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# OPTIMISATION OF VESSEL JOURNEYS FOR OIL PRODUCTS DISTRIBUTION

HOANG Thi Minh Ha <sup>(1)</sup> and Gerrit K. JANSSENS <sup>(2)</sup>

Logistics Research Group, Hasselt University  
Agoralaan, 3590 Diepenbeek, Belgium

<sup>(1)</sup> [thiminhha.hoang@uhasselt.be](mailto:thiminhha.hoang@uhasselt.be)

<sup>(2)</sup> [gerrit.janssens@uhasselt.be](mailto:gerrit.janssens@uhasselt.be)

## KEYWORDS

Routing, scheduling, oil products, mixed-integer programming.

## ABSTRACT

The research deals with a routing and scheduling problem of specialized vessels carrying oil products. A heterogeneous fleet transports the products from several loading ports to several discharging ports. Time windows are involved on the discharging side due to production and storage plans, and on the loading side as a result of negotiations with customers. Demand may be delivered by more than one vessel. The routing and scheduling problem is formulated as a mixed-integer programming problem. It includes information and constraints about the supply and demand, but also about the vessels, the vessel routes, and the ports and their restrictions.

## INTRODUCTION

The problem under study in this article is similar to the one of Hennig et al. [1] who formulates the problem as a split pickup and delivery problem. The pickup and delivery problem (PDP) is an extended case of the Vehicle Routing Problem (VRP), which can be formulated as a mixed-integer programming model but, as most VRP's, are NP-hard (Savelsberg and Sol [2]). Seldom exact methods are used for solving these type of problems like in a Traveling Salesman Problem with pickup and delivery (Gendreau, Laporte and Vigo [3]).

The Dial-A-Ride problem is a special case of the PDP in which one has to consider the pickup, delivery and travel time of the customers in the vehicles. The Dial-A-Ride Problem (DARP) is a special case of the PDP in which the shipments to be transported represent people (Cordeau & Laporte [4]). In the majority of papers on dial-a-ride problems, a single user type and a homogeneous fleet of vehicles are assumed. In reality, the problem is often more complex due to the presence of users with special requirements and a heterogeneous fleet of vehicles (e.g. Parragh [5] and Braekers et al. [6]).

The model here is an optimization model to find a solution for ship routing and scheduling for specialized tankers of oil products. Specifically, the model incorporates tanker routes and determines the loading or discharging amount of each tanker at one port to find the minimal total shipping cost. The

contribution of the research is recognizing the similarity in the model of Hennig et al. [1] to refer to the one of oil products that has different constraints for distribution, namely tankers capacity, terminal characteristics, shipping distance, shipping amount of products. Identifying these scenarios from the case study in Vietnam is the initial and important result that encourages the future work.

The model is tested via scenarios to see in which route and by which vessel oil products are transported and the amount of products which can be loaded or discharged so that the total shipping cost is minimized.

## MODEL FORMULATION

The model is formulated mathematically below including the objective function and constraints. In the objective function, there are three parts of costs are included of which the total needs to be minimized. They include fixed costs of vessels taking routes, fuel costs of operation of vessels visiting ports and fuel costs of vessel while vessels wait in ports. Specific products for loading or discharge as well as constraints on port terminal, tanker and supplier/customer are defined for optimization. Various assumptions and requirements for distribution are raised for the model for the case study in Vietnam.

The fixed cost of a vessel,  $C_v$ , is calculated based on distance, vessel size and port terminal. Similarly, loading time or discharging time  $T_{qi}$  is based on pumping speed of machine of tanks on vessel or storage at port terminal. On the other hand, fuel cost  $F_v^P$  when operating in port is based on the size, temperature, water level of terminal and vessel size when operating and fuel cost of idle time  $F_v^I$  based on the size, temperature, water level of terminal, vessel size, availability of terminal when waiting in the port.

The speed and the amount of products allowed in each vessel is first determined. It is also important that location of vessels and distribution areas need to be given beforehand for bunker fuels and other preparation for each route. By this, each tanker route  $r$  including several single voyages is taken by a vessel  $v$  alongside the country with the distance between ports compiled by Netpas Distance [7]. Then, capacity of port terminals as well as tank storage for loading and discharge is also known before the operation and the service.

Each tanker  $v$  can take only one route  $r$ . We use specialized tankers for shipping oil products with deadweight ton range of 5000 dwt – 10 000 dwt to travel routes through domestic ports in Vietnam via the South East Asia Sea. It is also supposed that a route includes two first loadings then three discharges. A single-voyage tanker route  $A_{ij}$  is shown in Figure 1.

