs are $68 for direct shipping and an additional $34 for every transhipment. Furthermore, the port fees are equal to $628 per port visit [Kalem, 2015].

4.5 Ship types

All required information for the five available ship types are listed in Table 3 below. For convenience, in this thesis I assume that every port is capable of handling every type of ship, i.e., we do not take the maximum ship draft for a given port into account, which is also assumed in Kalem [2015].

Vessel:	Capacity [TEU]:	Design Speed [kn]	Min. Speed [kn]	Max. Speed [kn]	Idle Costs Per day [$]	Fixed Costs daily [$]	Fuel costs [$]/nmi
Feeder 450	900	12	10	14	1440	5000	39.17
Feeder _800	1600	14	10	17	1500	8000	42.32
Panamax_1200	2400	18	12	19	2400	11000	72.92
Panamax_1750	3500	18	12	20	2700	15000	76.39
Panamax_2400	4800	16	12	22	3180	21000	89.69

Table 3: Available shiptypes and their specifications

These ships are based on the data of Maersk and on Wardana [2014]. The idle consumption is the fuel a ship uses when waiting in a port, i.e., both when a ship is (un)loading and when it is waiting for its next trip. It is based on the fuel consumption per 24 hours given by Wardana [2014] and a fuelprice of $600 per ton. No exact data on the daily fixed costs of the Panamax_1750 was given. Therefore, the assumption is made that this lies in between those from the Panamax_1200 and Panamax_2400 and is set on $15000 per day.

5 Methodology

5.1 Decision-making Levels

On the strategic level, the composition of the fleet has to be determined, the so-called fleet-design problem. In this paper, I start off with an empty fleet, i.e, there is no existing fleet and it can be composed from any combination of shiptypes presented in Section 4.5.

Constructing the network design is the main problem on the tactical planning level. It consists of two problems; the construction of the shipping routes and the assignment of the different types of ships to the routes. For the construction of routes, several types of routing are possible. One can make use of a feeder network, port-to-port routes and butterfly routes.

In a feeder network, vessels are used to ship cargo from and to smaller ports to a so-called hub port. The hub-port collects cargo from different smaller ports. The cargo is then loaded onto vessels capable of carrying a larger number of TEU's. These larger ships can be economical more efficient than smaller vessels when they are sailing for larger distances. Within the feeder network there is no transshipment of cargo. The decision on which ports should be seen as hub ports can be based on a combination of mutual distances to other ports and throughput. A hub port should be located relatively centrally compared to other ports.

In the case of intra Indonesian shipping, it might be a good decision to select as hub ports the ports with the largest throughput, which are Tanjung Priok and Tanjung Perak.

On a port-to-port route, every port is visited exactly once. The route is cyclical, so the begin port is the same as the end port of the route. The major drawback of this system is that cargo sometimes has to go a nearly full-cycle when it has a destination that was visited just before the origin port. Butterfly routes are also cyclical, but the difference is that subcycles are now possible, i.e., ports can be visited multiple times in one cycle.

The main problem on the operational planning level is the assignment of cargo to the ships sailing the determined routes. This problem is called the cargo-routing problem and can be formulated as an LP-model. In Mulder and Dekker [2013] a formulation is already provided for this problem, which requires the routing network and port demand as input.

5.2 Combined Problem

Clearly, those sub-problems are all strongly related to each other. For instance, the selection of routes to be sailed depends on the ship type chosen in the fleet-design problem and vice versa. Whereas the cargo allocation of course depends on the routes to be sailed. Since all three sub-problems relate closely to each other, solving all of them simultaneously is of great importance, i.e., all decisions on the different planning levels have to be taken at the same time [Mulder and Dekker, 2013].

The above-mentioned formulation of the cargo-routing problem presented by Mulder and Dekker [2013] can be used as a foundation for the combined problem. By rewriting the objective funtion and some of the constraints the model changes to a MIP-problem and can be used to determine the optimal fleet, routes and cargo-allocation.

The objective function changes, such that the fixed costs are included. f_s are the weekly fixed costs of using route s. Furthermore, the total fuel costs also have to be substacted and are calculated with the relationship given in Section 5.3 and Table 1.

