Computers & Industrial Engineering 61 (2011) 289–299

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Solving the ship inventory routing and scheduling problem with undedicated compartments

Nurhadi Siswanto *, Daryl Essam, Ruhul Sarker

School of Engineering and Information Technology, The University of New South Wales at The Australian Defense Force Academy (UNSW@ADFA), Building 15 Room 110, Northcott Drive, Canberra ACT 2600, Australia

ARTICLE INFO

Article history:
Received 30 November 2009
Received in revised form 11 April 2010
Accepted 19 June 2010
Available online 27 June 2010

Keywords:
Routing and scheduling
Ship/marine transportation
Undedicated compartment
Oil product delivery
Multiple-heuristics

ABSTRACT

This paper presents a ship inventory routing and scheduling problem with undedicated compartments (sIRPSP-UC). The objective of the problem is to find a minimum cost solution while satisfying a number of technical and physical constraints within a given planning horizon. In this problem, we identify four sub-problems that need to be decided simultaneously: route selections, ship selection, loading, and unloading activity procedures. To solve this problem, first, we developed a mixed integer linear programming model. We then developed a one-step greedy heuristic, and then based on this heuristic, we propose a set of heuristics. Each heuristic has a combination of rules for each sub-problem. A number of problem instances are used to compare the solutions of the two approaches. We applied selected good combinations of rules to solve each problem using the heuristic approach. The results show that 8 out 12 of the considered problem instances have no gap with MILP solution solved using LINGO. We also find that the average gap is 1.96%. In contrast when we consistently use the same combination for all iterations, there are no dominant combinations of heuristics that can find good solutions for all the problem instances.

1. Introduction

In this paper, we present a ship inventory routing and scheduling problem with undedicated compartments (sIRPSP-UC). This problem is a class of inventory routing problem (IRP) which considers an integration of an inventory management problem and a routing problem. In maritime literature, this problem can be categorized as industrial shipping as the same company controls both the inventory levels and the transportation of products. A recent survey on ship scheduling research is given in Christiansen et al. (2007).

Likes other IRP, sIRPSP-UC is concerned with the repeated distribution of a set of liquid bulk products from a number of production depots to a number of demand nodes over a given planning horizon. Unlike the vehicle routing problem (VRP) where a company assigns vehicles to meet customer orders, there are no direct orders from its customers. The company assigns a fleet of ships to maintain the stock level of the commodities within their limits at minimal cost during a given planning horizon. In this problem, we need to determine the type and the quantity of products to be loaded, the ship routing and delivery schedules, and the type and the quantity of products to be unloaded at the destinations ports simultaneously.

This paper is a variation to the model considered by Christiansen (1998, 2007, 2009) and Al-Khayyal and Hwang (2007). Christiansen (1998, 2007, 2009) considers a single product model. Al-Khayyal and Hwang (2007) extends the problem to have multiple non-intermixable products. The heterogeneous ships distributing these products have several compartments to keep products separately. However, they assume that compartments are dedicated for certain products. This means that it is not permissible to assign a product to a compartment that has been used previously by other products.

As a variation to the model considered by Al-Khayyal and Hwang (2007), the sIRPSP-UC relaxes the problem to consider an assignment of multi-undedicated compartments to products. We call this assignment as multi-product loading assignment (MPLA). MPLA exists in practice in delivering of oil products as discussed, for example by Bruggen and et al. (1995), and Cornillier et al. (2008a, 2008b, 2009). Furthermore, we also found a real world problem in transporting oil products in the South East Asia region. The problems discussed in Bruggen et al. (1995) and Cornillier et al. (2008a, 2009) basically are VRP because they concern single period problems. Cornillier et al. (2008b) extends their previous research to deal with a multi period problem. All of these papers assume that partially unloading is not permitted. This assumption is common when we discuss oil product delivery using land-based transportation, such as a truck. In our problem, maritime transportation, the capacity of compartment of a ship is mostly larger compared to

* Corresponding author. Tel.: +61 2 626 88173; fax: +61 2 626 88581.
E-mail address: n.siswanto@adfa.edu.au (N. Siswanto).

0360-8352/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2010.06.011

the quantity to be unloaded. Because of that, we assume that partial unloading is permitted. The detailed comparisons between land-based and maritime transportation are described in Ronen (2002) and Christiansen et al. (2007). In addition to the above papers, MPLA has also been discussed in many papers, such as in Yuceer (1997), Bukchin et al. (2004, 2006), and Smith (2004).

In this paper, sIRPSP-UC problem is formulated as a mixed integer linear programming (MILP) model. Considering the difficulty of solving large problems, we have developed a multi-heuristics based approach. The methodology is validated against MILP solution using LINGO for a number of problem instances.

The remainder of this paper is organized as follow. A mathematical model of sIRPSP-UC is presented in Section 2. A one-step greedy heuristic method is described in Section 3. In Section 4, heuristics for solving the problem is described. In Section 5, an illustrated example is discussed. The result of both the mathematical model and heuristic methods are presented and compared in Section 6, and this is followed by conclusions in the last section.

