Approaches Method to Solve Ships Routing Problem with an Application to the Indonesian National Shipping Company

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Abstract: - In archipelagic countries with long shorelines or with many wide rivers, water transportation may play a significant role also in domestic trades, e.g. Indonesia. Indonesia is an archipelago that includes roughly 17,508 islands where the total area is 741,052 square miles and with an area of ocean is 35,908 square miles. The Indonesian archipelago stretches 3181 miles from east to west (Longitude: 97ºE - 141°E) and 1094 miles from north to south (Latitude: 6°N - 11ºS). Indonesia needs a system of sea-based for inter-island transportation that can assist in overcoming isolation arising from geographic differences. Sea-based transportation systems depend on effectiveness of the route and ships. This research proposes a method called CAB-Method and help to find a set of routes giving minimal total travel cost satisfying some constrains are specification of the ships, and sea-depth in the ports. From the result presented shows that route made by CAB-Method will increase the performance improvement of PT. PELNI (PT. PELayaran Nasional Indonesia = the Indonesian National Shipping Company) by save the total cost about $US 75,957.20 for serve all port in Indonesia and also with more number port visited, compared existing route. Increasing number port visited will increase the number of passengers who could be served.

Key-Words: - CAB-Method, PELNI, Vehicle Routing Problem, Ship, Transportation

1 Introduction
Transportation is a basic of develop the people and economic, and increasing the growth of nation industry. Geographic location of a region will affect the efficient transportation system. In archipelagic countries with long shorelines or many wide rivers, water transportation play a significant role and also in domestic trades, e.g. Philippines, Indonesia, and Japan. And for the wider situation, water transportation is the major conduit of international trade. It is causes the share of its weight borne by sea.

The need transport sea will cause the ship as well as his supporter (port, route and management) to have to be increased [1, 9, 10]. Ships come in a variety of types who each made for different uses. Ships operate between ports. Ports are used for loading and unloading cargo/passenger as well as for loading fuel, fresh water and supplies, and discharging waste. Ports impose physical limitations on the dimensions of the ships (ship draft, length and width), and usually charge fees for their services.

In order to be able to make strategic decisions one usually needs some tactical or even operational information. Models used for fleet size and network design decisions often require evaluation of ship routing strategies. Such routing models usually fall into one of two categories, arc flow models or path flow models [10]:

1. In arc flow models a binary variable is used to represent whether a specific vessel v travels directly from port (or customer) i to port (or customer) j. The model constructs the routes that will be used by the vessels and the model have to keep track of both travel time and load on each vessel.

2. In path flow models the routes are predefined, one way or another and a binary variable represents whether vessel v performs route r. A route is usually a full schedule for the vessel that specifies expected arrival times and load on the vessel along the route. Such a model can focus on the set of ports or customers to serve, and only feasible routes are considered.
Shipping routes may be classified according to their geographical characteristic of the ports (e.g. sea-depth); and the corresponding type and size of vessel used (e.g. ship draft and speed). Design route for path flow model seen as VRP. The VRP arises naturally as a central problem in the fields of transportation, distribution, and logistics [6]. The VRP may actually be considered a broad class of routing problems, composed of many specific variants of the basic definition. Some of these VRP variants and their unique constraints are presented below [3, 5, 12]:

1. Capacitated Vehicle Routing Problem (CVRP), VRP with the additional constraint that all vehicles within the fleet have a uniform carrying capacity of a single commodity. The commodity demand along any route assigned to a vehicle must not exceed the capacity of the vehicle.
   a. Heterogeneous CVRP (or Mixed Fleet CVRP), the fleet is composed of different vehicle types.
   b. Homogeneous CVRP (or Uniform Fleet CVRP), each vehicle in the fleet has the same capacity.
2. Site Dependent Capacitated VRP (SDCVRP), is a variant of the Heterogeneous Capacitated VRP where there exists a dependency between the type of vehicle and the customer, meaning that not every type of vehicle can serve every type of customer because of site-dependent restrictions.
3. Multiple Depots VRP (MDVRP).

Note that these variants do not necessarily exclude each other, combinations of two or more of these variants can be made to form more complex variants of the VRP.

2 Problem Description

This study is a combination of SD-CVRP and multiple depots by adding constrain, the fuel port. Which variants of the VRP with multiple depots are referenced to as MD-VRP. Since the fleet is composed of different vehicle types (Heterogeneous CVRP) then there exists a dependency between the type of vehicle and the customer, meaning that not every type of vehicle can serve every type of port because of site-dependent restrictions (Site Dependent CVRP).

