Ship Routing Design for the Oily Liquid Waste Collection

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Summary

This paper addresses the issue of ship routing design for collecting and transporting the oily liquid waste from a number of ports to a waste treatment center. The aim is simultaneously to construct a set of ship routes and to determine the number and the types of ships in a fleet at the minimum total cost. The problem is considered as a vehicle routing problem with heterogeneous fleet of vehicles and multiple trips (VRPHMT). The VRPHMT is a combination of two variants of the classical vehicle routing problem (VRP) by including two additional features. The first is the heterogeneous fleet of vehicles where number and types of vehicles have to be determined, and the second is multiple trips where vehicles may perform more than one route or trip as long as the total duration of each vehicles does not exceed the planning period.

1. Introduction

This paper addresses the issue of ship routing design for collecting and transporting the oily liquid waste from a number of ports to a waste treatment center. The aim is simultaneously to construct a set of ship routes and to determine the number and the types of ships in a fleet at the minimum total cost. The total cost includes the sum of fixed cost depending on the ship type and variable cost depending on the ship type and the duration of sailing time.

The description of the ship routing design of the oily liquid waste collection has been described by Iskendar et al1. The ship routing design involves the problem for transporting the oily liquid waste from ports to a waste treatment center. In their work, a set of alternative routes is generated and the solution is found by evaluating the given routes. The alternative ship types for transporting the waste has not been considered yet.

In this paper, another solution approach for ship routing of the oily liquid waste collection problem is proposed. The problem is considered as a vehicle routing problem with heterogeneous fleet of vehicle and multiple trips (VRPHMT). The VRPHMT is a variant of the classical VRP that is a combination between the vehicle routing problem with heterogeneous fleet of vehicles (VRPH) and the vehicle routing problem with multiple trips (VRPMT).

In the VRPHMT, the ports, waste treatment center and ships in the oily liquid waste collection problem are considered as customers, depot, and vehicles, respectively. Three constraints are included, i.e., ship's capacity, port's water depth, and time (planning period). In the capacity constraint, a ship performs a particular route as long as the total demand of ports belonging to that route does not exceed its capacity. The water depth constraints ensure that a ship services a route if its draft is less than the water depth

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Received 10th July 2001
Read at the Autumn meeting 15, 16th Nov. 2001
of any port in that route. The time constraints state
that the total sailing time of any route must be less
than or equal to the planning period given.

This paper is organized as follows. The VRPHMT is
outlined in Section 2. A description of the oily waste
collection problem is presented in Section 3. In this
section, information necessary for designing ship
routes is presented. Because of unavailability of the
ship specifications including technical and cost data,
simple linear regression equations are made to
roughly estimate relevant data. In Section 4, the
solution approach of the VRPHMT is given. The
solution result is given in Section 5. The last section
gives the conclusion.

2. Vehicle routing problem with heterogeneous
fleet of vehicles and multiple trips

The vehicle routing problem (VRP) is a problem in
which a set of geographically dispersed customers
with known demands must be served with a fleet of
vehicles stationed at a central facility or depot such a
way as to minimize a particular objective. The VRP is
one of important concerns in the distribution
management.

The vehicle routing problem with heterogeneous
fleet of vehicles and multiple trips is a combination of
two variants of the classical VRP. The vehicle routing
problem with heterogeneous fleet of vehicles (VRPH)
differs from the classical VRP in that the VRPH deals
with a heterogeneous fleet of vehicles. The classical
VRP assumes that a fixed number of vehicles with the
known capacity are already available. The VRPH
chooses the number and the types of vehicles in the
fleet from known available types and construct a set of
routes for every vehicle where vehicles may perform several
routes.

To our knowledge, the variant of a combination of
the VRPH and VRPMT is relatively new and one of
few studies was done by Fagerholt10,11). The aim of this
variant is simultaneously to determine number and
types of vehicles in the fleet from known available
types and construct a set of routes for every vehicle
where vehicles may perform several routes.

