Solving Order Batching and Assignment Problem with Multiple Pickers and Central Depot

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Abstract

Efficient and effective warehouse management is one of the most important issues in any supply chain. Order picking, which occurs in a warehouse or distribution center (DC), is the most costly and labor-intensive operation. As a result, many researchers have focused on optimizing this process and finding near-optimal solutions. This study presents a heuristic solution approach to address the order batching and assignment problems in a warehouse with multiple pickers and a central depot. In the proposed method, order batching problem is solved using the proximity batching approach. Additionally, a one-way S-shape routing strategy is implemented, as it is easy for order pickers to follow and reduces congestion in the aisles. In the literature, the majority of studies assume S-shape routing strategy in their solution approach. When assigning batches to pickers, workload balance among pickers is also taken into consideration. The proposed solution approach is applied to both a 6 aisle and 8-aisle warehouse layout. The performance of proposed solution approach is compared with First-Come-First-Served (FCFS) batching method and left-most depot location. The results indicate that constructing a central depot can slightly decrease the order picking distance. However, the followed batching strategy has a much greater impact on order picking performance when compared to the depot location. The proximity batching strategy can significantly reduce the order picking distance when compared to the FCFS batching approach. Furthermore, pairwise comparisons demonstrate that a central depot location with a proximity batching strategy has the most positive effect on increasing order picking performance.

Keywords

warehouse management, order batching, S-shape routing, assignment, central depot

1. Introduction

Managing warehouse operations in an efficient way is very significant issue for production companies, DCs, and e-commerce retailers. By doing this, any firm can decrease their operation costs by eliminating unnecessary operations and increase customer satisfaction. The most basic and comprehensive warehouse management process that affects other warehouse operations is the order picking process. Order picking can be defined as retrieving the necessary items requested by customers from their storage locations (Chan and Chan 2011). This extensive process includes other interactive warehouse operations that have a significant impact on each other's performance such as order batching, routing, assignment, and picker scheduling. In other words, following a certain strategy in one of this process can impact the performance of the other operation. Therefore, in recent years researchers have started to handle these interrelated operations in a holistic way (Cheng et al. 2015), (Scholz et al. 2017), (Valle et al. 2017), (Menéndez et al. 2017), (Zhang et al. 2017), (Van Gils et al. 2019), (Briant et. al. 2020), (Cano et al. 2022).

It will be suitable to explain each warehouse processes with single sentences. Order batching involves grouping customer orders into comprehensive batches to be collected in a single picking tour, aiming to reduce the total order picking distance (Yu et al. 2009; Kulak et al. 2012). Routing involves determining the sequence in which order batches or items will be retrieved from the storage shelves. Assignment, on the other hand, determines which batches will be assigned to specific pickers for retrieval from the shelves.

This study handles the order batching and batch assignment problems under the considerations of multiple pickers and central depot by following one-way S-shape routing strategy. A heuristic solution approach is proposed to solve this problem. In most of the studies in the literature, the left-most depot location is applied and generally single order picker is employed. But this assumption is unrealistic when compared real-life companies. In real-life systems, multiple pickers are employed to collect order batches. In actual warehouse systems, multiple pickers are employed to collect order batches, introducing the need to solve the batch assignment problem. Furthermore, this study takes into account workload balance among pickers during the assignment of batches to ensure fairness and efficiency.

1.1 Objectives

The objective of this study is to examine the impact of constructing a central depot instead of a left-most depot on the total order picking distance. Additionally, by comparing proximity batching procedure against FCFS, it is expected to show the benefits of using proper batching strategies instead of simple procedures like FCFS. Furthermore, the study seeks to analyze the relationship between various warehouse sizes (6 and 8 aisles) and order sizes (20, 40, and 60 orders) with the specified parameters.

2. Literature Review

As mentioned earlier, order picking process is one of the most significant topics that has gained huge attention of researchers. For this reason, it has been discussed from many different perspectives in the literature, distinct solution methods have been developed and performance comparisons have been made.

Previous articles about this topic can be grouped into two big categories, solving single order picking process such as batching, routing, scheduling etc. and solving integrated form of two or more problems like batching and routing, batching and assignment or batching, scheduling and routing etc.

