Remarshaling in A Bin-to-Person-based Smart Automated Warehouse

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Abstract. In a bin-to-person warehouse, robots lift and then transport racks that contain items from the replenishment area to the storage area and from the storage area to the pickup area. In such an automated warehouse, it is necessary to ensure smooth item flows. One of the important decisions is on which racks the items should be placed on to shorten the item replenishment and picking time. In this study, we propose a new concept of remarshaling items in the storage area to make future picking-up operations more efficient. In the remarshaling activity, items on the rack are moved to other racks to allow grouping items of the same pickup order onto the least number of racks. We list some potential remarshaling strategies (with their characteristics), a framework to select which one to apply, decisions to make at different levels, and what kinds of predictions need to be applied further to optimize the remarshaling activity given the existing big data. Our study provides insights for researchers to develop more detailed solution methods to solve the listed problems.

Keywords: Bin-to-Person, Smart Automated Warehouse, Remarshaling.

1 Introduction

Recently, new autonomous technologies have been implemented in warehouses, including bin-to-person systems, but not many studies discussed them yet [1]. In the bin-to-person system, items placed on the racks are carried by robots and visit the workers' locations, where the items are replenished or picked up. Examples of such a system can be seen in Alibaba [2] and Amazon Kiva [3, 4]. The bin-to-person system is also called the robotic mobile fulfillment system (RMFS) [5].

The process in the Kiva system is explained in Fig. 1 [6]. It starts from (1) receiving the items, (2) replenishing them, (3) storing them, (4) picking them up, and (5) shipping them. The items are stored on movable racks, and the racks could be lifted

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by robots (on the ground) and then moved between the replenishment station, storage area, and picking station. An illustration of the picking process, including how the robots (automated guided vehicles) move the racks, is shown in Fig. 2 [7]. As shown in [7] and [8], several movable racks wait in front of the station workers while waiting for the items to be replenished or picked up.

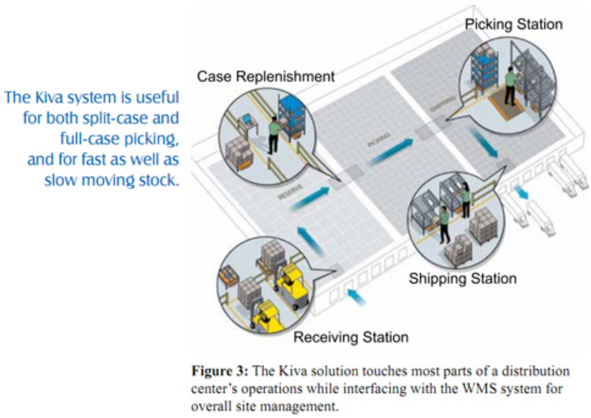

Fig. 1. Process in Kiva system [6].

Fig. 2. Illustration of the picking process [7].

It is important to ensure an efficient process in the automated warehouse to increase the system's throughput. Some decisions to optimize in such an automated warehouse are shown in Fig. 3 [9]. In this study, we propose a new optimization decision to consider in such an automated warehouse, which is remarshaling. Remarshaling operation is a well-known activity in container terminal logistics [10, 11].

When an outbound container arrives at a container terminal, it is stored at a temporary specific location in the storage yard before being moved to a permanent specific storage location closer to the quayside, where the containers will be loaded to its designated vessel. This last operation is called remarshaling. In the automated warehouse, we consider the same situation. Each item arrives at the replenishment area, then is placed in the racks. After being stored at the storage area, before the item is picked up, at any time possible, we conduct the remarshaling by moving the item from its current rack to another rack that contains other items that will be picked by the same customer or at the same schedule. Thus, when the items need to be picked up, the racks containing the items could travel for a shorter time and arrive consecutively to be picked up without causing any long picker idle times. Such a remarshaling operation has not been considered yet in current warehouses, as shown in [9].

