Computers & Industrial Engineering 62 (2012) 13–20

Contents lists available at SciVerse ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Heuristic algorithms for container pre-marshalling problems

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ARTICLE INFO

Article history:
Received 29 July 2010
Received in revised form 11 May 2011
Accepted 15 August 2011
Available online 25 August 2011

Keywords:
Container pre-marshalling
Heuristic algorithm
Labelling algorithm

ABSTRACT

A container pre-marshalling problem is to find a sequence of container movements to reach final container layout satisfying certain conditions. Two container pre-marshalling problems that are denoted as problem Type-A and Type-B are defined in this paper. Two labelling algorithms, which denote as Heuristic-A and Heuristic-B, are proposed to solve these two container pre-marshalling problems, respectively. Experiments retrieved from past literature and generated by computer program are used to verify the performance of the two algorithms. According to the output results, these proposed algorithms are able to yield a competitive solution in comparison with other methods. Computational results and model variations are discussed.

1. Introduction

Most cargo is transported in containers through major seaports today. Thus, berthing time has become one of the most important measures for terminal performances (Imai, Nishimura, & Papadimitriou, 2008; Imai, Sasaki, Nishimura, & Papadimitriou, 2006). Among all operations, loading and unloading containers from the containership or container-yard are critical ones which affect berthing time significantly (Kim & Bae, 1998). Because of disordered arrival of the containers or lack of accurate information from time to time, the container that is supposed to be handle earlier may be buried in the container stacks beneath other containers that would be handled later. In order to reach the correct container, the containers on its top have to be removed first. This operation is called a "re-handle." It is a non-productive operation to dig a container out from the bottom of a stack. Hence, this container-shuffling operation results in long loading and unloading time, which incurs long berthing time.

Pre-marshalling is an effective action to utilize the loading/unloading operations. It sorts containers according to certain priorities in advance so that the actual processing times of loading/unloading operations can be decreased. However, there are not many research results about optimizing the pre-marshalling process in a container yard. Kim (1997) proposed a methodology to estimate the expected number of rehandles to pick up an arbitrary container and the total number of rehandles to pick up all the containers in a bay for a given initial stacking configuration. Kim, Park, and Ryu (2000) considered the configuration of the container stack and the weight distribution of containers in the yard-bay and proposed a methodology to determine the storage location of an arriving export container. These two researches related to the container arrangement but not exactly the container pre-marshalling problem. Besides, Kim and Kim (1997) discussed how to route transfer crane during loading operation of export containers in port container terminal. The objective is to minimize the total container handling time of the transfer crane including the set-up time at each yard-bay and the travel time between consecutive yard-bays. They also proposed an algorithm to determine the working route of a transfer crane for a similar loading operation later on Kim and Kim (1999). The most relevant research to our topic is Lee and Hsu (2007), which deals with the container pre-marshalling optimization. They model the problem as an integer programming which was a multi-commodity network flow problem embedded within. The optimization goal is to minimize the number of container movements during pre-marshalling. In addition, Lee and Chao (2009) proposed another method – neighborhood search process – to solve the per-marshalling problem. The heuristic takes a neighborhood search approach by starting from a feasible solution and improving the solution through iterations. Our research is basically an extension of Lee's research. Two different pre-marshalling problems are described and two simple heuristic algorithms are provided to solve the problems.

The remainder of this paper is organized as follows. Section 2 states the definition and assumptions to identify the two types of pre-marshalling problems. The heuristics are described in Section 3 and the experiments are provided in Section 4. Section 5 discusses the analysis and a brief conclusion is presented.

2. Problem statement and assumptions

Containers are piled up in the container yard for further operations. Each pile is denoted as a "*stack*." Each stack is located in a

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doi:10.1016/j.cie.2011.08.010

"*cell*" of a container yard. A container pre-marshalling problem is to rearrange the containers in a container yard so that the stacking order conforms to certain criteria. It is denoted that the container can only be accessed from the top of a stack. The objective of the problem is to find the minima movements that make the stacks in correct arrangement. This problem can be treated as a quasi-Hanoi Tower problem. The difference between the Hanoi Tower problem and the container pre-marshalling problem is that the arrangement of the objects has to obey the piling rules in process for Hanoi Tower problem but not for container pre-marshalling problem. Similarly, these two problems are to re-arrange the objects in the stacks to a pre-defined arrangement.

Some notations are needed before introducing the problems. Let the container yard Y be an array, which has R rows and C columns and contains a stack in each cell (r, c). For each cell of the array, one stack can be placed and its maximum height is denoted as H. Let $s(r, c)$ denote the stack locating at (r, c). The maximum height H of a stack in a yard depends on the type of cranes, which is different for diverse yards. The true height (number of containers) is symbolized by $h_{r,c}$. The "*index*" i, is a number representing the priority or classification of a container. Symbol $i_{r,c}$ indicates the index of the top container on stack $s_{r,c}$. Assume the container with smaller index value possess higher priority and vise versa.