Since in the original formulation every inputted ship and route was utilized and in the new formulation the decision on usage of a ship or route has to be determined, an integer variable for every route has to be made. For every route, this variable is equal to the number of times the route is used and 0 otherwise. All used sets, parameters and variables are listed below.

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 wheter ship passes poth 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 $k = (h_1, h_2, s)$

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 $s \in S$
f_s	Fixed costs of using route $s \in S$
$dist_{h_1,h_2}$	Distance from sailing from port $h_1 \in H$ to $h_2 \in H$
f_s^f	Fuelprce of ship $s \in S$ per nautical mile

Variables:	
$x_{h_1,h_2,s}$	Cargo flow on ship route $s \in S$ between consectutive ports $h_1 \in H$ and $h_2 \in H$
y_s	integer variable that denotes the number of times the route is used.
$x^{od}_{h_1,h_2,s}$	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 the 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 route $s_1 \in S$

The formulation becomes:

$$max \sum_{h_1 \in H} \sum_{h_2 \in H} \sum_{s \in S} r_{h_1,h_2} \left(x^{od}_{h_1,h_2,s} + \sum_{t \in T} x^{ot}_{h_1,t,h_2,s} \right)$$
$$- \sum_{h1 \in H} c^h_{h_1} \left(\sum_{t \in T} \sum_{h_2 \in H} \sum_{s \in S} [x^{ot}_{h_1,t,h_2,s} + x^{ot}_{h_2,t,h_1,s}] + \sum_{h_2 \in H} \sum_{s \in S} [x^{od}_{h_1,h_2,s} + x^{od}_{h_2,h_1,s}] \right)$$
$$- \sum_{t_1 \in T} c^t_{t_1} \left(\sum_{t_2 \in T} \sum_{h_2 \in H} \sum_{s_1 \in S} \sum_{s_2 \in S} [x^{tt}_{t_1,t_2,h_2,s_1,s_2} + \sum_{h_2 \in H} \sum_{s_1 \in S} \sum_{s_2 \in S} x^{td}_{t_1,h_2,s_1,s_2} \right) -$$
$$\sum_{s \in S} f_s y_s - \sum_{s \in S} \sum_{k \in K} dist_{h_1,h_2} y_s f^f_s \tag{1}$$

s.t.:

$$\sum_{t \in T} \sum_{s \in S} x^{ot}_{h_1,h_2,s} + \sum_{s \in S} x^{od}_{h_1,h_2,s} \leq d_{h_1,h_2} \quad h_1 \in H, h_2 \in H \tag{2}$$

$$x_{h_1,h_2,s} \leq b_s y_s \quad (h_1, h_2, s) \in K \tag{3}$$

$$\sum_{h_1 \in H} x^{ot}_{h_1,t_1,h_2,s_1} + \sum_{t_2 \in T} \sum_{s_2 \in S} x^{tt}_{t_2,t_1,h_2,s_2,s_1} - \sum_{s_2 \in S} x^{td}_{t_1,h_2,s_1,s_2} - \sum_{t_2 \in T} \sum_{s_2 \in S} x^{tt}_{t_1,t_2,h_2,s_1,s_2} = 0 \quad (t_1, h_2, s) \in J \tag{4}$$

$$x_{h_1,h_2,s} - \sum_{h_3 \in H} \sum_{h_4 \in H} x^{tot}_{h_3,h_4,s} I^{path}_{h_3,h_4,h_1,h_2,s} = 0 \quad (h_1, h_2, s) \in K \tag{5}$$

$$x^{tot}_{h_1,h_2,s_1} - x^{od}_{h_1,h_2,s_1} - \sum_{h_3 \in H} x^{ot}_{h_1,h_2,h_3,s_1} - \sum_{s_2 \in S} x^{td}_{h_1,h_2,s_2,s_1} - \sum_{h_3 \in H} \sum_{s_2 \in S} x^{tt}_{h_1,h_2,h_3,s_2,s_1} = 0 \quad h_1 \in H,\ h_2 \in H,\ s_1 \in S \tag{6}$$

$$x_{h_1,h_2,s} \geq 0 \quad (h_1, h_2, s) \in K \tag{7}$$

$$x^{od}_{h_1,h_2,s} \geq 0 \quad h_1 \in H \; h_2 \in H, \; s \in S \tag{8}$$

$$x^{tt}_{t_1,t_2,h,s_1,s_2} \geq 0 \quad h \in H \; s_1 \in S, \; (t_1, t_2, s_2) \in J \tag{9}$$

