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Scheduling for inland container truck and train transportation

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ABSTRACT

Inland container transportation refers to the container movements among customer locations, container terminals, and depots in a local area. In this paper, an Inland container transportation problem by truck and train is investigated. Containers are classified into four types according to the direction (inbound containers and outbound containers) and container state (full containers or empty containers). Containers can be delivered not only by truck but also by train and the time windows of containers are considered. A mathematical model is developed by a graph model and a hybrid tabu search is proposed. The performance of the proposed method to find near optimal solutions is investigated by numerical examples generated randomly.

1. Introduction

The importance of container transportation and the proportion that it holds in the transportation market have been increased significantly over the last two decades (Zhang et al., 2009). The inland container transportation refers to the container movements among customer locations, container terminals, and depots in a local area. It usually involves two main transportation modes: truck and train. When a customer asks to export freight, a truck will carry an empty container from a depot or a train station, and deliver it to the customer location, pack the freight into the container and then deliver it to the terminal or a train station for transfer and so on. An optimization problem for assigning containers to trucks and trains to transport between customer places and container terminal is dealt with in this paper.

The inland container transportation problem can be classified into traveling salesman problem (TSP) or vehicle routing problem (VRP). A network can be constructed from container flows in the problem. If a network is defined appropriately, some problems in this area can be reduced to ones near to multiple traveling salesman problems with time windows (m-TSPTW) or multiple vehicle routing problems with time windows (m-VRPTW). There are a number of papers in which various methods are proposed to find optimal or good solutions in this area. Wen and Zhou (2007) developed a GA (Genetic Algorithm) to solve a container vehicle routing problem in a local area. Jula et al. (2005) formulated truck container transportation problems with time constraints as an asymmetric multi-traveling salesman problem with time windows (m-TSPTW). They applied a DP/GA (dynamic programming and genetic algorithm) hybrid algorithm for solving large size problems. Zhang et al. (2009) addressed a similar problem, a graph model was built up, and a cluster method and RTS (Reactive Tabu Search) were proposed and compared with each other. Liu and He (2007) decomposed a vehicle routing problem into several sub-problems according to vehicle-customer assigning structure and a new tabu search algorithm was applied to each sub-problem, respectively. However, these papers addressed the problems in this area only considering truck transportation and proposed the methods correspondingly. This paper focuses on the background of intermodal transportation in which truck and train transportation could be considered together. For this new problem, these algorithms are not suitable anymore and they need to be redesigned or new methods are needed.

In general, there are two transportation modes (truck and train modes) in inland container transportation problems. Truck transportation is a more efficient mode in door-to-door service for containers than train transportation but it brings higher cost. In this paper, we consider truck and train transportation together to transport four types of containers. There is little literature addressing inland container transportation problems in which truck and train are considered together. Intermodal transportation problems with time windows are hard to deal with, especially when a container is related to more than one time windows. A number of papers tried to make change and/or to relax constraints related to time windows. Lau et al. (2003) considered the vehicle routing problem with time windows under a limited number of vehicles, and they provided a mathematical model to calculate an upper bound by selecting one of the biggest times to return to the depot from nodes, which are calculated only from upper bounds of time windows. Zhang et al. (2009) considered

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two time windows (to origin and destination) of each container and combined them into one serving time window. Wang and Regan (2002) tried to fix the service time for each load to the lower bound or upper bound of the corresponding time window to simplify the problem with hard pick-up and delivery time windows into over-constrained and under-constrained models. They solved these two models as bounds of the original problem. Additionally they designed a window-partition-based method to find more accurate solutions in reasonable times. Zhang et al. (2010) studied a more complex truck scheduling problem for container transportation in a local area with multiple depots and multiple terminals. They used the same method of combining two time windows and then applied the window-partition-based method proposed in Wang and Regan (2002) to solve the problem. Kopfer et al. (2010) proposed another way to deal with the time windows of each container. They considered the lower and upper bounds of a time window independently and treated them as nodes. In this paper, truck and train transportation modes with hard time windows are considered together to transport four types of containers.