The maximum number of spaces N in a yard Y can be represented as following equation:

$$N = R \times C \times H \tag{1}$$

In order to have containers marshalled, "*buffers*" are necessary. The definition of buffer is an empty spot in a stack. The buffers of each stack are equal to $H - h_{r,c}$. Therefore, the total number of buffers B of the container yard can be described as following equation:

$$B = \sum_{r=1}^{R} \sum_{c=1}^{C} (H - h_{r,c}) \tag{2}$$

Since the smoothness of the pre-marshalling depends on whether there are enough buffers or not, the buffer size rate α is defined as following equation:

$$\alpha = \frac{B}{N} \times 100 \tag{3}$$

where $0 \leqslant \alpha \leqslant 100$. Basically, the easiness of marshalling increases as long as α increases. The problem becomes infeasible while α equals 0 and no container exists in the yard while α equals 100.

In this research, two different kinds of container pre-marshalling problems are defined. For notational purpose, they are denoted as problem Type-A and Type-B, respectively. Before introducing the two problems, some assumptions have to be made in advance and are listed as follows.

1. The operation of pre-marshalling is taken place in a bay. This assumption limits the pre-marshalling process to an area in which one crane is able to lift a container.
2. All the containers in the bay are in the same dimension. This implies that the problem of arranging containers with different lengths is not taken into account in this research.
3. The position of each container in the container yard is known in advance.
4. The priority of a container to be loaded is given.

The priority of a container may be calculated according to its destination, weight, or other parameters. In practice, containers may be roughly arranged according to their destinations as soon as they arrive the container yard; however, most of them are also stacked in the wrong order due to different arriving time or other reasons. To facilitate container loading efficiencies at subsequent

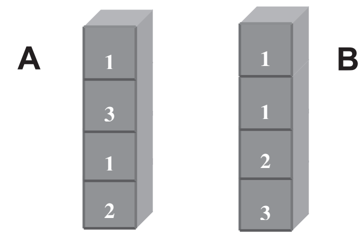

Fig. 1. Demonstration of the arrangement of container stacks.

ports, containers have to be stored on board according to the stowage plan, which specifies the location of each and every container on the ship. Thus, parameters attached to a container should include the destination, weight, and the storing position according to the stowage plan.

The definitions of the two container pre-marshalling problems are described as follows.

2.1. Container pre-marshalling problem Type-A

The definition of container pre-marshalling problem Type-A is basically the same as the problem defined by Lee and Hsu (2007). After the process of pre-marshalling, the container with higher priority has to be on the top of the containers with lower priority in a stack. Fig. 1 illustrates different arrangements of two stacks A and B. It can be observed that stack A in Fig. 1 is in incorrect arrangement because the second container from top has lower priority than the third one. On the contrary, containers in stack B is in correct arrangement because each container's index value is smaller or equal to the index value of the container beneath it.

2.2. Container pre-marshalling problem Type-B

The Type-B problem for container pre-marshalling is slightly different from problem Type-A. This problem is to sort the containers so that each type of container is located in pre-defined cells. Instead of using the integer programming and neighborhood search approach, (Lee and Hsu, 2007; Lee and Chao, 2009) the containers need to be classified into different groups so that the loading process can be accelerated. The containers in each group have a same characteristic such as the same ship to be loaded or the same destination to be shipped. In this case, a bunch of containers with different characteristics can be classified into groups by Type B strategy. The well-classified container groups can facilitate the loading process.

For instance, discriminate containers from loading to different ships. Fig. 2 is an illustration of a container yard in which containers can be classified to have three index values. The container yard was divided into K (=3 in Fig. 2) sections corresponding to K types of containers. The ultimate goal of marshalling is to place all the *type-k* ($k \in K$) containers to the *type-k* section. The term "*type-k*" is equivalent to "index" value that may result from the characteristics of containers, such as destination or loading boat. Because this problem is different from problem Type-A, one more presumption has to be made in order to have the problem solved. The presumption is that there are no containers in a zone that are out of K. This means that there are limited kinds of containers that can be placed in a specific bay. For instance, there are sections *1*, *2*, and *3* in a bay in Fig. 2. Thus, all the containers in this bay should belong to *type-1*, *type-2*, and *type-3* only. As shown in Fig. 2, the containers constituting the stacks on zone 1 and 3 are all have to be rearranged because zone 1 is expecting type 1 containers as well as zone 3 is expecting type 3 containers. The bottom container in the stack on zone 2 is the only one container which does not need