For solving batching problem, it is stated that if the constructed batch contains more than two customer orders, this problem will belong to NP-Hard problem class (Gademann and Velde 2005). Because of this, most studies propose heuristic solution approaches like Iterated Descent Algorithm (Gademann and Velde 2005), Classic Tabu Search and Attribute-Based Hill Climber (Henn and Wäscher 2012), Genetic Algorithm (Hsu et al. 2005), Greedy Approach (Le-Duc and De Koster 2007), Iterated Local Search with Tabu Thresholding (Öncan 2015) or constructive heuristic (Hwang* and Kim 2005) to find near optimal solutions in a reasonable time.

In order to solve the routing problem, (Weidinger et al. 2019) proposed an improvement heuristic with the aim of minimizing total travel distance. On the other hand, Dynamic Programming (Roodbergen and De Koster 2001), Lin-Kernighan_Helsgaun heuristic (Theys et al. 2010) or simulation approaches (Shqair et al. 2014) are other solution methods to handle this problem. At this point, it should be stated that some researchers prefer to follow basic routing heuristics defined in the study of (De Koster et al. 2007) like S-shape, largest gap, midpoint or combined methods while solving other order picking problems. For example, (Muter and Öncan 2015) proposed exact solution approach (mathematical model with column generation) to solve batching problem while assuming order picker follows S-shape, midpoint, and largest gap routing heuristics.

Researchers in this field have conducted extensive studies and have observed that the processes involved in the order picking operation are interconnected, and improvements in one process can impact the performance of others. Consequently, researchers have begun addressing more than two order picking processes simultaneously. One commonly studied combination is the batching and routing problem. In order to solve this problem; Cluster-based Tabu Search Algorithm (Kulak et al. 2012), Improved Particle Swarm Optimization (ImPSO) (Lin et al. 2016), hybrid approach based on PSO and Ant Colony Optimization (ACO) (Cheng et al. 2015), heuristic solution approach batching with overlapping channels and ACO with Local Search (BOC-ACOLS) (Li et al. 2017), Integer Programming (IP) (Valle et al. 2017) are some solution approaches proposed by researchers.

Also, three order picking processes have been combined in order to improve order picking performance. For example, in order to solve integrated order batching, sequencing and routing problem (Chen et al. 2015) has proposed hybrid coded genetic algorithm and ACO with the aim of minimize total travel distance. In this study, it is assumed that only one single picker is responsible for order picking process. The studies in which multiple order pickers have been employed are also taken into consideration. One of these studies, a meta-heuristic algorithm based on Iterate Local Search (ILS) has been proposed by researchers (Van Gils et al. 2019). In another study with the same scope, Variable Neighborhood Descent (VND) Algorithms has been proposed as a solution approach with the aim of minimizing total tardiness (Scholz et al. 2017).

In the literature, most of the studies assume that the depot (Input/Output I/O or Pickup/Drop-off P/D point) is located at left-most aisle in the warehouse. To the best of our knowledge, only a limited number of studies have explored alternative depot locations within warehouse layout. One such study utilized a simulation approach to investigate the impact of depot location and different storage strategies on order picking distance (Merkuryev et al. 2009). However, this study did not consider order batching and batch assignment, making it distinct from the scope of our study. In another study, effects of multiple depots have been analyzed using mixed-integer linear programming model (Tran-Vo et al. 2022). Also, the assignment problem of batches to pickers has not been handled.

3. Methods

This study focuses on analyzing the effect of using central depot instead of left-most depot while solving batching and assignment problem with multiple pickers. Also as stated before, order picking processes are interrelated and correct combination of different strategies can significantly improve order picking performance. Therefore, two different batching approaches (proximity batching and First-Come-First-Serve (FCFS)) are also taken into consideration with two different depot locations (left-most depot and central depot). While assigning batches to pickers, workload balance among pickers is satisfied as possible.

The assumptions of this study can be explained as follows:

- One way S-shape routing method is followed by order pickers because of its simplicity and decreasing order picking errors (like selecting wrong product for any customer order). Detailed information about routing will be given.
- In real-life, most of the customer orders can include at most 4 different order lines (means four diverge products) in an e-commerce retailer. Therefore, in this study, customer orders are generated randomly between 1-4 order lines.
- 6-aisles and 8-aisles warehouse layout with 20 different products in each aisle is configured.
- Combination of Fixed-Time-Window-Batching (FTWB) and Variable-Time-Window-Batching (VTWB) approach is used for batching. Also, proximity batching strategy is applied while constructing batches. Additional information will also be given.
- Random storage strategy is applied.
- Batch capacity is determined as 3 different customer orders (C = 3). This means that, each order picker can pick at most 3 different customer orders in one picking tour.
- Order splitting is not allowed. In other words, all of the ordered items in one customer order should be picked by one order picker in one picking tour.

