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A simultaneous container assignment and ship scheduling optimisation model in container shipping

Christine Natalia*, Michael Holine, Agustinus Silalahi

Industrial Engineering Department, Atma Jaya Catholic University of Indonesia, Jalan Raya Cisauk, Sampora, Cisauk, Tangerang, Banten 15345, Indonesia

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ABSTRACT

Maritime transportation is preferred over other transportation forms for trade and has seen a significant increase worldwide. One of the problems that often occur in maritime transportation is the high cost because vessels' availability and capacity will always be the same while the demand tends to increase and erratic for each period. A mathematical model was developed in this study to determine the optimal value of container cargo and shipping frequency simultaneously to minimise the shipping cost for each voyage. To solve the container cargo optimisation problem, we presented an integer linear program, while for the scheduling, we used the greedy algorithm. Microsoft Excel Solver and LINDO software were used to solve the problem in this study. We provided computational calculations to simulate our mathematical model. The results show that the developed model produces feasible solutions for all scenarios due to the objective function and the constraints. Overall, our scheduling results can reduce the shipping frequency. The optimal solution value of container cargo and the scheduling results for each scenario are different because the total number of transported containers for each scenario is different.

1. Introduction

Logistics is an essential factor that every company must consider to distribute consumer's demand optimally according to the existing request. Logistics can be simply interpreted as distributing goods from the owner to the recipient or producers to consumers. Several transportation choices can be used in logistics systems, but the most widely used transportation and growing worldwide for international trade is maritime transportation. UNCTAD (2018) reported that around 80% of global trade by volume and over 70% of global trade by value are transported by sea and handled by ports that spread all over the world. Furthermore, we can say that maritime transportation is one of the main factors that significantly impact international trade and the global economy. The widely used maritime transportation for international trade can occur because of its larger capacity, lower cost, and more flexible shipping routes than the other transportation, like land or air transportation.

As an archipelagic country with more than 13,466 islands and around two-thirds of its area being the seas, Indonesia faces several issues regarding its logistics system, such as price disparity between Indonesia's Eastern and Western regions (Rumaji & Adiliya, 2019). This issue is primarily caused by the unbalanced flow of goods between these two regions, where a high percentage of carriers travels from the eastern to western regions with almost no freight to transport and make a higher freight cost. Thus, the Indonesian government initiates the Sea Toll road programme, a maritime transportation service concept involving 24 strategic ports with aims to reduce the national logistics costs and lower the price disparity between regions in Indonesia. This program was started in 2016 by operating six service networks or routes connecting the main ports with sub-feeder ports located on the country's small islands. The pilot project was appointed to PELNI, a state-owned enterprise. After evaluating its implementation, the Indonesian government decided to revise the routes and added several new routes, and the total number of the routes increased to 13 (Rumaji & Adiliya, 2019). Every year, this programme is evaluated to maintain its continuity, focusing on improving their service networks and cargo utilisation.

When designing and evaluating their service networks, shipping lines have to trade-off between the customers' requirements and their operational cost factors to be efficient and effective (Natalia et al., 2016). Shippers require direct services between their preferred ports of loading and unloading. The demand side thus exerts intense pressure on the shipping schedules, port rotations and feeder linkages. Cargo utilisation refers to vessel capabili-

* Corresponding author.
E-mail addresses: chrisnatalia@atmajaya.ac.id (C. Natalia), michael.holine@gmail.com (M. Holine), agustinus.silalahi@atmajaya.ac.id (A. Silalahi).

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ties to carry goods. A vessel comes in different sizes, and each vessel has its maximum capacity for each route. Nevertheless, shipping lines have to develop their liner services and networks to optimise cargo utilisation and gain maximum benefits in vessel size from economies of scale. Therefore, one problem that often occurs related to liner shipping's service networks is about the vessel's utility, which causes the expensive shipping cost (Korinek & Sourdin, 2010). It might happen because on one side, vessels availability and capacity will always be the same, but on the other side, the demand tends to increase while its number is erratic for each period. Their objective is to optimise their shipping networks by rationalising coverage of ports, shipping routes and transit time (Zohil & Prijon, 1999; Lirn et al., 2004). Shipping lines may direct flows along paths optimal for the system, with the lowest cost for the entire network being achieved by indirect routing via hubs and the amalgamation of flows (Bendall & Stent, 2001; Kemeny et al., 2011). However, the more efficient the network from the carrier's point of view, the less convenient it could be for shippers' needs (Notteboom, 2006).