The VRPHMT can be defined as the VRPH by
adding the feature that the vehicles may perform
several routes. The following we define the VRPHMT
adapted from the definition of the VRPH defined by
Gendreau et al.5). Let $G = (V, A)$ be directed graph
where $V = \{v_0, v_1, ..., v_n\}$ is the node set and $A = \{(v_i, v_j) : v_i, v_j \in V, i \neq j\}$ is the link set. Node $v_0$ represents a
depot at which a fleet of vehicles is based, while the
remaining nodes correspond to customers. Each
customer $v_i$ has a non-negative demand $q_i$. There are $k$
vehicle types available. The fixed cost of a vehicle of
type $k$ is denoted by $f_k$, the variable cost per distance
unit of a vehicle of type $k$ by $g_k$, the capacity of a
vehicle of type $k$ by $Q_k$. The number of vehicles of each
type is assumed to be unlimited. Each link $(v_i, v_j)$ is
associated with a distance $d_{ij}$. The VRPHMT is to
construct a set of vehicle routes starting and ending at
the depot such that each customer is visited exactly
once, and the total demand of a route does not exceed
the capacity of vehicle assigned to that route. The
vehicles may perform several routes as long as the
total duration of the routes for each vehicle does not
exceed the planning period.

As we know that exact formulations of the classical
VRP can be stated as the traveling salesman problem
(TSP)-based formulation or the set partitioning
problem (SPP)-based formulation. The presence of
multiple trips makes it difficult to be formulated as
TSP-based formulation. To our knowledge, no exact
formulation based on TSP exists for this variant. To
find the exact solution, this problem can be solved using set partitioning problem (SPP)-based formulation. Explanation of SPP-based formulation for the classical VRP can be found in Christofides et al.12).

The SPP-based formulation is applied by Fagerholt11) in his solution approach. Before applying the formulation, first the approach generates single routes that are feasible with respect to capacity and time constraints. The next phase is to combine single routes to multiple routes. Each feasible combination must satisfy the time constraint. All feasible routes generated in the first and second phases are included in the formulation of the SPP. To find an optimal solution, the formulation is solved using a common algorithm of 0-1 integer programming that are available in commercial software.

3. Description of the oily liquid waste collection problem

The background of this paper involves developing a ship routing system for collection of the oily liquid waste from some ports in the Indonesian Port Corporation II to a waste treatment plant. The description of this problem has been defined by Iskendar et al.1). They defined the problem for collecting the waste from four main ports in the Indonesian Corporation II including Palembang, Pontianak, Tanjung Priok, and Teluk Bayur to a designed location of the waste treatment in Plaju (Fig. 1).

Daily waste production at Palembang, Pontianak, Tanjung Priok, and Teluk Bayur 1,300 liters; 1,400 liters; 3,600 liters; and 500 liters, respectively. These amount are equivalent to 39 m³/month (Palembang), 42 m³/month (Pontianak), 108 m³/month (Tanjung Priok) and 15 m³/month (Teluk Bayur) m³/month (assuming that 1 month = 30 days). The capacity of waste treatment plant at Plaju is 3,000 m³. Characteristics of each port including port's water depth are given in Table 1. Port's water depth data are taken from the water depth data for conventional berths in the OCDI's report13).

The distances between ports including the waste treatment plant are shown in Table 2. The distances from the waste treatment location (Plaju) to four waste production ports are 5 miles (Palembang), 366 miles (Pontianak), 350 miles (Tanjung Priok) and 846 miles (Teluk Bayur). Table 3 shows a distance table between ports.

To generate alternative ships, it is assumed that the ships are specialist tankers. Data of eight specialist tankers under 10,000 deadweight (DWT) shown in Table 3 are used as information for estimating technical data of alternative ships. In this case three technical data are required for solving the ship routing problem, i.e., capacity, draft, and speed.

Based on the data in Table 3, three simple linear regression equations are derived showing relationships between DWT (as an independent variable) and draft, speed, and capacity (as dependent variables). The summary of each simple linear regression equations is given in Table 4.

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![Fig. 1. Map of ports and waste treatment location](image-url)

**Table 1. Waste production and water depth of ports**

<table>
<thead>
<tr>
<th>Ports</th>
<th>Waste production¹ (m³/month)</th>
<th>Water depth² (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaju</td>
<td>-</td>
<td>7.0</td>
</tr>
<tr>
<td>Palembang</td>
<td>39</td>
<td>7.0</td>
</tr>
<tr>
<td>Pontianak</td>
<td>42</td>
<td>6.0</td>
</tr>
<tr>
<td>Tanjung Priok</td>
<td>108</td>
<td>7.0</td>
</tr>
<tr>
<td>Teluk Bayur</td>
<td>15</td>
<td>9.5</td>
</tr>
</tbody>
</table>

¹Source : Iskendar et al.¹¹  
²Source: OCDI¹⁰
Table 2. Distance table (miles)

