Routing and Scheduling Optimization Model of Sea Transportation

Mika debora br barus¹, Habib asyrafy², Esther nababan³ and Herman mawengkang⁴
Department of Mathematics, University of Sumatera Utara, Medan, Indonesia.
E-mail: ¹Deboramika9@gmail.com, ²habib.asyrafy@gmail.com, ³ester@usu.ac.id, ⁴hermifa@yahoo.com

Abstract. This paper examines the routing and scheduling optimization model of sea transportation. One of the issues discussed is about the transportation of ships carrying crude oil (tankers) which is distributed to many islands. The consideration is the cost of transportation which consists of travel costs and the cost of layover at the port. Crude oil to be distributed consists of several types. This paper develops routing and scheduling model taking into consideration some objective functions and constraints. The formulation of the mathematical model analyzed is to minimize costs based on the total distance visited by the tanker and minimize the cost of the ports. In order for the model of the problem to be more realistic and the cost calculated to be more appropriate then added a parameter that states the multiplier factor of cost increases as the charge of crude oil is filled.

Keyword: Optimization, Routing and Scheduling, Transportation of crude oil

1. Introduction
The global logistics problem becomes an important issue in increasing the global environments. The integrated optimization of production planning and distribution planning is required from the viewpoint of global supply chain optimization (Nishi, Hiranaka, & Grossmann, 2011; Nishi, Konishi, & Ago, 2007).

This paper examines the routing and scheduling optimization model of sea transportation. One of the issues discussed is about the transportation of ships carrying crude oil (tankers) which is distributed to many islands. The consideration is the cost of transportation which consists of travel costs and layover costs at the port. Crude oil to be distributed consists of several types.

Scheduling of crude oil transportation is a crucial challenge for petrochemical industries. In a petrochemical company, demands of various types of crude oils are given every month. A fleet of very large crude oil carrier (VLCC) tankers is used for international crude oil transportation. Each tanker can load several items of crude oils with finite capacity. The assignment of demands, visiting sequence of ports, and loading volume of multi items of crude oils should be determined simultaneously to minimize the total cost considering the capacity of tankers.

In many practical situations, these decisions are still made manually by the negotiation between the human operators based on the contract with individual supplier. In order to help the decision making of human operators, it is highly required that the practical ship routing and scheduling can be
generated automatically to increase the efficiency and to avoid human errors. It is also easier for new human operators to execute the scheduling system once personnel change occurs. Based on previous research we have discussed the model of route problem and scheduling for crude oil load planning that is to minimize the total distance visited by tanker and minimize harbor cost imposed from each visited place (Tatsushi Nishi & Tsukasa Izuno, 2014). However, the existing model is not realistic enough to develop a more realistic model. In this research will be discussed about the problem of crude oil delivery more realistic by adding a parameter. Where the parameter states that there is an increase in cost / km when the tanker visited loading place. With the addition of cargo where the greater the burden of crude oil transported by the tanker will affect the additional cost. The load in question is not exceeding the maximum and minimum capacity of the tanker.

2. Literature review

The automating international transportation is demanded rapidly (Waters, 2010). Several works have been addressed related to ship scheduling for maritime transport. An analytical model concerning the international maritime transport market has been studied (Kuruda, Takebayashi, & Tsuji, 2005). An optimization approach to solve the ship scheduling as a generalized set-packing model has been addressed (Kim & Lee, 1997). They generate a feasible ship routing and schedule by a directed acyclic graph. An optimization model as a multi-ship pickup and delivery is proposed in Fagerholt (2001). They use a dynamic programming to solve the shortest path problem. A heuristic search algorithm for ship routing and scheduling with split loads is introduced in Korsvik, Fagerholt, and Laporte (2011) dan Yin, Nishi, and Izuno (2012). In order to solve more practical problems, heuristic approaches are applied (Paessens, 1988). New saving based algorithms are introduced to deal with pick up and delivery of full truckloads problem under time window constraints (Gronalt, Hartl, & Raimann, 2003).