The problem solution consists in determining a feasible set of routes $R_{ps}$ served by ships $s$, with constrain:
1. The objective function is expected to minimize the total voyage cost
2. All the ports should be served
3. Each port is served by minimum a ship.
4. Each ship is assigned exactly once by exactly one route.

Let,
- $P$ is a port set, and each port $(p \in P)$ with a different geographical characteristic is sea-depth, $h_p$, in meter. $P$ port set has some $F$ fuel port, $F \subset P$.
- $i$ is a departure port and $j$ is an arrive port.
- $d_{ij}$ denotes the distance from port $i$ to port $j$ in nautical miles, and travel from port $i$ to port $j$ does matter, so $d_{ij} \neq d_{ji}$ for all port $i$ and $j$.
- $S$ is a ship set, and each ship $(s \in S)$ has a different ship drafts ($\delta$, in meter) and speeds ($V_s$, in knot).

$R_{ps}$ is a set of feasible route for port $p$, which port $p$ is feasible served by ship $s$ with hard constrains:
1. The path between all ports in a feasible route for ships $s$ (called a total voyage) of any route does not longer than $D$, $D$ is the total travel time allowed.
2. Ship $s$ with ship draft $\delta$ will serve route $r$, without exceed the sea-depth in any port in $R_{ps}$.
3. The set of feasible route $R_{ps}$ has minimum one fuel port.

3 Model Formulation

The classical VRP can be defined as follow [8], let $G = (V, A)$ be a graph where $V = \{1, \ldots, n\}$ is a set of vertices representing cities with the depot located at vertex 1, and $A = \{(v_i, v_j) \mid v_i, v_j \in V, i < j\}$ is the set of arcs. With every arc $(i, j)$ is associated a non-negative distance matrix $C = (c_{ij})$. In some contexts, $c_{ij}$ can be interpreted as a travel time or a travel cost.

In order to present the mathematical formulation of the models, needs to follow notations:
- $S$ set of ships to be scheduled, indexed by $s$
- $P$ set of ports, indexed by $i, j, p$
- $R$ set of route, indexed by $r$
- $R_{ps}$ set of feasible route clusters for ship $s$ to serve port $p$ without exceed the constrains, indexed by $r_{ps}$
- $R_{is}$ set of route clusters for ship $s$ with leaving port $i$, indexed by $r_{is}$
- $NS$ Number of ships to be scheduled.
- $NP$ Number of ports.
- $NR_{ps}$ Number of feasible routes for ship $s$ to serve port $p$ without exceed the constrains.
- $F$ fuel port, $F \subset P$.

Parameters:
- $Cost(R_{ps})$ is the cost of assigning a ship $s$ to route cluster $R_{ps}$.
- $Y_{ris}$ is a binary variable that equal to 1 if route $r$ served by ship $s$ and leaving a port $i$; and 0 otherwise.
Variable:

- $X_{rs}$ is a binary variable that equal to 1 if route $r$ served by ship $s$ and it is selected in the solution; and 0 otherwise.

\[
\text{minimize } \sum_{k \in K} \sum_{s \in S} \text{Cost}(R_{ps}) \cdot X_{rs} \quad (1)
\]

\[
\sum_{r \in R} \sum_{s \in S} X_{rs} \cdot Y_{rs} = 1, \quad \forall i \in P
\]

\[
\sum_{r \in R} X_{rs} = 1, \quad \forall s \in S
\]

\[
X_{rs} \in \{0,1\}, \quad \forall s \in S, \quad \forall r \in R_{ps}
\]

Constraint (1) the objective function is minimizes the transportation costs; Constraint (2) ensure that all ports are serviced; Constraint (3) ensure that route $r$ served by ship $k$ and it is selected in the solution; and Constraint (4) imposes binary requirements on the variables.

In order to present mathematical formulation of the constrain model that needs the following notation:

- $\alpha$: Penalty associated with constrain violation respect to the sea-depth and ship-draft.
- $\beta$: Penalty associated with constrain violation respect to the route without any fuel port.