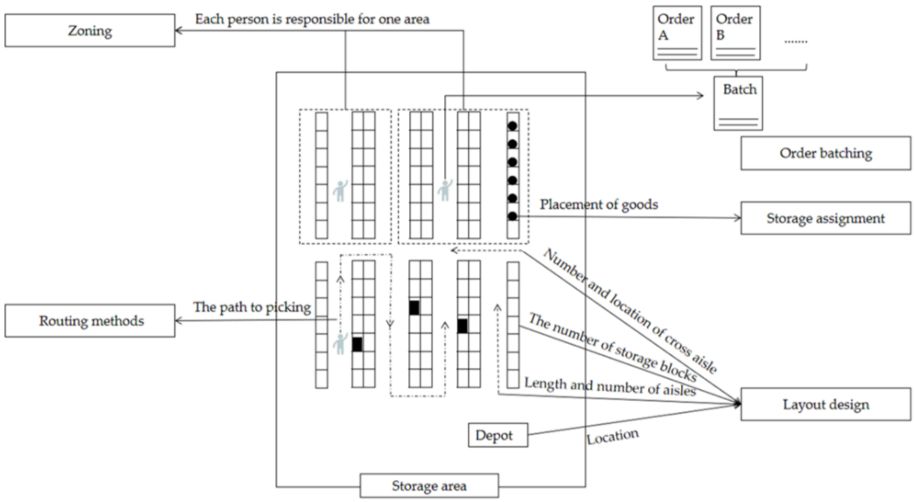

Fig. 3. Optimization decisions in a bin-to-person-based automated warehouse [9].

The outline of this study is as follows. Section 2 presents the types of remarshaling operations we propose with situations when each type could be conducted. Section 3 lists important terminologies. Section 4 states the decisions to be made for the remarshaling operation and some ideas to incorporate the advancement in big data technologies. Section 5 concludes the study.

2 Types of Remarshaling and How to Select Them

We differentiate the types of remarshaling operations based on when and where each of them is conducted (**Error! Reference source not found.**). During the warehouse operation, their selection could be based on the flowchart presented in Fig. 4. Selecting the location to perform the remarshaling could be based on two factors: (1) the distance from the rack's position to the replenishing or picking area and (2) the utilization of the replenishment or picking area. For the first case, if the distance of each target remarshaling-rack is close to the replenishing or picking area, the remarshaling operation could be completed faster. For the second case, the remarshaling operation could be performed when the utilization of the replenishing or picking station is not high.

Table 1. Types of remarshaling in bin-to-person automated warehouse.

Remarshaling type	When	Location
Pure remarshaling at replenishing area	Robot idle	Replenishing area
Pure remarshaling at picking area	Robot idle	Picking area
Remarshaling while replenishing	During item replenishment	Replenishing area
Remarshaling while picking	During item picking	Picking area

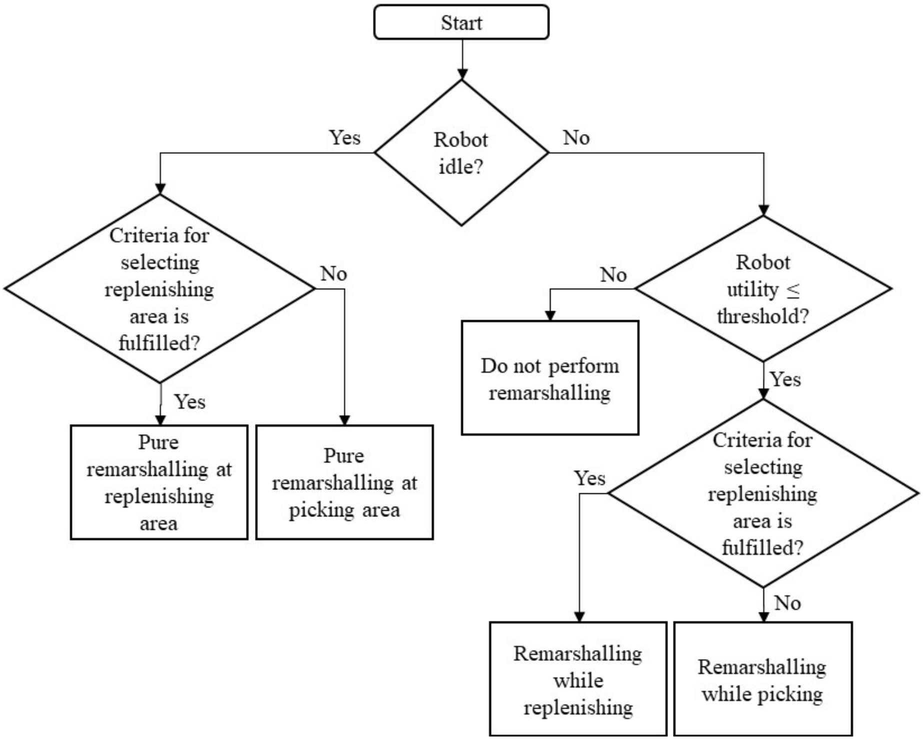

Fig. 4. Flowchart for selecting the remarshaling type.