There are many aspects of shipping network optimisation, such as port selection, routing and scheduling, ship assignment and scheduling, and container movement. Tran and Haasis (2013) conducted a literature survey regarding optimisation problems, methodologies, and research tendencies related to network optimisation in container liner shipping. Container routing problems in liner shipping are different from the ones in tramp shipping or special cargo shipping. Problems in container shipping are related to a large number of shipments, various pick-up and delivery points, many routing options, a strict schedule of service, and complicated containers exchange process according to different route services.

Based on these existing problems, we should determine the optimal value of container cargo and schedule to realise an optimal shipping system with minimum shipping cost according to the capacity of the vessels and ports on each route. The container assignment problem is an important issue, especially for the shipping company as a carrier, because vessel utility is one of the main factors that affect the carrier's profitability. As an ongoing dynamic issue, the container assignment problem will always appear due to the global economy's erratic growth. As each period has its new challenges and problems to be solved, we are also required to respond to the uncertain condition appropriately to help shipping companies or the other related parties maintain an optimal shipping system all over the world.

This paper provides a simultaneous container assignment and ship scheduling optimisation model to determine the optimal value of container cargo and shipping frequency simultaneously for each route. We try to develop a simultaneous model in this study to simplify solving the container cargo and ship scheduling problem because both problems are strongly correlated. By developing a simultaneous model, we hope that we can fasten the problems solving process more accurately. In this study, we used the integer linear programming approach to develop the model, and we applied the greedy algorithm to allocate the vessels and determine the optimal shipping frequency for each route in our scheduling calculation. We hope shipping companies can apply the results as an alternate solution to reduce the total shipping cost and improve their service quality.

2. Literature review

As we mentioned before, maritime transportation, especially the container assignment problem and the shipping scheduling problem, has been discussed many years ago. Mehrez et al. (1995) developed a mathematical model to determine the container cargo flow and the vessels allocation that provided maximum profit in industrial shipping by considering the container logistics cost on land, both from port to customer and otherwise. The model was developed using a mixed-integer linear program. BrØnmo et al. (2007) also conducted a mixed-integer linear program mathematical model and solved the scheduling problem with a column generation-based algorithm to determine the optimal cargo routing and ship schedule with the flexible cargo sizes, but this time was for the tramp shipping.

Furthermore, Agarwal and Ergun (2008) proposed an integrated cargo routing and ship scheduling model to design an optimal shipping network that provided maximum profit in container liner shipping using a mixed-integer linear program. A greedy heuristic, a column generation-based algorithm, and a two-phase Benders decomposition-based algorithm were developed and compared to generate the optimal ship schedules. The model assumed that the demand and the total revenue for each container transported were known, while to simplify the problem, the container transhipment cost was not considered at the network design phase. A dynamic programming algorithm and a greedy algorithm have been applied by Sampurno et al. (2018) to solve the Knapsack problem in freight transportation. The basic concept and the steps of using both algorithms were described in the paper, including comparing the results.

The greedy algorithm is an algorithm used to solved optimisation problems (Cormen et al., 2001). The principle of the Greedy algorithm itself is to determine a step-by-step solution or a local solution by taking the most of the available resources every step of the way until all available resources are used without considering the impact of the solution taken for determining the solution in the next step. This principle is also the advantage of the Greedy algorithm compared to other algorithms, where in addition to optimising the use of available resources, decision-making with the concept of the Greedy algorithm can be done in a short time. However, the greedy algorithm sometimes may fail to find the optimal global solution because they do not consider all the data. Furthermore, the use of the greedy algorithm is more effective if the resources or solutions offered are not too many because if there are too many, the process will be longer, and it will be more challenging to produce optimal global solutions.

The differences between liner, tramp, and industrial shipping in the global shipping industry were described in detail by Christiansen et al. (2004). In liner shipping, the shipping routes and frequencies are fixed for each period, and all cargoes are primarily containerised. It means that the vessel only departs on predetermined schedules, even though the vessel capacity has not been fully loaded. In tramp shipping, the vessel will depart in uncertain routes and schedules because they usually wait until the vessel capacity has been fully loaded before departing to maximising the profit. While in industrial shipping, a shipping company or a carrier owns the vessels and usually minimises the total shipping cost. In this business, the vessel also departs in an uncertain departure time to distribute a specific industry cargo. A more comprehensive review of the cargo routing and ship scheduling problem can be found in Ronen (1983) and Ronen (1993).