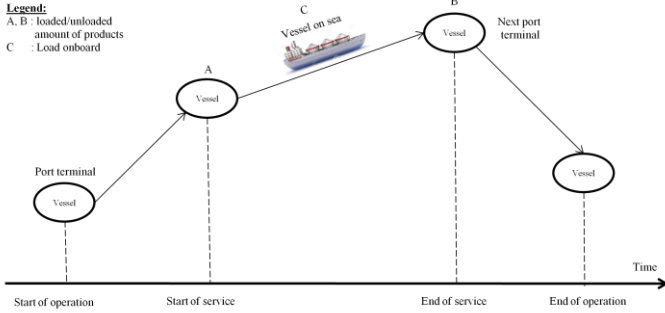


Figure 1: Single tanker route  
(Source: Hennig et al. [1])

### Indices

Decision or other variables, sets and (cost or technical) data contain indices. The indices refer to the following entities:

$i, j$	ports (e.g. previous or following port)
$v$	vessel
$r$	route
$o(v)$	origin position of vessel $v$
$d(v)$	destination position of vessel $v$
$c$	oil product

### Variables

The variables which appear in the objective function and/or in the constraints are the following:

$y_{vr}$	binary journey variable; =1 if vessel $v$ sails route $r$ ; otherwise = 0
$q_{iv}$	cargo amount loaded or discharged by vessel $v$ at port $i$
$t_{iv}$	time vessel $v$ starts service at port $i$
$t_{jv}$	time vessel $v$ starts service at port $j$
$l_{ijcv}$	load of product $c$ onboard vessel $v$ on leg $(i, j)$
$l_{jicv}$	load of product $c$ onboard vessel $v$ on leg $(j, i)$

### Sets

$V$	vessels
$R_v$	routes for vessel $v$
$N_v$	ports that vessel $v$ can visit
$A_v$	arcs $(i, j)$ vessel $v$ can sail including arcs (from origin and to destination)
$N^P$	loading ports
$N^D$	discharging ports
$V_i^N$	vessels that can visit port $i$
$A_v^W$	arcs for vessel $v$ that possess a possibly binding cargo weight restriction
$A_v^V$	arcs for vessel $v$ that possess a possibly binding cargo volume restriction
$C$	oil products

### Given data

$C_{vr}$	fixed part of cost for sailing route $r$ by vessel $v$
$T_{qi}$	loading/discharging time per weight unit of product
$F_{pv}$	reduced fuel cost used when operating in port per time unit for vessel $v$
$F_{lv}$	fuel cost per time unit of idle time in port for vessel $v$
$T_{ijv}^S$	sailing time between ports $i$ and $j$ for vessel $v$
$A_{ijvr}$	= 1 if vessel $v$ sails leg $(i, j)$ on route $r$ ; = 0 otherwise
$E_i$	earliest time for start of service in port $i$
$L_i$	latest time for start of service in port $i$
$U_{ijv}$	sailing leg and vessel specific big-M constant for unused sailing legs
$Q_i$	cargo amount to be loaded/unloaded in total by all vessels in port $i$
$C_i$	product supplied or demanded in port $i$
$D_c$	density of oil product $c$
$I_i$	sign modifier; =1 if port $i$ is a loading port; = -1 if port $i$ is a discharging port
$d_{c,C_i}$	Kronecker data; =1 for $c = C_i$ ; =0 otherwise
$W_{ijv}$	maximum allowed cargo weight for sailings from port $i$ to port $j$ by vessel $v$
$V_{ijv}$	maximum allowed cargo volume for sailings from port $i$ to $j$ by vessel $v$
$Pmin_{iv}$	minimum loading amount in port $i$ for vessel $v$
$Pmax_{iv}$	maximum loading amount in port $i$ for vessel $v$

### Objective function

$$\min \sum_{v \in V} \sum_{r \in R_v} C_{vr} \cdot y_{vr} + \sum_{v \in V} \sum_{i \in N_v} F_v^P \cdot T_i^Q \cdot q_{iv} + \sum_{v \in V} F_v^I \cdot (t_{dv} - t_{ov}) \quad (1)$$

The objective function contains three terms. The first term relates to the fixed costs of the vessels for their entire route. They include port fees and sailing costs, both of which are determined by the routing choice. The second and third term relate to port operation costs and waiting costs: they are time-dependent. The second term relates to the cost during loading or discharging, which of course depends on the quantity loaded or discharged. The cost is called 'reduced fuel cost' because  $i$  represents the topping-up over the lowest cost per time unit, which occurs while waiting. The matter is found back in the third term: the fuel cost while waiting is multiplied with the duration of the whole voyage. So the fuel cost during sailing in the first term is a topping-up over the fuel cost while waiting.

