Transportation Research Part E 45 (2009) 810–820

Contents lists available at ScienceDirect

Transportation Research Part E

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

A heuristic algorithm for yard truck scheduling and storage allocation problems

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ARTICLE INFO

Article history:
Received 15 November 2008
Received in revised form 8 January 2009
Accepted 10 April 2009

Keywords:
Container terminal operations
Yard truck scheduling
Storage allocation
Heuristic algorithm

ABSTRACT

The yard truck scheduling and the storage allocation are two important decision problems affecting the efficiency of container terminal operations. This paper proposes a novel approach that integrates these two problems into a whole. The objective is to minimize the weighted sum of total delay of requests and the total travel time of yard trucks. Due to the intractability of the proposed problem, a hybrid insertion algorithm is designed for effective problem solutions. Computational experiments are conducted to examine the key factors of the problem and the performance of the proposed heuristic algorithm.

1. Introduction

Container terminals perform as joints of land and marine transportation, and they serve as hubs and transfer stations of multimodal transportation. Shipping industry accounts for more than 75% market share in modern logistics. The efficiency of the stacking and the transportation of large number of containers to and from the quayside is critical to any container terminal (Stahlbock and Voß, 2008).

Typically, there are three types of container handling systems engaged in container terminals: chassis, straddle-carrier and transtainer systems, the latter being the most popular in major terminals due to the need for high container storage capacity in the yard. For the transtainer system, there are three types of handling equipments employed, namely quay cranes, yard cranes and yard trucks. Quay crane is usually the most expensive handling equipment, and also potentially the bottleneck in the loading and discharging operations in container terminals.

After discharged from container vessels, containers will be allocated to yard blocks for temporary storage. In yard, yard cranes are engaged for picking and stacking containers from and to yard blocks. Yard trucks move containers between quayside and yard side, so as to satisfy the schedules of quay crane and yard crane.

Due to the limitations of modeling and computation, the complete container terminal operations are rather unlikely to be analytically formulated and efficiently solved (Steenken et al., 2004). A practical way of improving the efficiency of container terminal operations is to identify and resolve a series of optimization problems. In general, these optimization problems include berth allocation problem, quay crane scheduling problem, yard truck scheduling problem, yard crane scheduling problem and storage allocation problem.

This paper focuses on the yard truck scheduling and storage allocation problems. Followed by this introductory section and a literature review in Section 2, it also describes the integrated yard truck scheduling and storage allocation problems. A

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1366-5545/$ - see front matter
doi:10.1016/j.tre.2009.04.008

mixed integer programming (MIP) model is formulated for the proposed problem in Section 3. In Section 4, a heuristic solution algorithm is developed for effective problem solutions. A series of computational experiments are illustrated in Section 5 to test some key factors of the problem and the performance of the solution algorithm. Finally, Section 6 concludes this paper.

2. Literature review

In the area of yard truck scheduling problem, Kim and Bae (2004) proposed an extended approach for automated guided vehicle (AGV) dispatching to a network-based MIP model. The objective was the minimization of the total idle time of a quay crane resulting from late arrivals of AGVs as well as the associated total travel time. It was assumed that storage locations of containers and schedules for (un)loading operations by quay cranes are given.

Nishimura et al. (2005) proposed a truck assignment method for solving the yard truck routing problem at container terminals where yard trucks are usually assigned to specific quay cranes until the work was completed. An MIP was proposed, and a genetic algorithm (GA) was developed to solve the problem. A new dynamic routing scheme was shown. It aimed at saving yard operation time as well as container handling costs.

Ng et al. (2007) addressed the problem of scheduling a fleet of yard trucks at a container terminal in order to minimize the makespan. Yard trucks had to perform a set of shipping jobs with sequence-dependent processing times and different ready times. The problem was solved by a GA.

For storage allocation problems, Kim and Kim (1999) considered how to allocate storage space for import containers. A segregation strategy was proposed, in which stacking newly arrived containers on top of the containers that arrived earlier was not allowed. Spaces were allocated for each arriving vessel so as to minimize the expected total number of rehandles.

Kim and Kim (2002) discussed a method of determining the optimal amount of storage space and the optimal number of transfer cranes for handling import containers. A cost model was developed and solved with a proposed heuristic.

Zhang et al. (2003) modeled the storage allocation problem using a rolling-horizon approach. For each planning horizon, the problem was decomposed into two levels, and each level was formulated as a mathematical programming model.

Both yard truck scheduling and storage allocation problems have attracted a lot of research efforts. However, these problems are highly related to each other. Bish et al. (2001) was the first study that combined these two problems into a whole. Bish et al. (2001) assumed that each container had a number of potential locations in the yard where it could be stored. Containers were moved from the ship to the yard using a fleet of yard trucks, each of which could carry one container at a time. A heuristic was developed by decomposing the problem into two isolated steps, where Step One determined the location assignments by ignoring the vehicle schedule and Step Two determined the vehicle schedule for the location arrangements obtained from Step One. Bish (2003) extended this study to examine the problem of determining a storage location for each discharging container, dispatching vehicles to containers, and scheduling the discharging and loading operations of quay cranes to minimize the maximum time needed to serve a given set of ships. The problem was shown to be NP-hard and a heuristic algorithm was proposed for its solution. Bish et al. (2005) developed easily implementable heuristic algorithms for the problem studied by Bish (2003) and derived both the absolute and the asymptotic worst-case performance ratios for these heuristics. Though the three studies considered the yard truck scheduling and storage allocation problems in an integrated way, these two problems were still solved separately without interactions between them. In contrast, this paper proposes the integrated yard truck scheduling and storage allocation problems, the objective function of which is to minimize weighted average of the total travel costs of yard trucks and the total delay penalties according to soft time windows. The solution algorithm is capable of capturing the interactions between these two problems.

Han et al. (2008) provided another way of integrating yard truck operations and storage allocation by proposing an approach to allocate storage space for containers in transshipment terminal, which aimed to balance the workload of each yard block so as to minimize the traffic congestion caused by yard trucks. The mathematical model was solved by dedicated heuristic algorithms. This provided another way of integrating yard truck operations and storage allocation.

Lee et al. (2008) proposed an integrated model for yard truck scheduling and storage allocation for import containers. The problem was formulated as an MIP that considered the two problems as a whole. The objective was to minimize the makespan of operations. Due to the NP-hardness of the problem, a GA and a dedicated heuristic algorithm were developed to solve the problem.

3. Problem formulation

In this paper, the movement of a container from its origin to destination is defined as a *request*, denoted by i and j. The origin of a loading container is the yard location where it is stored, and its destination is the location of the quay crane by which the container is loaded onto the vessel. For discharging container, its origin is the location of quay crane where it is unloaded from the vessel, and its destination is the yard location that is allocated to the container for temporary storage. Let J^+ be the set of loading requests and J^- the set of discharging requests in the planning horizon, with the cardinalities of n^+ and n^-, respectively. We also define the set $J = J^+ \cup J^-$ and $|J| = n$.

Before vessel arrival, a berth will be allocated to each container vessel, according to the tonnage, arrival time and berthing time of the vessel. A certain number of quay cranes will be assigned to serve the vessel after docking. Quay crane schedule is