<table>
<thead>
<tr>
<th></th>
<th>Plaju</th>
<th>Palembang</th>
<th>Pontianak</th>
<th>Tanjung Priok</th>
<th>Teluk Bayur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaju</td>
<td>5</td>
<td>366</td>
<td>350</td>
<td>846</td>
<td></td>
</tr>
<tr>
<td>Palembang</td>
<td>5</td>
<td>361</td>
<td>345</td>
<td>841</td>
<td></td>
</tr>
<tr>
<td>Pontianak</td>
<td>366</td>
<td>361</td>
<td>428</td>
<td>907*</td>
<td></td>
</tr>
<tr>
<td>Tanjung Priok</td>
<td>350</td>
<td>345</td>
<td>428</td>
<td>573</td>
<td></td>
</tr>
<tr>
<td>Teluk Bayur</td>
<td>846</td>
<td>841</td>
<td>907</td>
<td>573</td>
<td></td>
</tr>
</tbody>
</table>

Source: MOC\(^{14}\)
*Estimated by authors

Table 3. Reference ship data

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>DWT (tons)</th>
<th>Main dimension (m)</th>
<th>Speed (knot)</th>
<th>Capacity liquid (m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Theodora</td>
<td>5,200</td>
<td>103.00</td>
<td>17.00</td>
<td>6.10</td>
</tr>
<tr>
<td>2</td>
<td>Tasco</td>
<td>4,592</td>
<td>99.90</td>
<td>15.80</td>
<td>5.71</td>
</tr>
<tr>
<td>3</td>
<td>Weserstern</td>
<td>8,795</td>
<td>103.60</td>
<td>17.70</td>
<td>8.40</td>
</tr>
<tr>
<td>4</td>
<td>Nathalie Sif</td>
<td>8,603</td>
<td>110.00</td>
<td>19.00</td>
<td>7.51</td>
</tr>
<tr>
<td>5</td>
<td>Marinor</td>
<td>7,930</td>
<td>105.00</td>
<td>18.00</td>
<td>7.50</td>
</tr>
<tr>
<td>6</td>
<td>Trans Arctic</td>
<td>7,000</td>
<td>108.40</td>
<td>17.50</td>
<td>7.71</td>
</tr>
<tr>
<td>7</td>
<td>Katarina</td>
<td>6,000</td>
<td>95.52</td>
<td>17.50</td>
<td>6.10</td>
</tr>
<tr>
<td>8</td>
<td>Janana</td>
<td>8,850</td>
<td>119.60</td>
<td>19.00</td>
<td>7.60</td>
</tr>
</tbody>
</table>

Source: Watson \(^{15}\)

Fig.2 Relationship between DWT and draft

Fig.3 Relationship between DWT and speed

Fig.4 Relationship between DWT and capacity

Table 4. Linear regression equations

<table>
<thead>
<tr>
<th>Linear regression equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft (D)</td>
</tr>
<tr>
<td>(D = 3.356 + 5.228.10^4 \times DWT)</td>
</tr>
<tr>
<td>Speed (S)</td>
</tr>
<tr>
<td>(S = 13.084 + 8.216.10^2 \times DWT)</td>
</tr>
<tr>
<td>Capacity (C)</td>
</tr>
<tr>
<td>(C = 1.093 \times DWT)</td>
</tr>
<tr>
<td>(DWT = DWT)</td>
</tr>
</tbody>
</table>
Table 5 gives a relationship between ship size (DWT) and annual unit costs (dollar per DWT per year). To estimate cost per DWT, we use linear regression analyses by taking inversion of values of costs (fixed and variable costs). Estimated values using the linear regression equations are given in Table 6.

Seeing to the waste production in all ports that are relatively small, we select only two ship types with sizes of 100 and 200 DWT that will be included in the solution. The specifications of these ships are given in Table 7.

4. Solution Approach

The solution approach used for solving the ship routing of the oily liquid waste collection problem follows the Fagerholt's work\(^{11}\). In our approach, we add water depth constraints in the problem. In addition to the feasibility of vehicle's capacity and time (planning period) constraints, the single routes generated must be feasible with respect to water depth constraints. The ships assigned to a particular route must have a draft less than the water depth of any ports belonging to that route.

As Fagerholt's procedure, there are three phases in the approach, i.e., generating single routes, generating multiple routes, and solving the set partitioning problem formulation. There are some changes to the original procedures, especially in the first phase. Two basic changes are as follows. First, in our approach we generate all feasible routes for every ship type to anticipate that ships have different service speed. The second, we include the water depth constraints mentioned in the previous paragraph.