An earlier study about the container assignment problem has also been discussed in Bell et al. (2011) to develop a frequency-based container assignment model by adopting the classic Spiess and Florian (1989) frequency-based transit assignment method first time. Spiess and Florian's method assigns an origin-destination matrix for a passengers transit network to minimise passengers expected travel time. This method then was modified by Bell et al. (2011) to minimise sailing and dwell time by replacing passengers with containers and replacing routes with strings. As the maritime transportation issue presents, Bell et al. (2013) proposed a modified frequency-based model from his previous research as a cost-based maritime container assignment model to minimise the total container shipping cost. The model assumption and its properties were thoroughly described there so that the reader can understand the model clearly. The three main factors of the liner shipping cost were also provided to explain the model properties deeply. As the model is cost-based, it can only determine the total container shipping cost without considering the ship scheduling calculation.

Lots of research has been conducted to solve both container assignment and ship scheduling problems similar to this study. However, as the issue continuously grows, the study also needs to be updated, and so far, a simultaneous container assignment and ship scheduling optimisation model is still rarely found. We provide this study to optimise the container cargo flow on each existing route without changing the shipping network. Therefore, we develop this study to improve the previous studies and solve the common problem.

3. Assumptions and methodology

Our scheduling process began by finding out the containers that must be transported on each shipping route. A frequency-based maritime container assignment model of Bell et al. (2011) has been modified and applied in Bell et al. (2013) as a cost-based maritime container assignment model for full and empty containers. Furthermore, that model was also modified and applied in this study to determine the optimal value of container cargo and shipping frequency simultaneously to reduce the total shipping cost immediately as a result. We applied the integer linear programming approach to develop the model and find the optimal solution. Our model's objective function was to determine the minimum total container shipping cost by considering the operational shipping cost, loading-unloading cost, container warehousing cost, and ship docking cost, with the vessel and port capacity as the constraints

After obtaining the mathematical model equation, the next step is the verification model and validation. A verification model is done to determine whether the mathematical model can run to produce its optimal solutions according to its objective function and its predetermined constraints, and several conditions. As the model was a linear program, Microsoft excel solver and software LINDO was applied to run and solve the problem. Validation needs to be done to measure how well the developed mathematical model serves its intended purpose (McCarl & Spreen, 1997). In this paper, validation by construct is justified because the approach is consistent with the sample industry, previous research and theory, and the model data specified by deducing the data from the historical company's data. Moreover, model validation is carried out by assigning a random number into the model and checking the results. The model is valid if given specific inputs randomly; the model can produce an optimal solution value according to the objective function equation and the limitations used in the calculation.

The model was then be used to calculate several alternative possibilities according to the actual conditions that often occur in the container shipping system called a scenario. Scenario calculation was needed to analyse the model's ability to adapt to several conditions in the container shipping system.

After getting the decision variable values for each route, we allocated the available vessels to the existing route according to the vessel's capacity. We determined the optimal shipping frequency to fulfil the consumer's demand for each period by applying greedy algorithm concepts. The vessel with the largest capacity was allocated to the highest container flow value's route, and so on until the smallest capacity' vessel was allocated to the smallest container flow value's route. Meanwhile, the shipping frequency was determined by dividing the container flow on each route with the vessel capacity assigned to the route. With this method, we could increase the vessel's utility and minimise the total shipping cost.

In this study, the basic concepts of the task network approach described in Jourquin et al. (2008) were adopted. Those basic concepts that were adopted here were route, link, and leg defined as explained below:

- Route: A scheduled operated by a shipping company.
- Link: A pair of ports visited by a vessel on a route.
- Leg: A transport task operated by a route.

Remember that in this case, multi-legs were possible. It happened when a pair of ports were connected by more than one route. To reflect the route capacity constraint, it was essential to associate each leg with the relevant links. Container flows on the several relevant legs summed up to decide the flow on each link, and in turn, it compared with the route capacity constraint.

