Optimal Storage Assignment for an Automated Warehouse System with Mixed Loading

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OPTIMAL STORAGE ASSIGNMENT FOR AN AUTOMATED WAREHOUSE SYSTEM WITH MIXED LOADING

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Abstract. In this study, an automated warehouse system with mixed loading is considered. The majority of previous studies considered assumptions that were similar to those for a single-shuttle system with single loading. Due to the increased number of items in recent years, storage assignment strategies with single loading are not feasible because of the shortage of storage racks. This study adopts a storage policy with mixed loading for an automated warehouse system, which enables the use of one warehouse. Additional movement and transshipment operations, which involve mixed loading, are considered in this paper.

Keywords: Automated warehouse, storage assignment policy, mixed loading.

1 Introduction

In this study, an automated storage and retrieval system (AS/RS) for multiple items is considered. The basic components of an AS/RS are the input/output (I/O) locations, storage racks, and automated stacker cranes (Fig. 1). An important measure of system performance is the cycle time of a stacker crane, which is the sum of the expected travel time and pickup/deposit time. The expected travel time is dependent on the storage assignment strategy. A low expected travel time is critical in the selection of the storage assignment strategy for an AS/RS.

In the past 30 years, studies of AS/RSs have addressed storage policies to reduce the travel time of a stacker crane. Hausman et al. [1] analyzed the cycle time of a stacker crane in a single-shuttle system in an AS/RS using a mathematical model. They analyzed different storage assignment strategies (dedicated storage policy and randomized storage policy) and demonstrated that full turnover-based dedicated storage was a suitable assignment policy. Hackman and Rosenblatt [2] considered the allocation of items to an AS/RS when it has insufficient space to store all of them. Using a dedicated storage policy, a set of storage locations is reserved for each product for the duration of the planning horizon. While the literature deals mostly with dedicated storage policies. Francis et al. [3] discussed about the four storage policies. They are: dedicated storage policy, randomized storage policy, class-based dedicated storage policy, and shared storage policy. A shared storage policy, allows units of different products to successively occupy the same location, and can provide substantial benefits when precise information is available concerning the timing of storages and retrievals.

Maximal benefits of this type of system are dependent upon the optimal system design. Eynan and Rosenblatt [4] and Wen et al. [5] demonstrated the influence of the system design (e.g., the length and height of the storage racks and the horizontal and vertical speeds of the stacker crane) on the optimal storage assignment policy. They clearly showed that the system design does not influence an optimal storage assignment policy.

The manufacturing industry is converting to multi-item small-sized production. Thus, a dedicated storage policy requires numerous storage racks because of the increased number of items. In addition, a dedicated storage policy may lack a storage rack. However, the replenishment factor for a storage rack is decreasing. In recent years, many companies load two or more items together to prevent shortage of storage racks. The influence of mixed loading on the optimal storage assignment strategy remains ambiguous.

In this study, an AS/RS with mixed loading is designed. High-performing storage assignment strategies are analyzed using a simulation technique.

2 The Model

2.1 Nomenclature

I	the number of items
N	the number of orders (I/O)
K	the number of storage locations
t_f	forking time
t_k	S/R machine travel time from the I/O point to the storage location k (k = 1,…, K) for $K < I$
t_p	time to mix items or divide items
λ_k	the turnover of a single loading pallet in the storage location k
μ_k	the turnover of a mixed loading pallet in the storage location k

2.2 Model

The assumptions of Hausman et al. [1] are employed throughout the paper:

- The analyzed single-shuttle system consists of a single stacker crane serving as a single one-sided aisle.
- A “First In First Out (FI-FO)” storage strategy was implemented in this system.

- The length and height of the storage rack and the S/R machine velocities in the horizontal v_x and vertical v_z directions ($v_x > v_z$) are known. The acceleration and deceleration of the S/R machine are not considered.
- The pickup and deposit times are assumed constant and equivalent to the forking time.
- The location number is set to in the order of early arrival from an I/O point ($t_1 \le t_2 \le \cdots \le t_K$).

The following assumptions are added to consider mixed loading:

- One pallet is deposited by a storage location. The replenishment factor of the storage location per item is less than 50%.
- If two or more items are deposited on the same pallet, these items will be mixed to create one pallet. If an item is picked up from the mixed loading pallet, the pallet will be divided into two pallets.

