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Scheduling the truckload operations in automated warehouses with alternative aisles for pallets

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ABSTRACT

In this study, the scheduling of truck load operations in automated storage and retrieval systems is investigated. The problem is an extension of previous ones such that a pallet can be retrieved from a set of alternative aisles. It is modelled as a flexible job shop scheduling problem where the loads are considered as jobs, the pallets of a load are regarded as the operations, and the forklifts used to remove the retrieving items to the trucks are seen as machines. Minimization of maximum loading time is used as the objective to minimize the throughput time of orders and maximize the efficiency of the warehouse. A priority based genetic algorithm is presented to sequence the retrieving pallets. Permutation coding is used for encoding and a constructive algorithm generating active schedules for flexible job shop scheduling problem is applied for decoding. The proposed methodology is applied to a real problem arising in a warehouse installed by a leading supplier of automated materials handling and storage systems.

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1. Introduction

Automated storage and retrieval system (AS/RS) is a warehousing system that uses mechanic devices for the storage and retrieval of products in both distribution and production environments [1,2]. Automatic cranes move through aisles between racks to put the items on the racks and retrieve those items from storage to the collector for fulfilling the customer orders. AS/RS is fully automated, because no intervention of an operator is needed for handling the pallets [2]. When an order is received for an item, a stacker crane retrieves the pallet from its storage location and carries it to the collector at the top of the aisle that is a gravity roller conveyor. At the end of the roller conveyor, the conveyed pallet is picked up using a forklift truck. High space utilization, improved material flow, and improved inventory control are some of the advantages of AS/RS [3]. The best utilization from such a system can be succeed by optimal design and optimal scheduling of the system.

Warehouse scheduling optimization is a combinatorial optimization problem which cannot be solved with exact algorithms in reasonable computational time for high dimensional instances.

Because of the high complexity of the problem, simulation and metaheuristics have been widely used in warehouse scheduling optimization [4]. A detailed literature review about the methodologies developed for AS/RS design and scheduling is given in Section 3.

In this study, the scheduling of truck load operations arising in AS/RS is investigated. The problem is modelled as a flexible job shop scheduling problem (FJSP) by considering the loads as jobs and pallets of a load as its operations. The forklifts which are used for transportation of pallets from collectors to trucks are considered as machines. The main contributions of this paper are twofold: (1) scheduling of truck load operations is modelled as a flexible job shop scheduling problem, (2) a real problem arising in an AS/RS warehouse installed by a leading supplier of automated materials handling and storage systems is solved by using a priority based genetic algorithm and the effect of aisle selection flexibility is investigated. To the best of the authors' knowledge, this work is the first time that the FSJP is used to model the retrieving operation of pallets in an AS/RS warehouse.

The paper is organized as follows. Section 2 provides a brief explanation on investigated automated storage system. In Section 3, a literature review on scheduling of truck load operations is given. Section 4 represents a mixed integer programming (MIP) formulation for a truckload operations scheduling problem in AS/RS and discusses the modelling of the problem as a flexible job shop scheduling problem. Section 5 presents the devoted methodology.

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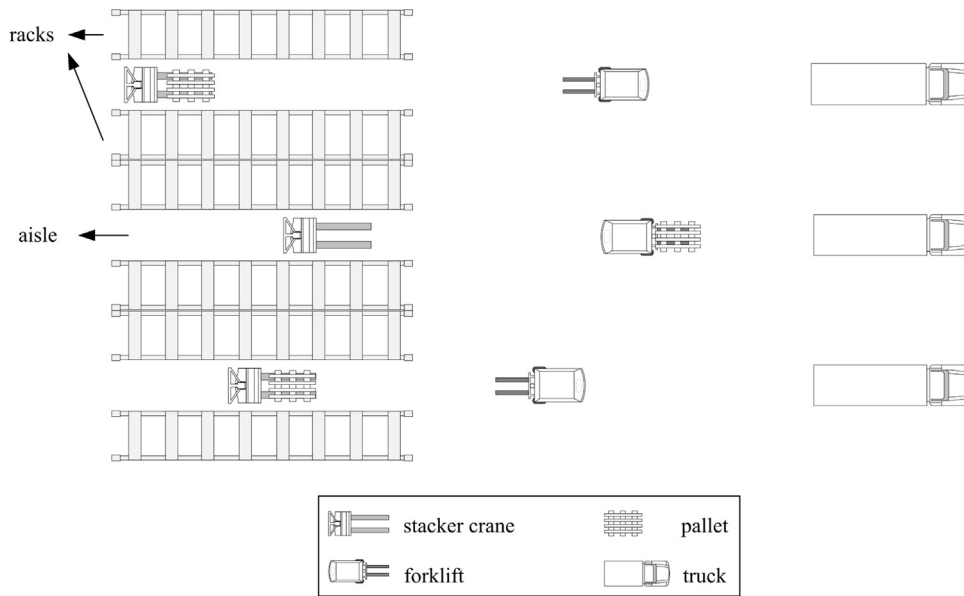


Fig. 1. Schema of the warehouse.