It was assumed that all parameters data in the model, such as the routes, basic costs, current frequencies, sailing time, vessels and ports capacity, must be known before running the model and obtaining the optimal objective function values and decision variables. All data used in this paper were provided by PELNI, a state-owned enterprise appointed as an operator of the Sea Toll Road programme. More recently, to simplify the problem and illustrate the developed model, the following assumptions were also made:

- Only a full general cargo container with 20 feet size was considered. The assumption was made based on the current condition that primarily ports in Indonesia served by PELNI is categorised as medium to small ports that can only use 20 feet container. All containers were assumed to be interchangeable on each port and usually assigned on the existing routes to minimise an objective function measured in cost units.
- The value of the cargo is excluded and it is not taking account in the model.
- Only a full container considered; thus, empty container repositioning was not calculated.
- Containers were carried by the liner shipping company that operated fixed routes with the vessel's arrival and departure time at each port was random for each route.
- Geographical conditions were good, and there was no weather disruption; therefore, sailing time, depreciation cost, and fuel cost were considered fixed.
- Only the shipping company's container was used and operated; thus, the model did not calculate the container rental cost.

4. Mathematical model

As we mentioned before, we adopted and modified the model of Bell et al. (2013) to solve the container assignment and scheduling problem in this study. The notation description for our mathematical model is as follows:

TBM_n^y = loading unloading cost per container for a leg type y on route n

x_{as} = containers flow on link a to destination port s

Ta = sailing time on route a, including loading unloading time at the destination port

BBj = sailing cost for vessel type j

N = set of routes

L = set of links

L_n = set of links on route n

Y = set of leg types

A_n^y = set of leg type y on route n

A = set of legs

A_n = set of legs on route n

A_i^+ = set of legs entering port i

A_i^- = set of legs leaving port i
I = set of ports
D = set of destination ports
O = set of origin ports
f_a = sailing frequency on leg a
k_i = maximum throughput of *port* i
RC_n = vessel capacity on route n
t_{rs} = containers flow from origin r to destination s
$\delta_{\frac{a}{n}}$ = 1 if leg a using link l on route n, and 0 otherwise
$\mathrm{tw}_{\mathrm{is}}$ = expected dwell time for containers at port i en route to destination port s, it can be calculated by Eq. (6)
BW_{i} = warehousing cost for containers on port i
ts_{i} = vessel docking time at port i, it can be calculated by Eq. (7)
BS_{i} = vessel docking cost at port i
ts_{s} = vessel docking time at port s, it can be calculated by Eq. (8)
BS_{s} = vessel docking cost at port s
$\mathrm{KBM}_{\mathrm{i}}$ = loading unloading capacity on port i
$\mathrm{KBM}_{\mathrm{s}}$ = loading unloading capacity on port s

There are four types of leg presented in this study. Those are legs connected to the origin and destination port, legs that connect to the origin and transhipment port, legs that connect to the two transhipment ports, and legs that connect to the transhipment and destination port. Our cost parameters are variable costs because the value depends on the containers flow value that should be transported on each route. The simultaneous container assignment and ship scheduling model in this study can be expressed as the following linear program:

Objective Function:

$$Z = \begin{matrix} Min \\ opensq2pt]x,t \end{matrix} \sum_{n \in N} \sum_{y \in Y} \sum_{a \in A_n^t} TBM_n^y \ (x_{as}) + (\sum_{a \in A} \sum_{j \in J} (x_{as})(Ta.BBj)$$

$$+ \sum_{i \in I} (tw_{is}.BW_i) + \sum_{i \in I} \sum_{s \in S} (ts_i.BS_i + ts_s.BS_s)$$

Constraint:

$$\sum_{a \in A_i^+} \mathrm{x_{as}} - \sum_{a \in A_i^-} \mathrm{x_{as}} = \mathrm{b_{is}} \text{ for all } \mathrm{i} \in \mathrm{I},\ \mathrm{s} \in \mathrm{D} \tag{1}$$

$$\mathrm{b_{is}} = \begin{cases} -\mathrm{t_{rs}}\ if\ i = r \in O \\ \mathrm{t_{+s}}\ if\ i = s \in D \\ 0\ else \end{cases} \tag{2}$$

$$\mathrm{x_{as}} \le \mathrm{tw_{is}}.\mathrm{f_a} \text{ for all } \mathrm{a} \in \mathrm{A_i^-},\ \mathrm{i} \ne \mathrm{s} \in \mathrm{I},\ \mathrm{s} \in \mathrm{D} \tag{3}$$

$$\mathrm{k_i} \ge \sum_{a \in A_i^-} (\mathrm{x_{as}}) + \sum_{a \in A_i^+} (\mathrm{x_{as}}) \text{ for all } \mathrm{i} \in \mathrm{I} \tag{4}$$

$$\mathrm{RC_n} \ge \sum_{a \in A} (\mathrm{x_{as}}) \delta_{\frac{a}{n}} \text{ for } \mathrm{l} \in \mathrm{L_n},\ \mathrm{n} \in \mathrm{N} \tag{5}$$

$$\mathrm{x_{as}} \ge 0 \text{ for all } \mathrm{a} \in \mathrm{A},\ \mathrm{s} \in \mathrm{D} \tag{6}$$