Robots' allocation and scheduling decisions for each type of remarshalling involve real-time data analysis, optimization algorithms, and communication with other systems. Robots rely on input from warehouse management systems, inventory data, and order information to make informed decisions. Robots can efficiently allocate resources, prioritize tasks, and optimize warehouse operations by leveraging artificial intelligence and advanced algorithms. This results in increased productivity, reduced lead times, and improved customer satisfaction in a bin-to-person warehouse system. In a bin-to-person warehouse system, robots play a crucial role in allocating and scheduling decisions for each type of remarshalling. There are generally four types of remarshalling in the bin-to-person warehouse system:

- pure remarshalling at the replenishing area
- pure remarshalling at the picking area
- remarshalling while replenishing
- remarshalling while picking

In a bin-to-person warehouse system, pure remarshalling at the replenishing area refers to moving products from the bulk storage area to the pick face area to ensure sufficient stock availability for order picking. While in pure remarshalling at the picking area refers to rearranging products within the pick face area to optimize storage space, facilitate efficient picking, and maintain order accuracy. In remarshalling while replenishing refers to rearranging products within the storage area while simultaneously restocking or replenishing inventory. Lastly, remarshalling while picking involves rearranging products within the storage area while simultaneously fulfilling customer orders or picking items for shipment. Robots play a crucial role in allocating and scheduling decisions for all types of remarshalling.

3 Terminologies

Important terminologies to consider in the remarshaling operation are:

1. Consecutive remarshaling

   Consecutive remarshaling occurs when one or more racks are included in consecutive remarshaling operations at the replenishing or picking station. The consecutive remarshaling is illustrated in Fig. 5. In Fig. 5, Rack 2 is first included in the first remarshaling operation with Rack 1, then included in the second remarshaling operation with Rack 3. Deploying Rack 2 to be included in consecutive remarshaling operations reduces the number of used robots and increases the availability of other racks at each operation period (because they are not chosen at the moment). When performing such a consecutive remarshaling, in the remarshaling while replenishing or remarshaling while picking, it is necessary to consider racks that are scheduled for the replenishing or picking activities.

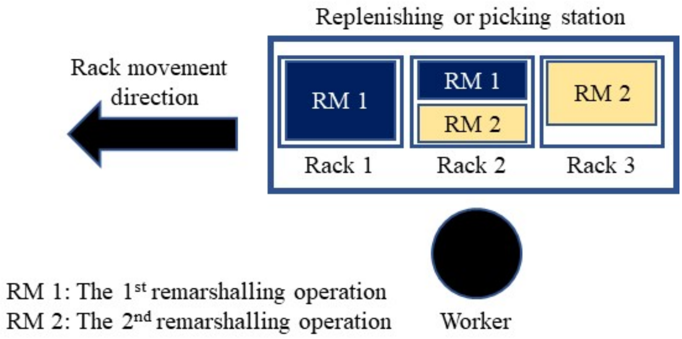

Fig. 5. Consecutive remarshaling.

2. Number of racks per picking customer
   The number of racks used to store items of a single customer will strongly affect the efficiency of the picking activity. It is better to use a smaller number of racks for each customer to minimize the number of deployed robots at the same time and allow the unused robots to be allocated to other replenishing, picking, or remarshaling operations.

3. Same-class-racks-placement
   The number of racks per picking customer needs to be also considered when determining the location of the racks right before the picking process. In general, the racks should need a similar travel time to arrive at the picking station so the picker can complete the picking activity for the specific order as soon as possible and minimize the total waiting time for the picking-up truck. For this first case, we can minimize the standard deviation of the travel times for the racks to arrive at the picking station for the order. In more detail, considering that each rack would require a certain picking time by the worker, the next rack should arrive right before the previous rack for the same order has completed its picking process. For this second case, we can minimize the total time for the worker to wait for the next arriving rack when dealing with the same order. An illustration of how to calculate the worker's waiting time is shown in Fig. 6.
   For both cases, when the determined locations could be based on the ABC analysis that is commonly used in a warehouse, as shown in Fig. 7. Based on the ABC analysis, items with the same level of importance are placed at a similar distance from the input or output door (depot in Fig. 7) [12]. In our case, racks containing items for the same customer must be placed at the warehouse storage area that requires a similar moving time from their positions to the replenishing or picking station to ensure they arrive at a similar time at the replenishment or picking station.

