International Journal of GEOMATE, Aug, 2017, Vol.13, Issue 36, pp.87-93
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.36.2844

DESIGNING LINER SHIPPING NETWORK IN INDONESIA WITH DEMAND UNCERTAINTY

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ABSTRACT: The problem of maritime logistics in Indonesia lies on the unbalanced trade flow between west and east region of Indonesia. Since the east region does not have many comodity to be transported, to accommodate the demand on the east region liner shipping companies have to face the increasing amount of operational costs which makes the company failed to achieve the optimal profit. According to that situation, liner shipping companies needs a service network design which accomodate demand on each ports and give maximum profit. This research uses stochastic modeling to best portray the real condition of maritime logistics by taking demand uncertainty into consideration. The algorithm used in this research aims to determine the ship routes, ship types, and the cargo allocation that yields higher profits. The result was presented as a comparison between deterministic and stochastic modeling. The result shows that companies can yield higher profit if they use stochastic modeling approach from the initial decision making stage. The proposed solution method was designed to optimize Indonesian liner shipping services.

Keywords: Liner Shipping, Demand Uncertainty, Container Shipment, Stochastic Model

1. INTRODUCTION

Indonesia's logistics costs are quite high, which is 27% of its GDP, if compared to other countries (Meeuws, Sandee, & Bahagia, 2013). Even though there is fluctuation over the years, in average the transportation cost component gives the biggest contribution (State of Logistics Indonesia, 2013). One of the factors influencing the high logistics costs in Indonesia is the unbalanced trade flow between the west and the east region.

The trading activities take place in the western part of Indonesia, mostly in Java and Sumatera, while there are not much trading activities going on in the eastern part of Indonesia (BAPPENAS, 2011). The commodities for Eastern Indonesia are actually shipped from the western regions. This might due to lacks of industrial development in Eastern regions. In a frequent basis, ships sailing to the Eastern regions have to sail back with empty containers because there is no commodity to pick up. As a result, shipping companies must spend a high amount of operational costs. This leads to the elevation of prices in the market.

This issue emphasizes the importance of designing a better liner shipping network that is potent to solve the problem above. However, the uncertainty of demand becomes the main challenge in solving maritime logistics problems. Moreover, Wang and Meng (2010) point out that cargo demand has a quite high level of uncertainties and makes container shipment is hardly done in precise way (Wang, 2013). This issue has not been well-addressed in the growing research concern in maritime logistics studies. This paper aims to generate a model that optimizes liner shipping network in Indonesia by including cargo demand uncertainty in order to maximize the profit of liner shipping company.

2. LITERATURE REVIEW

There are three types of service in the shipping market: industrial shipping, tramp shipping, and liner shipping (Lawrence, 1972). In liner shipping, the company determines which demand to fulfill by which ships schedule. Liner shipping is widely used since it is carries containers. Liner shipping aims to determine which port that will be visited and in what order (Wang, Meng, Niu, & Tan, 2013). In liner shipping there are three levels of decision making: strategic level, tactical level, and operational level (Pesenti, 1995). Since the decisions made on each level are strongly related to each other, it is important to solve the problem simultaneously. This research are made based on Mulder and Dekker's research on 2014 which offered a formulation to solve the problems on each decision making level simultaneously.

In this research we develop deterministic model and stochastic model. Deterministic model is a model which predict the output of an event by using known parameter, while stochastic model predicts several possible output based on the event's characteristics (the characteristics are usually described as probabilityin stochastic model is a series of stochastic events along with the probability of the event's realization (Bisschop, 2016).

3. RESEARCH METHOD

This research uses stochastic modeling because it includes the uncertainty of container demand.

3.1 Problem Formulation

The stochastic model used in this research is developed based on the liner shipping network problem formulation made by Mulder and Dekker (2014).