The remaining context of this paper is organized as follows. Assumptions and notations are listed in Section 2. A graph model and a mathematics model are given in Section 3. A hybrid tabu search algorithm is developed to solve the problem in Section 4, and tested with randomly generated examples in Section 5. Finally, Section 6 concludes this paper.

2. In inland container transportation

In this paper, we consider an inland container transportation problem and should determine how to transport containers (four types of containers) between container terminal and customer places. There are two transportation modes (truck and train) available. All containers have time windows for pick-up and delivery and we should transport containers to satisfy the time windows.

2.1. Assumptions

1) There exists one maritime terminal, one train station, and one depot in the system. The terminal is the station of the train and truck. Outbound (export) containers are transported from a customer or the depot to the terminal. Inbound (import) containers are transported from the terminal to a customer place or the depot. The depot has enough empty containers and trucks. The depot can be visited at any time.
2) Trains transport containers between the terminal and the train station. Train timetable is given.
3) All containers have same type of size (40 ft).
4) All the trucks are identical. One truck only carries no more than one container at any time. They are initially located at the depot and finally return to the depot.
5) Costs of loading/unloading and packing/unpacking are negligible.
6) Inbound or outbound full container has origin and destination time windows. An inbound empty container only has an origin time window and an outbound empty container only has a destination time window.

2.2. Notation

C_t Unit cost per unit time by a truck
C_S^r Unit cost per container by train r
t_{ij} Traveling time from location i to location j by truck. It is assumed that $t_{ij}=t_{ji}$. $i=0$ or $j=0$ if the corresponding location is the terminal, $i=D$ or $j=D$ if the corresponding location is the depot, and $i=S$ or $j=S$ if the corresponding location is the train station ($S=1$) or the terminal ($S=0$)
RT^r Traveling time of the train r between the station and terminal
$IDT(r1)$ Departure time of the import freight train $r1$ at the terminal
$IAT(r1)$ Arrival time of the import freight train $r1$ at the inland train station
$EDT(r2)$ Departure time of the export freight train $r2$ at the station
$EAT(r2)$ Arrival time of the export freight train $r2$ at the terminal
Q_r Capacity of the train r
$[\tau_{Ai},\tau_{Bi}]$ Time window of the origin of container i
$[\tau_{Ci},\tau_{Di}]$ Time window of the destination of container i
$tlus_i$ Loading/unloading time of the container i at the station
$tlut_i$ Loading/unloading time of the container i at the terminal
$tlud_D$ Loading/unloading time of an empty container at the depot
$tluc_i$ Loading/unloading time of the container i at its customer location
$tpuc_i$ Packing/unpacking time of the container i at its customer location

3. Graph and mathematical models

In this section, a graph model is built up first and then the scheduling problem is formulated as a mathematical model based on the graph model.

3.1. Graph Modeling

In this subsection, we transform our optimization problem to a network connection problem. Containers are classified into four types: inbound empty containers, inbound full containers, outbound empty containers, and outbound full containers.

This network mainly focuses on activities by the trucks and it can be decomposed into two main parts. The first part is related to service activities that a truck performs and the second one is related to the process activities that a truck moves from the last location to the next service. In the graph model, the activities relevant to a service are treated as an entire entity (vertex) and other activities are treated as connections (arcs) between these entities. Then the graph model can be proposed below.

Let $G=(V,A,T,C)$ indicate this graph model, where V means vertices, A is arcs, T is time needed for each vertex and arc, and C stands for the transportation cost for given vertex and arc. Fig. 1 shows the structure of this graph model. For example, customer A needs to export a container of freight. At the customer place, there is a pick-up time window and at the terminal there is a delivery time window. The vertex is the activities for a truck from customer location to the terminal as shown by solid lines. That is, a truck first arrives at the customer place in advance. Then some activities in the vertex are done, for example, packing a container at the customer place and loading the container on the truck, and the truck will deliver the container to the terminal and unload it. Serving time window is calculated to satisfy the time windows. That means a truck should begin the service during this time period due to time windows at origin and destination. There is a different case if this container can be carried by train. The