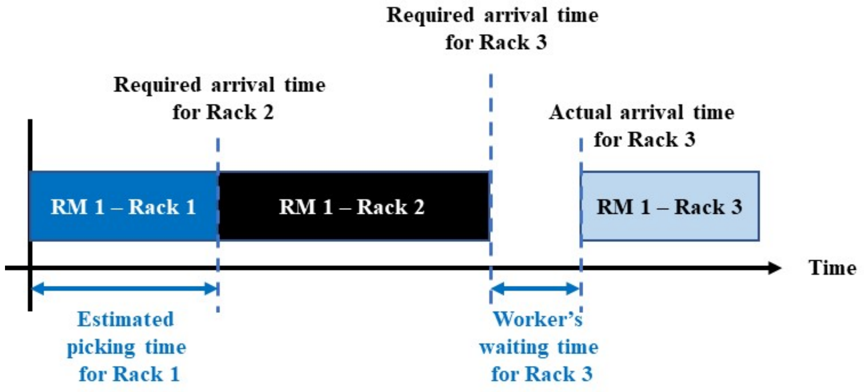

Fig. 6. Illustration on the worker's waiting time for the next rack containing items for the same customer order.

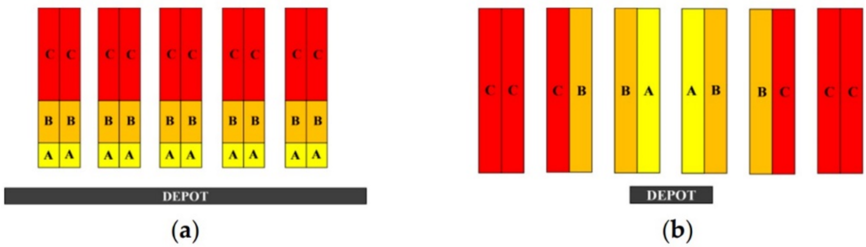

Fig. 7. Rack placement based on ABC analysis in a warehouse [12].

4. Cross-customer-similar-schedule racks
   When performing the remarshaling while replenishing or remarshaling while picking, the arriving racks carry items that belong to different customer orders. Those racks could be included in the same remarshaling operation because they have a similar replenishing or picking schedule.

4 Decisions on Various Levels

Decisions related to the remarshaling operation can be classified into strategic, tactical, and operational levels based on how long the effect of the decisions would be, as shown in Fig. 8.

Levels	Decisions
Strategic	• Number of robots to deploy for remarshalling
Tactical	• Number of racks to be included in a single remarshalling operation • Selection of the pure remarshalling or other remarshalling operations • Number of robots for remarshalling • Layout of racks that belongs to the same picking or remarshalling operation
Operational	• Schedule of racks visit to the remarshalling area (replenishing or packing station), including the consecutive remarshalling • Items to remarshal from one rack to another • Return location for racks after remarshalling

Fig. 8. Decisions related to remarshaling operation on different levels.

Each decision could be taken more effectively when we take advantage of the big data at the automated warehouse, which includes:

- Predicted arrival times of customers at the picking station to determine when the racks must arrive when performing remarshaling while replenishing or remarshaling while picking.
- Predicted waiting times of the pickers based on the related rack and robot data (e.g., robot availability and number of robots used for the remarshaling operation).
- Effect of each remarshaling operation on the throughput of the warehouse.

Reducing the frequency of remarshalling in automated warehouse operations requires careful planning and implementation of effective strategies. Some strategies that could be implemented like optimize product placement. This strategy can be done by organizing the warehouse layout by grouping products with similar demand patterns. It reduces the need for frequent remarshalling by ensuring that frequently picked items are located in easily accessible areas. Another strategy is implementing efficient order-picking algorithms. By utilizing advanced algorithms for order picking, such as wave picking or batch picking, this strategy will optimize the sequencing of orders and minimize the need for remarshalling. It will reduce travel time and increases productivity. The other approach implements real-time inventory tracking systems that provide accurate stock level and location information. This strategy helps to prevent stockouts and enables efficient order fulfilment, minimizing the need for remarshalling. Regularly analysing demand patterns will identify trends and adjust product placement accordingly. Understanding customer preferences and seasonal fluctuations will reduce the need for remarshalling. More investment will be needed if the strategy uses automation technologies dan warehouse staff training and empowerment. Implementing advanced automation technologies, such as conveyor systems, robotic picking, and automated storage and retrieval systems (AS/RS), can improve efficiency and reduce the need for manual remarshalling. For the staff, providing comprehensive training to warehouse staff will optimize their picking and replenishment processes. It is necessary to empower the team to make decisions that minimize remarshalling, such as adjusting product locations based on demand. By implementing these strategies, warehouses can significantly reduce the frequency of remarshalling, optimize operational efficiency, and improve overall productivity in automated warehouse operations.

