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A chain heuristic for the Blocks Relocation Problem

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ABSTRACT

In the Blocks Relocation Problem (BRP) one is given a block retrieval sequence and is concerned with determining a relocation pattern minimizing the total number of moves required to enforce the given retrieval sequence. The importance of the BRP has been constantly growing in recent years, as a consequence of its close connection with the operations inside of a container terminal. Due to the complexity of the BRP, a large number of methods has been developed for finding near optimal solutions. These methods can be divided in two main categories greedy heuristics and more complex methods. The latter achieve results of higher quality, but at the cost of very long execution times. In many cases, this increased calculation time is not an option, and the fast heuristic methods need to be used. Greedy heuristic approaches, in general, apply the heuristic based only on the properties of the block that is being relocated and the current state of the bay. In this paper we propose a new heuristic approach in which when deciding where to relocate a block we also take into account the properties of the block that will be moved next. This idea is illustrated by improving the Min–Max heuristic for the BRP. We compare the new heuristic to several existing methods of this type, and show the effectiveness of our improvements. The tests have been conducted on a wide range of sizes of container bays, using standard test data sets.

1. Introduction

With the globalization of the world economy, container transport is becoming of great importance. Container terminals are gigantic logistic centers, that are used for the distribution of containers. More precisely, they can be seen as temporary storage points, that make possible unloading operations from very large transport vessels and loading operations onto smaller vehicles, like trains or trucks, for further distribution, but also the same process just in the opposite direction. Due to the fierce competition of the global market, the efficiency of container terminals is of utmost importance. One way of improving their productivity is by using new technologies like automated guided vehicles (AGVs), systems based on automated lift vehicles (ALVs), more efficient cranes, etc. (Duinkerken, Dekker, Kurstjens, Ottjes, & Dellaert, 2006; Stahlbock & Voß, 2008). Increasing the effectiveness of the container terminal operations can also be done by optimizing the way in which such operations are carried out using existing equipment.

One of the most important aspects of a storage system is the time needed for container loading to transport vehicles and vessels. This is due to the fact that the faster the retrieval operations are completed, the sooner expensive and scarce resources (e.g., trucks, staff, cranes, etc.) can be used for new jobs, or in other words they are used more efficiently. Furthermore, terminals usually have a limited amount of storage space, which has the consequence that containers are piled up at the container yard in such a manner to increase the space utilization. Block stacking is the most common way for container storage at container yards (Kim & Hong, 2006). The problem with block stacking is that only the top container can be retrieved from each stack, while containers often need to be loaded to transport vehicles in a certain order. This order (approximate) is usually known before the loading process starts, but it does not generally correspond to the state of the container yard (Fig. 1). This means that not only do containers need to be moved from the container block to the transport vehicle but they will also have to be relocated within the container block to make retrieval in the specified order possible. The movement of containers is time consuming and the number of relocations should be minimized. There are several approaches to solving this practical problem which have been formalized in the form of the Blocks Relocation Problem (BRP), the Re-Marshalling Problem

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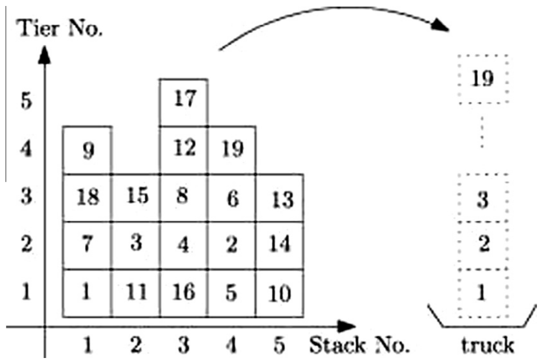

Fig. 1. Container bay with 19 containers in five stacks; containers need to be retrieved in increasing order of their numbering. Image taken from Caserta et al. (2012).

(RMP), i.e. intra-block marshalling and the Pre-Marshalling Problem (PMP) (Caserta, Schwarze, & Voß, 2011a).

The BRP, which we shall consider in this paper, is defined in the following way. First we will consider the problem setup with some simplified assumptions as they are consistently used in literature (Kim & Hong, 2006):

- All blocks (containers) are of the same size.
- The container bay will be viewed as a two dimensional stacking area, with W stacks, for which a maximal height (number of tiers) H is given.
- The initial configuration of the container bay and the retrieval sequence are known in advance (Fig. 1).
- The reshuffle operations (movement of containers within the bay) are only allowed while a target container needs to be retrieved, which means no pre-marshalling.
- Only blocks from the top of a stack can be accessed.
- Blocks can only be placed either on top of another block, or on the ground (tier 0).
- When a block is retrieved, it is removed from the container bay.

