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MULTI-PERIOD MARITIME LOGISTICS NETWORK OPTIMIZATION USING MIXED INTEGER PROGRAMMING

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ABSTRACT: Indonesia, as an archipelago country, is dependent to maritime logistics on transporting goods and transportation. However, its performance is still poor, indicated by high cost of logistics. Designing maritime logistics network is crucial for shipping company on developing their business. The objective of this research is to design a liner shipping logistics network on multi-period planning horizon using mixed integer programming with maximizing profit as objective function. Three given scenarios (fixed route and fleet size, fixed route but fleet size may increase, and random route and fleet size) are analyzed for ten years within three different conditions of demand (demand equals to forecasted demand, demand equals to forecasted demand of certain period, and demand is constant). The result shows that the second scenario gives the most satisfying result of objective function in profit and fleet allocation variables. The third scenario gives the highest profit on every condition and first scenario has the lowest number of vessels. The profit margin between the third and second scenario on each condition are 2.99%, 1.32%, and 0.004 % and fleet allocation gap between the first and second scenario are 1 ship, 1 ship, 0 ship respectively.

Keywords: Maritime Logistics, Liner Shipping, Multi-Period, Mixed Integer Programming.

1. INTRODUCTION

According to Meeuws and Bahagia (2012), Indonesia as an archipelago country is dependent to maritime-based logistics for transporting goods and transportation. However, its performance is still poor. According to Logistics Performance Index 2014 from World Bank, the score of Indonesia’s logistics performance is 3.08. The indicators are: customs, infrastructure, international shipments, logistics competence, tracking and tracing, timeliness. The score puts Indonesia in 53rd place worldwide and 5th place in ASEAN. Furthermore, logistics cost in Indonesia is relatively high. According to State of Logistics 2013 from World Bank, Indonesia logistics cost until 2011 made up 24.64 percent of Indonesia GDP. The growth of Indonesia is centralized in the western part, especially in Java Island. This cause the imbalance trade activities on both parts of Indonesia. Moreover, often times the ships from the east have to go back empty loaded. That is why the cost of logistics in Indonesia becomes high. Hence, it leads to the disparity of commodity price in the western and eastern part of Indonesia. Liner shipping is the fastest growing sector among shipping services. Liner shipping company usually operates on various fleets or various sizes of vessels on many routes that creates shipping networks on regular basis, to transport containers between ports. Liner shipping company is seeking for optimization technology for an effective cost planning in operating and enhancing their fleets. This plan is intended to match the capacity of the fleets with container demand effectively. However, in a multi-period planning, the container demand between ports may vary from one period to another. To cope with container demand pattern from one period to another, liner shipping company has to adjust their fleet planning, including fleet size, mix and allocation of vessels periodically.

2. BASIC THEORY

Maritime logistics networks are the main channels for transporting goods with large volume on long distance. Three distinctions are made in the shipping market: tramp shipping, industrial shipping and liner shipping (Lawrence, 1972). The cargo owners on industrial shipping are also the owners of the ships who strive to minimize the cost of transporting container between ports. On tramp shipping, vessels are sent to ports according to the availability of container demand. Goods carried in tramp shipping are bulk cargo. Liner shipping is the common container shipping type where there are fixed routes on regular schedules. The focus of this research is on liner shipping. Operation of liner shipping is based on characteristics associated with routing and scheduling of transporting containers and cargo. Liner shipper is a company that owns or operates fleets of container ships. Liner shipping usually operates on close routes, loading and unloading cargo at any ports of destination. The purpose of liner shipping services is to design network services that can provide a stable and regular service schedule and also operations that generate profit (Carranza, 2008). The decision making in the liner shipping consists of three different time-horizon level by Pesenti (1995): strategic level (3-5 years), tactical level (4-12 months) and operational level (1-4 weeks). Strategic level has the longest time-horizon. On a strategic level optimal fleet size is determined. Planning on a tactical level is done in several months and it involves determining the routes used. While on the operating level that has the shortest span of time, planning the allocation of cargo must be done. Liner shipping company usually operates on various fleets or various sizes of vessels on many routes that creates shipping networks on regular basis, to transport containers between ports. Liner shipping company is seeking for optimization technology for an effective cost planning in operating and enhancing their fleets. This plan is intended to match the capacity of the fleets with container demand effectively. However, in a multi-period planning, the container demand between ports may vary from one period to another. To cope with container demand pattern from one period to another, liner shipping company has to adjust their fleet planning, including fleet size, mix and allocation of vessels periodically. Traditional multi-period liner ship fleet planning begins with a forecasted or estimated container shipment demand pattern for each single period using some demand forecasting techniques such as regression and time series models. However, a forecasted container shipment demand pattern as a necessary input of the multi-period liner ship fleet planning problem can never be forecasted with complete confidence. It is almost impossible to precisely match estimated demand with the one realized. In reality, the container shipment demand at one period has effect on the future demand, which indicates that the container shipment demand is dependent on the demand in previous periods (Meng and Wang, 2015). There have been many studies on multi-period fleet planning problems over the last few decades. Cho and Perakis (1996) developed an integer linear programming model for a long-term liner ship fleet planning to determine the optimal fleet size, mix and route allocation. However, the model is a period-independent model. Xinlian et al. (2000) thus reformulated the model as a dynamic programming model. They divided the multi-period planning horizon into single periods. Integer linear programming was used for each period to determine the optimal fleet size, mix, and routes allocation in order to minimize cost. However, the annual operating cost and capacity of each vessel on each route were assumed constant. This assumption is unrealistic because the costs are voyage-dependent. Recently, Meng and Wang (2011) formulated multi-period liner shipping fleet planning problem as a scenario-based dynamic programming model. However, the study did not consider container transshipment into account.