The solution approach is applied to the following characteristics. Given a set of ports and the depot. Each port has demand \( q_i \) and water depth \( h_j \). The distance between port \( i \) and \( j \) is \( d_{ij} \). There are \( K \) ship types. Each ship type \( k \) has capacity \( Q_k \), speed \( S_k \), draft \( D_k \), fixed cost \( F_k \) and variable cost per time unit \( V_k \). In this case, service times in the ports are not considered. Thus, the duration of the routes are determined only by sailing times. Details of the solution approach are described as follows.

### Table 5. Relationship between DWT and costs

<table>
<thead>
<tr>
<th>Ship size (DWT)</th>
<th>Fixed cost (US$'000)</th>
<th>Variable cost (US$'000)</th>
<th>Total cost (US$'000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>1,414</td>
<td>680</td>
<td>2,094</td>
</tr>
<tr>
<td>40,000</td>
<td>1,476</td>
<td>778</td>
<td>2,254</td>
</tr>
<tr>
<td>65,000</td>
<td>1,633</td>
<td>972</td>
<td>2,605</td>
</tr>
<tr>
<td>150,000</td>
<td>1,940</td>
<td>1,458</td>
<td>3,398</td>
</tr>
<tr>
<td>170,000</td>
<td>2,120</td>
<td>1,620</td>
<td>3,740</td>
</tr>
</tbody>
</table>

Source: Stopford\(^{16}\)

### Table 6. Estimated values of cost per DWT

<table>
<thead>
<tr>
<th>Ship size (DWT)</th>
<th>Fixed cost per DWT (US$/year)</th>
<th>Variable cost per DWT (US$/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>99.53</td>
<td>29.35</td>
</tr>
<tr>
<td>200</td>
<td>99.11</td>
<td>29.32</td>
</tr>
<tr>
<td>500</td>
<td>97.87</td>
<td>29.20</td>
</tr>
<tr>
<td>1000</td>
<td>95.86</td>
<td>29.02</td>
</tr>
<tr>
<td>2000</td>
<td>92.07</td>
<td>28.65</td>
</tr>
<tr>
<td>5000</td>
<td>82.33</td>
<td>27.61</td>
</tr>
<tr>
<td>10000</td>
<td>69.98</td>
<td>26.03</td>
</tr>
</tbody>
</table>

### Table 7. Specification of alternative ships

<table>
<thead>
<tr>
<th>Type (DWT)</th>
<th>Capacity (m(^3))</th>
<th>Draft (m)</th>
<th>Speed (knot)</th>
<th>Fixed cost (US$/yr)</th>
<th>Voyage cost (US$/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>109</td>
<td>3.41</td>
<td>13.09</td>
<td>9,954</td>
<td>2,935</td>
</tr>
<tr>
<td>200</td>
<td>219</td>
<td>3.46</td>
<td>13.10</td>
<td>19,822</td>
<td>5,863</td>
</tr>
</tbody>
</table>

**Phase 1: Generation of single routes**

First stage is to generate single routes satisfying all constraints, i.e. ship's capacity, water depth, and time constraints. The single routes are generated for each ship type. To ensure that each route has an optimal sequence, the TSP procedure is applied. The sailing time of any route is associated with the minimal sailing time obtained by a TSP procedure.
The procedure of phase 1 starts with calculating sailing time between ports (including the depot) for each ship type. Let \( d_{ij} \) be distance between port \( i \) and \( j \) and \( S_k \) the speed of ship type \( k \). The sailing time between port \( i \) and \( j \) using ship type \( k \) can be determined by

\[
    t_{ik} = \frac{d_{ij}}{S_k}
\]

(1)

The next step is to generate subsets from a given set of ports. In addition to the depot, the subsets consist of at least one port and at most all ports. Define \( B \) be the number of subsets generated and \( \Omega_u \) the set of subsets \( (u = 1, \ldots, B) \). For each ship type \( k \) and each subset \( u \), a series of procedures is applied for checking conditions of capacity, water depth, and time. The feasibility of capacity constraints can be checked by the following relationship

\[
    q_u \leq Q_k
\]

(2)

where \( q_u \) is the total demand of all ports belonging to subset \( u \) and \( Q_k \) the capacity of ship type \( k \).

The water depth constraints can be formulated as follows

\[
    h_j > D_k, \quad \forall j \in \Omega_u
\]

(3)

where \( h_j \) is the water depth of port \( j \) \( (j \in \Omega_u) \) and \( D_k \) the draft of ship type \( k \).