3. Problem description

The ship routing and scheduling problem for crude oil transportation mainly consists of two part is the outbound ship loading planning problem that determines the visiting route for a fleet of tankers in various countries. The second part is the inbound ship unloading loaded oil into several domestic factories considering both of inbound and outbound transportation simultaneously. This paper deals with only the first step of the ship routing and scheduling for outbound load planning, which is formulated as a vehicle routing problem with split deliveries. L is the set of loading places where crude oil types. Figure 1 shows the model of ship routing and scheduling problem for crude oil load planning. Each loading place has one or more than two type of crude oils. Each tanker has different capacity. All tankers originate and return to a common point after visiting multiple destinations. An

![Figure 1: Ship routing and scheduling problem for crude oil transportation](image-url)
intermediate point \((s=g)\) is the depot which should be started and returned after visiting some of loading places. The different settings: open routes, multiple origins and multiple destinations can be incorporated by setting the graph model of fig. 1. The distances between loading places denoted by \(d_{ij}\) are not symmetric \((d_{ij} \neq d_{ji})\) but satisfy the triangular inequality, \((d_{ij} + d_{jk} \geq d_{ik})\). \(T\) is the set of available tankers whose capacity of loading volume is given. The total demand volume \(D_o\) for each oil type \(o \in O\) is given by the contract from the suppliers in every month. The problem is a multi product heterogeneous fleet split pickup ship routing problem with finite capacity and loading volume for a fleet of tankers in order to minimize the total cost.

In practical point of views, we assume the following conditions which especially appears in maritime crude oil transportation.

1. The number of loading places visited by a tanker is less than or equal to three. The port charge is imposed if a tanker occupies one port. If one tanker visits one port, visiting time should be sufficient in order to complete loading operations.
2. The loading volume of tanker should be close to be full and the number of tankers should be minimized. This is because the visiting from domestic site to international sites is time consuming and requires lots of costs.
3. The loading condition is different for each loading place.
4. Travel costs increase with increasing cargo.

The objective function is the total cost for the operation of all tankers is one month that should be minimized. The total cost consists of the total sum of the bunker costs which is proportion to the distance, and the sum of the port charge which depends on the number of visiting time.

3.1 Problem formulation
The problem is formulated as a mixed integer linear programing problem in this section.

\[
\begin{align*}
L & : \text{set of loading places} \\
O & : \text{set of crude oil types} \\
T & : \text{set of tankers} \\
L & : \text{depot, g end point} \\
i,j & : \text{loading place} \\
k & : \text{tanker} \\
o & : \text{type of oil} \\
s & : \text{depot s=L start point s-g the our problem} \\
\end{align*}
\]

Decision variables:
\[
\begin{align*}
q_{k,i,o} & : \text{loading volume of crude oil type o at loading place for tanker k,} \\
to & : \text{loading time of loading place I for tanker k} \\
x_{k,i,j} & : \text{binary variable that takes 1 + } f_k(n) \text{ when tanker (k) visits from loading place i to loading place j, and 0 other wise.} \\
\vartheta_{k,i} & : \text{binary variable that takes 1 when tanker k visits loading place I, and 0 otherwise.} \\
\end{align*}
\]

Parameters:
\[
\begin{align*}
c_i & : \text{port charge imposed by visiting loading place i for tanker k,} \\
c_{k}^{\text{max}} & : \text{maximum loading volume for tanker k,} \\
d_{ij} & : \text{distance between loading place i and loading place j,} \\
D_o & : \text{demand of crude oil type o,} \\
E_{k,i,j} & : \text{loading date from loading place i to loading place j for tanker k,} \\
M & : \text{sufficiently large positive constant} \\
q_{i}^{\text{min}} & : \text{minimum loading volume at loading place i.} \\
q_{i}^{\text{max}} & : \text{maximum loading volume at loading place i,}
\end{align*}
\]
$w_1$: weighting factor of the total distance traveled by tankers,

$w_2$: weighting factor of the total cost imposed by visiting loading place,

$\tau_m$: maximum number of loading places visited by one tanker,

$\mu_{t,o}$: binary constant that takes 1 if crude oil type $o$ can be loaded at loading place $i$, and 0 otherwise.

$f_k(n)$: Specifies the cost / km increase multiplier as the load is filled with $n$ between 0 and 1.