To calculate the expected dwell time for a full container at the port i en route to destination port s we use:

$$tw_{is} = \frac{x_{is}}{\sum_{a \in L_{is}^f} f_a} \tag{7}$$

Furthermore, to determine the vessel docking time at origin and destination port we use:

$$ts_i = \frac{\mathrm{x_a}}{\mathrm{KBM_i}} \tag{8}$$

$$ts_s = \frac{\mathrm{x_a}}{\mathrm{KBM_s}} \tag{9}$$

Our mathematical model's objective function is the sum of operational shipping cost, loading-unloading cost, container warehousing cost, and ship docking cost. Note that the fuel and vessel's depreciation costs are treated as fixed. Constraint (1) ensures the equality of the incoming and outgoing container flow at the transhipment ports, while at the origin and destination port, the container flow must be fulfilled the container assignment value, as given in constraint (2). Constraint (3) depicts that the value of container flow on its legs that are attractive at port i is equal to the inverse of the combined shipping frequency. Constraint (4) indicates that the total of loaded and unloaded containers at a port does not exceed the port capacity. Constraint (5) ensures that each route's carried containers do not exceed the vessel's capacity. The last constraint (6) is to ensure that all the results should be a positive value. This linear program model can be solved using a simplex method or any linear programming solver, such as Microsoft excel solver and LINDO software used in this study to illustrate the model.

5. Numerical example and discussion

In order to simulate and illustrate our model, the following numerical example is provided. The shipping network for the numerical example in this study, presented in Fig. 1, is based on the current Indonesia container liner shipping system. All our numerical example data regarding the model parameters are primarily sourced from PT. Pelayaran Nasional Indonesia (PELNI), as one of the largest shipping company in Indonesia. In addition, the following assumptions were made for the shipping network:

- Dumai is the origin port in the westernmost of Indonesia and Merauke is the destination port in the easternmost of Indonesia.
- All containers are transported only from Dumai as the only origin port to Merauke as well as the only destination port and so on for the return, while the other ports just become the transhipment or loading unloading ports.

The numerical example was calculated through excel solver and software LINDO for the three existing scenarios. As mentioned before, scenario calculation is needed to analyse the model's ability to adapt to several conditions that often occur in container shipping. Basic data for the numerical example calculation are presented in Tables 1–3.

The decision variable presented through the container flow for each route then be used as an input in our scheduling calculation to allocate the vessels with their different capacities for each type to the current shipping routes. It determines the optimal shipping frequency according to the existing consumers' request. Therefore, the vessel's utility can be increased while the total shipping cost can be minimised. Furthermore, we also applied the greedy algorithm concepts to allocate the vessels with various sizes into the existing routes. As the greedy algorithm applied, a vessel with the biggest capacity should be assigned for the route with the highest demand and so on until the smallest vessel will be assigned for the lowest demand. In this case, the demand means the total value of containers transported from the origin port to the destination port on each route. Meanwhile, the shipping frequency is obtained by dividing the container flow on each route with the vessel capacity assigned on the route.

In the first scenario, 150 containers are transported from Dumai as the origin port to Merauke as the destination port, and 100 containers will be transported from Merauke to Dumai. The calculation results for the first scenario can be seen in Table 4.