The time constraints are given by

\[
    t_{uk} \leq T
\]

(4)

where \( t_{uk} \) is the sailing time of visiting ports including in the subset \( u \), starting and ending at the depot, and \( T \) the planning period. \( t_{uk} \) is associated with the minimal sailing time obtained by the TSP procedure.

In the solution approach, the Hungarian assignment algorithm is applied as the TSP procedure to determine the optimal sequence of visiting ports. By making a special structure, the Hungarian assignment algorithm can be used to solve the TSP. The algorithm attributed to Lawyer is explained briefly in Phillips and Garcia-Diaz\(^{17}\). Park et al.\(^{18}\) has made a code of TSP solver based on this algorithm. By making a small modification, we incorporate their code to the first phase of this solution approach.

If the route (related to each ship type \( k \) and each subset \( u \)) is feasible with respect to all constraints, then the route is added to the route set. All relevant information concerning to this route is calculated, i.e., sailing time, fixed, variable, and total costs. The flowchart in Fig. 5 shows details of the single route generation (phase 1).

**Phase 2: Generation of multiple routes**

A multiple route means that the route has two or more single routes, where each single route consists of a sequence of visiting ports, starting and ending at the depot. These single routes have been generated in the phase 1.

For each ship type \( k \), phase 2 starts with combining the two single routes to generate double routes. After generating double routes, the procedure continues by combining each route in the single route set to each route in the double route set to generate triple routes. The procedure proceeds until there is no multiple routes can be generated.

The combination of two routes must be feasible respect with two conditions. The first condition is that the two routes do not service the same node, and the second is that the total sailing time of two routes does not exceed the planning period.

Let \( n \) be the route type, i.e., \( n = 1 \) for single route, \( n = 2 \) for double route, and so on. For each ship type \( k \), \( R^k_n \) is the set of route type \( n \) and \( NR^k_n \) is the number routes belonging to set \( R^k_n \). Let \( x \) and \( y \) be a route in the \( R^k_n \) and \( R^k_n \). \( A^k_{xy} \) is a binary constant that is equal to one if route \( r \) services port \( j \) using ship type \( k \) and zero otherwise. \( t_{rk} \) is the sailing time for route \( r \) using ship type \( k \). The first and second condition in the previous paragraph can be stated as follows.

\[
    n(\sum_{x=1}^{NR^k_n} A^k_{xy}) \leq Q_k
\]

(5)

\[
    \sum_{x=1}^{NR^k_n} t_{rk} + t_{rk} \leq T
\]

(6)

During the generation of multiple trips, especially for \( n \geq 3 \), two or more equivalent routes may be generated. These equivalent routes are identical, i.e., they service the same set of nodes. To eliminate the generation of unnecessary routes, a checking procedure is applied to keep only one of the equivalent
Phase 3: formulation of set partitioning problem

Phase 3 consists of formulating the set partitioning problem (SPP). Let $R$ be the set of candidate routes including single and multiple routes for all ship type $(R = \bigcup R_k)$. $A_r$ is a constant which equal to 1 if route $r$ services port $i$, and 0 otherwise. $C_r$ is the cost for route $r$ (fixed cost plus variable cost). $x_r$ is a binary variable, which is equal to 1 if route $r$ is selected in the optimal solution. The SPP can be formulated as follows:

$$\text{minimize } \sum_{r \in R} C_r x_r$$

$$\text{subject to } \sum_{r \in R} A_r x_r = 1, \ \forall i \in N$$

$$x_r \in \{0, 1\} \ \forall r \in R$$
The objective function (7) minimizes the total cost including fixed cost of the fleet and variable costs for shipments. Constraints (8) ensure that ships in the fleet service all ports. Constraints (9) impose binary restrictions on the variables. The optimal solution can be obtained by solving the SPP formulation using the integer programming solver.

5. Solution Result

This section presents results of using the solution approach to the problem of oily waste collection problem described in Section 3. There are four ports and one depot (waste treatment center) considered. Demands and water depths of ports are given in Table 1. Distance data are provided in Table 2. Ship data including capacity, speed, and draft are given in Table 7. In this case, we only considers two ship types, namely, ship type 1 (100 DWT) and ship type 2 (200 DWT). We assume that the period planning is one month. Therefore, fixed cost data in Table 7 are converted in monthly unit and the variable costs are changed into hourly basis.