3. METHODS

On the strategic level, the composition of the fleet has to be determined, we call it fleet-design problem. In this research, it is assumed that the company has no fleet in the beginning and the company is the sole container shipment provider to fulfill all of demand. 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 this research, the route that is used is port-to-port. In the case of intra Indonesian shipping, it might be a good decision to select hub ports as the ports with the largest throughput. The ports used in this research are Belawan, Tanjung Priok, Tanjung Perak, Banjarmasin, Makassar, and Sorong. Aggregation of ports are based on throughput and geographical position of each ports. Hence, there are 15 combinations of ship routes. There are 5 types of vessels that are used on this research, therefore the total of routes become 75 combinations. The main problem on the operational planning level is the assignment of cargo to the ships sailing to the determined routes. This problem is called the cargo-routing problem and can be formulated as a linear programming model. Mathematical model that is used in this research was made by Mulder and Dekker (2014) with modification of objective function and few constraints by Meijer (2015). By rewriting the objective function and some of the constraints the model changes to a mixed integer programming problem and can be used to determine the optimal fleet, routes and cargo-allocation. Sets, parameters, decision variables, and equation that are used in this research, are listed in the following.

3.1 Sets

$h \in H$,	Set of ports
$t \in T \subseteq H$,	Set of transhipment ports
$s \in S$,	Set of ship routes
$j \in J$,	Indicator set denoting whether ship passes both ports $h_1 \in H$

and $h_2 \in H$ on ship route $s \in S$, where $j = (h_1, h_2, s)$

$k \in K$, Indicator set denoting whether port $h_2 \in H$ is directly visited after port $h_1 \in H$ on ship route $s \in S$, where $k = (h_1, h_2, s)$

3.2 Parameters

$r_{h_1,h_2,s}$	Revenue of transporting one TEU from port $h_1 \in H$ to $h_2 \in H$
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 cost of using route $s \in S$
$dist_{h_1,h_2}$	Distance from sailing from port $h_1 \in H$ to port $h_2 \in H$
f_s^f	Fuel price of ship $s \in S$ per nautical miles

3.3 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 $s \in S$ is used
$x^{od}_{h1,h2,s}$	Direct cargo flow between ports $h_1 \in H$ and $h_2 \in H$ on ship route $s \in S$
$x^{ot}_{h1,t,h2,s}$	Transhipment flow between port $h_1 \in H$ and transhipment port $t \in T$ on ship route $s \in S$
$x^{td}_{t_1,h_2,s_1,s_2}$	Transhipment flow on ship route $s_2 \in S$ between transhipment port $t \in T$ and destination port $h_2 \in H$ where the flow to transhipment port $t \in T$ was transported on ship route $s_1 \in S$
$x^{tt}_{t_1,t_2,h_2,s_1,s_2}$	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 $h_2 \in H$, where the flow to transhipment port $t_1 \in T$ was transported on route $s_1 \in S$

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. Constraint (2) makes sure that the cargo shipped between every combination of ports does not exceed the demand for those combinations. Constraint (3) makes sure that the amount of cargo transported on each leg, does not exceed the capacity of the ship sailing this route. Constraint (4) ensures that all containers which have to be transhipped, will also be loaded on another route. Constraint (5) defines the amount of flow between two consecutive ports. Constraint (6) defines the total flow between each two ports in the same cycle. Constraints (7) - (11) all make sure that cargo flow is nonnegative.