3.1.1 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 a ship passed 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 $k = (h_1,h_2,s)$;

3.1.2 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

3.1.3 Decision 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 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 $h_1 \in H$;

$x^{td}_{t_1,t_2,h_2,s_1,s_2}$ — Transhipment flow on ship route $s_2 \in S$ between transhipment port $t \in T$ and destionation port $h \in H$, where the flow to transhipment port $t \in T$ was transported on ship route $s_1 \in S$;

$x^{tt}_{t_1,t_2,h_2,s_1,s_2}$ — 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 $h \in H$, where the flow to transhipment port $t_1 \in T$ was transported on route $s_1 \in S$;

$x^{tot}_{h_1,h_2,s}$ — Total cargo flow on ship route $s_1 \in S$ between ports $h_1 \in H$ and $h_2 \in H$.

3.1.4 Linear Programming Formulation

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

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

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

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

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

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

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

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

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

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

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

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

The objective function (1) maximizes the profit, which is equal to the revenue minus all costs; fuel costs, transhipment costs, handling costs and fixed costs. Constraints (2) make sure that the cargo shipped between every combination of ports doesn 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..

3.2 Algorithm Used to Design Liner Shipping Service Network with Demand Uncertainty

The above-mentioned linear programing formulation was translated into a mathematical programming on Netbeans IDE 8.1 using Java programming language optimized by using Gurobi Optimizer 6.5.0. The following passage would explain how we create a liner shipping service network design in Indonesia under demand uncertainty:

1. Generate combinations of back and forth route between 6 ports and 5 types of ships. There will be 75 routes combination as a result.
2. For each route, calculate the optimal speed by setting the route duration such that the route duration is an integer number of weeks or as close as possible. The sailing speed has to be set between the maximum and minimum speed.
3. Determine the number og ships needed for each route by assuming that the number of ships needed is equal to the rote duration in weeks (rounded above).
4. Calculate the total fuel costs by calculating the sailing costs and idle costs.
5. Calculate fixed costs of each route.
6. Use the calculation result from step 4 and 5 as an input in deterministic model.
7. Generate scenario of stochastic container demand from the data.
8. Include the scenario inside the model in order to get the stochastic model as a result.
9. Check the profit yielded from deterministic and stochastic models.

3.3 Verification

Netbeans IDE 8.1 facilitates its users to check whether there is a code error inside a model or not. It shows if there is an error by showing the line number and describing what kind of error on that line. The first verification step, debugging, is done by using the embedded function within the program.

The verification process is later done by evaluating the process which the model performs. It is done by checking whether the desired process inside the models are running as planned in the concept or not.

The verification process were done for each stage of decision. There are two stages of decision making in a stochastic model. In this research, the first stage decision is to decide which route and type of ships to use. After running the model we can see that it is successfully generate the first stage decision; route and ships type to use.

In this research, the second stage decision is to decide the amount of container shipped based on the scenario. The container shipment has worked well both for direct shipping and transhipment.

The containers are sent to its destination ports. The model also showed that it does the loading and unloading process based on the container destination. All of those process were successfully built inside the model. Table 1 shows the result of the verification process.

3.4 Validation

The model was validated by comparing its result to Meijer's result (2015). Meijer's research was also about designing liner shipping network design in Indonesia by using the same 6 ports mentioned in this research. The comparison between model's result and Meijer's result can be seen at Table 2.

There are 4 components that was validated, revenue, handling costs, transhipment costs, and weekly profit. The main idea of validation process is to the error percentage between model and Meijer's result. The error was calculated by subtracting the result of both mentioned models. As shown in Table 2, the model are able to produce the same result as Meijer. Revenue, handling costs, and transhipment costs are showing exactly the same output as Meijer's produce in his research. However, there is a slightly difference on the weekly profit. The error is 1% which means the model is validated because the normal limit of error is 5%. Therefore, we can consider that the model is quite representative to portray Indonesian maritime logistics.