Since the ship is composed of different ship types then there exists a dependency between the type of ship and the port, meaning that not every type of vehicle can serve every type of port. This study introduces a variable $\alpha$ that is 1 if the ship draft < sea-depth, and 0 otherwise.

\[
\sum_{i \in P} \delta_s < h_p \quad (5)
\]

\[
\sum_{s \in S} X_{rs} + \alpha_i = 1, \quad \forall i \in P
\]

Restrictions (5) and (6) ensure that the ship-draft of the ships should not same or exceed the sea-depth of the ports.

The other constrain is route served by ships $k$ should possess a fuel-port. This study introduces a variable $\beta$ that is 0 if the route $r$ has not a fuel port and 1 otherwise.

\[
\sum_{i \in P} F \geq 1, \quad F \subseteq P \quad (7)
\]

\[
\sum_{r \in R} X_{rs} + \beta = 1, \quad \forall i \in P
\]

\[
X_{rs} \in \{0,1\}, \quad \forall i \in P
\]

\[
\alpha_i \in \{0,1\}, \quad \forall i \in P
\]

\[
\beta_i \in \{0,1\}, \quad \forall i \in P
\]

Restrictions (7) and (8) ensure that the route $r$ possess a fuel port. Which (9), (10), and (11) are imposes binary requirements on the variables.

4 CAB-Method

The approximate algorithm used to solve VRP. The approximate algorithm mainly includes two kinds of algorithms, constructive heuristic algorithm and meta-heuristic algorithm. Some research efforts were oriented towards the development and analysis of approximate heuristic techniques capable of solving real VRP problems. Bowerman et al. [15] classified the heuristic approaches to the VRP into five classes:

1. Cluster-first and route-second (CFRS),
2. Route-first and cluster-second (RFCS),
3. Savings and insertion,
4. Improvement and exchange,
5. Simpler mathematical programming representations through relaxing some constraints.

This study proposes 3-phases algorithm, CAB-Method:

1. Clustering the ports based on total of the travel time allowed
2. Assign vehicles to the routes in conformance with the restrictions on ships and ports.

4.1 Cluster Ports

Anderberg [13] stated that a clustering is a classification technique to group a set of objects into clusters such that the objects in the same cluster are similar in some sense and those in different clusters are dissimilar in the same sense. Cluster-Algorithm in this phase used for solving cluster problem based on soft constrain, as example: load factor, travel distance and other. Clustering is performed to ensure the appropriate port into groups based on soft constraints.

Phase 1: Let, $P$ is a set of port \{p1, p2, ... NP\}, $S$ is a set of ships \{s1, s2, ... NS\}, and $R_{ps}$ \{r1, r2, ... NR_{ps}\} is a set of feasible route for ship $s$ to serve port $p$ without exceed the restrain. For port cluster \{Cluster(p,s): p \in P, s \in S\}.

Phase 2: Starting with the port, $p_n$ and ship, $s_n$ \{n=1, 2, ..., n\} For port cluster \{Cluster(p,s): p \in P, s \in S\}.

Phase 3: Sort the port and keep inserting the nearest unvisited port. Assign port to new route without exceed the restrain, $D$.

Phase 4: Calculate total $D$ of the ports, which $(D = D_{n-1} + D_n)$:

- If the any ports of the route is not exceed the restrain D, keep the port $p_{n+1}$ that available for ship $s_n$ into route cluster $R_{ps}$ and then the cycle index $n=n+1$ for the next port $(p_{n+1})$, return to phase 3.
• Otherwise, leave the port $p_{n-1}$ and then the cycle index $n=n+1$ for the next ship $(s_{n+1})$, go to phase 2 for next route.

Phase 5: Finish the algorithm until all ports served by all ships, and ensure the appropriate ports into cluster groups $R_{ps}$. The example is show in Figure 1.

4.3 Build Heuristic or Meta-heuristic

Build heuristic or meta-heuristic based on two phases above (clustering the ports and assign vehicle) for the best solution. Types of heuristic methods many exist [11, 12, 16] and there are some AI-oriented methods [3, 5], which can be roughly categorized into:

1. Construction algorithms
   - Start with an empty route and extend it gradually, keeping the total cost as low as possible.

2. Tour Splitting Algorithms
   - Start with one big tour and split it into capacity-feasible sub-tours.

3. Savings based algorithms
   - Start with a lot of small routes and combine them as long as this improves the solution (“combine and conquer”).

This research used heuristic method to determine the optimal solution of the problem and should ensure the restraints are not violated, that is: The combination of the selected routes (booths of clusters) is to have a lowest total cost with all the ports should be served, and the combinations of the routes will served by all ships.

