Transportation Research Part E 89 (2016) 70–85

Contents lists available at ScienceDirect

Transportation Research Part E

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

A model for a multi-size inland container transportation problem

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ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 28 January 2016
Accepted 27 February 2016
Available online 11 March 2016

Keywords:
Container hinterland transportation
Mixed-integer programming
Multi-size containers
Pickup and delivery

ABSTRACT

In the multi-size Inland Container Transportation Problem (mICT) trucks are able to transport up to two 20-foot or one 40-foot container at a time along routes with various pickup and delivery locations. A mixed-integer linear program for the mICT is presented using two alternative objective functions: minimization of the total travel distance and minimization of the total operation time of the trucks. The presented model is tested on instances which vary in size. Computational experiments show that by means of the presented model small problem instances can be solved optimally.

1. Introduction

Intermodal container transportation refers to the movement of empty containers or containerized cargo by different means of transportation (modes) in one transportation chain. A typical transportation chain can be subdivided into three sections, each section being operated by a distinct transportation mode (Macharis and Bontekoning, 2004). The first section is called *pre-haulage*. In pre-haulage, trucks fetch containerized cargo from the actual customers (*senders*) by carrying fully loaded containers to terminals. The longest distances are covered in the *main-haulage*. This second section is mostly carried out by barge, deep sea shipping or rail to move containers between terminals. The last section implies container transportation by truck from terminals to customers (*receivers*) and is referred to as *end-haulage*. Between 25% and 40% of the total intermodal container transportation costs are accrued in the trucking sections (*drayage*) of an intermodal transportation chain (Macharis and Bontekoning, 2004). Notteboom and Rodrigue (2005) state that in sea transportation inland costs range between 40% and 80% of the total transportation costs and are thus even higher. Since most flows of containerized cargo are asymmetric, there is a need for unproductive movements caused by empty container repositioning. While the share of empty containers that are repositioned at sea is around 20% of all containers transported, the rate of repositioned empty containers on land is estimated to be even twice as high (Konings, 2005). Consequently, the movement of empty containers is a significant cost factor in container transportation which should not be neglected.

This paper addresses a problem arising in the field of drayage. One trucking company has to transport containerized cargo between customers, terminals and one depot. Empty containers needed as transportation media for cargo can be stored at the depot. All containers of a given size are assumed to be interchangeable with each other; i.e., for a cargo request it does not matter which container of that size is used to transport cargo. Then the problem is two-fold: container assignment and truck routing. On the one hand, empty containers have to be assigned to cargo transportation requests. There are two ways to

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http://dx.doi.org/10.1016/j.tre.2016.02.010
1366-5545/

assign them: As the depot is assumed to be storage space for empty containers, empty containers which are assigned to cargo transportation requests can be obtained from and delivered to the depot. Another way to assign empty containers is constituted by the *street-turn* methodology. By performing a street-turn, empty containers are directly carried from receivers to senders (Jula et al., 2006). On the other hand, routes for trucks have to be constructed in such a way that the trucking company performs all container movements resulting from a given set of cargo transportation requests. The common problem formulation found in literature is restricted to the transportation of 40-foot containers only. Such intermodal drayage truck routing and scheduling problems are representatives of the class of Full Truckload Pickup and Delivery Problems (Erera and Smilowitz, 2008), or Full Truckload Pickup and Delivery Problems with Time Windows (FT-PDPTW), if in addition time restrictions are given. Surveys on pickup and delivery problems are given by e.g. Savelsbergh and Sol (1995) and Parragh et al. (2008a,b). The FT-PDPTW can be transformed into an asymmetric multiple Traveling Salesman Problem with Time Windows (amTSPTW). Among others Wang and Regan (2002), Jula et al. (2005), Zhang et al. (2010), and Braekers et al. (2013) show how to transform problems arising in the field of drayage into amTSPTW's. This paper extends the common problem formulation by considering containers of different sizes (i.e., 20-foot and 40-foot containers). Trucks can either transport up to two 20-foot containers or one 40-foot container at a time. To obtain a formal description of the considered problem, a graph representation and a mathematical formulation as a variant of the amTSPTW are presented. The model builds optimal routes that are allowed to consist of more than four stops for the transportation of 20-foot and 40-foot containers. As far as we know, the implementation of a mathematical model for the first time has been able to compute solutions to this problem type.