$$x^{td}_{t,h,s1,s_2} \geq 0 \quad s_1 \in S \; (t, h, s_2) \in J \tag{10}$$

$$x^{ot}_{h_1,t,h_2,s} \geq 0 \quad h_2 \in H \; (h_1, t, s) \in J \tag{11}$$

The objective function (1) maximizes the profit, which is equal to the revenue minus all costs; fuel costs, transshipment costs, handling costs and fixed costs. Constraints (2) make sure that the cargo shipped between every combination of ports does not exceed the demand for those combinations. Constraints (3) make sure that the amount of cargo transported on each leg, does not exceed the capacity of the ship sailing this route. Constraints (4) ensure that all containers which have to be transhipped, will also be loaded on another route. Constraints (5) define the amount of flow between two consecutive ports. Constraints (6) define the total flow between each two ports in the same cycle. Constraints (7) - (11) all make sure that cargo flow is nonnegative.

5.3 Sailing Speed

Given the minimum and maximum speed of every vessel (Table 3 and considering the fuel, fixed - and idle costs, it is possible to calculate whether it is more economically efficient to have more ships on the same route or to sail with a higher speed, such that a smaller number of vessels is needed.

By the changing the sailing speed, the fuel consumption changes as well. Brouer et al. [2014] provides a simplified relationship between the fuel consumption and the sailing speed:

$$f(x) = \begin{cases} f^f_s(v) = \left(\frac{v}{v^*_s}\right)^3 \cdot f^f_s(v^*_s), & \text{if } v_{min} \leq v \leq v_{max}. \\ f^f_{si}, & v = 0. \end{cases} \tag{12}$$

Where, $f^f_s(v)$ denotes the fuel consumption in bunker ton per day at speed v, v^* is the design speed of shiptype s and $f^f_s(v^*_s)$ denotes the fuel consumption of ship type s, sailing at design speed. f_{si}^{f} is the idle fuel consumption per day.

5.4 Model Input

The input for the combined formulation consists of all combinations of routes and ships. That is, every route is duplicated for every ship type, resulting in a large number of possible routes. For instance, when there are 15 possible routes, the total number of ship-route combinations equals 75 ($15 \cdot 5$ (5 types of ships)) However, there are a lot of duplicate routes. For instance, route {2-3-1-2} is the same as route {1-2-3-1}, when sailed multiple times. **In order to limit the number of routes and thereby the complexity, in this thesis, only routes visiting every port at most once are considered.**

For all of these route-ship combinations a calculation is made for the duration of the route, based on max speed and a port duration of 24 hours. Since weekly frequencies of sailing the routes is required, the number of ships needed on every route is equal to route-duration in weeks, rounded off upwards. Next, it is checked whether it is possible to lower the speed, such that sailing is more efficient. This speed is subject to some constraints; the speed should be within the upper and lower bound of the vessel and the speed should be kept at such speed, that the duration is shorter than the multiple of weeks. Otherwise a new vessel has to be added, which is always less efficient. Hence, no new vessel should be added.

Given the found optimal speed, the total fuel costs can be calculated according to the relation given in Section 5.3. Furthermore, since we know the duration of every route, including loading time, the total idle costs can be computed. This is done by multiplying the daily idle costs of a ship by the time it is not sailing, i.e., it is either (un)loading or waiting for the next trip, which is of course inefficient.

5.5 Reducing the Input-Matrix

When making use of larger routes, i.e., all routes visiting at least two and at most six different ports, the problem rapidly increases in complexity. By ennumerating, the number of possible routes, given that every port is visited at most once, except for the starting port, turns out to be equal to 409. Combining those with all ship types leads to a route input-matrix of 2045-by-7, where a row denotes a route and a column denotes a port. After attempting to run the procedure in AIMMS for several hours, it turns out the problem is too complex for the computer used. A new method for choosing the right input is thus called for.