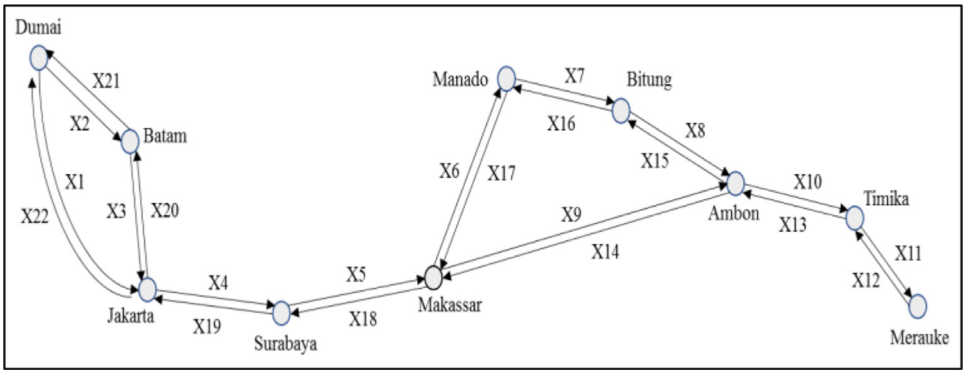

Fig. 1. Shipping Network Scheme.

Table 1
Basic Costs.

No	Port	Loading-Unloading Cost		Container Warehousing Cost		Ship Docking Cost	
		IDR/TEUS	US$/TEUS	IDR/TEUS/Day	US$/TEUS/Day	IDR/GRT/Day	US$/GRT/Day
1	Dumai	600,000	42.43	7,500	0.53	1,800	0.13
2	Batam	627,300	44.36	6,000	0.42	1,100	0.08
3	Jakarta	900,000	63.65	7,000	0.50	1,200	0.08
4	Surabaya	728,000	51.48	7,000	0.50	1,200	0.08
5	Makassar	623,000	44.06	8,000	0.57	1,400	0.10
6	Manado	627,300	44.36	7,000	0.50	1,800	0.13
7	Bitung	623,000	44.06	8,000	0.57	1,400	0.10
8	Ambon	1,120,000	79.20	8,000	0.57	1,400	0.10
9	Timika	1,700,000	120.22	10,000	0.71	1,800	0.13
10	Merauke	2,000,000	141.44	11,000	0.78	1,800	0.13

Source: PT PELNI, 2019.

Table 2
Vessels Deadweight, Capacity, and Speed.

No	Vessel	Deadweight (Ton)	Capacity (TEUS)	Speed (knots)
1	KM Caraka Jaya Niaga III-4	3,000	112	10
2	KM Logistik Nusantara 1	5,822	180	10
3	KM Kendhaga Nusantara 1	2,193	100	10
4	KM Caraka Jaya Niaga III-32	3,650	115	10
5	KM Logistik Nusantara 3	3,901	124	10
6	KM Logistik Nusantara 4	3,901	124	10
7	KM Logistik Nusantara 2	4,500	145	10
8	KM Caraka Jaya Niaga III-22	3,901	124	10

Source: PT PELNI, 2019.

The second scenario develops from the first scenario, where in the second scenario, 150 containers are transported from Dumai to Merauke. However, a transhipment port as a loading port that participates in sending 25 containers to Merauke as the destination, while the return route is the same as the first scenario. The result for the second scenario calculation can be seen in Table 5.

The third scenario is also the development of the first scenario, where in the third scenario 150 containers will be transported from Dumai to Merauke, but there is a transhipment port as an unloading port that will receive 25 containers from the origin port, while the return route is also the same as the first scenario. The result of the third scenario calculation can be seen in Table 6.

As the numerical example calculation results have been obtained, the three scenarios of container assignment problem calculation in this study provide the same number of decision variables for each scenario because the shipping network is the same for each scenario. Therefore, we can see that the calculation results provide 22 decision variable values for each scenario. Based on the objective function values, it can be seen that the results are different for each scenario because the total container flow on each route is different. A shipping network with a more considerable total container flow value that must be transported requires a higher total container shipping cost. It is proven by the objective function value of each scenario, where scenario 2 has the most expensive shipping cost because the network of scenario 2 has the most significant total container flow value, which is 175 containers in total. In contrast, scenario 3 has the cheapest shipping cost because its network has the smallest total container flow value, 125 containers in total. Furthermore, we can see that Microsoft Excel Solver and LINDO software provide the same results for the decision variables and objective function values for all scenarios. It shows that the optimal solution value from the developed mathematical model is correct.

On the other side, based on the scheduling results, we can see that the vessels allocation and the shipping frequency are different for each scenario. It happens because the total container flow that must be transported on each route is different for each scenario. Overall, it can be seen that the scheduling results can minimise the shipping frequency for each month according to the existing request. However, it can also be seen that some routes produce more often shipping frequency compared to the existing frequency,

Table 3
Shipping Route, Distance, Sailing Time, and Shipping Frequency.

