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Innovative Applications of O.R.

Yard Crane Scheduling for container storage, retrieval, and relocation

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ABSTRACT

This paper introduces a novel optimization problem resulting from the combination of two major existing problems arising at storage yards in container terminals. The Yard Crane Scheduling Problem is typically concerned with routing the crane given a sequence of storage and retrieval requests to perform, while the Container Relocation Problem tackles the minimization of relocations when retrieving containers in a simpler setting. This paper is the first to consider a model that integrates these two problems by scheduling storage, retrieval and relocations requests and deciding on storage and relocation positions. We formulate this problem as an integer program that jointly optimizes current crane travel time and future relocations. Based on the structure of the proposed formulation and the linear programming relaxation of subproblems, we propose a heuristic local search scheme. Finally, we show the value of our solutions on both simulated instances as well as real data from a port terminal.

1. Introduction

Container terminals, where containers are transferred between different modes of transportation both on the sea side and land side, are crucial links in intercontinental supply chains. The rapid growth of container shipping and the increasing competitive pressure to lower rates result in demand for higher productivity of both sea and land operations. At a typical container terminal, seaside operations include assigning ships to quay slots or discharging and loading ships with quay cranes while land-side operations mostly involve routing internal trucks or storing and delivering containers in the storage area. For both types of operations, the efficiency of container terminals can be clearly enhanced by investments in new terminal devices (see Speer & Fischer (2017)). These investments can range from just improving current devices to buying new state-of-the-art cranes. Another direction for improvement is to develop new techniques to operate more efficiently existing devices, thus explaining the increasing research interests in optimizing operations in container terminals (see Gharehgozli, Roy, & de Koster (2016)). This paper focuses on improving the efficiency of the storage and delivery of containers in the storage area through combinatorial optimization.

Due to limited space in the storage area, containers are stacked on top of each other. The resulting stacks create blocks of containers as shown in Fig. 1. If a container that needs to be retrieved is not located at the top of its stack, that is, it is covered by other containers, the blocking containers must be relocated to another stack. As a result, during regular operations, one or more relocation moves are performed by the yard cranes. Such relocations (also called reshuffles), which cannot be charged to customers, create delays in operations, thus resulting in a substantial loss of revenue. Therefore, while this block structure represents a gain in space, it results in a loss in operational efficiency.

As more thoroughly explained in Section 3, two problems have been studied separately in the literature. One, the Container Relocation Problem, is concerned with minimizing the number of relocations given a sequence of requests in a restricted setting, most of the time a single bay ($Y = 1$ in Fig. 1). The other, the Yard Crane Scheduling Problem, focuses on the routing of the crane and scheduling of storage and retrieval requests given space assignments for storage and relocations. This paper bridges the gap between these two problems in a unified framework. To the best of the our knowledge, this paper is the first to consider jointly these problems and to show the important benefits of jointly considering these decisions. We model this new problem using a binary integer programming formulation and study some properties of the problem. In practice, this problem has to be solved in real-time (a few minutes before the actual operations occur). Hence, we provide a heuristic procedure to generate promising solutions in a

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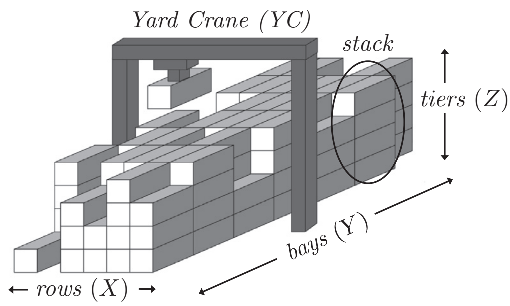

Fig. 1. Container block with a single yard crane in port yard.

limited amount of time (1 minute), thereby showing the practical relevance and applicability of our approach.

The rest of our paper is organized as follows: After describing the problem of interest in Section 2, Section 3 explains the contributions of this work in light of an extensive literature review of both the Yard Crane Scheduling Problem and the Container Relocation Problem. Subsequently, Section 4 formulates the problem as a binary integer program and states some properties about this mathematical formulation. Section 5 builds upon these results to introduce a practical heuristic procedure. Algorithms are tested through computational experiments in Section 6. Finally, concluding remarks and future directions are given in Section 7.

2. Problem description

This section describes the problem of interest in this paper. Appendix A summarizes all assumptions and notations defined in this section.

2.1. Problem geometry

We consider the following situation. A block consists of X rows, Y bays and Z tiers (see Fig. 1) and we assume that this block is served by a single yard crane (YC), as shown in Fig. 1. Each slot of the block can store a unique type of container (for example, twenty-foot or forty-foot equivalent units). Note that X is limited by the width of the crane while Z is limited by the height of the crane. Z corresponds to the maximum number of containers that can be stacked on the top of each other. Typically, these values range from 6 to 13 for X, 10 to 40 for Y and 3 to 6 for Z. Note that the tiers are counted from bottom to top. In this block, a stack s is uniquely characterized by a two-dimensional vector denoted by (s_x, s_y) corresponding to its position in the $x - y$ dimensions. We denote by $\mathcal{S}_B$ the set of stacks in the block and note that $|\mathcal{S}_B| = X \times Y$.