5 Real World Problem

The proposed method is applied for the real-world problems. Transportation problem in PT. PELNI (PT. PELayaran Nasional Indonesia = the Indonesian National Shipping Company) interesting to use for testing proposed method, because:

1. Indonesia is an archipelago that includes roughly 17,508 islands Indonesia where the total area is 741,052 square miles and with an area of ocean is 35,908 square miles. The Indonesian archipelago stretches 3181 miles from east to west (Longitude: 97ºE - 141°E) and 1094 miles from north to south (Latitude: 6°N - 11ºS). Indonesia needs a system of inter-island transportation that can assist in overcoming isolation arising from geographic differences. And as developing country, the sea-based transports play an important role [19].

2. PT PELNI operated 26 passenger ships on January 2007 with differences in size and the speed. The ships will serve 96 ports that have a difference of geographic characteristics [2].

3. Generally, objective function of the concept for finding a set of ships routes is to minimize total voyage cost. Then becomes a problem is the real situation that PT. PELNI is Indonesian state-owned ship company. PT. PELNI apart from being based on the profit but must give priority to the interests of the people, in view of the fact that PT. PELNI as Indonesian national shipping company that involve in the service of the voyage service must could
become a link inter-island and give the contribution towards the transportation sea based mode in Indonesia. Therefore the objective is must to find a set of routes giving minimal total travel cost with maximal total distance travel [19].

6 Result and Analysis

Z. Ismail [18] proposes several ways for measuring the quality of heuristics and Silver et al. [4] stated that a good heuristic should possess the following four properties:
1. Realistic computational effort to obtain solution.
2. The solution should be close to the optimum on the average, i.e., we want good performance on the average.
3. The chance of a very poor solution (i.e., far from the optimum) should be law.
4. The heuristic should be as simple as possible for the user to understand, preferably explainable in intuitive terms, particularly if it is to be used manually.

During the execution for the compute result, the combination optimal solution is recorded in Table 1.

<table>
<thead>
<tr>
<th>ROUTE</th>
<th>PORT</th>
<th>DISTANCE (miles)</th>
<th>VOYAGE TIME (days)</th>
<th>COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Route</td>
<td>318</td>
<td>165,428</td>
<td>245.12</td>
<td>4,450,185.49</td>
</tr>
<tr>
<td>CAB-Method</td>
<td>472</td>
<td>162,743</td>
<td>249.68</td>
<td>4,254,228.26</td>
</tr>
</tbody>
</table>

All the data can be show in the following graph in Figures 2, 3 and 4. Figure 2 shows the sailing cost of existing route is about $US 4,450,185.49, and will decreasing to 4,254,228.26 with proposed route by using CAB-Method. The reduction in the voyage cost is $US 75,957.20.

Figure 2. Voyage cost

Figure 3 shows comparing both of existing route and route developed by CAB-Method. The total number ports that served by routes developed by CAB-Method is 472, and it is more than number port could served of existing route (318 ports). Increasing number of port visited will increase the number of passengers who could be served.

Figure 3. Number of port

Minimal cost on routes developed by the CAB-Method does not reduce the travel distance, as show in Figure 4.

Figure 4. Voyage time

The total voyage time to serve all port on the available route and satisfying some constrains as propose by CAB-Method is 249.68 days. It is more than total voyage time to serve all ports of the existing route, about 245.12 days. Increasing voyage time will increase time to serve passengers and it is meaning could be serving more passengers.

The results are compared both of existing route and route developed by CAB-Method; generally speaking, the performance of the routes could be improved by using the CAB-Method. CAB-Method able use to find minimal total travel cost and with maximal distance travel.
6 Conclusion
From the result presented shows that route made by CAB-Method will increase and improve performance of PT. PELNI (PT. PElayaran Nasional Indonesia = the Indonesian National Shipping Company) by save the total cost about $US 75,957.20 for serve all port in Indonesia.

Total number of ports visited will increase, 318 port when the routes developed by existing method and to 472 ports when the route developed by using CAB-methods; that enhance the performance of PT. PELNI as a link between islands in Indonesia.

Route develop by CAB-Method will increase the total round voyage time about 4.56 days and decreasing total travel distance about 2.683 miles. Increased round voyage time will be effects to the ability to serve more passengers.

From the results showed that CAB-method is one method that exciting to be studied its ability for solve routing problem and encourage further applications to other problems.

References: