ENHANCING PENDULUM NUSANTARA MODEL IN INDONESIAN MARITIME LOGISTICS NETWORK

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ABSTRACT

One of the main factors affecting high logistics cost in Indonesia is unbalanced trades between the western and the eastern regions of Indonesia. Particularly, shipments between the two regions are rarely transported using full capacity in both directions. Government has proposed Pendulum Nusantara that guarantees fixed schedule between the two regions to cut the logistics cost. This paper uses Pendulum Nusantara and enhances it to further bring the cost down. The enhancements are achieved using combinations of routes that have not considered in Pendulum Nusantara. The problem is modeled as a mixed integer program and a commercial solver is used to generate the solutions. Optimization results show higher profits can be obtained in an acceptable computation time.
Keywords: liner shipping, pendulum nusantara, logistics maritime, mixed integer programming.

1. INTRODUCTION

Sea cargo shipment is an alternative transportation mode to send goods in between islands (Lawrence, 1972). In compared with air cargo, it is relatively cheaper but with a higher transportation time. Several commodities that are needed in an island in Indonesia is sometimes fulfilled using supplies from other islands. On one hand, excess commodities from an island can be used to supply other islands. On another hand, some commodities are not produced in the islands so the commodities need to be brought from outside. Examples of the traded commodities in between Indonesian islands are cement, rice, coal, automotive, etc.

Commodities trading in between islands and continents nurtures liner shipping industry (Liu, et. al., 2014; Kalem, 2015). Cargo shipments can achieve full efficiency if the shipments are using full capacities of the vehicle. Moreover, the accuracies of the schedule and the predicted demand can help to increase the efficiency.

Based on this situation, Indonesian government has performed study to generate an efficient liner shipping network in Indonesia. As a result, Pendulum Nusantara network has been generated and it is depicted in Figure 1. Pendulum Nusantara specifies a network that run back and forth between west to east regions with fixed weekly schedule. This guarantees that each port is connected to other ports in Indonesia. In addition, it guarantees regular shipments can be made because of its fixed schedule.

Recent research suggest that Pendulum Nusantara can be developed further. Using the liner shipping model from Mulder & Dekker (2014), Van Rijn (2015) and Meijer (2015) proposed iterated methods to generate router for liner shipping in Indonesia. In particular, their approaches aimed to determine the number and the type of ships and their routes that can maximizes weekly profit considering a fixed weekly demands. The results show that their approaches result in a significant profit margin the one from Pendulum Nusantara.

The current paper aimed to proposed the number and the type of ships and their routes that can maximizes weekly profit considering a fixed weekly demands. The model is the same with the ones of Mulder & Dekker (2014), Van Rijn (2015) and

Meijer (2015). However, in the current paper we consider a higher number of route candidates. Specifically, the routes that have not been considered in the previous research.

The rest of the paper is organized as follows. Section 2 reviews the liner shipping problem. Section 3 the liner shipping mathematical model due to Mulder & Dekker (2014) is presented. Section 4 discusses the results of the experiments. Finally, conclusions and further research directions are provided in Section 5.

Figure 1. Pendulum Nusantara Routes

2. THEORETICAL BACKGROUND

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 is 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 operate 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 fleet or various size 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

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opreating 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.

3. RESEARCH METHOD

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 as hub ports 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 the determined routes. This problem is called the cargo-routing problem and can be formulated as an integer 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.

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 $k = (h_1, h_2, s)$

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 $s \in S$
$I_{h_1,h_2,h_3,h_4,s}^{path}$	(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 $h_2 \in H$

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f_s^f Fuel price of ship $s \in S$ per nautical miles

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 $s_1 \in S$

Objective Function:

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

Subject to:

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

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

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

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

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

$$x_{h_1,h_2,s} \geq 0 \quad (h_1,h_2,s) \in K \tag{7}$$
$$x^{od}_{h_1,h_2,s} \geq 0 \quad h_1 \in H \;\; h_2 \in H,\; s \in S \tag{8}$$
$$x^{tt}_{t_1,t_2,h,s_1,s_2} \geq 0 \quad h \in H \;\; s_1 \in S,\;\; (t_1,t_2,s_2) \in J \tag{9}$$
$$x^{td}_{t,h,s_1,s_2} \geq 0 \quad s_1 \in S \;\; (t,h,s_2) \in J \tag{10}$$
$$x^{ot}_{h_1,t,h_2,s} \geq 0 \quad h_2 \in H \;\; (h_1,t,s) \in J \tag{11}$$

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. 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 run using Gurobi solver and Java programming language. The CPU used in running the optimization model is Intel Core i3 U 380 1.33 GHz.

4. RESULT AND DISCUSSION

In the experiments, we consider two scenarios. The first scenario considers all routes that each route is a combination of a port and its three closest ports. In this way, we have 180 new routes besides the original 75 routes of Meijer (2015). In total, we have 255 routes in the first scenarios.

The second scenario is the same with the first scenario, except we only use two of the three closest ports. On other words, the routes in the second scenarios are the routes of the first scenarios with the port next to the last port dropped. In this formulation, we have 180 new routes besides the original 75 routes of Meijer (2015). In total, we have 255 routes in the second scenarios.

