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An algorithm with performance guarantee for the Online Container Relocation Problem

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ABSTRACT

This paper introduces and investigates the Online Container Relocation Problem, where containers have to be retrieved from a bay in a container terminal so as to minimize the number of relocations. Unlike the offline version of the problem, the order of container retrievals is revealed one at a time in an online fashion. We analyze the so-called leveling heuristic using the perspective of worst-case competitive analysis of online algorithms and derive its competitive ratio. We then provide some computational experiments which give insights on the actual average performance of the heuristic.

1. Introduction

Container terminals stack containers on top of each other so as to use their scarce land efficiently. The drawback of stacking is that only the topmost container of each stack can be accessed directly.

If another container has to be retrieved, parasite movements – called relocations, reshuffles or rehandles – are necessary to free the target container. Relocations increase the time needed to retrieve containers and thereby decrease the overall productivity of the terminal. However, relocations cannot be avoided completely as little information about future retrievals is known when containers have to be stored or relocated, or because of limited yard space.

The following problems have been addressed for yard optimization: the storage space allocation problem to determine storage locations for incoming containers; the yard crane assignment/scheduling problem to assign yard cranes to storage areas and to define a schedule of storage and retrieval operations for each crane; the remarshalling/premarshalling problem to reorganize parts of the storage area (a block/a bay) in less busy periods as new information becomes available to reduce the number of relocations during the subsequent retrieval process; the container relocation problem to retrieve all containers from a bay in a given sequence with a minimum number of relocations. For a comprehensive literature review on problems related to container storage, retrieval and rehandling at terminals see Caserta, Schwarze, and Voß (2011) and Lehnfeld and Knust (2014).

This study deals with the container relocation problem (CRP) which is NP-hard (Caserta, Schwarze, & Voß, 2012). Few exact and several heuristic solution approaches exist. Exact solution approaches use integer linear programs to model and solve the problem (Caserta et al., 2012; Lee & Hsu, 2007; Petering & Hussein, 2013; Tang, Zhao, & Liu, 2012; Zehendner, Caserta, Feillet, Schwarze, & Voß, 2015) or a branch and price approach (Zehendner & Feillet, 2014). Most of the heuristic approaches are based on branch and bound and apply different branching and exploring strategies (Caserta, Schwarze, & Voß, 2009; Caserta & Voß, 2009; Forster & Bortfeldt, 2012; Kim & Hong, 2006; Rei & Pedroso, 2012; Ünlüyurt & Aydin, 2012; Wu & Ting, 2010; Zhang, Guo, Zhu, Lim, & Cheang, 2010; Zhu, Qin, Lim, & Zhang, 2012). Other authors use tabu-search (Wu, Hernández, & Ting, 2009), or the so-called corridor method (Caserta et al., 2011).

The dynamic container relocation problem (DCRP) is an extension of the CRP where containers are both received and retrieved from a single yard-bay. The arrival (departure) sequences of containers to (from) the yard-bay is assumed to be known a priori. Akyüz and Lee (2014) present a BIP formulation and three types of heuristics for the DCRP. Borjian, Manshadi, Barnhart, and Jaillet (2015) introduce the time-based DCRP. They require that each retrieval and stacking operation is completed within a given service time window but do not impose a sequence of operations.

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They aim to jointly minimize the number of relocation moves and service time. They propose an IP for this problem.

All these papers deal with the offline problem where the entire retrieval/storage sequence of containers or their time windows are given in advance. In practice, the exact retrieval/storage sequence of containers in a bay is not known in advance. Especially, for import containers the retrieval sequence is revealed over time as trucks arrive at the terminal.

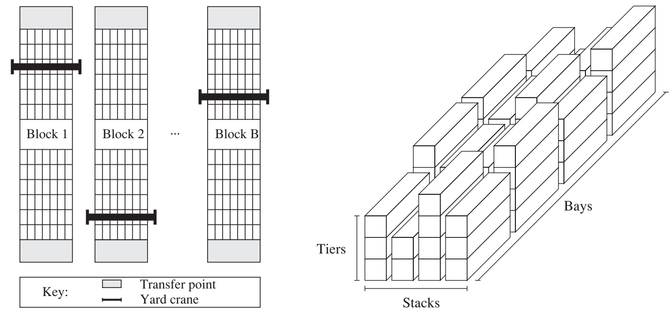
Only a few articles deal with stacking and/or relocation operations of containers with uncertain arrival and departure times. Borgman, van Asperen, and Dekker (2010); Dekker, Voogd, and van Asperen (2006); Duinkerken, Evers, and Ottjes (2001) use simulation to compare different storage space assignment and reshuffle strategies with different levels of departure time information. van Asperen, Borgman, and Dekker (2013) use simulation to analyze the impact of truck announcements on different storage space assignment and reshuffle strategies. Yu and Qi (2013) use simulation to compare single-period and multiple-period strategies to allocate arriving containers to storage space with regard to the average expected container retrieval time. These studies model the entire yard and consider storage and retrieval operations. Yang and Kim (2006) deal with the problem of assigning arriving containers to the yard so that the expected number of reshuffles is minimized. Jang, Kim, and Kim (2013) show that the number of relocations can be reduced if the load type of an arriving container is used to determine its storage location.