2. Problem description

We present the sIRPSP-UC that involves the delivery of multiple bulk liquid products which cannot be mixed. This delivery uses heterogeneous types of ships in term of capacity, traveling cost and time. The ships also differ in number of compartments. These compartments are not dedicated to specific products. This means that each compartment can load any type of product but only one at a time. In each delivery trip, a ship can visit more than one port. However, it is assumed that all products are unloaded at the end of a voyage. Only a ship with emptied compartments returns to the production ports. Because of that, we assumed that there is no additional change-over cost or time required when a compartment of a ship is loaded with a different product.

Each loading port can produce multiple bulk products. It is assumed that each product has a finite daily production (or supply) rate. Moreover, every demand node may consume certain products. It is also assumed that each product has a daily average consumption rate. The nature of the products requires them to be stored separately into the storages of the ports. These storages have a maximum capacity. A fleet of ships travels between ports to ensure that the levels of storages are within their limits. A ship may load one or more products from production storages, and discharge them at a demand port. The number of ships visits a port and the quantity loaded or unloaded are not known in advance. However, partial loading and unloading are allowed.

It is assumed that each port can receive more than one ship at a time. Several ships can load or unload products simultaneously. However, a ship cannot load or unload different products at the same time. In a port, waiting time is also permitted. In production ports, a ship may delay its departure to have more products. However, this delay must take into account the arrival time in destination ports in order not to cause a stock shortfall at those ports. In demand ports, a ship may wait until there is space in storage so as to unload more products.

At the beginning of the planning horizon, the compartment contents and position of ships are known. Compartments of a ship may be empty or they may have one or more products in its compartments. The position of a ship may be in a port or a point at sea. We create artificial ports as ship initial positions.

In this problem, we are concerned with short or medium term operational planning. We assume that the number of ships and their total capacities are fixed and sufficient to serve the ports during the planning horizon. Therefore, we ignored the fixed cost of the ships, such as leasing or investment cost. We also disregard inventory cost because the products both in the production and consumption storages are owned by the same company. In this case, we are only concerned with the cost charged in the port and the cost of sailing. Under the above condition, we need to simultaneously determine the type and the quantity of products to be loaded, the assignment of products to ship compartments, the ship routing and delivery schedules, and the type and the quantity of products to be unloaded at the destinations ports. The objective of the problem is to find a minimum cost solution for the ship routing and loading/unloading schedules.

3. Mathematical model

The development of this model is similar to Christiansen (1998, 2007, 2009) and Al-Khayyal and Hwang (2007), but with significant modifications to account for loading (or unloading) activities in undedicated compartments of ships. The sIRPSP-UC model can be formulated into five-parts: routing, loading and unloading, scheduling, inventory and objective function, as shown below:

3.1. Routing constraints

Let V be a set of ships to be routed and scheduled. A ship $v \in V$ has an artificial origin port, $o(v)$, where the ship begin its journey. Ships visit and serve a set of physical ports, defined as H. The subset of physical ports that can be visited by ship v is defined as $H_v \subseteq H$. So, the set of all possible locations for ship v is $H_v \cup \{o(v)\}$. A port $i \in H$ can be visited several times during the planning horizon. We define $M_i > 0$ as the maximum number visits of ships at port $i \in H$. Obviously, the maximum number of visits at artificial ports is 1.

Let $G = (N, A)$ be a directed graph where N is the node set and A is the arc set. The node set $N = \{(i, m){:}i \in H, m = 1, \ldots, M_i\} \cup \{o(v), 1\}$ is represented by a pair of a port and a number of ship visits at that port. This set denotes as all possible positions of ships. Then, we define $N_P \subseteq N$ as a subset of ship positions at production ports. Moreover, the arc set A is defined as all possible connections between two nodes. A subset of all feasible arcs for ship v is given as $A_v \subseteq A$.

In the routing formulation, there are three binary variables:

- x_{imjnv} equals 1 if ship v routes from node (i, m) to node (j, n), and 0 otherwise;
- y_{im} equals 1 if node (i, m) is not visited, and 0 otherwise;
- z_{imv} equals 1 if ship v finishes its route at node (i, m), and 0 otherwise.

The routing constraints are as follows:

$$\sum_{(j,n)\in N} x_{o(v)1jnv} + z_{o(v)1v} = 1, \quad \forall v \in V \tag{1}$$

$$\sum_{(j,n)\in N\cup\{o(v),1\}} x_{jnimv} - \sum_{(j,n)\in N} x_{imjnv} - z_{imv} = 0, \quad \forall (v,i,m) \in V \times N, \ i \neq j \tag{2}$$

$$\sum_{(i,m)\in N} z_{imv} = 1, \quad \forall v \in V \tag{3}$$

$$\sum_{v\in V} \sum_{(j,n)\in N\cup\{o(v),1\}} x_{jnimv} + y_{im} = 1, \quad \forall (i,m) \in N, \ i \neq j \tag{4}$$

$$y_{im} - y_{i(m-1)} \geqslant 0, \quad \forall (i,m) \in N, \ m \neq 1 \tag{5}$$

$$x_{imjnv} \in \{0,1\}, \quad \forall v \in V, \ \forall (i,m,j,n) \in A_v \tag{6}$$

$$z_{imv} \in \{0,1\}, \quad \forall v \in V, \ \forall (i,m) \in N \cup \{o(v),1\} \tag{7}$$

$$y_{im} \in \{0,1\}, \quad \forall (i,m) \in N \cup \{o(v),1\} \tag{8}$$