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Range-based truck-state transition modeling method for foldable container drayage services

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ABSTRACT

Manufacturing technologies of foldable containers have almost matured. The use of foldable containers might save transportation costs; however, incorporating them into drayage services also creates great challenges. The foldable container drayage (FCD) problem is formulated as a sequence-dependent multiple traveling salesman problem with time windows using a range-based truck state transition method. An improved reactive tabu search algorithm is designed and validated to solve the FCD problem. The methodology is evaluated extensively on the basis of randomly generated instances. Compared to the use of standard containers, the use of four-in-one foldable containers can save approximately 10% on transportation costs.

1. Introduction

Container drayage is an important aspect of global container logistics. It refers to the pre- and end-haulage among initial shippers, final receivers, and container terminals, and it is typically carried out by trucks (Caris and Janssens, 2009). Drayage is necessary in the chain of container transportation because door-to-door services can be offered with it. However, other means of transportation, for example, vessels that sail between ports (Akyuz and Lee, 2016; Wang et al., 2016a), usually cannot provide direct delivery to end users. The transportation cost per container in drayage is relatively high despite the relatively short drayage distance (Cheung et al., 2008). Furthermore, drayage creates the main sources of road congestions, shipment delays, and emissions of greenhouse gases and particles (Wang et al., 2016b).

Recently, manufacturing technologies of foldable containers have become mature. Companies and research institutes such as Dutch Holland Container Innovations, American Staxxon, Korea Railroad Research Institute and Cargoshell have designed and produced variants of foldable containers. The typical length of these containers is 20 or 40 feet. The height of a folded container is either one-quarter or one-sixth the height when it is unfolded. Correspondingly, such foldable containers are called four-in-one or six-in-one containers. Some foldable containers, including 4FOLD containers, have been put into the commercial operations of shipping companies such as Samudera Indonesia and the Transworld Group.

Drayage services for containers have been investigated relatively extensively. However, the literature regarding container drayage has focused on standard (i.e., unfoldable) containers. The few published articles on foldable containers mainly offer discussions on general transportation (e.g., by vessels) or the repositioning of foldable containers. Section 2 offers a brief literature review on container drayage services and an exhaustive survey on the transportation and repositioning of foldable containers. However, to the best of our knowledge, the routing and scheduling of drayage services using foldable containers have not been publicly reported.

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Therefore, in this research, we addressed a foldable container drayage (FCD) problem.

Introducing foldable containers into drayage services creates great challenges. In drayage services, the transportation of loaded containers, referred to as the *implementation of orders*, and the repositioning of empty containers must be considered simultaneously. This dual process is also a basic feature of drayage that is different from other means of container transportation. In addition, compared to the scenario in which standard containers are used, a truck in the FCD problem might carry several empty containers at a time. The number of empty containers carried by a truck needs to be decided. Moreover, both collection and distribution orders are dictated by time window constraints as determined by customers. The handling of an emptied container after a distribution order is delivered to a receiver and the source of the empty container for a collection order must be optimized simultaneously with the scheduling of trucks; this effort adds complexity to the model, making it more difficult to solve. To fully utilize resources, truck routes need to be well organized. We propose a range-based truck state transition (RTST) method to model the FCD problem and design an improved reactive tabu search (IRTS) algorithm to solve the problem.

The contributions made by this research can be summarized as follows. First, an FCD problem for which collection and distribution orders are considered with time windows explains the handling of the transportation of loaded foldable containers and the repositioning of empty containers, and it minimizes the total work time, including the waiting time of all involved trucks. Second, we propose an RTST method to model the range-based state of trucks and the coupled activities between the transportation of loaded containers and the repositioning of empty containers. Based on the RTST method, the FCD problem is formulated as an extension of the sequence-dependent multiple traveling salesman problem (SDMTSP) with time windows. Third, we design and validate an IRTS algorithm to solve the FCD problem. We evaluate the modeling and solution method on the basis of many randomly generated instances and offer several concluding remarks.

The remainder of this paper is organized as follows. Section 2 reviews two streams of literature related to container drayage and foldable containers. In Section 3, we formally define the FCD problem. Sections 4 and 5 show the formulation of the FCD problem using the RTST method and the number of empty containers assigned to a truck in the RTST method, respectively. Sections 6 and 7 present the description and evaluation of the IRTS algorithm, respectively. Finally, we conclude this paper in Section 8.

2. Literature review

In this section, we present a survey of the literature related to FCD services. In addition to an extensive literature review on the transportation and repositioning of foldable containers, we also present a brief survey on the research addressing container drayage.

2.1. Container drayage

Container types are seldom mentioned in the research of container drayage. Most articles in this field describe 40-foot dry standard containers because they are the container type that is most commonly used. Some articles do not account for container types but are based on the assumption that one truck can carry exactly one container; in other words, the researchers considered only truckload requirements. Hence, the formulations of container drayage problems under these scenarios are almost identical.

For example, Wang and Regan (2002) modeled a local truckload pickup and delivery problem as a multiple traveling salesman problem with time windows (m-TSPTW) and presented an iterative solution method for which time window partitions were used. Jula et al. (2005) formulated a similar problem in which work shifts of drivers were limited as an m-TSPTW with social constraints, and they designed a two-phase exact algorithm for which dynamic programming is used to solve it. Similarly, Caris and Janssens (2009) presented a full-truckload pickup and delivery problem with time windows and a local search heuristic to solve the pre- and end-haulage container transportation. Using the Hong Kong area as an example, Cheung et al. (2008) established an attribute-decision model to formulate a cross-border container drayage problem and implemented an adaptive labeling algorithm to solve it.

Research addressing container drayage has been enriched recently in various respects. For instance, Braekers et al. (2013) integrated the transportation of loaded and empty containers as a hierarchical programming model in which the flexible transport of empty containers is defined; that is, either the origin or the destination of a task was not predefined. Zhang et al. (2011) studied a similar problem with a limited number of empty containers available at depots and solved the problem using a reactive tabu search (RTS) algorithm. Xue et al. (2014) investigated a local container drayage problem under a new operation mode in which trailers (i.e., chassis) can be separated from tractors when loading or unloading freight. Ting and Liao (2013) presented a selective pickup and delivery problem, relaxing the constraint that all pickup nodes must be visited. A dynamic version of this problem has also attracted attention. Zhang et al. (2014) studied a container drayage problem with updatable logistic information, formulated it using a determined-activities-on-vertex graph, and solved it using a batch of re-optimization schemes. Escudero et al. (2013) introduced the real-time knowledge of vehicle positions, which was based on geographical information systems, into the daily drayage problem to take into account transportation time uncertainties.

Few articles reported drayage transportation problems with multiple container sizes. Chung et al. (2007) built several models for various container drayage problems. One of the problems studied by Chung et al. (2007) addressed both 20- and 40-foot containers and three types of trucks: 20-foot only, 40-foot only, and vehicles with a combined chassis. Lai et al. (2013) described a similar problem with heterogeneous trucks by assuming that the trucks had capacity to carry one or two containers, which served as the means to create truck types. Vidović et al. (2011) formulated a drayage problem with both 20- and 40-foot containers and a homogeneous fleet of trucks in which each vehicle had the capacity for two 20-foot equivalent units (TEUs) as a multiple matching problem. Similar research can also be found in Vidović et al. (2017).

Zhang et al. (2015) studied a drayage problem with multiple container sizes in which a truck with a combined chassis can carry