Notation	Port		Distance (Nm)	Sailing Time (hour)	Sailing Time (day)	Frequency (Number of trips/month)
	a	s				
X_1	Dumai	Jakarta	687	69	2.88	4
X_2	Dumai	Batam	189	19	0.79	4
X_3	Batam	Jakarta	598	60	2.50	4
X_4	Jakarta	Surabaya	386	23	0.96	10
X_5	Surabaya	Makassar	437	44	1.83	10
X_6	Makassar	Manado	812	82	3.42	6
X_7	Manado	Bitung	63	8	0.33	4
X_8	Bitung	Ambon	551	56	2.33	4
X_9	Makassar	Ambon	587	59	2.46	4
X_{10}	Ambon	Timika	537	55	2.29	4
X_{11}	Timika	Merauke	357	36	1.50	2
X_{12}	Merauke	Timika	357	36	1.50	2
X_{13}	Timika	Ambon	537	55	2.29	4
X_{14}	Ambon	Makassar	587	59	2.46	4
X_{15}	Ambon	Bitung	551	56	2.33	4
X_{16}	Bitung	Manado	63	8	0.33	4
X_{17}	Manado	Makassar	812	82	3.42	6
X_{18}	Makassar	Surabaya	437	44	1.83	10
X_{19}	Surabaya	Jakarta	386	23	0.96	10
X_{20}	Jakarta	Batam	598	60	2.50	4
X_{21}	Batam	Dumai	189	19	0.79	4
X_{22}	Jakarta	Dumai	687	69	2.88	4

Source: PT PELNI, 2019.

Table 4
Calculation Results for Scenario 1.

Notation	Decision Variable (TEUS)	Vessel	Frequency (Number of trips/month)
X_1	75	KM Caraka Jaya Niaga III-22	3
X_2	75	KM Caraka Jaya Niaga III-32	3
X_3	75	KM Caraka Jaya Niaga III-32	4
X_4	150	KM Logistik Nusantara 1	10
X_5	150	KM Logistik Nusantara 2	13
X_6	90	KM Logistik Nusantara 3	6
X_7	90	KM Logistik Nusantara 4	4
X_8	90	KM Logistik Nusantara 4	4
X_9	60	KM Kendhaga Nusantara 1	3
X_{10}	150	KM Logistik Nusantara 2	5
X_{11}	150	KM Caraka Jaya Niaga III-4	4
X_{12}	100	KM Caraka Jaya Niaga III-4	4
X_{13}	100	KM Logistik Nusantara 2	5
X_{14}	50	KM Kendhaga Nusantara 1	3
X_{15}	50	KM Logistik Nusantara 4	4
X_{16}	50	KM Logistik Nusantara 4	4
X_{17}	50	KM Logistik Nusantara 3	6
X_{18}	100	KM Logistik Nusantara 2	13
X_{19}	100	KM Logistik Nusantara 1	10
X_{20}	50	KM Caraka Jaya Niaga III-32	4
X_{21}	50	KM Caraka Jaya Niaga III-32	3
X_{22}	50	KM Caraka Jaya Niaga III-22	3
	Objective Function Value	IDR	4,417,469,065
	US$	312,393.90	

Table 5
Calculation Results for Scenario 2.

Notation	Decision Variable (TEUS)	Vessel	Frequency (Number of trips/month)
X_1	75	KM Caraka Jaya Niaga III-32	3
X_2	75	KM Caraka Jaya Niaga III-4	3
X_3	100	KM Caraka Jaya Niaga III-22	3
X_4	175	KM Logistik Nusantara 1	9
X_5	175	KM Logistik Nusantara 2	11
X_6	105	KM Logistik Nusantara 3	5
X_7	105	KM Logistik Nusantara 4	3
X_8	105	KM Logistik Nusantara 4	3
X_9	70	KM Kendhaga Nusantara 1	3
X_{10}	175	KM Logistik Nusantara 2	5
X_{11}	175	KM Caraka Jaya Niaga III-32	3
X_{12}	100	KM Caraka Jaya Niaga III-32	3
X_{13}	100	KM Logistik Nusantara 2	5
X_{14}	50	KM Kendhaga Nusantara 1	3
X_{15}	50	KM Logistik Nusantara 4	3
X_{16}	50	KM Logistik Nusantara 4	3
X_{17}	50	KM Logistik Nusantara 3	5
X_{18}	100	KM Logistik Nusantara 2	11
X_{19}	100	KM Logistik Nusantara 1	9
X_{20}	50	KM Caraka Jaya Niaga III-22	3
X_{21}	50	KM Caraka Jaya Niaga III-4	3
X_{22}	50	KM Caraka Jaya Niaga III-32	3
	Objective Function Value	IDR	4,843,723,859
	US$	342,537.72	