3.1 Information About Batching Strategies

Order batching process is one of the most important parts of order picking operation. In most of the previous studies in the literature, it is stated that order batching reduces the total order picking distance (De Koster et al. 2012). Selecting the proper customer orders to be grouped in the same batch can significantly affect order picking performance. There are two important batching strategies explained in the literature. The first one is Fixed-Time-Window-Batching (FTWB) strategy in which customer orders arrive into the system during predefined (fixed) time interval are batched (Van Nieuwenhuyse and de Koster 2009). In this method, the number of customer orders that are needs to be grouped are variable. On the other hand, in Variable-Time-Window-Batching (VTWB) the predetermined (fixed) number of customer orders need to be batched. In this method, the time is variable.

In this study, the combination of FTWB and VTWB is applied while batching customer orders and completing the order picking operation of these batches. In other words, the fixed number of customer orders should be batched and picked during fixed time interval. In this study, three categories which include 20, 40, and 60 customer orders are batched in analyses.

The time duration in order to batch and complete order picking process of these categories are as follows:
- 20 orders = 1 hour
- 40 orders = 1,5 hours
- 60 orders = 2 hours

Based on these predetermined fixed time intervals, we want to determine the maximum picking distance of all batches which is assigned to each order picker. In order to determine this distance, we need to calculate two parts of order picking process which are *search and pick time* and *batch setup time*. Based on this calculation and predetermined time interval, we define the maximum picking distance of each picker for 20, 40, and 60 customer orders.

For batch setup time, average 3 min is needed to prepare each batch (Henn 2015). Based on this information and batch capacity (C = 3) for 20 orders, at most 6,6666 batches can be assigned to a picker. We should round up this number to 7. For 40 orders, at most 14 batches can be assigned if one order picker is employed. Actually, at the beginning of the experiments, we cannot know beforehand how many order picker employees are needed to pick all orders. Therefore, we need to do all calculations as if there was only one order picker. Finally, for 60 customer orders, utmost 20 batches can be assigned to an order picker.

For search and pick time, average 10 seconds is required for each item (Henn 2015). At the beginning of this study, it is stated that approximately 1-4 diverge items are ordered by customers. Therefore, as in order picking case, we need to take highest number (this means 4 items) of items for each customer order.

Finally, the average travel time of each order picker is 20 LU/min (Henn 2015)

Based on this given information, following calculations are made for 20, 40 and 60 customer orders:

<u>For 20 orders:</u>
- Batch setup time = 7 * 3 min = 21 min
- Search and pick time = 4 min (approximately)
- Travel time remaining from batch setup time and search and pick time for predetermined time interval (60 min) = 35 min
- Maximum order picking distance for each picker to collect assigned batches = 34 * 20 LU = 700 LU

<u>For 40 orders:</u>
- Batch setup time = 14 * 3 min = 42 min
- Search and pick time = 10 min (approximately)
- Travel time remaining from batch setup time and search and pick time for predetermined time interval (90 min) = 38 min
- Maximum order picking distance for each picker to collect assigned batches = 38 * 20 LU = 760 LU

<u>For 60 orders:</u>
- Batch setup time = 20 * 3 min = 60 min
- Search and pick time = 14 min (approximately)
- Travel time remaining from batch setup time and search and pick time for predetermined time interval (120 min) = 46 min
- Maximum order picking distance for each picker to collect assigned batches = 46 * 20 LU = 920 LU

Based on these upper distance limits, each customer orders are grouped and assigned to each order picker. By following this method, also we can ensure that each customer order is satisfied timely manner.

The final aspect to be discussed in this section is the two batching methods utilized in this study. The first one is the proximity batching approach which takes into account the similarity of items in each customer order. The similarity of items between two orders increases, the probability of grouping these two orders in one batch increases. The other method is the FCFS approach, which only considers the arrival time of the orders and assigns the incoming orders to the batches according to the batch capacity. In this method, the similarity of the products in the customer orders is not taken into account.

