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Optimizing container relocation operations at container yards with beam search

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A B S T R A C T

Container relocation problem (CRP) involves the retrieval of all containers from the container yard with a minimum number of relocations. The CRP is an NP-hard problem such that the large-scale instances cannot be solved to optimality by exact solution methods within a reasonable computational time. This article proposes a beam search (BS) algorithm embedded with heuristics to evaluate the problems. The proposed beam search is tested on benchmark instances and compared with other leading heuristics from the literature. Computational results demonstrate that the beam search algorithm is compatible with other heuristics and can obtain good solutions in short time.

1. Introduction

Recent increases in the demand for maritime transportation of containers have led to the construction of numerous mega container vessels, many of which have the capacity to carry more than 18,000 twenty-foot equivalent units (TEU) containers. The challenges faced at container terminals in handling this enormous traffic enforce the development of efficient strategies to increase terminal productivity and reduce operational costs.

This study considers an unloading problem from the perspective of relocating containers within the container yard. Containers are usually stored in stacks to maximize spatial utilization, particularly in terminals with limited storage space. As shown in Fig. 1, a *stack* is obtained by stacking containers vertically. Several stacks in a row form a *bay*, and bays are placed side by side to form a *container block*.

Relocation involves the movement of a container from one stack to another, which must be performed whenever a container is located atop a desired container that is immediately required (the highest priority). We called this immediately desired container as the *target container*. Relocating containers cannot be avoided because the locations of containers cannot always be arranged according to their retrieval priorities. The retrieval priorities for export containers depend on their loading sequence onto the vessel. However, outside trucks transporting export containers arrive at the container terminal in random and hence, containers are not necessarily placed within the bay according to the loading sequence. On the other hand, the stowage plan provided by the shipping companies regarding an export container at the time of its arrival might be inaccurate or changed. Clearly, relocations are non-value added activities that must be minimized to increase the efficiency of operations in the container terminal and impair the customer satisfaction. In this paper, we investigate the container relation problem for export containers which must be retrieved in a predetermined order based on the vessel's stowage plan.

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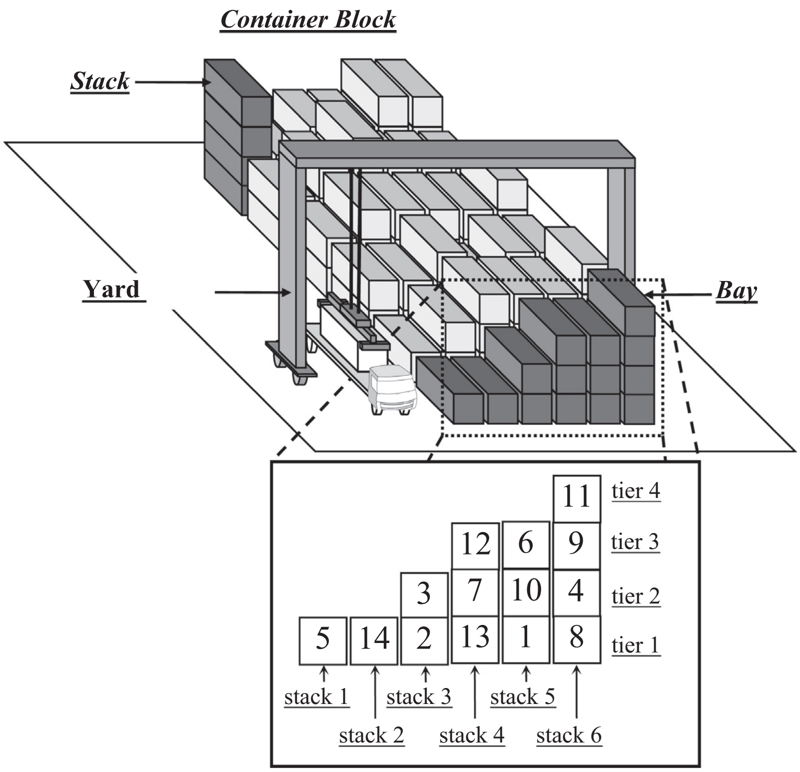

Fig. 1. Stacking containers in bays and container blocks.

The unloading problem can be classified as restricted or unrestricted problem according to the moving fashion of relocated containers. In the restricted problem, only the blocking containers above the target container can be relocated. On the other hand in the unrestricted problem, voluntary moves (or cleaning moves) of the containers that located at other stacks are allowed to make. This study focuses on the restricted problem, in which containers are retrieved according to a predetermined order with the minimum number of relocations.

To deal with the restricted relocation problem, we first propose a new novel heuristic to estimate the upper bound of the CRP by considering all the blocking containers above the target container. This heuristic is compared with other state-of-the-art algorithms on benchmark instances. The heuristic is embedded in a beam search (BS) algorithm as the evaluation heuristic. The structure of the beam search is similar to the tree search algorithm, but only permitted nodes is reserved in the search procedure. The permitted nodes are chosen depend on the proposed evaluation heuristic, which determines the location of relocated container with a changeable sequence. The performance of the BS is validated through experiments of benchmark instances from the literature.

The remainder of this study is organized as follows. Related works are reviewed in Section 2. Section 3 defines the container relocation problem. Section 4 introduces evaluation heuristics and Section 5 describes the beam search method embedded with the evaluation heuristics in Section 4. Section 6 presents experimental results drawn from a wide variety of scenarios. Finally, in Section 7, we summarize our findings.

2. Related literature

Container relocation in container terminals has attracted considerable attention since the 1980s. Reviews on related issues of container relocation problem can be found in Carlo et al. (2014) and Lehnfeld and Knust (2014). The former article focused on the layout, the material handling equipment, and other characteristics for the storage problem. The latter article reviewed the optimization problems specifically on the loading and unloading operations. Caserta et al. (2011a) provided a thorough overview on the rehandling of containers at maritime container terminals. We refer to the above articles for details.

Kim (1997) proposed a methodology to evaluate an expected number of relocations when a specific container is retrieved. The approach can solve the problem with the number of stacks ranges from 2 to 10 and from 4 to 12 for the number of tiers. Kim and Kim (1999) expanded this work by allocating import containers according to a segregating policy, in which containers are unloaded from the vessel to an empty slot. They defined the problem as a search for the stacking height which minimizes the expected number of relocations. Two mathematical models were formulated, one for import containers with