This can be done by reducing the number of routes used as input in the model. To do so, one can remove all routes going from and to a certain port which is located in the outskirts. However, in order to still be able to serve demand from and to this port, some new routes have to be added. This can be done by inspecting both the demand - and distance matrices and check where most demand from this port is going to.

A measure that can be used to detect candidate ports to be 'excluded' is:

$$\frac{\sum_{h_2 \in H} d_{h_1,h_2}}{\sum_{h_2 \in H} dist_{h_1,h_2}} + \frac{\sum_{h_2 \in H} d_{h_2,h_1}}{\sum_{h_2 \in H} dist_{h_1,h_2}}, \quad for \quad h_1 \in H \tag{13}$$

The port with the lowest value either has a low back-and-forth demand, or is located relatively non-centrally of other ports and therefore might be a good candidate to be excluded. This can be done until the problem is decreased to the desired complexity. If there is no clear candidate port to be excluded, a general method is presented in the next section.

5.6 Iterating over Subsets of Routes

Another method to handle a large number of routes within acceptable computation times is to compute the optimal composition by not taking all possible routes simultaneously. That is, to calculate the best solution by iterating over different subsets of all the routes. When a route is used, it is included in the next iterations and the cargo-allocation problem is solved. Routes are included into the next iteration as long as they were selected in the network in the previous iteration. Although the found results will not be optimal, the computation times can be kept at a low level. Furthermore, this approach can be used in more general cases. That is, in not every case it is possible to exclude certain ports, as seen in Section 5.5.

6 Results

6.1 Back and forth routes

When making use of only the smallest routes possible (back and forth), and duplicates removed, there are 75 combinations $((5+4+3+2+1)\cdot 5)$ of routes and ships. When running the procedure in AIMMS, it turns out that it is capable of finding the optimal solution well under a minute, using a Intel Duo Core T6400 2.00GHz CPU. The used solver is CPLEX 12.6.1. Results are given in Table 4.

Ship type:	Route:	Number of Ships Needed:	Fixed Costs Per Week [$]:	Total Fuel Costs Per Week [$]:	Optimal Speed [kn]:
Feeder_800	{1,3,1}	2	112.000	104.261,22	10,33
Panamax_1750	{1,2,1}	1	105.000	160.839,63	17,73
Panamax_1750	{1,2,1}	1	105.000	160.839,63	17,73
Panamax_1750	{2,3,2}	1	105.000	30.514,95	12,00
Panamax_1750	{2,5,2}	1	105.000	56.584,14	13,43
Panamax_1750	{3,4,3}	1	105.000	27.597,95	12,00
Panamax_1750	{3,6,3}	2	210.000	196.233,62	12,61
Panamax_2400	{2,4,2}	1	147.000	55.165,86	12,00
Panamax_2400	{3,5,3}	1	147.000	50.128,15	12,00
Total:	-	**11**	**1.141.000**	**842.165,16**	-

Table 4: Weekly Results of Required Ships using Back-and-Forth Routes

Revenue:	$12.062.360
Handling Costs:	$3.815.072
Transhipment Costs:	$68.510
Fuel Costs (sailing):	$774.650,15
Fixed Costs:	$1.141.000
Port Fees:	$11.304
Idle Costs:	$67.515
Total Weekly Profit:	**$6.184.308,85**
Percentage of cargo delivered:	100.00%

Table 5: Weekly Performances Back-and-forth Routes

When we look at Table 5, we see that, in the optimal configuration, the weekly profit is equal to $6.184.308,85 and in which 100% of all cargo is delivered.

6.2 Larger routes

By further inspection of the data, we see that the demand from and to Sorong is largely linked to Tanjung Perak. In Table 6 we see that Sorong has the lowest value, using Formula 13. Therefore, removing all routes that visit Sorong and using a ship that goes back and forth from Sorong to Tanjung Perak, is likely to be fruitful. Adding up the demands from and to Sorong, calls for the utilization of a Panamax_1750. When we look at Belawan, we see that almost all demand is linked to Tanjung Priok and Tanjung Perak. Hence, we can also leave Belawan out of consideration.

Port:	Value:
Belawan	**1,88**
Tanjung Priok	6,56
Tanjung Perak	5,89
Banjar-Masin	3,55
Makassar	3,25
Sorong	**0,57**

Table 6: Values per Port using Formula (13)

However, the routes {1,2,1} and {1,3,1} have to be included instead. The total demand from and to Belawan is roughly 8000. Since it is not obvious which combination of ships is most efficient to carry this, all route options have to be included.