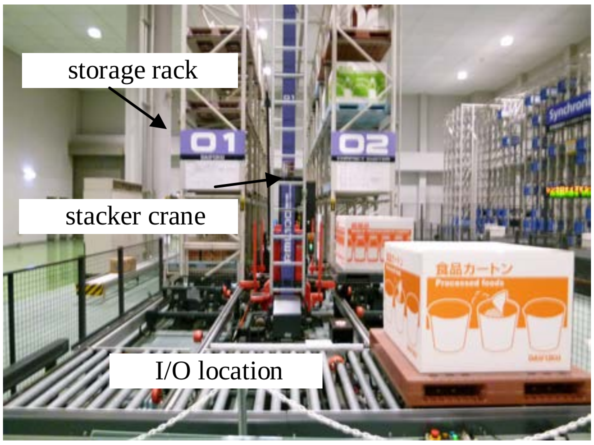

Fig. 1. Configuration of an AS/RS.

2.3 CYCLE TIME OF A STACKER CRANE WITH MIXED LOADING

Fig. 2 shows the movement of a stacker crane with single loading. When depositing a pallet with single loading, a stacker crane receives the item at the I/O point and carries it to a previously determined storage location (t_k). After depositing the pallet in a storage location (t_f), the stacker crane returns to the I/O point (t_k). In the case of a pallet with single loading, the required time for depositing and picking up for movement to location k is

$$\omega_k = 2 \times t_k + t_f \ . \qquad (1)$$

Fig. 3 shows the movement of a stacker crane with mixed loading. When depositing a pallet of mixed loading, it is necessary to pick up a pallet with single loading from the storage location (ω_k) and to mix these items at an I/O point (t_p). A stacker crane receives the pallet at the I/O point, carries it to a storage location, and returns to the I/O point (ω_k). Thus, the movement of the stacker crane with mixed loading consists of the movement of the pallets with single and mixed loading. In the case of the pallet with mixed loading, the required time for depositing and picking up for movement to the location k is

$$\omega_k + (\omega_k + t_p)\,. \tag{2}$$

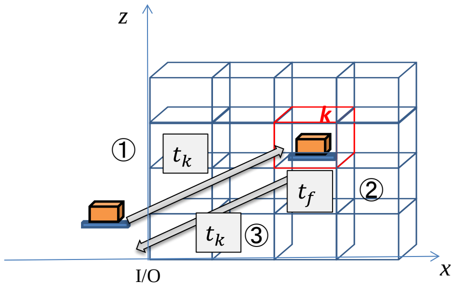

Fig. 2. Movement of a stacker crane with single loading

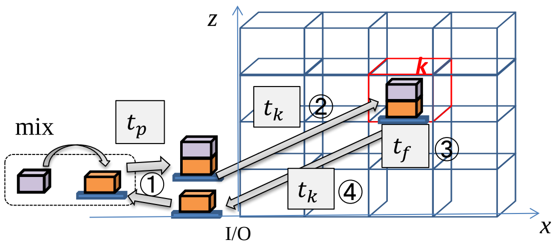

Fig. 3. Movement of a stacker crane with mixed loading

As previously mentioned, the average cycle time is expressed using λ_k and μ_k as follows:

$$CT = \frac{1}{N}\left\{\sum_{k=1}^{K} \omega_k \times \lambda_k + \sum_{k=1}^{K}\left[(\omega_k + t_p) \times \mu_k\right]\right\}. \tag{3}$$

$$N = \sum_{k=1}^{K} \lambda_k\,. \tag{4}$$

Here, if k_1 is smaller than k_2, ω_{k1} is smaller than ω_{k2} because the relation of $t_{k1} \le t_{k2}$ is consistent with the assumption. As the first terms of Eq. (**3**) decrease, the turnover of the location near an I/O point increases for the condition of Eq. (**4**). Hausman et al. [1] proposed full turnover-based dedicated storage using an item's turnover. That is, the first term of Eq. (**3**) can be minimized by assigning items with larger turnover to the order near the I/O point. The results of a numerical experiment indicate that a full turnover-based dedicated storage policy was an acceptable assignment policy compared with a randomized policy. Items with a large turnover are combined and assigned near the I/O point to effectively minimize the first terms.