Table 1 Model Verification

No.	Process	Result
1.	Container shipment using direct shipping	Successful
2.	Container shipment from origin port to transhipment port	Successful
3.	Container shipment from transhipment port to destination port.	Successful
4.	Revenue calculation	Successful
5.	Handling costs calculation	Successful
6.	Transhipment costs calculation	Successful
7.	Fuel costs calculation	Successful
8.	Fixed cost calculation	Successful
9.	Profit calculation	Successful
10.	Determining which route to use	Successful

Table 2 Result from model and result from Meijer (2015) in comparison

	Result from Model	Meijer's Result (2015)	% error
Revenue	$12,062,360	$12,062,360	0%
Handling cost	$3,815,072	$3,815,072	0%
Tranship-ment cost	$68,510	$68.510	0%
Weekly profit	$6,094,145	$6,184,309	1%

4. RESULT AND DISCUSSION

The analysis of the result simulation is divided into three parts. The first part compares the result of deterministic model with the result of predetermined-route stochastic model. The second part compares the result of predetermined-route stochastic model with the result of stochastic model. The third part discusses the analysis of sensitivity, which compares three different stochastic models distinguished by a variety number of scenario and level of standard deviation.

4.1 Comparison of Results of Deterministic Model and Stochastic Model

As shown in Figure 1, deterministic model tends to yield higher profit than stochastic model. Compared to stochastic model with 100 scenarios (N=100), deterministic model yields profit USD 151,374.55 higher, or, 2.5% higher. Compared to stochastic model with 50 scenarios (N=50), deterministic model yields profit USD 162,853.76 higher, or, 2.7% higher. At last, compared to stochastic model with 10 scenarios (N=10), deterministic model yields profit USD 207,675.10 higher, or, 3.5% higher.

The result shown in Figure 1 is common to be found when comparing deterministic and stochastic model. Deterministic model uses average demand as the model input which shows the same number every week, while stochastic model uses probability and uncertainty on the container demand. Stochastic model shows different conditions through its scenarios, that is why the demand is different on each scenario. The extreme condition appearing in the scenarios makes the model yield lower profit. However, it is important to note that the profit resulted by stochastic model is more realistic. A liner shipping company has to make a plan based on reality. The use of stochastic model helps company have a more precise estimation of container demand, thus, it helps the company to make a realistic decision.

4.2 Comparison of Results of Stochastic Model and Predetermined-Route Stochastic Model

Predetermined route stochastic model uses route and type of ships that is generated from the deterministic model, while stochastic model has no predetermined route. Those two types of stochastic models are created to analyze what happens if a shipping company uses stochastic model from the beginning of planning period. The results of those two stochastic models are shown in Figure 2.

Figure 2 shows that, with the same number of scenarios, the average profit of stochastic model is higher than the average profit of predetermined route stochastic model. Not only differs in generating the amount of profit, the models are also differs in generating the routes.

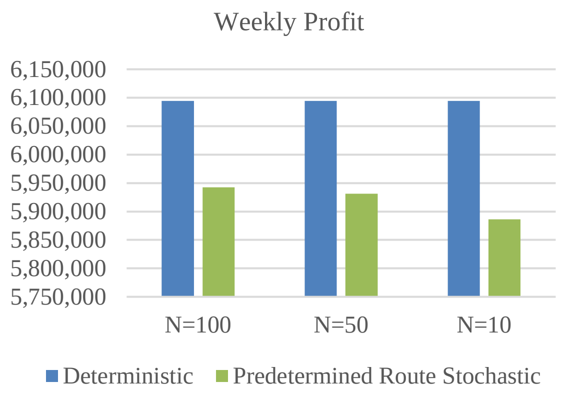

Fig. 1 Comparing profit of deterministic model and stochastic model (in USD)

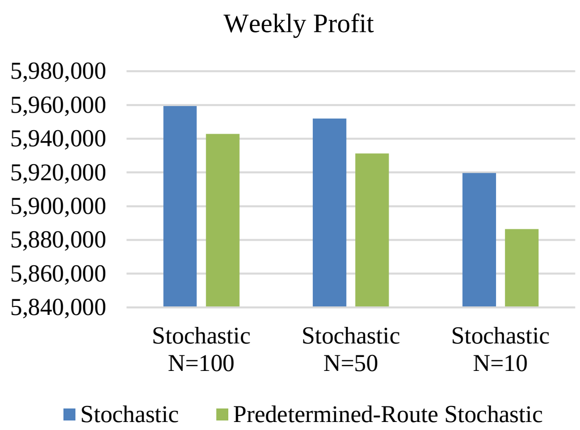

Fig. 2 Comparing profit of stochastic model and predetermined-route stochastic model (in USD)