**Objective function:** The first objective is to minimize the total distances traveled by tankers and the second one is to minimize the port charge imposed by visiting loading places. The weighted sum of the objective function of (1) is minimized.

$$
\min w_1 \left( \sum_{k \in T} \sum_{i \in LU(s)} \sum_{j \in LU(g)} d_{ij} x_{k,i,j} \right) + w_2 \left( \sum_{k \in T} \sum_{i \in L} c_{i} \partial_{k,i} \right)
$$

**Constraints:** The total demand constraints are denoted by (2).

$$s.t \sum_{k \in T} \sum_{i \in L} q_{k,i,o} = D_o \ (\forall o \in O) \tag{2}$$

The assignment constraints of loading places are denoted by (3) and (4).

$$\sum_{i \in LU(s)} x_{k,i,j} = \partial_{k,j} \quad (\forall k \in T, \forall j \in L \cup \{g\}) \tag{3}$$

$$\sum_{i \in LU(g)} x_{k,i,j} = \partial_{k,i} \quad (\forall k \in T, \forall i \in L \cup \{s\}) \tag{4}$$

Eqs. (5) and (6) respectively represent that each tanker starts from the starting point $s$ and stop at the ending point $g$ after visiting loading places.

$$\sum_{i \in L} x_{k,s,i} = 1 + f_k(n) \quad (\forall k \in T) \tag{5}$$

$$\sum_{i \in L} x_{k,i,g} = 1 \quad (\forall k \in T) \tag{6}$$

Eq. (7) restricts that the number of visiting time of loading places should be less than or equal to the maximum number of visiting time of loading places $\tau_m$.

$$\sum_{i \in L} \partial_{k,i} \leq \tau_m \quad (\forall k \in T) \tag{7}$$

Subtour elimination constraints are denoted by (8) where M is a sufficiently large positive number. M is the upper bound of the difference of loading dates for each tanker.

$$t_{k,i} + E_{k,i,j} x_{k,j} - M (1 - x_{k,i,j}) \leq 0 \quad (\forall k \in T, \forall i \in L \cup \{s\}, \forall j \in L \cup \{g\}) \tag{8}$$

The loading volume should be less than the capacity of a tanker where the capacity of tanker is different for each tanker. The constraints are denoted by (9).

$$\sum_{i \in L} \sum_{o \in O} q_{k,i,o} \leq C_{k}^{max} \quad (\forall k \in T) \tag{9}$$

The minimum and maximum loading volume constraints at each loading place are denoted by (10) and (11).

$$\delta_{k,i} \sum_{o \in O} \mu_{i,o} q_{k,i,o} \quad (\forall k \in T, \forall i \in L) \tag{10}$$

$$\sum_{o \in O} \mu_{i,o} q_{k,i,o} \leq \delta_{k,i} q_{i}^{max} \quad (\forall k \in T, \forall i \in L) \tag{11}$$

where $\mu_{i,o}$ is the given parameter that takes 1 if crude oil type $o$ can be loaded at loading place $i$, and 0 otherwise. The constraints for the variables are denoted by (12)–(15).

$$x_{k,i,j} \in \{0,1+f_k(n)\} \quad (\forall k \in T, \forall i \in L \cup \{s\}, \forall j \in L \cup \{g\}) \tag{12}$$
In order to reduce search space, the valid inequalities of (16) can be imposed. Each loading place must be visited by at least $H_i$ tankers. $H_i$ is obtained from $H_i = \frac{\sum_{d \in D} d_k}{\max_k c_k^{\text{max}}}$ from the given parameters. We have observed from the computational results that the computation time for general-purpose solvers can be significantly reduced with the constraints of (16)

$$\sum_{k \in T} \partial_{k,i} = H_i \quad (\forall i \in L)$$

(16)

The original problem (P0) can be regarded as a split delivery vehicle routing problem (SDVRP) that is known to be NP-hard (Salani & Vacca, 2011).

4. Conclusions and future research

The addition of parameters that calculate the current shipload creates these route model and scheduling to be more realistic so that the reckoned ship transportation cost becomes more appropriate. This research only develops model of route and scheduling on tankers that carry crude oil, while transportation problem which is connected with route and scheduling on tanker is difficult problem or Non-Polynomial Hard (NP-Hard Problem). This relates to the issue that is difficult to be solved by the exact method. Therefore it is necessary to apply a heuristic method.

It is expected for next research can develop methods of these problem, route and scheduling in heuristic. The problem of route optimization and scheduling on transport can be developed, constructed and completed using heuristic methods.

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