Int. J. Production Economics 143 (2013) 256–262

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

The optimization of mixed block stacking requiring relocations

Dong-Won Jang [a], Se Won Kim [b], Kap Hwan Kim [b,*]

[a] Port Research Division Port Management/Operation & Technology Department, Korea Maritime Institute, Mapo-gu, 121-915, Seoul, Republic of Korea
[b] Department of Industrial Engineering, Pusan National University, Geumjeong-gu 609-735, Busan, Republic of Korea

ARTICLE INFO

Available online 7 August 2012

Keywords:
Relocations
Storage location
Genetic algorithm
Block stacking system

ABSTRACT

This paper addresses the optimization of a block stacking storage system (BSSS) in which unit loads are stored vertically. One of the important problems in a BSSS is in the relocation required when unit loads are located on top of the next unit load to be picked. Relocations are bound to occur when multiple types of unit loads are mixed in the same stacking area. Relocation is a major source of inefficiency during a BSSS handling operation. This study shows how the number of relocations can be reduced by utilizing the information regarding the arriving unit load type when determining its storage location. For the case where the information is not available, statistical models have been developed that estimate the expected number of relocations. For the case where the information is available and utilized, a method based on a genetic algorithm is suggested for use in determining the storage location for each arriving unit load in such a way that minimizes the expected number of relocations. A discussion is presented regarding how to determine the optimal number of stacks allocated to a set of unit load types which will share the same storage area considering the expected number of relocations.

1. Introduction

Block stacking leads to frequent relocations of unit loads on top of the target unit load for retrieval to other stacks. Such relocations are a major source of inefficiency in the handling activities used in block stacking storage systems. Fig. 1 illustrates a storage block in a container terminal; a typical block stacking system. The storage area seen in Fig. 1 which consists of five bays, four tiers, and six stacks.

A group of unit loads group is defined as a set of homogeneous unit loads. If a retrieval request is issued for a unit in the group, then any unit load in the group may be picked up to fulfill the retrieval request. When all of the unit loads in the same storage area are in the same group, it is not necessary to relocate any of the unit loads when a unit load is retrieved. However, when all of the unit loads in the same storage area are not in the same group, relocation may be necessary during the retrieval operation. Unit loads from different groups are mixed in the same area in the case when the storage space is not sufficient to exclusively allocate an entire area to a specific group of unit loads.

Fig. 2(a) illustrates a storage area, consisting of six stacks, where each group consists of a single unit load. When a retrieval order is issued for a random unit load, the retrieval probability of each unit load is a reciprocal of the number of unit loads in the area, which is 1/24 for the example shown in Fig. 2(a). A typical example concerns inbound containers in port container terminals, in which the driver of an arriving road truck requests an arbitrary inbound container to be delivered to a consignee. In steel manufacturing companies, most steel plates are manufactured based on orders made by customers. Therefore, the individual steel plates already have predetermined customers when they arrive at the concerned warehouse. Therefore, the sequence of retrievals sequence of the steel plates is usually random.

Conversely, there are cases where the unit loads of multiple groups are stored in the same area and a retrieval order is issued for a specific group within these multiple groups, as illustrated in Fig. 2(b). Inbound containers in a storage area, unloaded from a single vessel, are normally picked up by several shipping companies and usually repositioned to their off-dock container yards for temporary storage before delivery to their consignees. The trucks arriving from a shipping company may pick up any container among multiple containers for which the shipping company is responsible in terms of delivery. In this case, the inbound containers for the shipping company can be considered unit loads of the same group. When pallets bound for several customers are mixed in the same area and the pickup sequence of pallets for a customer is not important, the pallets for each customer can be defined as a group of unit loads. When unit loads with different contents are stored in the same area, unit loads with the same content can be considered to be unit loads of the same group.

* Corresponding author. Tel.: +82 10 9207 0446; fax: +82 2105 2839.
E-mail addresses: dwjang@kmi.re.kr (D.-W. Jang), led1945@krri.re.kr (S.W. Kim), kapkim@pusan.ac.kr (K.H. Kim).

0925-5273/$ - see front matter © 2012 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ijpe.2012.06.033

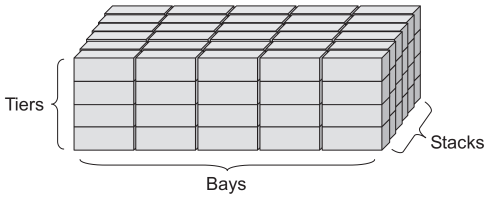

Fig. 1. An illustration of a storage block.

a

S	T	U	V	W	X
M	N	O	P	Q	R
G	H	I	J	K	L
A	B	C	D	E	F

b

H	T	U	U	U	U
T	H	T	H	T	H
U	T	H	T	H	U
H	U	T	U	T	H

Fig. 2. Two examples of a storage area with 24 unit loads.

