Automated Warehouse Scheduling Problem

Introduction

Complicated warehouses nowadays take a significant part in the production process of different companies like online marketplaces, electronic manufacturers, auto parts suppliers, etc. The general structure of such warehouses is common: a huge area, devoted to the storage of hundreds to thousands of items and a department, which should be able to extract certain items from this storage and send them to a customer quickly. It is well-known that this process can take more than 50% of the overall operating costs of the warehouse. Thus, it is quite important to ensure efficient use of available resources.

Usually, the internal structure of the warehouse facility consists of several areas, each of which serves its own purpose. The storage area presents a set of racks with shelves, where raw materials are located. In automated warehouses all the loading and unloading procedures in the storage area are performed by Automatic Guided Vehicles (AGVs), no human resources are needed. The order processing area is located near the the storage. Customer's order is the list of desired products and their quantities. Order processing goes in two stages - picking and packing. First, each order is processed through the picking stage. To this end, the pallets with the ordered products are executed from the storage and transferred to the picking zone by AGV's. The necessary amount of product units is extracted from the pallets and relocated to the universal carriage (UC) here. The pallets are returned to the storage while the UC is transferred to the packing zone. The packing machines are used to pack raw materials from the UC into specified shipping boxes. After this stage, the boxes proceed to the delivery area. The warehouse scheduling problem is to arrange picking and packing processes of all customer orders minimizing the makespan.

Picking and packing process is organized on several production lines, each devoted to its own types of products. All lines are equipped with identical parallel machines and an intermediate buffer between picking and packing zones. The picking process is serviced by a limited fleet of transportation robots which serves to deliver raw materials from the storage to picking zone and back. The schedule of different production lines is bounded by the conditions on the duration of the customers' order handling.

1 Problem Formulation

We describe a new makespan minimization problem for a two-stage hybrid flow-shop system with an intermediate buffer.

Order processing area has several production lines, $A, B, C, \ldots$ which work in parallel. Each production line has two production stages, the picking stage and the packing stage, and an intermediate buffer between them. Both stages have parallel identical machines, thus jobs can process through stages in parallel. Fig. 1 presents the example of a production line of the warehouse. We know the set of orders which have to be processed through the warehouse. Each order consists of several boxes. For each box, we know the list of types of items and their amounts. For each box, we also know the production line where it has to be processed. All boxes have to go through the picking stage, followed by the packing stage. The time interval between the start of the first box from the order at the picking stage and the end of packing of the last box from the same order cannot exceed the given threshold Ω. We will refer to this constraint as *order processing constraint.*

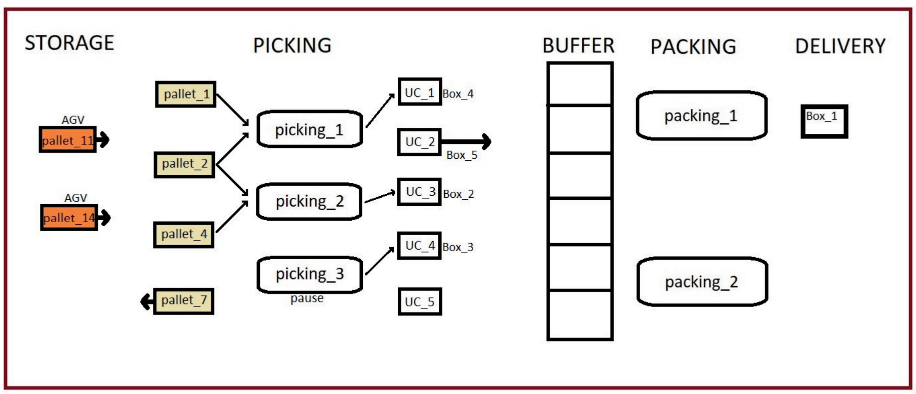

Figure 1: Scheme of a production line

Picking stage of each production line is organized as follows. We have several parking slots, where the pallets with raw material can be located. Each pallet can occupy one slot. The picking from the pallet is possible if and only if it is parked in a slot. There is also a fixed number of slots for universal carriage (UC). These UC serve as temporary storage of already picked boxes. Each UC corresponds to exactly one box. As soon as all the contents of the box are picked into the UC, it should be moved to the packing stage and replaced by a new empty UC. The picking process is carried out by identical picking machines that can work in parallel. They have parallel access to all pallets in parking slots, but each machine can process only one pallet and one box at a time. Each box can be processed by one machine at a time. But one pallet can be processed by several machines at the same time. Thus, we do not need to plan the pallet handling by picking machines. Picking of one box goes step by step: machine picks the necessary amount of one product in the list, then another product, etc. The sequence is not important here. If one or more pallets needed for the current box are not located on the parking slots, the picking process is produced for other pallets and then paused, this picking machine is blocked.

When the picking process is finished for a box, the corresponding UC should be moved to the packing stage. If all packing machines are occupied, then the UC can be moved to the intermediate buffer. If the buffer is also full, the UC is blocked. At the same time, this picking machine can start a new box by picking materials into another UC, located in another position (if there is one).

Intermediate buffer is located between the picking and parking stages and can serve as temporary storage for boxes after the picking stage. Each production line has exactly one buffer with a given capacity. Each UC can arrive at the buffer from any picking machine and can be sent to any packing machine of the same line.

Packing stage can be considered as the classical scheduling model for identical parallel machines for each production line. We have several identical packing machines which work in parallel. Each packing machine can process only one box at a time and each box can be processed by one machine only. Each machine takes a UC, packs all the contents into a shipping box, and sends it to the delivery area. All boxes in the delivery area are stored until the last box of the corresponding order is done. After that, the whole order is sent to the customer.

Automated guided vehicles service all transportation processes between storage and picking zone. Each AGV can bring one pallet only. The transportation time is known and the same for all pallets. The fleet of AGV's is known and common for all production lines. In this study, we ignore the routing problem for AGV's and consider this fleet as a resource. We assume that each AGV is unavailable when it performs a task. When the task is completed, the AGV returns to the fleet and can be used again immediately, no matter where it is located.

Fig. 1 presents an example of a production line. We have 3 picking machines that share 4 parking slots for pallets, 5 slots for UC, and 2 packing machines. The intermediate buffer has 6 parking slots for UC. The current state of the line shows, in particular, that:

- $Pallet_1$ is needed for box_4, which is picking on machine 1. $Pallet_4$ is used by machine 2 for box_2. $Pallet_2$ is used by both machines 1 and 2;
- all 4 pallet slots are occupied. Although $pallet_7$ is no longer needed, it is not transported back to the storage because of a lack of AGV's. It will be replaced by $pallet_{11}$, which is needed to continue the picking of box_3 on machine 3. Thus, machine 3 is paused;
- contents of box_5 were picked into the UC_2 and now is moving to the buffer;
- $Order_1$ consists of box_1 and box_3. Box_1 is ready and awaits for box_3 in the delivery area. When box_3 will be packed, they will be sent to the customer.