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Variable neighborhood search heuristic for storage location assignment and storage/retrieval scheduling under shared storage in multi-shuttle automated storage/retrieval systems

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ABSTRACT

This paper examines the joint optimization of storage location assignment and storage/retrieval scheduling in multi-shuttle automated storage/retrieval systems (AS/RSs) under shared storage, in which the reuse of empty location yielded by retrieval operation is allowed. From the view of analytical model, the advantage of operational mode under shared storage is verified. A variable neighborhood search (VNS) algorithm is developed to solve the large-sized problems. Various numerical experiments are conducted to evaluate the performance of the proposed algorithm and investigate the impact of different parameters on computational efficiency.

1. Introduction

Due to the merit of higher operational efficiency, multi-shuttle automated storage/retrieval systems (AS/RSs) become increasingly popular for storing products in factories and distribution centers. A typical multi-shuttle AS/RS has a series of storage aisles each of which is served by a multi-shuttle storage and retrieval (S/R) machine. The multi-shuttle S/R machine can carry multiple stock keeping units (SKUs) at a time, which implies that performing multiple operations (storage or retrieval) on a trip is feasible. The increase of storage and retrieval operations performed on a trip naturally leads to reducing the empty travel time of the S/R machine. Then the higher operational efficiency can be obtained compared with the single-shuttle AS/RS.

Multi-shuttle AS/RS processes the storage and retrieval requests in the form of operation cycles. Each operation cycle corresponds to a trip of the multi-shuttle S/R machine which starts from the I/O point with the storage items, visits the rack locations for storage or retrieval considering the capacity of the multi-shuttle S/R machine, and returns to the I/O point again with the retrieval items.

There are some different operational modes when performing the trip. The choice of operational mode depends on the storage location assignment policy. Under the dedicated storage policy, one storage/retrieval request only corresponds to

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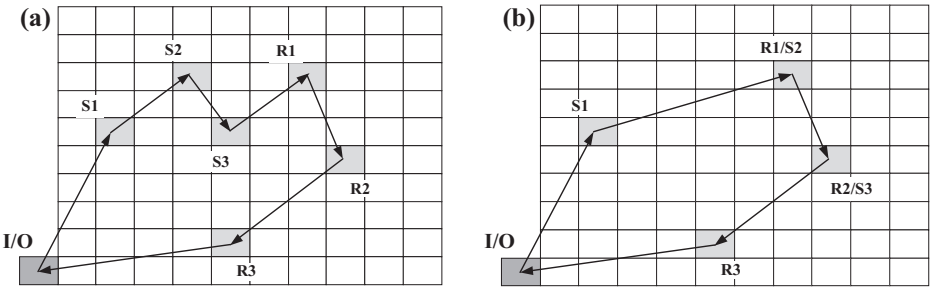

Fig. 1. Two typical operational modes in the multi-shuttle AS/RS.

one storage/retrieval location. The storage and retrieval request performed at the same location is not allowed. The operational sequences are feasible when the number of performed storage requests is equal to or larger than the number of performed retrieval requests at any point. Taking the triple-shuttle AS/RS for example, the typical feasible operational sequences are S1–S2–S3–R1–R2–R3, S1–R1–S2–R2–S3–R3, S1–S2–R1–R2–S3–R3, S1–S2–R1–S3–R2–R3, S1–R1–S2–S3–R2–R3, where S represents a storage operation and R represents a retrieval operation. In this mode, $2n$ locations (n denotes the number of shuttles) including n storage locations and n retrieval locations in the storage rack are visited in each trip. When the shared storage is adopted, the empty location newly yielded by retrieving item is immediately occupied to perform the following storage operation. Under the shared storage, the typical operational sequence for triple-shuttle AS/RS is S1–R1/S2–R2/S3–R3. It is easily observed that $n + 1$ locations including one storage location and n retrieval locations are visited in this mode. The two typical operational modes, of dedicated storage and shared storage, are shown in Fig. 1. Compared with the first mode, the number of locations visited decreases. Intuitively, the operational mode under the shared storage seems more efficient than other storage policy due to some travel-between time is eliminated.

The storage location assignment and storage/retrieval scheduling which determines how to pair and sequence the storage and retrieval operations are the two main and interrelated operating decisions for unit load multi-shuttle AS/RS. Optimizing the operating decisions individually will weaken the overall optimal performance. Maximum throughput of the multi-shuttle AS/RS may only be obtained from a joint optimal location assignment and storage/retrieval scheduling strategy. Yang et al. (2013) have explored the joint optimization of storage location assignment and storage/retrieval scheduling in multi-shuttle AS/RS. While it did not refer to the shared storage which is more efficient and suitable for the realistic operation, our work tries to fill this meaningful gap. The main contributions of this paper are that we firstly study the joint optimization problem of storage location assignment and storage/retrieval scheduling in multi-shuttle AS/RS under a new shared storage mode, in which the empty location newly yielded by retrieving item is immediately used to store the next item. This mode is potential for real-life application due to the reduction of locations needs to be visited.

The rest of the paper is organized as follows. Section 2 gives a brief review on the related work. The assumptions and notations are described in Section 3. In Section 4, we present the joint optimization model of storage location assignment and storage/retrieval scheduling problem under the shared storage. Based on the characters of optimization model, Section 5 develops a variable neighborhood search algorithm to solve the medium and large-sized problems. Section 6 conducts numerous experiments to assess the performances of proposed algorithms and reports the result of computational experiments. Finally, in Section 7, we present our conclusions and identify some future research directions.

2. Literature review

In order to operate a unit-load AS/RS efficiently, several operational decisions need to be considered. In the past decades, considerable attention has been focused on the storage location assignment and storage/retrieval scheduling problem. For the storage location assignment in unit-load AS/RS, four popular strategies including dedicated storage, random storage, class-based dedicated storage and shared storage are summarized by Francis et al. (1992). Chen et al. (2010) points out the shared storage policy is generally based on the duration-of-stay (DOS) of each item and allows more flexible use of space than a dedicated storage policy. When the precise information is available, the potential both to reduce the maximum effective storage area and to better utilize the more desirable storage locations can be provided by shared storage. Additionally, the correlated storage is also applied widely in practice. Under correlated storage, items with demand dependence are stored together. The more dependent they are, the more likely the routing length for a given list of orders reduces. Lee (1992), Hsieh and Tsai (2001), Xiao and Zheng (2010) are a typical work related to the correlated storage topic. These storage strategies are applicable for both single-shuttle AS/RS and multi-shuttle AS/RS. The decisions including warehouse layout, batching and aisle configuration also have an impact on the storage location assignment. Pohl et al. (2009), Schleyer and Gue (2012) and Gue et al. (2012) are the recent work to explore the above issues. More detailed reviews on storage assignment strategies can be found in Sarker and Babu (1995), De Koster et al. (2007) and Roodbergen and Vis (2009).

Definition of storage/retrieval scheduling problem is a little different between single-shuttle AS/RS and multi-shuttle AS/RS. For unit-load single-shuttle AS/RS, it is also be called interleaving policy by Chen et al. (2010), the storage/retrieval