Removing those two ports and adding possible back-and-forth routes reduces the input-matrix to 110-by-5 (100 for all combinations between the four ports, 6 possible back-and-forth routes for {1-2-1} and {3-6-3}), and the routes {1,2,3,2,1} and {1,2,3,1}. The results are shown in Tables 7 and 8. The computation time using an Intel Duo Core T6400 2.00GHz CPU and CPLEX 12.6.1 solver is 1447 seconds.

Ship type:	Route:	Number of Ships Needed:	Fixed Costs Per Week [$]:	Total Fuel Costs Per Week [$]:	Optimal Speed [kn]:
Panamax_1750	{5,2,5}	1	105.000	56.584,14	13.43
Panamax_1750	{5,3,5}	1	105.000	32.689,44	12,00
Panamax_1200	{5,4,3,5}	1	77.000	36.602,72	12,51
Panamax_1750	{2,3,4,2}	1	105.000	61.793,49	14,38
Panamax_1750	{2,4,3,2}	1	105.000	61.793,49	14,38
Panamax_1750	{3,6,3}	2	210.000	187.565,04	12,61
Panamax_1750	{1,2,1}	1	105.000	153.778,82	17,73
Panamax_1750	{1,2,1}	1	105.000	153.778,82	17,73
Feeder_800	{1,3,1}	2	112.000	104.285,15	10,33
Total:	-	**11**	**1.029.000**	**848.871,11**	-

Table 7: Weekly Results using Larger Routes

Revenue:	$12.062.360
Handling Costs:	$3.815.072
Transhipment Costs:	$52.394
Fuel Costs (sailing):	$791.721,10
Fixed Costs:	$1.029.000
Port Fees:	$13.188
Idle Costs:	$57.150
Total Weekly Profit:	**$6.303.834,90**
Percentage of cargo delivered:	100.00%

Table 8: Weekly Performances using Larger Routes

6.3 Iterative Method over all Routes

When using the iterative method, a balance between a higher profit and computation times has to be found. The larger the used subset within an iteration, the higher the likelihood of finding a higher profit. A larger subset of course results in a lower number of iterations when a fixed number of routes has to be checked. However, it turns out that computation times become longer when making use of larger subsets. Hence, the size of the subsets has to be limited, such that computation times are kept at an acceptable level. First, we check the results using subsets of 50 routes. With a total of 2045 route-ship combinations, this requires 41 iterations. Second, we increase the size of the subset to 100 (21 iterations) and compare both the computation times and the profit. The results are shown in Table 9. The computer used has an Intel Duo Core T6400 2.00GHz CPU and the used solver is CPLEX 12.6.1.

Subset Size:	Profit:	Computation Time:
50	**$6.254.064**	**7891 sec**
100	**$6.265.309**	**18790 sec**

Table 9: Optimal Profit and Computation Times using different Subsets

As we see in the table, making use of subsets of 100 routes indeed increases maximum profit. However, we see that differences are much less than 1% of total profit, while the computation times are more than doubled. Therefore, it may be better to keep the number of routes in a subset relatively low.

7 Conclusion and further research

In the thesis of Wardana [2014] only vessels with a capacity of 3500 TEU are taken into consideration. Moreover, there is some data missing (such as the fixed costs of the Panamax_1750), which had to be estimated. Therefore, it is hard to make a comparison with the results found by Wardana [2014].

As shown, the method of creating a network as presented in this thesis works well and is probably nearly optimal for a small number of ports. The computation time can then be held at an acceptable level. However, the complexity increases dramatically when new ports are added. By including all routes for the six ports, the solving duration for the cargo-routing problem already reaches a few hours. One can imagine that the computation time explodes when even more ports are added. Therefore, iterating over different subsets of all possible routes is proven to be useful, even though it is not optimal.

Further research is required on creating routes that visit ports multiple times, which increases the number of candidate routes dramatically. Furthermore, in this paper, some possible influencal factors are being neglected, such as the ship draft and some uncertainties as the weather and possibly stochastic demands, which also can be implemented in the model.

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