The remaining paper is organized as follows. A survey on research sources is presented in Section 2. In Section 3 a formal definition of the multi-size Inland Container Transportation Problem (mICT) is given. The mathematical model for the mICT presented in Section 4, and the results of computational experiments on randomly generated test instances as well as modified instances from literature sources are presented in Section 5. Section 6 concludes this paper.

2. Literature review

Although, the Traveling Salesman Problem (TSP) is NP-hard (Karp, 1972), there are fast methods for solving large instances optimally (see e.g. Hoffman et al., 2013 for a list of approaches). One of the exact methods is called *Concorde* (Applegate et al., 1995, 2011). Concorde is able to optimally solve instances like the 85,900-cities instance of *TSPLIB* (Reinelt, 1991). However, optimal solutions to instances of this size could only be obtained for the symmetric TSP. For some reasons, the asymmetric TSP seems to be much harder to solve (Grötschel, 2015). A generalization of the TSP is the multiple Traveling Salesman Problem (mTSP), which considers several salesmen. An overview on formulations and solution procedures for the mTSP is given by Bektas (2006). mTSP instances that could be optimally solved contain about 500 cities (Gavish and Srikanth, 1986). A further extension of the TSP/mTSP is to additionally consider time windows, in which salesmen have to arrive at cities. As Williams (2013) states, such a formulation could prove very difficult to solve for reasonable-sized problem instances. For surveys of time window constrained routing problems see e.g. Solomon (1987), Solomon and Desrosiers (1988), and Desroches et al. (1988).

Trucking problems arising in intermodal container transportation are for example studied by Jula et al. (2005). Jula et al. (2005) introduce a transportation problem, in which fully loaded 40-foot containers have to be transported between specified pickup and delivery locations respecting the given arrival time windows at the different locations. The authors model the problem as amTSPTW by introducing one node for each container pickup and delivery pair. They propose a two-phase algorithm based on dynamic programming that optimally solves the problem and additionally propose a hybrid methodology combining dynamic programming techniques with a genetic algorithm and compare the solutions constructed by this methodology with solutions of an insertion heuristic approach that is inspired by Jaw et al. (1986). If the simultaneous transport of fully loaded and empty containers is simultaneously considered, it is distinguished between *well-defined* and *flexible tasks* (Smilowitz, 2006). Well-defined tasks comprise the transportation of containers, in which pickup and delivery locations are known in advance. In contrast, either the point of origin or destination is left undefined for flexible tasks, and, thus, is a matter of optimization. Imai et al. (2007) study a problem including the following two kinds of flexible tasks: In delivery trips, a fully loaded container has to be carried from the intermodal terminal to a consignee, where the container is unloaded. The destination location of the obtained empty container can either be the intermodal terminal or it can be reused for a pickup trip. In a pickup trip, an empty container has to be transported either from a delivery location of a delivery trip or from the intermodal terminal to a shipper, where the container is filled. The obtained fully loaded container has to be transported to the intermodal terminal. In any case, i.e. for delivery and pickup trips, the assignment of a container to a truck remains unchanged during the whole trip from the truck's start at the terminal until its arrival at the terminal again. Consequently, new assignments of containers to trucks are only possible at the terminal. Imai et al. (2007) propose a subgradient heuristic approach based on Lagrangian relaxation to compute solutions to this problem definition. Caris and Janssens (2009) extend the problem definition of Imai et al. (2007) by introducing time windows and present a FT-PDPTW formulation. Afterward, Caris and Janssens (2009) improve an initial solution constructed by a two-phase insertion heuristic approach with local search techniques. By introducing multiple terminals, Zhang et al. (2010) extend the work of Zhang et al. (2009) and define the Inland Container Transportation Problem (ICT). The authors present a heuristic approach based on a window partitioning approach (Wang and Regan, 2002). Sterzik and Kopfer (2013) show a mathematical model and present a tabu