Ship Routing Problem Transporting Two Types of Commodities

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1. INTRODUCTION

In real transportation problem, ship often requires to deliver/pickup the same single cargo/commodity or multiple types of commodities. For liner shipping problem in Indonesia which is considered in this study, the study aims to develop minimum cost of weekly routes for a given heterogeneous fleet of semi-container ships transporting two types of commodities (container and un-containerized cargos). Moreover, the study aims to figure the CO2 emission caused by the operation of selected fleet of ships. In this study, the container unit loaded in the ship is counted in TEU while the un-containerized cargo is counted in ton unit.

Demands are spread by geographical area with given number of cargos to be delivered from a hub port (distribution center) in one week. Since the number of loaded containers onboard the ship usually the same, in the demand data, it is assumed that only the transportation of full containers influences the capacity constraints. It is also assumed that returning ship to the depot may carry at most the same capacity of cargos that are delivered at ports. In this condition, there is no difference between deliver and pickup cargos.

Ships are allowed to make several routes or multiple trips are allowed for each ship in the fleet as long as the total duration for each routes combination does not exceed planning period of one week. Instead of reducing some amount of slack time into planning horizon, in order to cover the uncertainty or slack time among the route time due to weather, sea current condition, navigation time etc., the average port time is considered in this study. The average time of operation in port was assumed based on average waiting time at port in Indonesia which is 16 hours. In this study, the average operation time of ships in port including waiting time is assumed to be 24 hours. Therefore, the problem of deciding weekly routes for semi-container ship can be considered as multi-trip and multi-commodity vehicle routing problem.

2. SOLUTION APPROACH

To solve the problem, we underlie the problem into routes generation and route selection sub problems. There are two phases in the routes generation sub problems. In phase 1, by giving demand, distance data, and available ships with different types (capacity and speed) a set of feasible single routes are generated for each ship type. In order to find the optimal routes with minimum cost including the cost due to CO2 emitted by the ships, the traveling salesman problem procedure which is implemented to find minimal distance route may consist of calculating all cost components such as fixed cost $F_k$, operational cost $O_k$ and cost due to CO2 emission $E_k$. Feasible routes are defined if capacity for both type of cargos loaded in ships do not exceed ship capacity and route time for making a route is less than one week. In phase 2, multiple trips were performed by combining single routes obtained in phase 1 as long as the combined routes do not exceed one week. Following figure shows illustration of route combination done in phase 2.

![Fig.1 Generation of multiple routes](image_url)

Selection of minimum routes cost is done in phase 3 by formulating the problem into set partitioning problem. The set partitioning problem is solved using commercial software called LINGO 6.0 that employs branch-and-bound method in order to cover integer variables that appear in the model. Therefore, the set partitioning problem is defined as follows:

$$\text{Min } \sum_{r \in R} (C_{p,r}^i + C_{o,r}^i + C_{e,r}^i)x_k^r$$

subject to:

$$\sum_{k \in K} A_{k}^i x_k^r = 1, \forall i \in N^r, \tag{2}$$

$$x_k^r \in \{0,1\}, \forall r \in R^i \tag{3}$$

The objective function (1) aims to select minimum cost of routes driven by fixed cost, operational cost, and cost due to CO2 emission. Constraints (2) assure that each port $i$ necessary to be served by route $r$ exactly once. The notation of $A_{k}^i$ are constants that equal to one if port $i$ served by route $r$ using ship $k$ and zero otherwise. The notation of $x_k^r$ are decision

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variables that equal to one if chosen in optimality and zero otherwise. The equation which is used for CO₂ calculation is defined as the following equation.

\[ CO₂ \text{ emission} (kg) = \frac{SFOC}{\rho} \cdot NCR \cdot t_r \cdot ER \]  

(4)

SFOC is specific fuel oil consumption (0.128 kg/bhp.hr), \(\rho\) is density of marine fuel oil (0.96 kg/l), NCR is normal continuous rating of main engine which is 0.85 of maximum continuous rating. \(t_r\) is time to operate main engine and diesel generator in all conditions (sea time, port time, and idle time). CO₂ emission ratio (ER) is (2.939 kg/l). Moreover the cost due to CO₂ emitted by the ships per ton is USD. 10.9. This value is taken based on average prices of certified emission reduction in 2006.

3. NUMERICAL EXAMPLE

Solution method is applied to a set of ports in a hub-and-spokes environment. Seven ports(index) in Indonesia are studied; Surabaya(1), Semarang(2), Sampit(3), Samarinda(4), Balikpapan(5), Makassar(6), and Pantoloan(7). As a second largest port in Indonesia, Surabaya, which is located in East Java was selected as a hub port and other ports as feeder ports/spokes. Table 1 shows the demand at each port.

<table>
<thead>
<tr>
<th>Port index</th>
<th>Port</th>
<th>Container (TEU)</th>
<th>Un-containerized cargo (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surabaya</td>
<td>24</td>
<td>425</td>
</tr>
<tr>
<td>2</td>
<td>Semarang</td>
<td>14</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>Sampit</td>
<td>31</td>
<td>490</td>
</tr>
<tr>
<td>4</td>
<td>Samarinda</td>
<td>37</td>
<td>530</td>
</tr>
<tr>
<td>5</td>
<td>Balikpapan</td>
<td>40</td>
<td>635</td>
</tr>
<tr>
<td>6</td>
<td>Makassar</td>
<td>12</td>
<td>175</td>
</tr>
</tbody>
</table>

16 alternatives ship varies in size (dwt/TEU cap./cargo cap.) (1500/40/780, 2500/55/1510, 3500/70/2240, 4180/80/2740 DWT) and speed (12.5, 15, 17.5, 20) with their cost structures are examined. In Indonesia, most of shipping companies operate their ships in the speed of 10-15 knot. However, in this study faster ships (above 15 knot) are considered in order to investigate the possibility of faster ships to be deployed in Indonesian liner shipping routes. Oil prices data used in this study is based on oil prices condition in Indonesia on 15 May 2008. The prices are USD. 654.50 and USD. 2,730 for marine fuel oil and lubricating oil respectively.

Fig. 2 presents minimum cost routes that achieved by employing three 1500 DWT ships and one 2500 DWT ship with the speed of all ships is 12.5 knot while Fig. 3 shows composition of total transportation costs. Total transportation costs are USD. 62,001.79.

Fig.3 Cost compositions

In addition, faster process time in port (12 hours) was simulated in order to investigate whether faster process time in port will significantly reduce total transportation cost as well as CO₂ emission. The result can be seen in Fig. 4. This figure shows, by faster process time, more possibility for 12.5 knot ships to make multiple routes in one week. As a result, only three ships are employed to cover the network as shown in the figure and total transportation costs are USD. 55,804.90 (10% lower than 24 hour port time).

Fig.4 Weekly minimum cost routes for faster port time

Lower weekly CO₂ emission can also be achieved by giving faster process time in port. 24 hours port time gives 135.03 ton CO₂ emission in comparison with 105.80 ton by 12 hours port time (21.65% lower).

4. CONCLUSION

In this paper, the method of ship routing design for liner shipping that operates semi containerships has been presented. The ships in a fleet are allowed to make several routes within a week. The problem was underlined into two subproblems and the proposed approach worked well on a given numerical example. Two different port times were examined and CO₂ emission for two scenarios has been shown.

ACKNOWLEDGMENT

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