Transportation Research Part C 52 (2015) 132–143

Contents lists available at ScienceDirect

Transportation Research Part C

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

The container retrieval problem with respect to relocation

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ARTICLE INFO

Article history:
Received 14 September 2014
Received in revised form 6 December 2014
Accepted 23 January 2015
Available online 14 February 2015

Keywords:
Container retrieval
Rail mounted gantry crane (RMGC)
Container yard
Multi-lift
Heuristic

ABSTRACT

The demand for container terminal yards is growing significantly faster than the supply of available land; therefore, containers are typically stacked high to better utilize the land space in container yards. However, in the process of container retrieval, non-productive reshuffling may be required to relocate the containers that are stacked on top of the target container. Container retrieval is directly related to the operational efficiency of terminals. Because the industry has become increasingly competitive, it has become critical to introduce a systematic approach to retrieving containers. In this study, we develop a heuristic that can generate feasible working plans for rail-mounted gantry cranes (RMGC) in container yards to minimize the number of container movements while taking the RMGC working time into consideration. The methodology takes into consideration the case that containers are grouped in terms of their retrieval order. Multi-lift RMGC models also are studied. Comprehensive numerical experiments reveal that the method runs faster than other methods published in the literature by several orders of magnitude; additionally, our method is able to solve instances larger than practical use. The number of movements approaches a theoretical lower bound, and the numerical results clearly demonstrate the tradeoff between the number of movements and the working time, and provide useful insights for yard planning.

1. Introduction

Recent decades have seen rapid growth in the marine container shipping industry. Containerized trade was estimated to have expanded at an average rate of 8.2% per year between 1990 and 2010 (Meng et al., 2014). To address the challenge of rapid growth, major carriers have built large vessels in the pursuit of lower costs and increased competitiveness. The maximum vessel size was 4300 TEUs in 1988, went up to 15,500 TEUs in 2006, and is 18,000 TEUs in 2014 (Tran and Haasis, 2015). As a result, terminal operators find elevated pressure in maintaining service quality due to increasing container throughput. The operational problems of container terminals merit additional study and have attracted significant attention in recent years. Stahlbock and Voss (2008) and Vis and de Koster (2003) provided a comprehensive overview of the operations and problems in container terminals and referred to solution methods for these critical issues.

For container terminals, one of the performance measures for customer service is the berthing time, which consists primarily of the time required for container loading and unloading for containerships. In most large yards, containers tend to be stacked high to better utilize the land space because the demand for land in yards grows significantly faster than the supply. To achieve high working efficiency, stacks are arranged side by side to form bays, and bays are organized into blocks.

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http://dx.doi.org/10.1016/j.trc.2015.01.024
0968-090X/

However, reshuffle operations may be unavoidable in the process of retrieving containers from high stacks. A reshuffle is an operation in which a container-lifting equipment is used to relocate a container from one stack to another; typically, a reshuffle is undertaken when one container blocks the access to the target container. These operations are unproductive and time/resource consuming, and should be avoided whenever possible to enhance the terminal performance.

A number of papers (for example, Kim et al., 2000; Dekker et al., 2006; Han et al., 2008; Wan et al., 2009; Zhang et al., 2010; Choe et al., 2011) have addressed the problem of assigning storage locations for containers to minimize reshuffling during the loading process. Unfortunately, reshuffling can hardly be completely avoided, for several reasons. First, the export containers typically begin to arrive at a terminal more than two weeks in advance of the shipping time, which is well before the loading sequence is available. Second, the information provided regarding an export container at the time of its arrival is often imprecise. Finally, even under ideal conditions, the limited storage capacity of a yard makes eliminating the need to reshuffle nearly impossible in practice.