Table 1
The classification of re-handling problems.

Uncertainty of priorities / Unit loads in a group	Deterministic (D)	Uncertain (U)
Single (S)	Kim et al. (2000) Kim and Hong (2006) Yang and Kim (2006) Lee and Hsu (2007) Lee and Chao (2009) Lee and Lee (2010) Wu et al. (2010) Zhu et al. (2010) Caserta et al. (2010) Zhang et al. (2010)	Watanabe (1991) Castilho and Daganzo (1993) Kim (1997) Park and Kim (2010)
Multiple (M)	Kim et al. (2000) Kim and Hong (2006) Caserta et al. (2010) Zhang et al. (2010)	Kang et al. (2006)

Two assumptions have traditionally been made regarding the retrieval priority for unit loads stored in the same area. The first assumption regards the certainty of the retrieval priorities amongst the different groups of unit loads in the same area. The retrieval priorities among the different groups of unit loads may be assumed to be deterministic; between any two groups it is known which group will be retrieved earlier than the other. Conversely, the priorities among different groups may be assumed to be uncertain. That is, between any two groups of unit loads in the same area it is not known in advance which will be retrieved earlier than the other.

The second type of assumptions regards the number of unit loads with the same priority. It may be assumed that each single unit load can be considered to be an independent group, as seen in Fig. 2(a); that is, the priorities are different among individual unit loads. Otherwise, it may be assumed that there are multiple groups, each of which consists of multiple unit loads (Fig. 2(b)) with the same priority of retrieval, as seen in Fig. 2(b). Table 1 classifies the re-handling problems by these two different types of assumptions.

Many researchers have analyzed the re-handling operation. Watanabe (1991), Castilho and Daganzo (1993) and Kim (1997) proposed formulas used to estimate the number of relocations needed for the random retrieval of a container from a container yard. Kim et al. (2000) addressed the problem of locating the arriving outbound containers by considering the weights of the containers. Zhang et al. (2010) improved the algorithms found in Kim et al. (2000). Kang et al. (2006) extended Kim et al. (2000) by relaxing the latter's assumption that the weight information of every arriving container is known with certainty. Kim and Hong (2006) suggested two methods for determining the locations of relocated blocks. Caserta et al. (2010) improved the algorithm found in Kim and Hong (2006). Lee and Lee (2010), Wu et al. (2010), and Zhu et al. (2010) proposed algorithms used to plan the retrieval operations concerning relocations, which is a problem similar to the one addressed by Kim and Hong (2006). Lee and Hsu (2007) and Lee and Chao (2009) discussed the method needed to construct a plan to reposition the export containers within a yard so that no extra re-handles were needed during the loading operation. Park and Kim (2010) compared the expected number of relocations needed in various types of storage systems.

Kang et al. (2006) extended Kim et al. (2000) by assuming that the grouping data regarding unit loads are uncertain, which can be considered to be, as laid out in Table 1, a case with multiple unit loads per group and uncertainties in priorities (MU). Unlike the source of the uncertainty in Kang et al. (2006), our study assumes that the group information is certain but the priorities among the groups are uncertain. Jang et al. (2011) derived statistical expressions estimating the expected number rehandles in stacks with mixed groups of inbound containers.

This study analyses the MU case in which the priorities of retrieval are uncertain and multiple unit loads of each group may be stored in the same area in a mixed manner. Two different cases are analyzed: the first being where the group information of each unit load is not available when it arrives at the storage system and the second being where the group information is available before its storage location is determined.

When the group information is available before its storage location is determined, the expected number of relocations may be reduced by optimally locating the arriving unit loads. This study suggests a method that finds the optimal storage location of each arriving unit load. We then compare the expected number of relocations under the optimizing decisions to that of the case without group information. By using the estimated number of relocations during the retrieval process, an enumeration method for finding the optimal number of stacks in a storage area is then presented.

Section 2 derives the expressions for the expected number of handlings per retrieval for the case without group information. Section 3 analyzes the case with group information and attempts to reduce the expected number of relocations during the retrieval process by optimizing the storage locations of the arriving containers. Section 4 proposes a method that determines the number of stacks allocated to a predetermined set of groups. Conclusions are drawn in the final section.

2. Estimating the expected number of relocations for the case without group information

For a given number of unit loads, when the number of stacks allocated to a specified set of groups decreases, the average height of the stacks must increase, which results in an increase in the expected number of relocations per retrieval. This section introduces statistical expressions for estimating the expected number of relocations for the case in where the group information of a unit load is not available when it arrives at the storage system (Jang et al., 2011). As a result, the unit load will be placed in the lowest possible tier in the storage area. Because the group information regarding the arriving unit load and unit loads already stored in the stacks is not used in locating the arriving