Table 8 gives outputs for ship type 1 during the first and second phases of the solution approach. For ship type 1, there are twenty-nine routes generated included single and multiple routes. Each row represents one route where row1 to 8 are single routes and the rests are multiple routes. The first column in the table shows the number route. The second column represents the route types, i.e., 1 for single route, 2 for double route, 3 for triple route, etc.
Ports serviced by each route are identified from numbers in the third to sixth columns. The number of 1 for each port at one row (route) represents that the port is serviced by that route, and 0 otherwise. For example, route 7 services port 2 and 4.

The seventh to fourteenth columns identify single routes included in each route. The number of 1 denotes the single route included in the route, and 0 otherwise. Route 8, 21 and 23, for example, service the same ports (1, 2 and 4). Route 8 is a single route. Route 21 is a double route comprising single routes 4 and 5. Route 23 is a triple route that is a combination of single routes 1, 2 and 4.

The fifteenth to eighteenth column represent information respect with each route, i.e., sailing time, fixed, variable, and total costs. The sailing time is given in day unit, while the cost is calculated based on unit time of the planning period (per month).

For the second ship type (ship type 2), an identical table is generated. The number of columns of the single routes included may differ depending on the number of single routes generated.

For solving the SPP formulation, the numbers in the columns of the ports serviced and the total cost are used as inputs. By solving integer formulation using LINGO 6.0, the optimal solution is given by route number 20. This route consists of two single routes where the first route is associated with a sequence of (0-1-2-4-1-0) and the second is (0-3-0). These routes are sailed by one ship of ship type 1 with the total sailing time of 8.973 days. The total cost is US$ 901.618. Fig. 7 shows the optimal solution.

Table 9 shows a comparison between single and multiple trips cases for the oily waste collection problem. For single trip case, there are two ships required where all ships are ship type 1 (100 DWT). First ship sails route (0-1-2-4-1-0) and the second sails route (0-3-0). The total cost for this case is $1,731.075/month. This cost is higher than the case of multiple trips.

Table 8. Outputs of phase 1 and 2 (for ship type 1)

<table>
<thead>
<tr>
<th>Route number</th>
<th>Route type</th>
<th>Ports serviced by each route</th>
<th>Single routes included</th>
<th>Total sailing time</th>
<th>Fixed cost</th>
<th>Variable cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1 0 0 0</td>
<td>1 0 0 0</td>
<td>0.032</td>
<td>829.457</td>
<td>0.256</td>
<td>829.713</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0 1 0 0</td>
<td>0 1 0 0</td>
<td>2.330</td>
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Using given data, it can be seen that only capacity constraints work to degenerate feasible routes during phase 1 and 2 of the solution approach. The water depth and time constraints do not work because all ports have the water depth greater than the ship’s draft and the sailing time is too short compared with the planning period. However, the solution approach can be applied to the more general situation where one or more ship types have the draft greater than the water depth of one or more ports and the sailing time is longer than the planning period.

6. Conclusion

In this paper we describe the ship routing design for the oily liquid waste collection. The problem is characterized as a vehicle routing problem with heterogeneous fleet of vehicles and multiple trips (VRPHMT) which is relatively new area in the VRP family. This paper is also one of contributions in the ship routing problem that are few in the literature.

We solve the problem using data presented in Iskendar1). Further works must be done to improve this study by obtaining more reliable data.

Basically, the solution approach is similar to the Fagerholt’s work1). In our solution approach, we add water depth constraints and consider that the alternative ship types have the different service speed. Consequently, our approach produces more routes.

As mentioned in Fagerholt’s conclusion11), the procedure has a major drawback that it is suitable for small-sized and well-constrained problems. If the problem become large, the number of routes increases exponentially, and the number of columns can be enormous and become very hard to be solved. Of course, this situation is not faced commonly in the ship routing problem where the size is relatively small. However, in areas other than ship routing, this situation may occur. Finding other procedures capable to solve larger and not so well constrained problems is a challenge for future study where the procedure can be applied in any practical situation.

Acknowledgement

We would like to thank to Dr. K. Fagerholt (MARINTEK Logistics, Norway) for his helps to give some useful references. We would like to thank also to Dr. L. Diawati (Bandung Institute of Technology, Indonesia) for her comments and to Prof. K. Kose (Hiroshima University) for his supports in JSPS program. The first author is grateful to the Ministry of Education, Culture, Sports, Science, and Technology of Japan (Monbusho) for supporting this research by granting the doctoral course scholarship.

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13) The Overseas Coastal Area Development Institute of Japan (OCDI) Final report, the study on the port development strategy in the Republic of Indonesia (1999).

14) Ministry of Communication, the Republic of Indonesia (MOC), Distance table.