In the result, stochastic model suggested to use route [69], unlike the predetermined route stochastic model that uses route [56]. Again, as stochastic model uses scenarios, it generates the routes based on various conditions of container demand. It is logical to say that the routes being used in stochastic model is better because it could tackle various conditions of container demand and yet yields higher profit than the predetermined route stochastic model. It gives a strong proof that using stochastic model from the beginning would be more beneficial for liner shipping company. The different routes being used in both models are shown in Figure 3 and Figure 4.

The difference lies on the route between Tanjung Perak and Banjarmasin. Stochastic model shows that it is better to use bigger ship on that route (Panamax 2400). This result further confirmed that it is more beneficial for liner shipping companies to use stochastic model from the beginning as it generates better routes and higher profit.

4.3 Sensitivity Analysis of the Number of Scenario Used in Stochastic Model

The stochastic models uses 10, 50, and 100 scenarios inside the model, N={10,50,100} which was formulated by using sample average approximation method. Table 3 shows the gap on each number of scenario. The result gathered by running the model using Gurobi Optimizer 6.5.0. Based on the table, we can see that the more number of scenario used the lesser the gap between best bound and best objective. The less gap shows that the method is effective.

Table 3 Statistics of various scenarios in stochastic model

N	Best objective	Best bound	Gap
10	5,919,764.74	5,924,893.06	0.09%
50	5,952,043.96	5,952,043.96	0.00%
100	5,959,340.97	5,959,340.97	0.00%

Not only takes effect on the gap between best objectie and best bound, using different number of scenario also takes effect on computation time. The more scenarios used in the model, the ore time needed for the software to generate solution. There is trade-off between optimal solution and computation time. That is why in creating stochastic model researchers have to use sufficient number of scenarios and it is not allowed to exceed the computer’s ability to process the model.

This research used a personal computer with Intel (R) Core (TM) i7-4930K CPU 3.40 GHz 3.70 GHz with 16.0 GB RAM under Windows 7. The comparison between computation time on different number of scenarios is shown in Table 4 below.

Table 4 Comparing computation time among different number of scenario

N	Computation Time
10	20 sec
50	2 min 55 sec

100	10 min 8 sec

The effect of using different number of scenario on company's profit can be observed on Figure 5. The graphic shows that models with more scenarios generate higher profit. Take a look back at the gap of each series, stochastic model with more scenario also generates lesser gap which means the high profit generated by more scenario is acceptable.

Fig. 2 Routes generated by deterministic model is used in predetermined route stochastic model

