Enhancing Pendulum Nusantara Model in Indonesian Maritime Logistics Network

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***Abstract*—One of the main factors affecting high maritime logistic cost in Indonesia is unbalanced trade between west and east region of Indonesia. Particularly, shipment between two regions were rarely transported using full capacity in both directions. Moreover in many occasion, shipments were carried empty. Therefore, cost of both direction shipment was increased twice or more than normal shipment. Indonesia government has proposed Pendulum Nusantara that guarantees fixed schedule between two regions to cut the logistic cost. This paper generates Indonesia maritime logistic networks using Pendulum Nusantara and enhances it to further bring the cost down and increase profit. The improvements were achieved using combinations of routes that have not considered in Pendulum Nusantara route networks. The problem was modeled as a mixed integer program and a commercial solver was used to generate the solutions. Optimization results show higher profits can be obtained in an acceptable computation time.**

***Index Terms*—liner shipping, Pendulum Nusantara, logistic maritime, mixed integer programming**

I. Introduction

Sea cargo shipment is an alternative transportation mode to send goods in between islands [1]. 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 within islands so the commodities need to be brought from outside. Examples of traded commodities in between Indonesian islands are cement, rice, coal, automotive, etc.

Commodities trading in between islands and continents nurtures liner shipping industry [2]. Cargo shipments can achieve full efficiency if shipments are using full capacities of the vehicle. Moreover, the accuracies of schedule and predicted demand can help to increase 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 Fig. 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 [3]. Using 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 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 from Pendulum Nusantara.

The current paper aimed to propose number and type of ships and their routes that can maximizes weekly profit considering a fixed weekly demands. However, we consider a higher number of route candidates. Specifically, routes that have not been considered in previous research.

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

Figure 1. Pendulum nusantara routes.

Maritime logistics networks are main channels for transporting goods with large volume on long distance. Three distinctions are made in shipping market: tramp shipping, industrial shipping and liner shipping. Cargo owners on industrial shipping is also owners of the ships who strive to minimize the cost of transporting container between ports. On tramp shipping, vessels are sent to

Manuscript received January 19, 2017; revised June 3, 2017.

doi: 10.18178/jtle.5.1.35-39

ports according to 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. We are focusing 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). Decision making in 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 routes uses. While on operating level that has shortest span of time, planning 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 [4] 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 capacity of fleets with container demand effectively. However, in a multi-period planning, 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.

II. Research Method

In this research, we try to formulate solutions of strategic, tactical, and operational planning level of maritime logistic problem.

On strategic level, the composition of fleet has to be determined, we call it fleet-design problem. In this research, it is assumed that company has no fleet in beginning and the company is sole container shipment provider to fulfill all of demand.

Constructing network design is the main problem on tactical planning level. It consists of two problems: construction of shipping routes and assignment of different types of ships to routes. For 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 case of intra Indonesian shipping, it might be a good decision to select as hub ports the ports with 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.

Recent research improves the combination of feasible port routes. Meijer (2015) has designed combination of three ports on previous research. There were 15 combinations of ship routes and 5 types of vessels that used to take containers based on PT. Pelindo II (Ports State Owned Company) that used on this research, therefore total of routes become 75 combinations. Improvement were made by enlarging feasible port combination in order to scaling up possibilities of better solution.

The main problem on operational planning level is assignment of cargo to ships sailing the determined routes. This problem is called cargo-routing problem and can be formulated as an integer linear programming model.

The objective of this research formulation is to optimize total profit that generated by scenarios. There are two reasonable scenarios that used by this research. Each scenario formulates every ports as an origin so that in every routes, every ships can travel around nearest ports and back to its origin on final destination. This idea generates 180 new ship routes. The performance is set by summing all revenue which produced by completing supply-demand cargo and subtracting all costs which generated by handling cost, transshipment cost, fuel cost, fixed cost, and port cost.

Mathematical model that is used in this research has made before [5] with modification of objective function and few constraints by Meijer (2015). By rewriting the objective function and some of constraints, 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 transshipment 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 transshipment 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 rute $s \in S$
$I_{h_1,h_2,h_3,h_4,s}^{path}$	(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 rute $s \in S$
$dist_{h_1,h_2}$	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

Variables:

$x_{h_1,h_2,s}$	Cargo flow on ship route $s \in S$ between consecutive ports $h_1 \in H$ and $h_2 \in H$
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 $s \in S$
$x^{ot}_{h1,t,h2,s}$	Transshipment flow between port $h_1 \in H$ and transshipment port $t \in T$ on ship route $s \in S$
$x^{td}_{t_1,h_2,s_1,s_2}$	Transshipment flow on ship route $s_2 \in S$ between transshipment port $t \in T$ and destination port $h_2 \in H$ where the flow to transshipment port $t \in T$ was transported on ship route $s_1 \in S$
$x^{tt}_{t_1,t_2,h_2,s_1,s_2}$	Transshipment flow on ship route $s_2 \in S$ between transshipment port $t_1 \in T$ and transshipment port $t_2 \in T$ with destination port $h_2 \in H$, where the flow to transshipment port $t_1 \in T$ was transported on route $s_1 \in S$