Zhao and Goodchild (2010) compare different levels of truck arrival information: complete truck arrival sequence, partial arrival sequence, information on arrival of groups of containers. They show that the complete arrival sequence is not required to substantially reduce the number of reshuffles. Wan, Liu, and Tsai (2009) tackle the CRP and the DCRP. They present an IP to minimize the total number of reshuffles for CRP, called MRIP. They propose a MRIP-based heuristic which generates a solution by solving a series of reduced $MRIP_K$ models which solve the problem optimally for the next K containers. For CRP and DCRP, they compare the $MRIP_K$ heuristics with different values of K to the lowest-slot heuristic, the reshuffling index heuristic (Murty et al., 2005) and the ENAR (expected number of additional relocation) heuristic (Kim & Hong, 2006). Borjian, Galle, Manshadi, Barnhart, and Jaillet (2015) introduce the so-called CRP with incomplete information, where the retrieval order of a subset of containers is known initially and the retrieval order of the remaining containers is revealed all at once at a later time. They assume a probabilistic distribution on the unknown retrieval orders and propose a 2-stage approximate stochastic optimization algorithm extending the A^* algorithm.

All these papers show that using information on container arrival and departure times (real or expected, for single containers or for groups of containers) reduces the number of reshuffles and the retrieval time considerably.

This study deals with the Online Container Relocation Problem (OCRP) where the retrieval sequence of containers is revealed over time. We investigate the worst-case situation where no information on the retrieval time or sequence is available. Kim (1997) proposes a methodology to estimate the expected number of relocations to pick up an arbitrary container and the total number of relocations to pick up all containers in a bay for a given initial bay configuration. They also run experiments to show the impact of the height and the width of a bay on the estimated number of relocations. They assume that all containers are equally likely to be picked up next and that a container is always relocated to the lowest empty position.

We provide evidence why relocating a container to the lowest empty position minimizes the expected number of relocations and give a worst-case analysis for this online heuristic. In addition, we report computational results giving insights about the performance of the heuristic in practice and compare it to other heuristics that also operate without the knowledge of the container retrieval sequence. The OCRP is introduced in Section 2. Section 3 presents the online relocation strategy: the leveling heuristic L. Section 4 provides a brief introduction to online optimization and proves results on the competitive ratio of leveling heuristic L. Section 5 reports our computational experiments and presents the average and worst case performance of the heuristic. Section 6 concludes the paper.



(a) A container yard (b) A single block

Fig. 1. Blocks, bays, stacks and tiers.

2. Online Container Relocation Problem

Generally, container terminals have no or little information on departure times as well as the departure sequence of containers (those picked-up by trucks) at bays. It is common that terminals obtain this information late when trucks check in at the terminal gate. If the target container is not on the top of its stack, blocking containers have to be relocated before the target container can be retrieved. The decision of where to relocate these containers has to be taken in real-time.

The container relocation problem studied in literature supposes that the whole retrieval sequence is known in advance. On the other hand, the Online Container Relocation Problem with incomplete information assumes that partial (or incomplete) information is available on container departures. Both cases apply to container terminals using yard cranes for storage operations. In this case, the yard area is divided into blocks as illustrated in Fig. 1. Each block consists of several bays, each bay has several stacks and each stack contains several tiers. The objective is to retrieve N containers from a bay with W stacks and H tiers in a given sequence with minimum number of relocations.

In the online case, the container retrieval sequence is revealed over time. Hence, relocation decisions have to be taken with no / limited knowledge of future retrievals. To represent this limited knowledge, we introduce a *look-ahead horizon* $\mathcal{H}$. It indicates how many future retrievals are known when a container is retrieved. If $\mathcal{H} = 0$, only the current retrieval container is known. If $\mathcal{H} \geq 1$, the current retrieval container and the next $\mathcal{H}$ retrieval containers are known. If $\mathcal{H} = N - 1$, the entire sequence is known in advance (offline case). We coin the OCRP with a *look-ahead horizon* $\mathcal{H}$ as OCRP_H.

The problem definition relies on assumptions A1–A8.

- A1: The initial bay layout is known.
- A2: The bay size is limited by the maximum numbers of stacks, W, and tiers, H.
- A3: Only the topmost container of a stack can be picked up. A relocated container can only be put on top of another stack or on the ground.

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