### Convexity constraints

$$\sum_{r \in R_v} y_{vr} = 1 \quad \forall v \in V \quad (2)$$

Each vessel is allowed to sail one route only.

### Scheduling constraints

In (3) a lower bound on the start of service at port  $j$  is calculated by added to the time for start of service at port  $i$ , the cargo handling time, and the sailing time from  $i$  to  $j$  (the first four terms in inequality (3)). The remaining term makes sure that

this inequality is not taken into account when vessel  $v$  does not sail leg  $(i,j)$  on route  $r$ . Constraint (4) makes sure that the start of service takes place within the time windows put forward by the port.

$$t_{iv} + T_{qi} \cdot q_{iv} + T_{ijv}^S - t_{jv} - U_{ijv} \cdot (1 - \sum_{r \in R_v} A_{ijvr} \cdot y_{vr}) \leq 0$$

$$\forall v \in V, (i,j) \in A_v \quad (3)$$

$$E_i \leq t_{iv} \leq L_i \quad \forall v \in V, i \in N_v \cup \{o, d\} \quad (4)$$

### Cargo constraints

Cargo loading constraints, both in terms of weight or volume, are only relevant if vessel  $v$  sails leg  $(i,j)$  in route  $r$ . The expression of relevance is expressed in constraint sets (5) and (6). Constraints (7) are balance constraints. It states that the sum of loads from whatever port  $j$  to the port under consideration  $i$  plus the amount loaded in port  $i$  is equal to the load on its way from port  $I$  to whatever port  $j$ . Constraints (8) takes care that the loading or discharging requirements are met at every port  $i$ .

$$\sum_{c \in C} l_{ijcv} - W_{ijv} \cdot \sum_{r \in R_v} A_{ijvr} \cdot y_{vr} \leq 0$$

$$\forall v \in V, (i,j) \in A_v^W \quad (5)$$

$$\sum_{c \in C} \frac{l_{ijcv}}{D_c} - V_{ijv} \cdot \sum_{r \in R_v} A_{ijvr} \cdot y_{vr} \leq 0$$

$$\forall v \in V, (i,j) \in A_v^V \quad (6)$$

$$\sum_{(j)} l_{jicv} + d_{c,Ci} \cdot l_i \cdot q_{iv} - \sum_{(j)} l_{ijcv} = 0$$

$$\forall v \in V, i \in N_v, c \in C \quad (7)$$

$$\sum_{v \in V_i^N} q_{iv} = Q_i$$

$$\forall i \in N^P \cup N^Q \quad (8)$$

### Variable type constraints

The constraints (9) till (13) express the data types of the variables. One additional explanation is required for constraint (10) which states that, in case loading takes place, the vessel loads at least a minimum amount  $Pmin_{iv}$  and at most a maximum amount  $Pmax_{iv}$ . Both bounds might appear due to technical or business reasons.

$$y_{vr} \in \{0,1\} \quad \forall v \in V, r \in R_v \quad (9)$$

$$q_{iv} \in \{0, [Pmin_{iv}, Pmax_{iv}]\}$$

$$\forall i \in N^P, v \in V_i^N \quad (10)$$

$$q_{iv} \geq 0 \quad \forall i \in N^D, v \in V_i^N \quad (11)$$

$$t_{iv} \geq 0 \quad \forall v \in V, i \in N_v \cup \{o, d\} \quad (12)$$

$$l_{ijcv} \geq 0 \quad \forall v \in V, (i,j) \in A_v, c \in C \quad (13)$$

## DISCUSSION OF THE RESULTS

Theoretically, there are various possibilities for ship routing plan of oil products distribution; however, in practice, three scenarios covers the whole problem. Specialized tankers for shipping oil products with deadweight ton range of 5000 dwt – 10 000 dwt are studied to travel routes through domestic ports in Vietnam via the South East Asia Sea. The vessels depart from the locations which may be the same as or different with those of loading sites. The vessels load oil products from two busiest distribution sites at Dung Quat port in Quang Ngai province and Nha Be port in Ho Chi Minh city and deliver them to other three distribution areas in QuangNinh, Ha Tinh, Can Tho province.