The results of the first and the second scenarios are provided in Table 1 and 2 respectively. They contain the selected routes, the number and the types of the ships along with the financial calculations. The routes are represented using sequences of number, with 1 represents Belawan (Medan), 2 represents Batam, 3 represents Tanjung Priok, 4 represents Surabaya, 5 represents Makasar and 6 represents Sorong.

The solutions of both scenarios are compared in Table 3. The solution of the first scenario yields higher revenue than the one of the second scenario. However, the profit of the second scenario is higher than the one of the first scenario. In addition, we compare the performances of the two scenarios with the approaches of van Rijn (2015) and Meijer (2015). It can be seen that the proposed approach, especially the second scenarios results in a higher profit than the ones from previous research.

Table 1 The generated routes, types of ships resulted from the first scenario

Route	Ship Type	Number of ships	Fixed Cost ($)	Fuel Cost ($)	Revenue ($)
1-4-2-3-1	Panamax 1750	1	106,256	533,829	2,807,255
4-5-3-2-4	Panamax 1750	1	106,256	217,156	1,890,280
6-5-4-3-6	Panamax 2400	1	148,256	731,604	1,970,690

2-6-2	Feeder 800	1	57,256	392,845	688,000
2-4-2	Panamax 1250	1	78,256	51,467	702,405
3-5-3	Panamax 1250	1	78,256	51,467	934,820
2-3-2	Panamax 2400	1	148,256	79,007	1,927,475
3-4-3	Panamax 2400	1	148,256	79,007	1,915,435
Total			871,048	2,136,381	12,836,360

Table 2 The generated routes, types of ships resulted from the second scenario

Route	Ship Type	Ship Total	Fixed Cost ($)	Fuel Cost ($)	Revenue ($)
5-4-3-5	Feeder 800	1	57,256	45,087	811,410
6-4-5-6	Feeder 800	1	57,256	232,687	811,410
4-2-5-4	Panamax 1250	2	156,512	142,753	2,381,985
5-3-2-5	Panamax 1250	1	78,256	141,240	1,039,095
5-3-4-5	Panamax 1750	1	106,256	52,417	1,369,765
3-4-5-3	Panamax 2400	1	148,256	75,393	2,366,935
1-2-1	Panamax 1250	1	78,256	163,175	450,210
5-6-5	Panamax 1750	2	212,512	490,933	2,888,095
Total			894,560	1,343,686	12,118,905

Table 3 Performance Comparisons between Both Scenarios

The first scenario		**The second scenario**	
Revenue	$ 12,836,360	Revenue	$ 12,118,905
Handling Cost	$ 3,349,624	Handling Cost	$ 2,998,395
Transshipment Cost	$ 310,624	Transshipment Cost	$ 245,208
Fuel Cost	$ 2,136,381	Fuel Cost	$ 1,343,686
Fixed Cost	$ 871,048	Fixed Cost	$ 894,560
Port Cost	$ 13,816	Port Cost	$ 13,816
Total Profit per Week	**$ 6,154,867**	**Total Profit per Week**	**$ 6,623,240**
Cargo Delivered Percentage	100%	Cargo Delivered Percentage	100%

Table 4. Performance of the both scenarios in compared with previous research

Approaches	Revenue	Profit ($)	Cargo Delivered
Meijer (2015	12,062,	6,184,	100%
Van Rijn (2015)	12,062,	5,364,	100%
Scenario 1	12,836,	6,154,	100%
Scenario 2	12,118,	6,623,	100%

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5. CONCLUSION

We have proposed a number of routes that can be added to enhance the performance of Pendulum Nusantara model. In particular, the routes that are constructed from combinations of a port and its three closest ports are need to be added.
Future research directions include investigation on the model on long term decision such as five or ten years in the future. Moreover, some stochastic variables need to be addresses such as uncertainty in demands and uncertainty in travel times.

6. REFERENCES

(a) Carranza, A. A. (2008). *Discrete-Event Simulation Approach for The Analysis of Liner Shipping Services of Containerized Cargo (Doctoral Disertation).* Louisville: ProQuest Dissertations and Theses database. (UMI No. 3308353).

(b) Kalem, H. (2015). *Container Liner Shipping Network Design Using A Path Formulation Model for Indonesia (Master Thesis).* Rotterdam: Erasmus School of Economics, Erasmus University Rotterdam.

(c) Lawrence, S. (1972). *International Sea Transport: The Years Ahead.* Lexington: Lexington Books.

(d) Meijer, J. (2015). *Creating A Liner Shipping Network Design (Bachelor Thesis).* Rotterdam: Erasmus University Rotterdam.

(e) Mulder, J., & Dekker, R. (2014). Methods for strategic liner shipping network design. *European Journal of Operational Research*, *235*(2), 367–377.

(f) Pesenti, R. (1995). Hierarchical Resource Planning for Shipping Companies. *European Journal of Operational Research*, 91-102.

(g) van Rijn, L. (2015). *Service Network Design for Liner Shipping in Indonesia (Bachelor Thesis).* Rotterdam: Erasmus University Rotterdam.