whereas to reduce total shipping costs, the proposed frequency should be smaller than the existing frequency. It might happen as one of the greedy algorithm effects, where vessels with the largest capacity should be allocated into the route with the most significant total container flow that must be transported and so on until the smallest so that it is probable that the assigned vessel has a smaller capacity than the previous one. That is why several routes could have more shipping frequency than the current running.

6. Conclusion and further research

This study provides a modified cost-based container assignment model described in Bell et al. (2013). The model assumed that the routes, sailing time, ports and vessels capacity, the current shipping frequency, and all basic costs considered in the model are known. The containers are assigned to the existing route to minimise the total shipping costs and increase the vessel's utility at once by taking the ports and vessels capacity as the constraints. As the feasible results of the numerical example have been obtained, it can be concluded that total shipping cost for the voyage with the more considerable total container flow value is as follows:

- The value of total shipping costs is affected mainly by the total container flow that must be transported. The more the container, the more the cost will be.

Table 6
Calculation Results for Scenario 3.

Notation	Decision Variable (TEUS)	Vessel	Frequency (Number of trips/month)
X_1	75	KM Caraka Jaya Niaga III-32	3
X_2	75	KM Caraka Jaya Niaga III-4	3
X_3	75	KM Caraka Jaya Niaga III-22	3
X_4	150	KM Logistik Nusantara 1	9
X_5	150	KM Logistik Nusantara 2	11
X_6	90	KM Logistik Nusantara 3	4
X_7	90	KM Logistik Nusantara 4	3
X_8	65	KM Logistik Nusantara 4	3
X_9	60	KM Kendhaga Nusantara 1	3
X_{10}	125	KM Logistik Nusantara 2	5
X_{11}	125	KM Caraka Jaya Niaga III-32	3
X_{12}	100	KM Caraka Jaya Niaga III-32	3
X_{13}	100	KM Logistik Nusantara 2	5
X_{14}	50	KM Kendhaga Nusantara 1	3
X_{15}	50	KM Logistik Nusantara 4	3
X_{16}	50	KM Logistik Nusantara 4	3
X_{17}	50	KM Logistik Nusantara 3	4
X_{18}	100	KM Logistik Nusantara 2	11
X_{19}	100	KM Logistik Nusantara 1	9
X_{20}	50	KM Caraka Jaya Niaga III-22	3
X_{21}	50	KM Caraka Jaya Niaga III-4	3
X_{22}	50	KM Caraka Jaya Niaga III-32	3
	Objective Function Value	IDR	4,177,475,033
	US$	295,442.03	

- The scheduling results provide different vessels allocation and shipping frequencies for each scenario according to the container flow value.

As our model is a linear program, it also can be applied to an extensive shipping network efficiently using a linear programming solver, as we used Microsoft excel solver and LINDO software in this study. The maritime container assignment model will usually provide valuable information for the shipping company, including port authorities, customers, and third-party carriers, to inform the decision-making. It will help the shipping company design a new shipping network or predict the consequences of changing shipping frequencies and vessel sizes. It will also help the port authorities to predict the alternative master plans about the investment and revenue projection. The customers might plan their container journey efficiently as well.

Our model assumes that all parameters data are mostly must be given for the model calculation. There is a new challenge in the future study to develop a network design problem by looking at the route or vessel size optimisation leading to the formulation. On the other side, our scheduling calculation is presented to allocate the vessels to the existing routes and determine the optimal shipping frequency to increase the vessel's utility without generating the specific time such as departure, arrival, and transit time on each port or considering the cargo's value. Thus, further work is needed to conduct a specific scheduling calculation to generate a specific time, such as departure, arrival, and transit time on each port and considering the cargo's value. Moreover, it is suggested to develop a different scenario to analysis the vessel's utility specifically. Other researchers might also modify our current model properties such as the objective function, the constrain, or the cost parameters according to the latest transformation of container shipping conditions.

Declarations of interest

None.

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