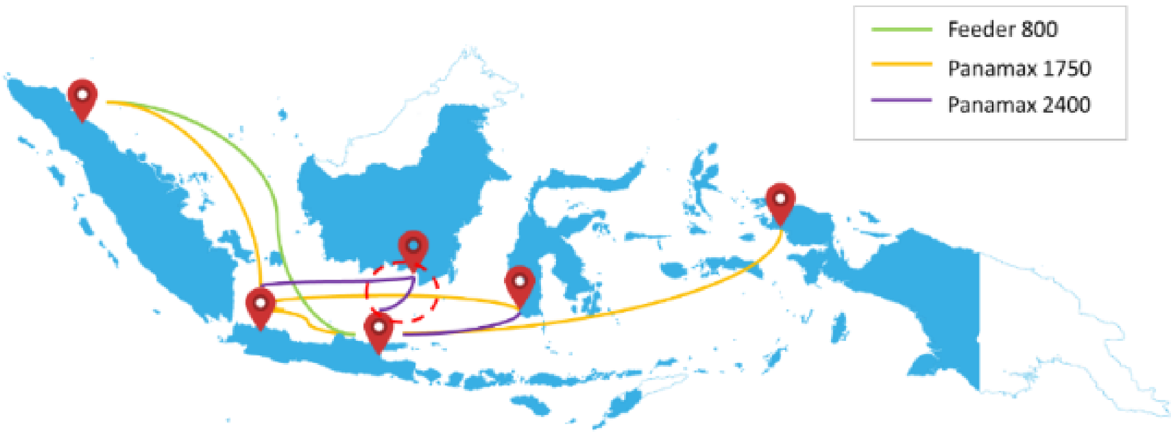

Fig. 3 Routes generated by stochastic model

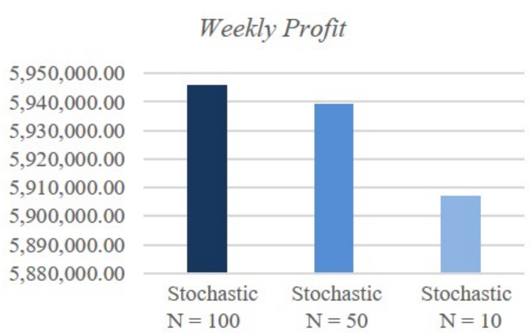

Fig. 4 Effects of using different number of scenario to profit of stochastic model

4.4 Analyzing Stochastic Model with Various Level of Standard Deviation

Figure 6 shows comparison between profit on deterministic model and profit on stochastic model with different level of standard deviation. The average profit generated by stochastic model decreases as the level of variance in container demand increase. It confirmed that the information related to container demand is significant for liner shipping company. The less the standard of deviation, the less variance on container deman, which means the container demand data is accurate. By usign the precise estimation of container demand, liner shipping company can make a decision based on reality and gain more benefits.

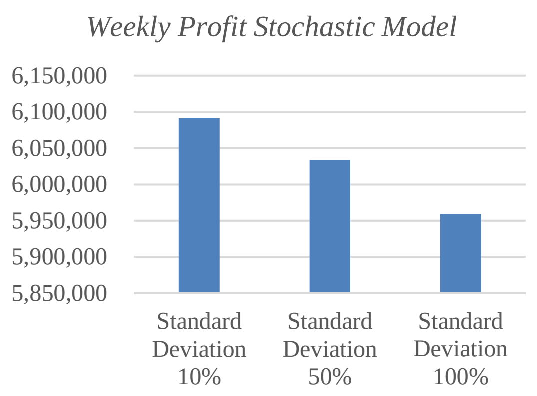

Fig. 5 Comparing profits in stochastic models with Different Level of Standard Deviation

5. CONCLUSION

Based on the analysis explained beforehand, we can see that compared to deterministic model, stochastic model yields lower profit. However, it is better for liner shipping company to rely on stochastic model as it is uses scenario that portray the variance and extreme condition of container demand. Stochastic model shows result which is closer to reality.

Using stochastic model from the beginning of planning period yields higher profit than predetermined stochastic model that used the route generated by deterministic model. It confirms that using stochastic model from the beginning is considered more beneficial for liner shipping companies.

The number of scenario influences the effectivity of solution generated by the model. The more scenario being used, the less gap appears which means the solution is nearly optimum. However, using more scenario needs more computation time. That is why researchers have to carefully choose between optimal solution and effectie computation time.

Variability on container demand scenario has significant effect on the solution. Increasing standard deviation resulting on decreased profit. Thus, we can also conclude that information about container demand is very important for liner shipping company.

According to the coclusions, the suggestions given for the future reearch is to create a stochastic model for liner shipping network design by taking other ports into considerations. Future research can also use route combinations other than back and forth or to create a multi-period stochastic model for maritime logistics in Indonesia.

6. ACKNOWLEDGEMENTS

The author greatly appreciate the support from the Systems Engineering, Modeling and Simulation Laboratory Universitas Indonesia (SEMS UI). Finanial support of this research was granted by Direcorate of Research and Community Service University of Indonesia.

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