3.2 Information About Routing Strategy

In the previous studies, diverge simple routing strategies like S-shape, largest gap, midpoint etc. have been applied while solving order picking problems. The most preferred basic routing heuristic for this purpose is S-shape routing method. In this method, there are two options as one-way and two-way S-shape routing. In one-way S-shape routing strategy, order picker(s) is allowed to go along only in one direction. This routing strategy is applied in warehouses especially in which there are narrow aisles. One important advantage of one-way S-shape routing is to prevent aisle congestion when multiple pickers are employed. In two-way S-shape routing, order pickers are allowed to go along two directions in an aisle. In this strategy, more space is needed as the distance between aisles should be wide. If there is not sufficient distance between two aisles, the probability of aisle congestion increases.

In this study, one-way S-shape routing is followed by order pickers because of mentioned benefits of this strategy. For a warehouse with 6-aisles, there is 12 possible one-way routes. Figure-1 shows the direction of each aisle with central depot in a 6-aisles warehouse.

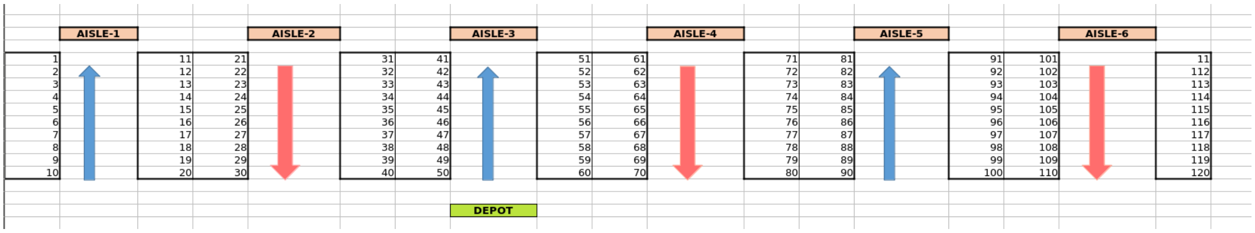

Figure 1. One-way S-shape routing directions in a 6-aisles warehouse with central depot

As shown in Figure-1, an order picker can only go from bottom to top in Aisles 1, 3 and 5. For example, if an order picker will pick only 4, 9, and 12 item IDs, he should pass along aisle 1 and return the depot passing along the Aisle-2. As stated before, there is 12 possible one-way S-shape routes in a 6-aisles warehouse. If the number of aisles is 8, then there will be 33 different routes. Based on the required aisles which include ordered items, order picker selects the route which ***maximum coverage with minimum distance.***

In order to calculate the distances of each route, following formulation can be used (Tran-Vo et. al. 2022):

$$L = L_a n_{va} + W_a(e-s) + W_a(|d-e| + |d-s|)$$

where;

- L_a = length of an aisle
- W_a = width of an aisle
- n_{va} = total number of aisles passed along by the pickers in a selected route
- s = starting aisle number for order picking in selected route
- e = ending aisle number after completing order picking in selected route
- d = aisle number where the depot is constructed

For example; the first route of these 12 different routes contains Aisle-1 and Aisle-2. With central depot (depot is located at Aisle-3), the length of this route can be calculated as follow with given information:

L_a = 21 LU (length of unit)
W_a = 2 LU
d = 3 (Aisle-3)
s = 1 (Aisle-1)

e = 2 (Aisle-2)
n_{va} = 2 aisles (Aisle-1 and Aisle-2)

$$L(1,2) = 21*2 + 2*(2-1) + 2*(|3-2| + |3-1|) = 50\ LU$$

As a result; one-way S-shape routing strategy is followed by order pickers in this study. The length of 12 possible one-way routes is calculated based on the above formulation and order pickers selects the most proper routes which maximum coverage with minimum distance based on the constructed batches.

3.2 Information About Assignment Strategy

The last part of this study is the assignment of constructed batches to order pickers while taking into account the predefined maximum order picking distances. In order to balance the workload among pickers, firstly the selected routes for constructed batches are aligned from the longest to smallest distances. Then, the order pickers are assigned one by one, taking into account the maximum distance limit. With this method, the order picking distances of each batch is distributed as evenly as possible among order pickers.