The second terms of Eq. (**3**) decrease when the movement of a mixed loading pallet does not occur. However, if items with a large turnover are combined, the number of movements for a mixed loading pallet will also increase.

2.4 GENERAL MODEL FORMULATION

In the study by Housman et al. [1], the discrete function t_k was approximated by a continuous function, and the turnover at the storage location λ_k was estimated using the mathematical method. They considered warehouse system configurations, such as square-in-time (SIT), and estimated the S/R machine travel time using the following equation:

$$t(j) = \sqrt{j}\ , \ (0 < j \le 1). \qquad (\mathbf{5})$$

Here, j is the index of a pallet in a rescaled rack and $j \in (0,1]$. However, when considering mixed loading, the travel time to the storage location k needs to be considered a discrete function. We can then estimate the S/R machine travel time using the following equation:

$$t_k = \sqrt{{x_k}^2 + {y_k}^2}\ , \ (k = 1,2,\cdots,K). \qquad (\mathbf{6})$$

and calculate the turnover of the storage rack k (λ_k and μ_k) using a simulation technique.

The results for the different policies for different s-parameter values of the ABC curve are shown in Fig. 3. The ABC curve is formulated by

$$G(i) = i^s\ , \ (0 < s \le 1). \qquad (\mathbf{7})$$

Assuming that the total demand = 1, a demand of item i is shown by the following equation:

$$D(i) = si^{s-1}\ , \ (0 < i \le 1). \qquad (\mathbf{8})$$

We created eight demand patterns using different values of s (1.000, 0.748, 0.569, 0.431, 0.317, 0.222, 0.139 and 0.065). If s increases, the demand for every item will be equivalent. In contrast, as s decreases, the demand differs significantly.

3 Comparison with the storage policy with mixed loading

In this section, the performance of the full turnover-based dedicated storage policy is compared with the performance of the randomized storage policy. The formulas for the full turnover-based dedicated and randomized storage policies are derived from Hausman et al. [1].

In a randomized policy, every item can be deposited to the vacant rack of the nearest neighborhood from an I/O point. If a shortage of empty racks occurs, a pallet will be loaded with various items together and deposit the rack near an I/O point. In a full turnover-based dedicated storage policy, the storage location of all items is determined in advance. Thus, even when the empty rack remains, it loads various items together at the previously determined location.

In Fig. 4, the average cycle time is plotted along the vertical axis, and the pattern number of demand is plotted along the horizontal axis. The pattern number of demand p was set to the descending order of s. Fig. 4 shows the results for three different values of t_p (0.0, 1.0, and 2.0) for each policy. In this study, t_p was set to 0 for simplification. The number of order N was set to 50,000.

In the case of single loading, the full turnover-based dedicated storage policy is optimal [1]. However, in the case of mixed loading, the randomized storage policy is optimal when the demand of items are similar (s is small). Fig. 5 and 6 display the average travel time and the number of mixed loading movements when $t_p = 0.0$ and 2.0. If a full turnover-based dedicated storage policy is used, the average travel time decreases and the number of mixed loading movements increases when p is large. However, if the randomized storage policy is used, the average travel time and the number of mixed loading movements have a slight influence on the variation of p. Furthermore, the number of mixed loading movements is small in the case of the randomized storage policy, and the randomized storage policy becomes effective when t_p is large.

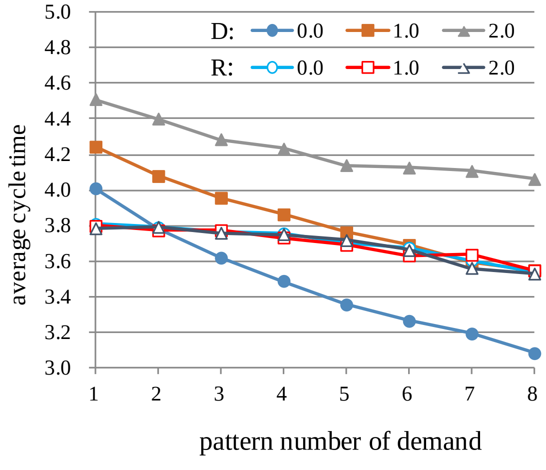

Fig. 4. Average cycle time for different values of demand (D: full turnover-based dedicated storage policy; R: randomized storage policy)