The problem is to minimize the number of moves needed for retrieving a given block sequence.

It has been shown that this problem is NP-hard (Caserta, Schwarze, & Voß, 2012). There have been several directions for solving this problem both for finding optimal and approximate solutions. In their article, Kim and Hong (2006) present a branch and bound method for finding the optimal solution of the BRP. In the same article, a heuristic method is presented for finding an approximate solution. The problem has been presented by a binary linear programming model, and solved using a heuristic method (Caserta et al., 2012; Caserta, Schwarze, & Voß, 2009). Another heuristic approach, in the form of the beam search algorithm, is given by Wu and Ting (2010). All the presented approximate algorithms are deterministic. Though, it is a well known fact that for NP-hard problems, in many cases probabilistic algorithms can achieve results of higher quality for a lower computational time. A nondeterministic algorithm has been implemented for the BRP using the corridor method paradigm (Caserta, Voß, & Sniedovich, 2011b). A population based approach is presented in (Hussein & Petering, 2012) where a variation of the BRP called block relocation problem with weights (BRP-W) has successfully been solved using a genetic algorithm. A very interesting version of the BRP is solved by Lee and Lee (2010) in which more than one bay is considered. This effectively transforms the initial problem into a three dimensional one which, as a consequence, is of much greater size (the authors mention considering problem instances with more than 700 containers).

Although the more complex methods can achieve results of higher quality than greedy heuristics, it is at a high computational cost. In many real life applications the extra calculation time is not available and it is necessary to use some fast heuristic approach. On the other hand heuristics used in greedy algorithms are often a basis for developing more complex methods. In this article we present a new approach to using a greedy heuristic for the BRP. The main idea is to use a heuristic function that is dependent on properties of more than one block, when deciding where to relocate a single block. We illustrate the effectiveness of this method by applying the new chain heuristic approach developed in this paper to the greedy algorithm given in Caserta et al. (2011b). We also present a simple improvement for the heuristic given in Caserta et al. (2011b).

We compare the new heuristic approach to several standard heuristics used on the BRP. We show that the new method achieves the best results of all the tested methods on some standard benchmark data sets. We also show that the new approach has a neglectable effect on the overall calculation time.

This article is organized as follows. In the next section we give an overview of greedy heuristics for the BRP, and introduce one simple improvement. In the third section, we explain the concept of a chain heuristic. In the fourth section we provide a comparison of different heuristics for the BRP. In the final section we give some concluding remarks.

2. Related work

There have been several greedy algorithms developed for solving the BRP. The general idea of this approach is to move a block that is blocking another block that needs to be retrieved, to a new stack. This stack is selected among the set of all stacks by some heuristic function that measures their desirability. Several different heuristics have been developed, for which we give a short overview.

The most basic idea for a heuristic is to move the blocking block to a new stack that has the lowest number of tiers filled with containers. This approach has also been called the Lowest Position heuristic (TLP) (Zhang, 2000). It is illustrated by the following equation:

$$s^* = f_{TLP}(r, Bay_n) = argmin_{i\in\{1,\ldots,W\}\setminus\{s\}}\, t(i) \tag{1}$$

In Eq. (1), s is the index of the stack from which the block r is moved, s^* is the index of the stack to which the block will be moved to, $t(i)$ gives us the number of tiers filled with containers for stack i. The variable Bay_n gives the state of the bay at step n, or, in other words, what are the elements at each stack. We wish to point out that the value of s is specified by the properties of block r, and is used as a separate variable simply for convenience. The effect of using TLP is that all of the stacks will have a similar number of tiers, so the average number of relocations would stay low. The idea behind this heuristic is to avoid extreme cases where a large number of blocks needs to be moved from a stack with many tiers when a block with high priority is blocked.

Murty et al. (2005) have proposed the Reshuffle Index heuristic (RI) for the BRP. In this approach, the blocking block will be moved to the stack in which it blocks the lowest number of blocks. More precisely, it will be moved to the stack which has the lowest number of blocks that have a higher priority than the block being moved. This heuristic can be illustrated by the following equation:

$$s^* = f_{RI}(r, Bay_n) = argmin_{i\in\{1,\ldots,W\}\setminus\{s\}}\, RI(r, i) \tag{2}$$

In Eq. (2), $RI(r,i)$ gives the number of blocks in stack i that have a higher priority than r. In this way it is expected that the overall number of reshuffles is lowered since every time a block is put over