Objective Function:

$$\begin{aligned} max \sum_{h_1 \in H} \sum_{h_2 \in H} \sum_{s \in S} r_{h_1,h_2} \left(x^{od}_{h_1,h_2,s} + \sum_{t \in T} x^{ot}_{h_1,h_2,s} \right) \\ - \sum_{h_1 \in H} c^h_{h_1} \left(\sum_{t \in T} \sum_{h_2 \in H} \sum_{s \in S} [x^{ot}_{h_1,h_2,s} + x^{ot}_{2,h_1,s}] \right. \\ \left. + \sum_{h_2 \in H} [x^{od}_{h_1,h_2,s} + x^{od}_{h_2,h_1,s}] \right) \\ - \sum_{t_1 \in T} c^t_{t1} \left(\sum_{t_2 \in T} \sum_{h_2 \in H} \sum_{s_1 \in S} \sum_{s_2 \in S} X^{tt}_{t_1,t_2,h_2,s_1,s_2} \right. \\ \left. + \sum_{h_2 \in H} \sum_{s_1 \in S} \sum_{s_2 \in S} X^{td}_{t_1,h_2,s_1,s_2} \right) \\ - \sum_{s \in S} f_s y_s - \sum_{s \in S} \sum_{k \in K} dist_{h_1,h_2} y_s f^f_s \qquad (1) \end{aligned}$$

Subject to:

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

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

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

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

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

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

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

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

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

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

The objective function (1) maximizes the profit, which is equal to revenue minus all costs; fuel costs, transshipment costs, handling costs and fixed costs. Constraint (2) makes sure that cargo shipped between every combination of ports does not exceeding demand for those combinations. Constraint (3) makes sure that amount of cargo transported on each leg, does not exceed the capacity of 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 total flow between each two ports in same cycle. Constraints (7) - (11) all make sure that cargo flow is nonnegative.

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

III. Results and Analysis

In the experiments, we consider two scenarios. The idea was to enlarge possibilities of routes combination from Meijer (2015) default routes. First scenario considers all routes that each route is a combination of a port and its three closest ports back and forth so that we generates 180 new routes contains 5 ports combination besides the original 75 routes of Meijer (2015). In total, we have 255 routes in first scenarios.

Second scenario is same with first scenario, except we only use two of three closest ports back and forth. On other words, routes in the second scenarios are routes of first scenarios with the port next to last port dropped. In this formulation, we have 180 new routes contains 4 ports combination besides the original 75 routes of Meijer (2015). In total, we have 255 routes in second scenarios.

The results of first and second scenarios are provided in Table I and Table II respectively. They contain selected routes, quantity and types of ships along with 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.

However, both scenario are good scenarios of maritime logistic solution depend on Indonesia government political will decision. Strategic, tactical and operational level of decision are covered by each scenario. Until recent times, there is no decision whether government choose combination of 5 ports or 4 ports. Other suggestion is that only 4 types of vessel will be needed, in other hand, the smallest vessel (Feeder 450) is not needed within scenarios.

Further, we show the performances of two scenarios alto scnearios provided Bay van Rijn (2015) and Meijer.

TABLE I. THE GENERATED ROUTES, TYPES OF SHIPS RESULTED FROM THE FIRST SCENARIO

Route	Ship Type	Qty	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		8	871,048	2,136,381	12,836,360

TABLE II. THE GENERATED ROUTES, TYPES OF SHIPS RESULTED FROM THE SECOND SCENARIO

Route	Ship Type	Qty	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		10	894,560	1,343,686	12,118,905

TABLE III. PERFORMANCE OF FIRST SCENARIO

The first scenario	
Revenue	$ 12,836,360
Handling Cost	$ 3,349,624
Transshipment Cost	$ 310,624
Fuel Cost	$ 2,136,381
Fixed Cost	$ 871,048
Port Cost	$ 13,816
Total Profit per Week	**$6,154,867**
Cargo Delivered Percentage	100%

TABLE IV. PERFORMANCE OF SECOND SCENARIO

The second scenario	
Revenue	$ 12,118,905
Handling Cost	$ 2,998,395
TransshipmentCost	$ 245,208
Fuel Cost	$ 1,343,686
Fixed Cost	$ 894,560
Port Cost	$ 13,816
Total Profit per Week	**$ 6,623,240**
Cargo Delivered Percentage	100%

TABLE V. PERFORMANCE OF THE BOTH SCENARIOS IN COMPARED WITH PREVIOUS RESEARCH

Approaches	Profit ($)	Cargo Delivered Percentage
Meijer (2015	6,184,308	100%
Van Rijn (2015)	5,364,201	100%
Scenario 1	6,154,867	100%
Scenario 2	6,623,240	100%

These scenario were built based on deterministic supply-demand data of each ports that also has imbalance trades. National trade has many factor of improvement which one of them is maritime logistics. Another thing to be considered is region development so that each region has an advantage to balance Indonesia national trade. Future research will be helpful to suggest government to make strategic decision.

IV. CONCLUSION

In this research, we have provided strategic, tactical, and operational level of maritime logistic solutions.

We have proposed two scenarios contain a number of ship routes with ship requirement type and quantity. Further, with 100% cargo delivery we suggest the projected revenue and cost in every route that can be added to enhance the performance of Pendulum Nusantara model.

Both scenarios are good solution to Indonesia recent maritime logistic problem depend on government political will decision.

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.

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