We assume that there are M input/output (I/O) points around the block that we consider, denoted by I/O_m for $m \in \{1, \dots, M\}$. These I/O points correspond to locations where vehicles, with storage or retrieval requests park. I/O points are "artificial" stacks where no container can be stored except when retrieving a container. We denote by $\mathcal{S}_I$ the set of artificial stacks corresponding to I/O points. For the sake of clarity, we denote $\mathcal{S} = \mathcal{S}_B \cup \mathcal{S}_I$ the set of all stacks.

General Automated Storage/Retrieval Systems (AS/RSs) can present many configurations of I/O points. In the case of port yards, Wiese, Suhl, and Kliewer (2010) and Carlo, Vis, and Roodbergen (2014) discuss the two most frequent configurations (see Fig. 2(a) and 2(b)), which are commonly referred to as Asian and European style configurations. The "double-sided" configuration is another configuration of interest (see Fig. 2(c)) but it has been less studied in related work. This latter configuration is mostly used in ports where internal and external yards are completely separated (for instance when the internal yard is automated or the external yard works on trains). The I/O points configuration is given as an input to the problem. In European and double-sided

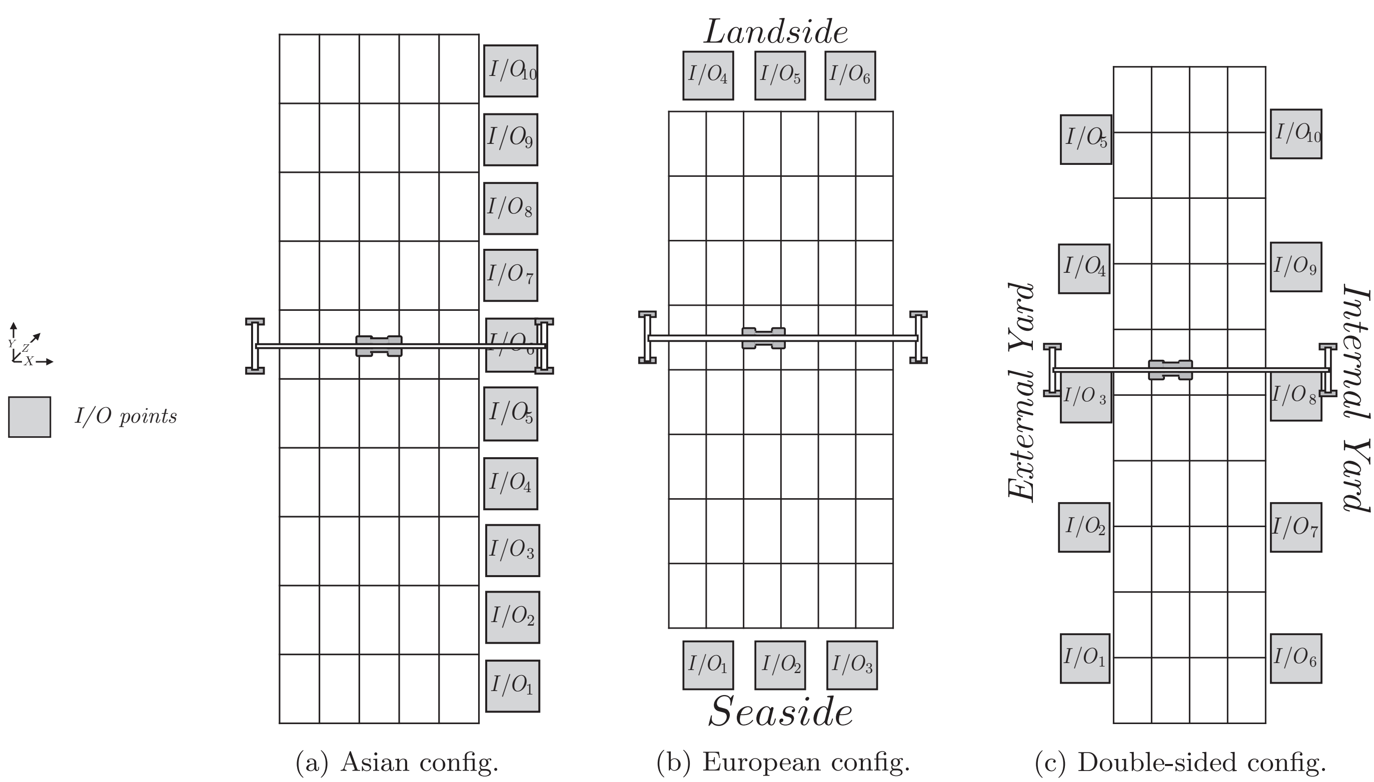

Fig. 2. A top view of a block with three different I/O points configurations.