Transportation Research Part E 65 (2014) 50–69

Contents lists available at ScienceDirect

Transportation Research Part E

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

Bi-objective optimization of drayage operations in the service area of intermodal terminals

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ARTICLE INFO

Keywords:
Drayage operations
Vehicle routing
Deterministic annealing
Bi-objective
Traveling salesman problem

ABSTRACT

A full truckload vehicle routing problem in drayage operations around intermodal container terminals is studied. Loaded and empty containers need to be transported in a small geographical area. Either the origin or the destination of empty container transports is unknown in advance. The problem is formulated as an asymmetric multiple vehicle Traveling Salesman Problem with Time Windows (*am*-TSPTW). For the first time, this type of problem is considered from a bi-objective perspective. Three solution algorithms are proposed and compared with each other. Best results are obtained by a two-phase hybrid deterministic annealing and tabu search algorithm.

1. Introduction

Due to problems of road congestion, environmental concerns and traffic safety considerations, intermodal container transport has received an increased attention in freight transport policy making. Intermodal container transport combines at least two modes of transport for transporting freight using one and the same container. Goods are not handled during transfers between modes at intermodal terminals and the largest part of the transport is carried out by a sustainable mode or transport like barge, train or ocean-going vessel (Bontekoning et al., 2004; Caris and Janssens, 2009).

Drayage operations are the full truckload container transport activities that take place on a regional scale around intermodal container terminals. These activities include the initial and final part of intermodal transports and the repositioning of empty containers between intermodal terminals, container depots, shippers and consignees. Drayage operations are mostly performed by truck and constitute a large part of the total costs of intermodal transport. This is mainly due to costly empty container transports and empty vehicle movements. Optimizing drayage operations in the service area of container terminals is therefore of crucial importance in order to preserve the competitiveness of intermodal transport with unimodal road transport (Bontekoning et al., 2004; Braekers et al., 2011; Caris and Janssens, 2009).

In this paper the operational planning of drayage operations is studied. The problem is to create efficient vehicle routes performing all loaded and empty container transports in the service area of one or several container terminals during a single day. Loaded containers need to be transported from shippers to container terminals (outbound loaded containers) and from container terminals to consignees (inbound loaded containers). Besides, shippers may request empty containers to be delivered at their sites while consignees may have empty containers available which have to be picked up. Respectively the origins and destinations of these empty containers are not determined in advance. Rather, they represent a choice to the decision maker.

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http://dx.doi.org/10.1016/j.tre.2013.12.012

In the past, often a sequential planning approach was proposed to plan (empty) container movements in drayage operations (Crainic et al., 1993; Huth and Mattfeld, 2009). First, an empty container allocation model is used to determine the optimal distribution of empty containers in the region, based on supply and demand information of consignees and shippers respectively. Next, a vehicle routing problem is solved to create efficient vehicle routes performing loaded and empty container transports. Recently, efforts to integrate both planning steps are introduced by several authors (Braekers et al., 2013; Ileri et al., 2006; Smilowitz, 2006; Zhang et al., 2009). With an integrated approach, empty container allocation decisions are not taken in advance. Instead, these decisions are taken simultaneously with vehicle routing decisions. The advantage of such an integrated approach over a sequential approach is shown in Braekers et al. (2013). In this paper, an integrated approach is taken as well.

Typically a hierarchical objective function is used in vehicle routing problems. The primary objective is to minimize the number of vehicles while the secondary objective is to minimize total distance, total travel time or total route duration (Bräysy and Gendreau, 2005; Gendreau and Tarantilis, 2010; Jozefowiez et al., 2008). In this paper, a bi-objective approach is considered. Two objectives, minimizing the number of vehicles and minimizing total distance traveled, receive the same level of priority. While minimizing the number of vehicles affects vehicle investment and labor costs, minimizing distance affects time and fuel resources (Ombuki et al., 2006). Clearly, both objectives might be conflicting in some cases (Caseau and Laburthe, 1999; Jozefowiez et al., 2008). Solutions with the minimal number of routes k_{opt} may have a total distance which is higher than the total distance of solutions with $(k_{opt} + 1)$ or $(k_{opt} + 2)$ vehicles. Using a hierarchical objective function will bias the search towards minimizing the number of vehicles, while a bi-objective approach will reveal the possible trade-off between both objectives. This trade-off information can be useful to the decision maker. For example, given a number of vehicles that are available, expected routing costs to perform all transportation tasks can be estimated. On the other hand, when the transportation tasks to be performed are known, the minimum number of trucks that need to be allocated to these tasks in order to keep the operational routing cost below a certain level can be deducted. Even long term decisions about changing the fleet size may be supported by the provided trade-off information (Tan et al., 2006a).

In Braekers et al. (2013), a two-phase deterministic annealing algorithm for an integrated drayage problem with a hierarchical objective function is proposed. This algorithm has been adapted in Braekers et al. (2011) to take a bi-objective optimization function into account. To the authors' knowledge, no other bi- or multi-objective approach is proposed for a drayage problem in intermodal freight transportation. In this paper, several improvements of the algorithm presented in Braekers et al. (2011) are proposed: the introduction of a new local search operator, the introduction of tabu search logic to prevent cycling and the gradual reduction of the maximum threshold value. The individual contribution of each improvement on solution quality is indicated. Besides, more details on the working of the algorithm and a more elaborate discussion of results are provided. Finally, it is shown that the improved algorithm provides considerably better results than the algorithm in Braekers et al. (2011) and a simple iterative method which uses the two-phase algorithm in Braekers et al. (2013).

Related literature is discussed in Section 2. In Section 3 the problem is described in detail and it is formulated as an asymmetric multiple vehicle Traveling Salesman Problem with Time Windows (*am*-TSPTW). Section 4 discusses Pareto optimality and the concept of dominance. Details of the two-phase deterministic annealing algorithm are proposed in Section 5. Next, the improvements of the algorithm are presented (Section 6). In Section 7, results on randomly generated problem instances are discussed, the different algorithms are compared and the contribution of each of the different improvements is analyzed. Finally, Section 8 contains the conclusions and future research opportunities.

2. Literature review

The routing problem addressed in this paper is related to two fields of research: drayage operations and multi-objective routing problems. Existing research on both topics is reviewed in this section.

2.1. Drayage operations

Routing problems in drayage operations can be classified as full truckload pickup and delivery problems (Erera and Smilowitz, 2008). Containers, representing full truckloads, are transported between their pickup and delivery location. When time windows at customers or container terminals are considered, the problem becomes a Full Truckload Pickup and Delivery Problem with Time Windows (FT-PDPTW). Such a FT-PDPTW may be transformed to an asymmetric multiple vehicle Traveling Salesman Problem with Time Windows (*am*-TSPTW) by collapsing a each transport request into a single node (Jula et al., 2005; Wang and Regan, 2002). Wang and Regan (2002) propose a time window partitioning method to solve this type of problem. The idea is to iteratively solve an under- and over-constrained version of the problem. Jula et al. (2005) present two exact approaches for solving small problem instances, using dynamic programming and genetic algorithms, and an insertion heuristic for larger problem instances. A Lagrangian relaxation-based heuristic for drayage operations without time windows around a single container terminal is proposed by Imai et al. (2007). A local search heuristic and a deterministic annealing meta-heuristic for a similar problem with time windows are proposed respectively by Caris and Janssens (2009, 2010). Other authors study specific aspects of the operational planning of drayage operations. Cheung et al. (2008) look at the cross-border drayage problem while the effect of the introduction of an appointment-based access control system at a port is studied by Giuliano and O'Brien (2007) and Namboothiri and Erera (2008). Dynamic versions of the drayage