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A decomposition approach to dual shuttle automated storage and retrieval systems

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ABSTRACT

Automated Storage and Retrieval Systems (AS/RS) have become vital in today's distribution and production environments, however it remains necessary to equip them with more efficient operational control policies. Motivated by real situations encountered by companies employing AS/RS, the present paper studies a miniload AS/RS system, with a dual shuttle crane in which a set of storage and retrieval requests must be scheduled such that the prioritized waiting time is minimized. Dual shuttle cranes have received minimal academic attention and thus continue to pose new problems that must be solved. The miniload AS/RS problem is addressed by decomposing it into a location assignment and sequencing problem. Different heuristic strategies are introduced for making the assignments, while a general mathematical model and efficient branch and bound procedure are proposed for optimizing the sequence. Additionally, a fast metaheuristic capable of solving larger instances is also developed. A set of real-world based benchmarks with varying characteristics is generated to evaluate the proposed methods. Very small instances prove the only for which optimal sequences are found in reasonable calculation time. Experimental results demonstrate the effectiveness of the heuristic decomposition method.

1. Introduction

An Automated Storage and Retrieval System (AS/RS) is a type of warehousing system (Van den Berg & Zijm, 1999) in which the storage and retrieval activities are performed by a crane (storage/retrieval machine) completely independent of operator interference. The primary components of an AS/RS are racks, cranes, aisles, input-output positions and picking positions (Roodbergen & Vis, 2009). Automated warehousing systems have been used for the storage and retrieval of products in both distribution and production environments since the 1960s. The implementation of such systems has considerably increased during the last decades given their several advantages over non-automated systems. Companies which have implemented these systems are satisfied with the improvements obtained (Kulwiec, 2006). MHI (2016), America's largest material handling, logistics, and supply chain association, details the following benefits of AS/RS systems: reducing wasted floor space by up to 85%, minimizing labor requirements by up to two-thirds, extended order cut off times, individual and departmental accountability, enhanced product security, increased ergonomics resulting from convenient height delivery to the operator, increased accuracy levels of up to 99.99%, increased throughput capabilities, new revenue generating activities by reclaiming otherwise wasted space and labor, and finally elimination of time lost walking, searching, lifting, bending, and twisting activities.

Designing an AS/RS involves two types of decision (Gagliardi, Renaud, & Ruiz, 2012; Roodbergen & Vis, 2009): physical design and control policies. Layout and the equipment employed is determined by physical design. This decision requires a high capital investment (Azzi, Battini, Faccio, Persona, & Sgarbossa, 2011; Howard Zollinger, 2001). It is therefore crucial to design it correctly from the very beginning given that short-term changes are almost impossible. The application of control policies must manage the system insofar as achieving maximum profitability. Sequencing storage and retrieval requests represents one of the most important policies. The company must determine the sequence in which the storage and retrieval requests are conducted in order to maximize the performance of the AS/RS system. The performance measures may differ: travel time per request, number of requests handled per time period, total time required to handle a certain number of requests, waiting times of the cranes or waiting time of requests to be stored/retrieved (Roodbergen & Vis, 2009).

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AS/RS may be categorized according to the size and volume of items to be handled, the storage and retrieval methods, and the interaction of the stacker crane and the human worker. Examples of such categories include Unit-load AS/RS, Deep-lane AS/RS, Mini-load AS/RS, Man-on-board AS/RS, Automated item-retrieval system, and Vertical lift storage modules (Vasili, Tang, & Vasili, 2012).

The miniload AS/RS system is common for small parts order picking, for example in electronic and pharmaceutical industries. In addition to the automated crane, the miniload system involves a picker (either human or robot). Storage racks consist of boxes that store small parts. A box is brought to the picker for retrieval of small items and is subsequently returned to a location in the rack (Mahajan, Rao, & Peters, 1998). The main characteristics of the real problem responsible for inspiring this study are:

1. *Racks and aisles*. There are two racks with an aisle in the middle (see left picture in Fig. 1). Racks are stationary and single deep, thus meaning every load is accessible by the stacker crane. The aisle has one stacker crane, which cannot leave its designated aisle (aisle-captive). The storage cells are homogeneous and each one holds one box.
2. *Cranes*. The stacker crane (SC) of the miniload AS/RS has two shuttles as opposed to the standard AS/RS system where each crane has only one shuttle. A crane's dwell-point is the position where it resides, or dwells, while the system is idle. The dwell-point of the system under study is the input-output zone. When the system is at work, cranes reside in their last visited location, while in the standard AS/RS problem cranes begin and end all routes at the input/output zone.
3. *Input-output locations*. There is one input and one output zone (I/O). The input zone is used when introducing full boxes from outside the system and has limited capacity. The output zone is used when removing empty, faulty or outdated boxes. When a box arrives at the output zone, it automatically leaves the system. The output zone's functionality differs from the standard AS/RS problem, where it is used to satisfy customer requests. In this study customer requests are satisfied at picking zones.
4. *Picking zones*. Warehouses with a miniload AS/RS system apply the *'product to man'* principle (Mecalux, 2014): the boxes located on the rack are handled automatically by a stacker crane bringing them to the operator's post where they take the required units of the product. Boxes are returned to the rack afterwards. The removed items are introduced by the picker in small containers. These containers are picked up and delivered to the customers. Picking zones are either located at each aisle's end or on the outboard side of a rack (Fig. 1). Picking zones located on a rack's outboard side represent the specific situation addressed by this study. Workers can easily access these zones, which may have different sizes.

This problem's objective is the efficient scheduling of requests in a dual shuttle miniload AS/RS system where such requests arrive dynamically to the system. Each request has its own release time, as well as a priority, assigned by the company. Ultimately the task consists of, for a set of requests, determining their process sequence while simultaneously positioning the boxes in the rack or picking zones such that the total prioritized waiting time is minimized.

This paper poses various exact and metaheuristic approaches to scheduling a dual shuttle miniload AS/RS system. Section 2 provides a review of the solution methods for AS/RS problems and for miniload systems in particular, while Section 3 introduces the studied system. Section 4 describes a decomposition approach in which the problem of assigning locations to boxes is solved first before addressing the problem of sequencing the requests so as to minimize the total weighted waiting time. Exact and heuristic procedures are developed for the first phase, whereas only exact procedures are developed for the second phase. Exact procedures are only capable of solving small instances to optimality, consequently a metaheuristic algorithm has been developed to solve realistic-sized instances. This metaheuristic is described in Section 5. Sections 6 and 7 present the computational results and conclusions.

2. Literature review

Roodbergen and Vis (2009) and Vasili et al. (2012) provide a good introduction to AS/RS systems. Han, McGinnis, Shieh, and White (1987) indicated that the problem of optimally sequencing a given list of requests is NP-hard. Consequently, the exact methods described in the literature only address AS/RS problems with a set of restrictive assumptions. The basic version of an AS/RS system has one crane per aisle, Cranes are only capable of transporting one unit-load at a time (single shuttle). Racks are stationary and single-deep. This AS/RS type is referred to as a single unit-load aisle-captive AS/RS. The list of retrievals and storages continually changes. When retrievals are performed they are deleted from the list, whereas dynamically occurring new retrieval and storage

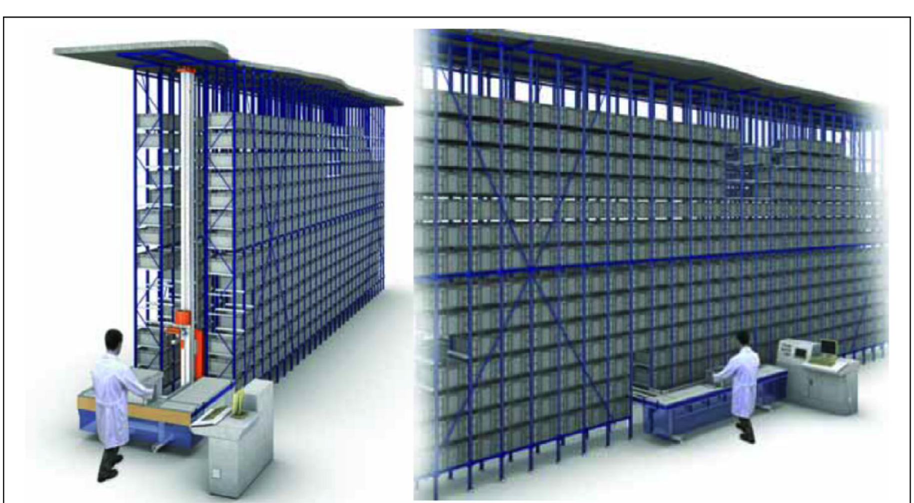

Fig. 1. Picking zone positions in a miniload AS/RS. Both end of aisle (left) and outboard side (right).