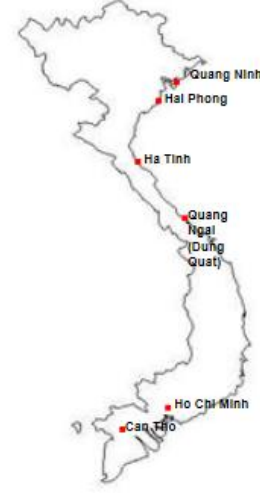


Figure 2: Position of terminals in the scenarios

### First scenario

The simplest scenario assumes that routes have different origin positions of vessels, same locations of suppliers and deliveries and same destination positions of vessels at the end of the route. The routes are supposed as follows in *Table 1*. The feasible and optimal result are the routes in which vessels are closest loading or unloading locations. Explicitly according to the map, the route R2 is the best option for all vessels.

Route	Origin port	Loading port		Unloading Port			Destination port
		Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	
R1	Hai Phong	Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh
		Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh
R2	Ha Tinh	Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh
R3	Ho Chi Minh	Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh
		Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh

Table 1: Routes for oil products distribution in the first scenario

### Second scenario

While routes have same original positions of vessels, different locations of suppliers or/and deliveries and same destination positions of vessels at the end of the route as illustrated in *Table 2*, the result becomes the routes which vessels have the most operations at the loading or/and unloading locations. Practically, two routes R1 and R5 are prior to be chosen because the first delivery is closest the last loading location. The second delivery of route R5 is nearer than the one of route R1. Consequently, the best choice is the route R5.

### Third scenario

The most complex scenario is shown in *Table 3* where routes have different original positions of vessels, different locations of suppliers or/and deliveries location and same destination position of vessels at the end of the routes. Thus, the feasible and optimal result will be the routes satisfying requirements that cost operations is minimized, vessels are closed by the loading or discharging g locations and that vessels have the most services at the loading or unloading sites. Accordingly, route R1 and route R5 are chosen for optimization. Furthermore, vessels starting in Hai Phong are nearest to the first supplier than those starting in Ho Chi Minh. As a result, route R1 is the optimal.

Route	Origin port	Loading ports		Unloading Ports			Destination port
R1	Hai Phong	Quang Ngai	Ho Chi Minh	Can Tho	Quang Ninh	Ha Tinh	Ha Tinh
	Hai Phong	Quang Ngai	Ho Chi Minh	Tinh	Quang Ninh	Can Tho	Can Tho
R3	Hai Phong	Quang Ngai	Ho Chi Minh	Quang Ninh	Ha Tinh	Can Tho	Can Tho
	Hai Phong	Quang Ngai	Ho Chi Minh	Ha Tinh	Can Tho	Quang Ninh	Quang Ninh
R5	Hai Phong	Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh

Table 2: Routes for oil products distribution in the second scenario

Route	Origin port	Loading port		Unloading port			Destination port
R1	Hai Phong	Quang Ngai	Ho Chi Minh	Can Tho	Quang Ninh	Ha Tinh	Ha Tinh
		Quang Ngai	Ho Chi Minh	Ha Tinh	Quang Ninh	Can Tho	
R3	Hai Phong	Quang Ngai	Ho Chi Minh	Quang Ninh	Ha Tinh	Can Tho	Can Tho
		Quang Ngai	Ho Chi Minh	Ha Tinh	Can Tho	Quang Ninh	
R5	Ho Chi Minh	Quang Ngai	Ho Chi Minh	Can Tho	Ha Tinh	Quang Ninh	Quang Ninh
		Quang Ngai	Ho Chi Minh	Th	Tinh	Ninh	

Table 3: Routes for oil products distribution in the third scenario

### FUTURE RESEARCH

Following work will focus on each specific scenario for testing the model to find out which route and by which vessel products have to be transported and how many products can be loaded or discharged the most to obtain the optimal results in oil products distribution in the Vietnam Sea.

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### BIOGRAPHIES

**Hoang Thi Minh Ha** holds a B.SC in Physics-Electronics from the University of Natural Sciences (HCMC, Vietnam) and a Master in Quality Management from the Université de Bruxelles Open University (HCMC, Vietnam). Currently she is pursuing a Ph.D. study at the Logistics Research group of the Hasselt University (Belgium) supported by a full scholarship of the Ministry of Education and Training, Vietnam. Her field of study is the application and development of operations research models for oil product logistics.

**Gerrit K. Janssens** is Professor of Operations Management and Logistics at the Hasselt University, Belgium within the Faculty of Business Economics. During the last twenty-five years he has been several times visiting faculty in universities in South-East Asia and in Southern Africa. His main research interests include the development and application of operations research models in production and distribution logistics.