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Optimization of loading sequence and rehandling strategy for multi-quay crane operations in container terminals

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ABSTRACT

In this paper, we consider the optimization of loading sequence and rehandling strategy in the terminal operation. We present an optimization strategy to minimize the number of rehandles, and establish a mathematical model to integrate the loading sequence and the rehandling strategy under the parallel operation of multi-quay cranes. Furthermore, we give an improved genetic algorithm to solve the model. We show the efficiency of the optimization strategy and algorithm by comparing them with previous strategies and heuristics.

1. Introduction

Container terminals play an important role in global manufacturing and international business by serving as multi-modal interfaces, usually between sea and land transport (Zhang et al., 2002). Terminal yard is one of the most important constituent part of container terminals. During the loading process, containers will be picked up from the yard to the vessel considering the stowage plan and yard stacking status. The stowage plan, illustrated in Fig. 1(a), shows a side view of the ship-bays, where the ship-bay is described with the two-dimensional coordinates of stack and tier. The yard stacking status, illustrated in Fig. 1(b), are described by the three-dimensional coordinates of bay, stack and tier. A bay consists of multiple stacks and a stack consists of multiple tiers. Since the containers are stacked in the vertical direction, rehandling must be performed for retrieving a container, called as a target container, which is not on the top tier. Furthermore, moving an obstructed container to another stack may lead to additional rehandling moves of containers during the retrieval process (Sauri and Martin, 2011). The obstructed container may be moved to the nearest, lowest or optimization stack in the same yard bay according to the nearest stack, lowest stack and optimization strategy. Different strategies result in different additional rehandling. Thus, there are two factors affecting the rehandling operation, one is the rehandling strategy (Petering and Hussein, 2013), and another is the loading sequence. Rehandling is time-consuming, because it is an unproductive move in container terminals. The number of rehandles is one of the most important factors affecting the operational efficiency in container terminals, and it is correlated with the loading sequence and the rehandling strategy. To improve the operational efficiency of container terminals, ports should focus on reducing the number of rehandles in the yard, including additional rehandling.

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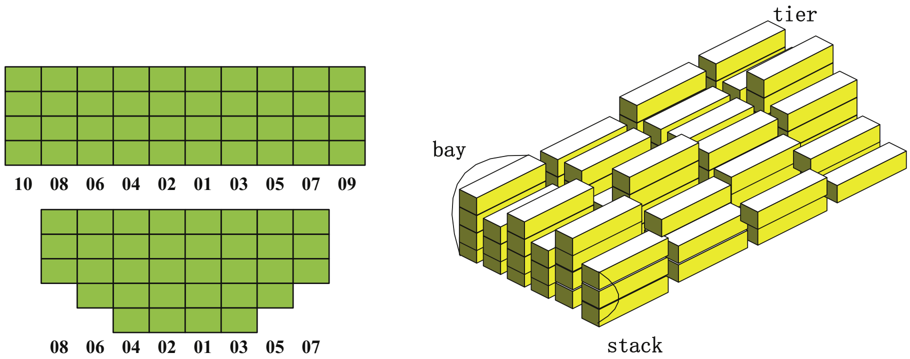

(a) Figure of ship-bays (b) Figure of the yard stacking areas

Fig. 1. Ship-bays and the corresponding yard stacking areas.

In this paper, we study the multi-quay crane parallel operations during the loading process without considering the number of vessels. Based on the given containership stowage plan and yard storage characteristics, we develop a mathematical model to minimize the number of rehandles. Moreover, we design a genetic algorithm integrated loading sequence and rehandling strategy (GA-ILSRS) for the lowest stack, the nearest stack and the optimization strategy. Finally, we verify the robustness of the algorithm compared with other heuristic.

This paper is organized as follows: Section 2 reviews the literature. A detailed description of the problem is given in Section 3. Section 4 presents mathematical models for different strategies. Section 5 outlines the design of GA-ILSRS to solve the model. Section 6 verifies the effectiveness of the GA-ILSRS compared with other heuristics, and shows the results for three rehandling strategies and different quay cranes. Additionally, the *t*-test and lower bound are showed. Lastly, this paper presents final conclusions.

2. Literature review

The rehandling problem is usually related to the stowage plan for container ships and yards. Some literatures considered rehandling problem in the perspective of the containership stowage plan or the yard storage characteristic. They focused on the rehandling strategy under a certain loading sequence without regarding for the effect of loading sequence on rehandling. Kim (1997) proposed an algorithm to calculate the expected number of unproductive moves, where the height and width of a bay in the container stack were important decision variables in designing the storage configuration. Differing from the previous research by Kim (1997), Avriel et al. (1998) presented an integer linear formulation to find the optimal solution for stowage in a single bay of a ship, where containers' origin and destination ports are known in advance. Similar to the previous work by Kim (1997), Kim et al. (2000), Kim and Hong (2006) and Imai et al. (2006) developed mathematical models and solution methods to determine the overall amount of rehandles. Later, Sauri and Martin (2011) described three stacking strategies, which take into account the containers' arrival and departure rates and the storage yard characteristics, and developed a model to estimate the number of rehandles. Woo and Kim (2011) introduced a method for allocating storage space to groups of outbound containers, and discussed the impacts of various space-reservation strategies on the productivity of the loading operation for outbound containers. Zhu et al. (2012) investigated iterative deepening A^* algorithms using new lower bound measures and heuristics, and examined a more difficult variant of the problem that had previously been ignored in the literature. Lee et al. (2013) discussed a novel approach that integrated yard truck scheduling and storage allocation, and designed a hybrid insertion algorithm for the problem.

Regarding the container yard operations, the rehandling process was usually described as a two-dimensional problem concentrating on the research of yard-stacks and tiers within a yard-bay. Based on some assumptions taken from Kim and Hong (2006), Caserta et al. (2011) described a dynamic programming formulation and determined a two-dimensional corridor with width and height parameters. The block relocation problem (BRP) is encountered in the maritime container shipping industry and other industries where containers are stored in stacks. Some papers discussed the BRP from a single yard-bay. After surveying the work done on the BRP, Petering and Hussein (2013) considered the containers in a single yard-bay, introduced a new mathematical formulation for the BRP, and expressed a new look-ahead algorithm to obtain superior solutions for the problem. Jin et al. (2014) extended the previous work (Jin et al., 2013), and presented an improved greedy look-ahead heuristic to find an optimized operation plan for the crane with the fewest number of container relocations. Moreover, considering the automated stacking problem, Gharehgozli et al. (2014) studied a yard crane scheduling problem to carry out a set of container storage and retrieval requests in a single container block.