Section 6 gives the computational results for a real life AS/RS warehouse problem. Finally, Section 7 presents the conclusion.

2. Storage system

The methodology proposed in this study is applied to an AS/RS warehouse in Italy which works as a distribution center. Products are stored by the warehouse and loaded to the trucks to fulfill the orders of customers. Routes of the trucks, which are known in advance, are determined considering the delivery deadline of customer orders. The warehouse consists of eleven aisles constituted by pallet racks with the capacity of 40,000 pallets. An automatic stacker crane or S/R machine works in each aisle to move the pallets from their respective rack to the collector at the beginning of the aisle. Forklifts transport the pallets to the trucks. The warehouse has 13 docking bays to load the trucks. A scheme of the loading process in this warehouse is shown in Fig. 1.

Warehouse Planning System (WPS) and Warehouse Management System (WMS) are used to operate the warehouse. Daily planning of loadings for each truck is executed by WPS. The sequence of retrieving pallets and the movement of S/R machines and forklifts are determined by WMS. Approximately one hundred loads are retrieved per day by a truck. Each truck has its own delivery time which is considered by WPS and loading must not be delayed. In the strategy defined for the WPS, the whole set of loads are divided into subsets called batches. Loads in a batch are processed simultaneously. Loading of a batch cannot be started before the loads of previous batch are finished. The size of a batch is determined with respect to delivery deadlines and the number of docking bays. A standard daily plan includes 15–20 batches with 6–13 loads for each one.

An order of a customer consists a product or a set of products that are delivered on one or more pallets. The set of products for an order is known in advance, and it is available in the warehouse. A truck load consists of a set of pallets transported for one or more clients. The sequence of loading pallets on the truck is determined by WMS with LIFO (Last In First Out) rule. Since the sequence of pallets in a load is predetermined and cannot be changed, precedence relations exist between pallets of a load.

The pallets of a load can be retrieved from any aisle. To facilitate the assignment of the trucks to the docking bays, several pallets

are placed in different aisles to reduce the time of load preparation, allowing a pallet to be selected in an aisle that is close to the truck and respecting the FEFO (First-Expired-First-Out) rule. The S/R machine is programmed to retrieve the pallets from the corresponding aisle.

We assume that each forklift can work for only one aisle. After a forklift receives a pallet from its own aisle, it can carry the pallet to any truck. For safety reasons, more than one forklift cannot be allowed to place pallets in a truck at the same time. So, one load should receive one pallet at a certain time. After a pallet is loaded to the truck, the forklift returns to its aisle and communicates to WMS that it is available for a new transportation. Then the next pallet for the same load is programmed. A forklift can receive only one pallet at each transportation. Detailed information about the analysed AS/RS warehouse can be obtained from [5].

Different sequences of pallets in a batch retrieved by S/R machines result in different processing times. An illustrative example is the following. Assume that there are 5 aisles in the warehouse represented by A_1, A_2, \dots, A_5 . The problem is planning the retrieving sequence of a batch including 3 loads. Each load consists of 4 pallets, which have precedence relations in advance, representing a total of 12 pallets to be retrieved in the batch. There is one forklift for each aisle to carry the pallets from the aisle to the corresponding truck. Although a pallet can be retrieved from several aisles, in previous studies [5,6] it was assumed that it is the WMS that previously selects the pallets considering the distance to the aisle where the load is prepared. The aisle for each pallet and the processing times are given in Table 1.

The aisle storing pallet j and the transportation time between related aisle and truck are shown as (A_k, t) where A_k refers the k th aisle and t is the transportation time from aisle A_k to truck. For example, the first pallet of the second load must be retrieved

Table 1
An illustrative example for real problem.

| Load i | jth pallet | | | |
|----------|------------|-----------|-----------|-----------|
| | 1 | 2 | 3 | 4 |
| 1 | $(A_1,1)$ | $(A_2,2)$ | $(A_3,3)$ | $(A_4,4)$ |
| 2 | $(A_3,1)$ | $(A_1,3)$ | $(A_3,1)$ | $(A_4,2)$ |
| 3 | $(A_4,2)$ | $(A_4,2)$ | $(A_3,3)$ | $(A_5,1)$ |

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