The model was runned using Gurobi and Netbeans software. CPU used in running the optimization model is Intel Core i3 U 380 1.33 GHz.

Model simulation are based on three conditions: (1) demand equals to forecasted demand, (2) demand equals to forecasted demand until certain period then constant, and (3) demand is constant. Each condition also has three scenarios: (1) fixed route and fleet size, (2) fixed route but fleet size may increase, (3) random route and fleet size.

3.4 Objective Function

$$\max \sum_{h_1\in H}\sum_{h_2\in H}\sum_{s\in S} r_{h_1,h_2}\left(x^{od}_{h_1,h_2,s}+\sum_{t\in T} x^{ot}_{h_1,t,h_2,s}\right) - \sum_{h_1\in H} c^{h}_{h_1}\left(\sum_{t\in T}\sum_{h_2\in H}\sum_{s\in S}\left[x^{ot}_{h_1,t,h_2,s}+x^{ot}_{h_2,t,h_1,s}\right]+\sum_{h_2\in H}\left[x^{od}_{h_1,h_2,s}+x^{od}_{h_2,h_1,s}\right]\right)$$

$$-\sum_{t_1\in T} c^{t}_{t_1}\left(\sum_{t_2\in T}\sum_{h_2\in H}\sum_{s_1\in S}\sum_{s_2\in S} x^{tt}_{t_1,t_2,h_2,s_1,s_2}+\sum_{h_2\in H}\sum_{s_1\in S}\sum_{s_2\in S} x^{td}_{t_1,h_2,s_1,s_2}\right) - \sum_{s\in S} f_s y_s - \sum_{s\in S}\sum_{k\in K} dist_{h_1,h_2} y_s f^{f}_{s} \quad (1)$$

Subject to:

$$\sum_{t\in T}\sum_{s\in S} x^{ot}_{h_1,h_2,s}+\sum_{s\in S} x^{od}_{h_1,h_2,s} \le d_{h_1,h_2} \qquad h_1\in H,\ h_2\in H \quad (2)$$

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

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

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

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

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

$$x^{od}_{h_1,h_2,s} \ge 0 \qquad h_1\in H\ \ h_2\in H,\ s\in S \quad (8)$$

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

$$x^{td}_{t,h,s_1,s_2} \ge 0 \qquad s_1\in S\ \ (t,h,s_2)\in J \quad (10)$$

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

4. RESULT AND ANALYSIS

The purpose of this study is to obtain maximum profit for liner shipping company. Thus, the intial step is analyzing profit generated in each scenarios. Based on the results of the model, we can see that third scenario generates the highest profit, compared to first scenario and second scenario, for each condition. Comparison of profit results is shown in Figure 1.

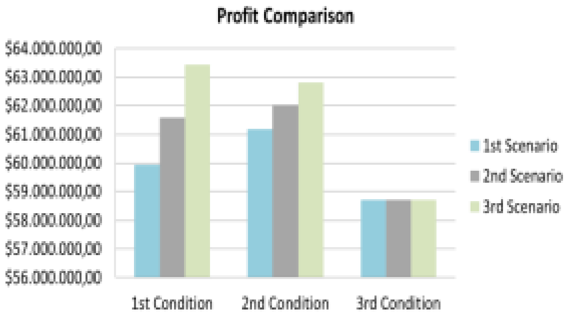

Fig. 1 Profit comparison.

Third scenario has the highest profit because it can adjust its route and the allocation of the fleet at each period based on demand and costs so as to provide maximum profit compared to first scenario, which routes and fleet size are fixed, and second scenario, which has a fixed route but allows the addition of vessels on each period.

Thus, the next step is to conduct an analysis of fleet allocation for each scenario on each condition. Table 1 shows the comparison of fleet size at the beginning of period.