4. Results and Discussion

This study focuses on solving the batching and assignment problem by implementing a one-way S-shape routing method with multiple pickers and a central depot. In order to solve this problem, proximity batching and route selection (maximum coverage with minimum distance) methods are integrated. While solving this problem, workload balance among order pickers is also taken into consideration. The proposed solution approach is tested and analyzed using warehouse layouts with 6 and 8 aisles. In order to compare the performance of this method, FCFS and left-most depot construction benchmark methods are utilized. In experiments, 20-40 and 60 customer orders are generated randomly. The attained results are explained with tables and figures as follows. In these tables and figures, the following abbreviations are used:

- PRO_C means proximity batching with central depot
- PRO_L means proximity batching with left-most depot
- FCFS_C means First-Come-First-Serve batching with central depot
- FCFS_L means First-Come-First-Serve batching with left-most depot

Table 1. Total order picking distances (in LU) in 6-aisles warehouse

	PRO_C	**PRO_L**	**FCFS_C**	**FCFS_L**
20 orders	7290	7324	8668	8736
40 orders	13392	13808	16684	16876
60 orders	19226	19654	25296	25444

In Table 1, the total order picking distances for all order pickers in 6-aisles warehouses with corresponding methods is shown. For examples; for 40 randomly generated customer orders, the total order picking distance is 13808 LU by using PRO_L approach. In this table, the minimum distances in 20, 40 and 60 customer order categories are in PRO_C method results. On the other hand, the maximum distances for these three order categories are attained in FCFS_L solution method. This means that to solve order batching and assignment problem, proximity batching approach with central depot location produces minimum distances among four approaches. In addition to this, Table 2 shows the percentage (%) in in total order picking distance with pairwise comparisons.

Table 2. Percentage (%) change in distance between solution approaches as pairwise comparisons

	PRO_C vs. PRO_L	***PRO_C vs. FCFS_C***	***PRO_C vs. FCFS_L***	***PRO_L vs. FCFS_C***	***PRO_L vs. FCFS_L***	***FCFS_C vs. FCFS_L***
20 orders	0.466	18.903	19.835	18.351	19.279	0.784
40 orders	3.106	24.582	26.016	20.829	22.219	1.151

60 orders	2.226	31.572	32.342	28.707	29.460	0.585

In Table 2, eighteen pairwise comparisons are shown for three order categories. As it can be seen from this table, the most dramatic change occurs between PRO_C and FCFS_L approaches for all three order categories. In other words, for example in 40 orders situation, choosing the FCFS_L approach instead of PRO_C method will result with 26.016 % increase in total order picking distance.

Figure 2 displays the graphical representation of percentage (%) change in the total order picking distance with pairwise comparisons are also shown. The figure indicates that the most significant change occurs between the PRO_C and FCFS_L approaches. On the other hand, the minimum change is FCFS_C and FCFS_L approaches. From these results, it can be concluded that, if FCFS batching method is selected it does not make much difference whether the depot is located central or left-most. Also, this result is valid for the comparison between PRO_C and PRO_L. But when the batching approach is changed, then the total order picking distance significantly changes. Proximity batching approaches produces much more efficient results for distance reduction when compared FCFS batching method.

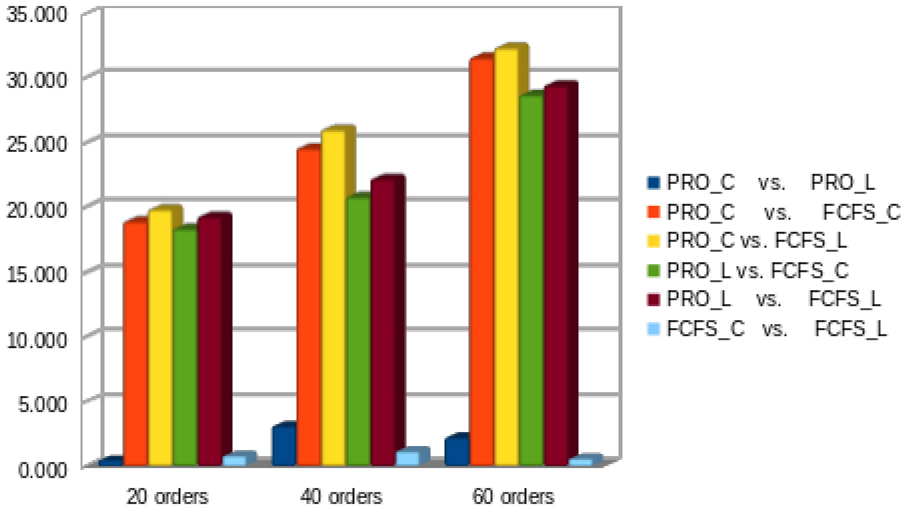

Figure 2. Graphical representation of % change in distance with pairwise comparisons for 6-aisles warehouse

In Table 3, total order picking distances for all order pickers in 8-aisles warehouse are shown. As in 6-aisles warehouse, the longest distance is in FCFS batching method with left-most aisle for all three order categories.