In this study, we investigate the container retrieval problem considering the relocations that occur when all of the containers stacked in a multiple-bay block must be loaded onto a ship in a given order. The problem also entails the determination of how relocated containers should be stored within the block if reshuffles must occur. In practice, the containers in the yard are often divided into groups according to the ship planning requirements, which concerns the position of each container in the ship. During loading, the containers must be retrieved group-by-group in a pre-determined order, although the containers of the same group can be retrieved in any order. Given an initial layout that specifies the set of containers as well as the location of each container in the block, the optimization goal is to minimize the total number of container movements. Variations of the container retrieval problem are explored in this research. In the first variation, we assume that only a single-lift rail-mounted gantry crane (RMGC) can be used. The second variation extends the first problem by investigating a situation in which the crane has multi-lift capability; that is, the crane is equipped with multiple spreaders, thus has the ability to lift multiple containers simultaneously.

To the best of our knowledge, only a limited number of papers have addressed the container retrieval problem while recognizing relocation events. The work by Kim and Hong (2006) suggested two methods for determining the locations of relocated containers during pickup operations. Their work assumes that relocations occur only in the same bay, and only at moments in which a target container must be retrieved. However, as will become clear later, it is sometimes beneficial to pre-relocate a container, especially when the yard is utilized close to capacity. Lee and Hsu (2007) provided a multi-commodity flow-based mathematical model for the container pre-marshalling problem, and presented an extension of the model to solve for an optimal plan to transfer a given initial yard layout to another specified final layout. A slight modification of that extension will make their model applicable to the container retrieval problem. Nonetheless, due to the complexity of the underlying multi-commodity flow model, numerically solvable problem instances are far smaller in scale than those seen in reality. Lee and Lee (2010) presented a three-phase heuristic that yields a working plan for a crane to retrieve all of the containers from a given yard according to a prescribed order. However, the empirical study undertaken in this paper indicates that our solution heuristic outperforms theirs, both in solution efficiency and solution quality. Caserta et al. (2011) proposed an algorithm, inspired by the corridor method, to identify a working plan that minimizes the number of relocations when retrieving a subset of containers from the yard in a given order. When retrieving a target container, their algorithm is allowed to relocate only the containers found directly above the target container in the same stack using a last-in-first-out (LIFO) policy, which also excludes the possibility of pre-relocation. A related problem, studied by Meisel and Wichmann (2010), is to convert the configuration of a bay on a ship into another configuration within a minimum working time. Their work assumed that reshuffled containers are always relocated exactly once. Based on this and other assumptions, Meisel and Wichmann (2010) constructed a binary integer program that minimizes the working time, and they proposed a heuristic to solve it. Forster and Bortfeldt (2011) proposed a tree search heuristic to find a sequence of crane moves in order to retrieve all containers from a block. Numerical results suggest that this method yields better quality solution than those obtained by Lee and Lee (2010), and takes less than 10 s to solve. Forster and Bortfeldt (2012) studied the container relocation problem, recognizing the grouping practice in container shipping. Pre-relocation is also considered, in that the algorithm is able to relocate a container at an appropriate time, before another container stacked beneath it is due to be retrieved. This work allows relocation within the same bay only, and assumes that the time required to move a container between any two stacks are the same. Yet, the multi-lift capability of RMGC was not explored in their work.

The current paper is differentiated from earlier works by taking into consideration some features that are critical when developing container retrieval plans in reality. Specifically, our heuristic explicitly utilizes opportunities to pre-relocate a container, allows inter-bay relocation, and takes the crane movement time into consideration when relocating containers. Furthermore, an extended version of the heuristic covers multiple-lift cranes. It is also worthwhile to note that all of the papers reviewed above that concerns the container retrieval problem attempts to solve the problem by constructing mathematical models, with the only exception of Forster and Bortfeldt (2012), which takes a procedural approach. Mathematical models are powerful tools, but they are also known for their relatively low flexibility. They also tend to be harder to solve, limiting the size of solvable instances. Due to this reason, none of the works presented computational results against real-sized instances, which can involve thousands of containers. Our work develops a procedural approach that is computationally efficient, and is able to solve container retrieval problems exceeding realistic sizes. Furthermore, minimizing the number of container movements has been the optimization goal for related models, but reducing the overall working time is also important in reality. By taking the crane movement time into consideration, we demonstrate, numerically, that the