Table 1 Comparison of fleet size at the beginning of period

	1st condition	2nd condition	3rd condition
1st scenario	17	17	16
2nd scenario	13	15	16
3rd scenario	16	16	16

At the beginning of period, first scenario has the highest number of fleet size and second scenario has the least. First scenario has the highest number of fleet size because the optimal fleet size has to be determined at the beginning of period and will have the same number on each period. Whereas second scenario has the least number because the number of fleet size is adjusted in accordance to demand on each period. Because on the second scenario, the number of fleet size can be fixed or increased as time goes by, based on demand and costs. Comparison of fleet size at the end of period is shown in Table 2.

Table 2 Comparison of fleet size at the end of period

	1st condition	2nd condition	3rd condition
1st scenario	17	17	16
2nd scenario	18	18	16
3rd scenario	23	21	18

From the table above, we can see that third scenario has the highest number of fleet size in comparison to first and second scenario. Third scenario has the highest number of fleet because it can determine routes and allocate the fleet freely. Thus, enabling fleet allocation randomly changes in each period. This leads to the allocation of the fleet in third scenario has greater number compared to first scenario, which has been determined at the beginning of the period and will remain until the end of the period, and also compared to second scenario, which already has the fixed composition of the fleet for each period but allows to increase the number of fleet.

The addition of vessels is certainly a cost for the company. On the composition of the fleet in third scenario it can be seen that each year, the number of ships needed are unstable. In addition, it tends to increase the number of ships from one period to another. The changing of demand makes third scenario are likely to change and replace the fleet composition, in order to achieve maximum profit.

First scenario has fixed routes and fleet size for each period. In multi-period planning horizon where demand will certainly change, the addition of ships is necessary for shipping company. But first scenario can not fulfill this condition.

Based on the results, it can be seen that the profit margin of second scenario and third scenario is relatively small. The profit margin between the third and second scenario on each condidition are 2.99%, 1.32%, and 0.004 % and fleet allocation gap between the first and second scenario are 1 ship, 1 ship, 0 ship respectively. The result shows that the second scenario gives the most satisfying result of objective function in profit and fleet allocation variables.

5. CONCLUSION

Planning a multi-period maritime logistics network services plays an important role in the business development of shipping company. A long-term planning is useful for liner shipping company for decision support such as routes used, fleet-design, fleet size, cargo allocation, vessels purchase, etc. Scenarios help to give comparison for company to be considered in decision-making. Based on results, the scenario that is suitable for maritime logistics multi-period planning on liner shipping services in Indonesia is the second scenario.

6. REFERENCES

[1] Bahagia N & Meeuws R, “Logistics Costs Indonesia”, Jakarta: NEA in collaboration with ITB, STC, and ALI, 2012.

[2] Logistics Performance Index [Internet]. Lpi.worldbank.org. 2014 [cited 14 February 2016].

[3] Bahagia N, Sandee H& Meeuws R, “State of Logistics Indonesia 2013”, Jakarta: NEA in collaboration with ITB, STC, and ALI, 2013.

[4] Lawrence S, “International sea transport: the years ahead”, Lexington, Mass.: Lexington Books, 1972.

[5] McLean Carranza A, “Discrete-event simulation approach for the analysis of liner shipping services of containerized cargo”, Louisville: ProQuest Dissertations and Theses database, 2008. (UMI No. 3308353).

[6] Pesenti R, “Hierarchical resource planning for shipping companies, European Journal of Operational Research, 1995, pp. 86(1) , 91-102.

[7] Meng Q, Wang T, Wang S, “Multi-period liner ship fleet planning with dependent uncertain container shipment demand”, Maritime Policy & Management, 2013, pp. 42(1):43-67.

[8] Cho S, Perakis A, “Optimal liner fleet routeing strategies”, Maritime Policy & Management, 1996, pp. 23(3):249-259.

[9] Xinlian X, Tengfei W, Daisong C, “A dynamic model and algorithm for fleet planning”, Maritime Policy & Management, 2000, pp. 27(1):53-63.

[10] Meng Q, Wang T, “A scenario-based dynamic programming model for multi-period liner ship fleet planning”, Transportation Research Part E: Logistics and Transportation Review, 2011, pp. 47(4):401-413.

[11] Mulder J & Dekker R, “Methods for strategic liner shipping network design”, European

Journal of Operational Research, 2014, pp. 235(2):367-377.
[12] Meijer J, “Creating A Liner Shipping Network Design (Bachelor Thesis)”, Rotterdam: Erasmus University Rotterdam, 2015.