Table 3. Total order picking distances (in LU) in 8-aisles warehouse

	PRO_C	PRO_L	FCFS_C	FCFS_L
20 orders	9192	9438	10842	10980
40 orders	17130	17922	21666	22140
60 orders	25068	25560	31890	32400

Again, pairwise comparisons between combination of batching methods and two diverge depot locations are made for 8-aisles warehouse and shown in Table 4. In this table, the most significant change can be seen between PRO_C and FCFS_L methods. On the other hand, the % change in distance between FCFS_C and FCFS_L methods is so small that it can be negligible. When the batching method is the same, in pairwise comparisons of FCFS_L and FCFS_C with PRO_C and PRO_L, it is seen that the central depot location reduces the total order picking distance a little. On the other hand, when the depot location is the same, the pairwise comparisons of FCFS_C and PRO_C with FCFS_L and PRO_L produces much more difference in order picking distance. This means that choosing the proper order batching method for order picking is much more important parameter than depot location parameter.

Table 4. Percentage (%) change in distance between the solution approaches as pairwise comparisons for 8-aisles warehouse

	PRO_C vs. PRO_L	**PRO_C vs. FCFS_C**	**PRO_C vs. FCFS_L**	**PRO_L vs. FCFS_C**	**PRO_L vs. FCFS_L**	**FCFS_C vs. FCFS_L**
20 orders	2.676	17.950	19.452	14.876	16.338	1.273
40 orders	4.623	26.480	29.247	20.891	23.535	2.188
60 orders	1.963	27.214	29.248	24.765	26.761	1.599

Also, the % change of picking distance for 8-aisles warehouse is shown in Figure 3 as graphical representation as in 6-aisles warehouse**.**

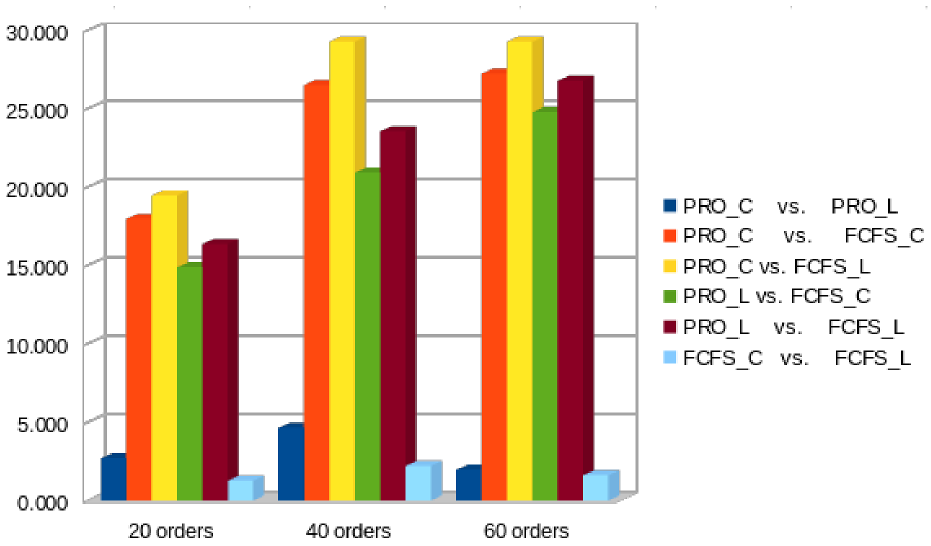

Figure 3. Graphical representation of % change in distance with pairwise comparisons for 8-aisles warehouse

5. Conclusion and Future Research

This study investigates the impact of depot location on order picking performance when employing a selected batching method with multiple pickers in 6-aisle and 8-aisle warehouses. Randomly generated order categories are used, with 10 experiments conducted for each category. The results of these experiments indicate that the selected batching method has a significant effect on decreasing order picking distance when compared different depot locations. In other words, batching methods significantly affect order picking performance. But the performance can also be increased a little by constructing central depot instead of left-most depot.

As future research directions, the study suggests exploring the effects of storage strategies in conjunction with depot location and batching approaches, considering multiple pickers. Furthermore, investigating different routing strategies, such as largest gap or midpoint, in these future studies could be beneficial. Additionally, the development of constructive heuristics to achieve a more balanced workload among order pickers is worth exploring.

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