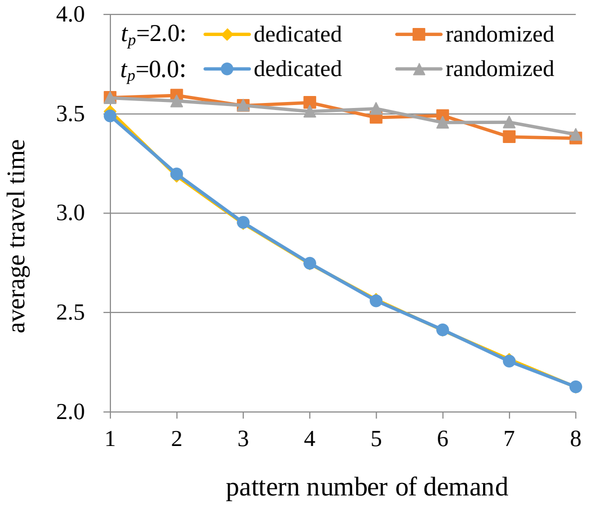

Fig. 5. Average travel time for each policy (t_p = 0.0 and 2.0)

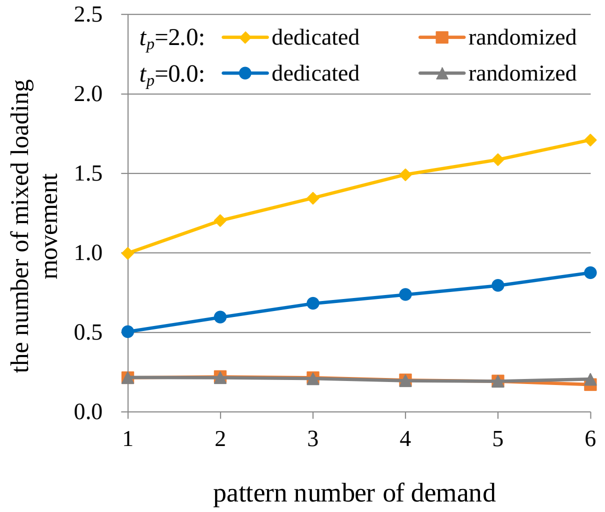

Fig. 6. Number of mixed loading movements for each policy (tp = 0.0 and 2.0).

Fig. 7 shows the comparison results for single and mixed loading using a full turnover-based dedicated storage policy. The mixed loading is effective when *p* is small. If *p* is small, many empty racks occur near the I/O point. Therefore, despite permitted mixed loading, the movements by single loading and the distance have decreased. This finding shows that a mixed loading of items is effective not only when a shortage of a storage location occurs but also when the demand of items is similar.

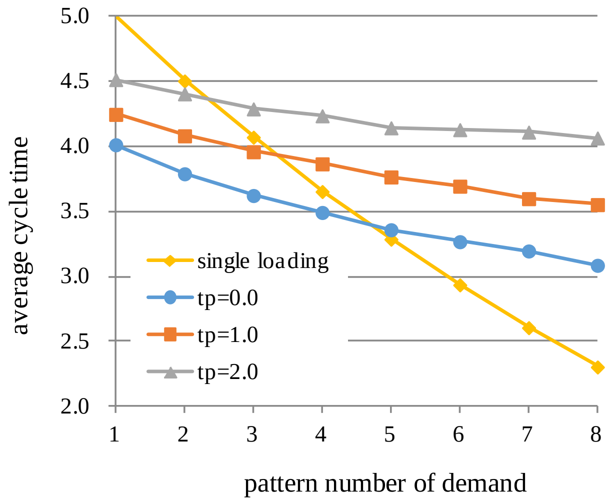

Fig. 7. Comparison results for single and mixed loading.

4 Conclusions

An AS/RS with mixed loading is designed and analyzed. In the case of single loading, the average cycle time was reduced using a full turnover-based dedicated policy. However, our experiments show that a randomized storage policy is effective for mixed loading. In this research, the testing is done on hypothetical data. The future issues include a real-life implementation and improvement in storage policy. The method for determining the combination of items in a shared storage policy is critical for future operations.

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