5 Conclusions

In this study, we propose a remarshaling operation framework in a bin-to-picker automated warehouse. Four types of remarshaling operations were introduced with a flowchart to determine when each type should be performed. Important terminologies and decisions made in the remarshaling operations were also listed.

For future research topics, models that show how each remarshaling type could be performed must be formulated. Hardware and software required for implementing the proposed remarshaling framework in an automated warehouse must also be discussed thoroughly to ensure its applicability.

Another future research topic is developing a bin-to-person warehouse operations system with an optimization model integrated with machine learning algorithms. Some suggestions for development will propose, starting with data collection and analysis. Machine learning algorithms can analyze this data and identify patterns, trends, and areas for improvement. Then it continues with using machine learning algorithms to forecast customer demand accurately. Develop machine learning algorithms can analyze factors to make dynamic routing decisions that improve efficiency and minimize delays. The utilization of machine learning algorithms will predict equipment failures or maintenance needs. Supporting the maintenance, implementation of machine learning algorithms can identify potential errors in order picking, packing, or labeling processes. Finally, using machine learning will incorporate a feedback loop into the optimization model, develop collaboration and integration, along with continuous evaluation of performance in the optimization model and fine-tune its parameters to achieve optimal results.

References

1. Da Costa Barros, Í.R., Nascimento, T.P.: Robotic Mobile Fulfillment Systems: A survey on recent developments and research opportunities. Robotics and Autonomous Systems. 137, 103729 (2021). https://doi.org/10.1016/j.robot.2021.103729
2. Inside Alibaba's smart warehouse staffed by robots. (2017)
3. A Day in the Life of a Kiva Robot. (2011)
4. Kiva robots in Amazon. (2015)

5. Merschformann, M., Lamballais, T., De Koster, M.B.M., Suhl, L.: Decision rules for robotic mobile fulfillment systems. Operations Research Perspectives. 6, 100128 (2019). https://doi.org/10.1016/j.orp.2019.100128
6. How Kiva Systems and Warehouse Management Systems Interact | RoboticsTomorrow, https://roboticstomorrow.com/article/2011/12/how-kiva-systems-and-warehouse-management-systems-interact/23/
7. Cai, J., Li, X., Liang, Y., Ouyang, S.: Collaborative Optimization of Storage Location Assignment and Path Planning in Robotic Mobile Fulfillment Systems. Sustainability. 13, 5644 (2021). https://doi.org/10.3390/su13105644
8. Wang, F., Wang, Y., Chang, D.: Joint Optimization of Order Allocation and Rack Selection in the "Parts-to-Picker" Picking System Considering Multiple Stations Workload Balance. Systems. 11, 179 (2023). https://doi.org/10.3390/systems11040179
9. Li, Y., Zhang, R., Jiang, D.: Order-Picking Efficiency in E-Commerce Warehouses: A Literature Review. JTAER. 17, 1812–1830 (2022). https://doi.org/10.3390/jtaer17040091
10. Kim, K.H., Woo, Y.J., Kim, J.G.: Space reservation and remarshaling operations for outbound containers in marine terminals. Marit Econ Logist. 23, 154–178 (2021). https://doi.org/10.1057/s41278-019-00125-7
11. Nasution, N.K.G., Jin, X., Singgih, I.K.: Classifying games in container terminal logistics field: A systematic review. Entertainment Computing. 40, 100465 (2022). https://doi.org/10.1016/j.entcom.2021.100465
12. Kapou, V., Ponis, S.T., Plakas, G., Aretoulaki, E.: An Innovative Layout Design and Storage Assignment Method for Manual Order Picking with Respect to Ergonomic Criteria. Logistics. 6, 83 (2022). https://doi.org/10.3390/logistics6040083