Research on order batch optimization based on comprehensive lane similarity

Chenxia Jin, Xi Wei, Baozhen Guo

Hebei University of Science and Technology, Shijiazhuang, China

Xi Wei:1756170266@qq.com

Abstract. Reasonable order batching methods can improve the efficiency of picking operations in warehouses, and order batching through aisle similarity is one of the ways. However, in the existing research on dual-zone e-commerce warehouses, the order batching optimization based on aisle similarity does not consider regional information, which increases the number of aisles passed during picking, longer walking paths for pickers, and an increase in picking operation time. In this paper, we propose a comprehensive lane similarity measure for the AB zone considering regional information and design an order-batching heuristic seed algorithm for solving the problem. The experimental results show that the model and method can significantly shorten the order picking operation time and improve the picking efficiency.

Keywords: order similarity; seed algorithm; order batching; e-commerce warehouse

1 Introduction

In recent years, the orders of e-commerce enterprises present the characteristics of high frequency, multi-species, and small batch, and order picking is one of the problems that e-commerce enterprises need to solve urgently. The research in the field of order picking mainly focuses on several aspects such as cargo space allocation, order batching, and picking path optimization. This paper discusses and researches the order batching problem.

Currently, the research on the order batching model mainly focuses on improving picking efficiency and reducing order delay. In the study of order batching with the optimization objective of reducing order delay time, Scholz studied the order batching and sequencing problem to minimize the order delay time[1]. Yanli Wang establishes a mathematical optimization model for order batching and solves it to minimize the weighted picking time and order delay time[2]. Lenble Nicolas et al. built a model to minimize order picking time and solved the model using a meta-heuristic algorithm[3]. Jinlong Zhao et al. constructed and solved an integer programming model for "goods-to-person" order picking optimization considering the delivery deadline to minimize the total order delay time[4].

B. K. Kandel et al. (eds.), *Proceedings of the 2023 8th International Conference on Engineering Management (ICEM 2023)*, Atlantis Highlights in Engineering 23,
https://doi.org/10.2991/978-94-6463-308-5_34

In the research of order batching to improve picking efficiency, most scholars conduct research on order batching based on order similarity. Aaya devised batch-solving methods for orders of different sizes to minimize the total transportation distance[5]. Arbex et al. solved orders in batches based on the similarity of picking paths[6]. Xiao Ke et al. combined the delivery date and item similarity of orders and solved orders in batches by a heuristic seed algorithm[7]. Qin Xin et al. constructed a mathematical model for order batching based on a clustering algorithm to minimize the number of times cargo handling and analyzed the solution results under different sizes of order data[8]. Wei Zou et al. used the joint optimization of order similarity and the firefly algorithm to achieve order batching[9]. Hu et al. construct a comprehensive similarity index based on order picking deadline and picking channel similarity for order batching study[10]. In the existing research on dual-zone e-commerce warehouses, the order batch optimization based on lane similarity does not take regional information into account, while for dual-zone warehouses, regional information is taken into account when calculating the lane similarity between orders, and the lane similarity between the two regions of the order is calculated separately, which is conducive to the division of the same region with a high lane similarity to the same batch, and the reduction of the number of lanes passing through the two regions in total, which reduces the walking distance of the picking process and the picking operation time.

In this paper, taking the dual-zone e-commerce warehouse as the research object, compared with the traditional aisle similarity calculation method, we propose an aisle similarity measurement method considering the regional information, construct an order batching optimization model aiming at minimizing the order picking operation time, and design an order batching seed algorithm, which also takes into account the batch allocation, sorting and picking path selection. Finally, the simulation experiment proves that the new batching method can improve the order-picking efficiency.

2 Problem description and model construction

2.1 Problem description and assumptions

The layout of an e-commerce warehouse is shown in Figure 1, with three main aisles running through the entire warehouse, which is divided into Zone A and Zone B. Ten aisles run through the two zones, and the ten aisles are respectively named Aisle 1 - Aisle 10, and the left and right sides of each aisle are filled with cargo spaces.

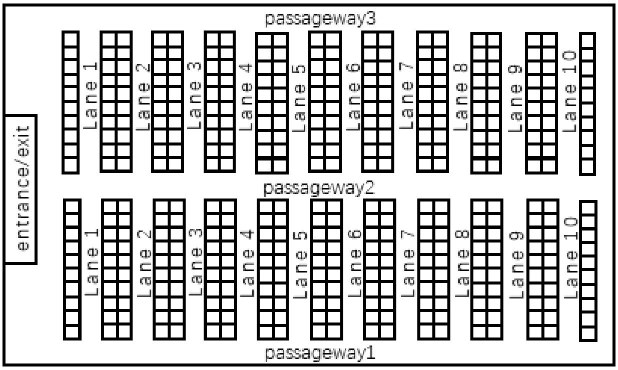

Fig 1. The layout of the order-picking area

For the above layout, the order batch optimization problem can be described as follows: multiple orders arrive randomly during a certain period (order information includes the items contained in the goods, shelf location, etc.), the order batch is a certain number of orders merged into several batches according to a certain set of rules, to carry out the picking by the batch.

The following assumptions are made on the order batching problem model:

(1) An order can only be divided into one batch;

(2) The goods on the order will not be out of stock and there is no emergency insertion of the order;

(3) The order picking volume of each batch is constrained by the capacity of the picking vehicle;

(4) The picking aisle is spacious enough for multiple pickers to pass through at the same time without congestion;

(5) Multiple pickers can pick up SKUs from the same storage space at the same time without waiting;

(6) The picker's walking speed and the speed of finding and extracting items are constant;

(7) The picking path is a closed loop;

2.2 Order batching model construction

The following notation is defined to facilitate the construction of the model:

i: Order Index, i=1,2,3, ……, N

k: Batch Index, k=1,2,3, ……, K

h: Personnel Index, h=1,2,3, ……, H

$\boldsymbol{T_k}$: Total picking time for lot k

$\boldsymbol{Z_k}$: Number of items included in lot k

$\boldsymbol{T_{kw}}$: Travel time for picking batch k

$\boldsymbol{T_{kp}}$: Time required to find and extract all items in batch k

$\boldsymbol{L_k}$: Distance traveled to complete lot k

$\boldsymbol{V_w}$: Travel speed of pickers
$\boldsymbol{V_P}$: Speed of pickers in finding and picking items
$\boldsymbol{X_{ik}}$: Whether order i is divided into batch k
$\boldsymbol{y_{kh}}$: Whether lot k is assigned to picker h
C: Number of orders the picking cart can hold
$\boldsymbol{T_k^{start}}$:Time of start of picking of the kth batch
$\boldsymbol{T_k^{end}}$: Picking completion time for the first k batches
$\boldsymbol{T_{kh}}$: Time for picker h to pick completed lot k

Based on the above symbols and variables, minimizing e-commerce warehouse picking operation time is constructed and represented by a mathematical model as follows:

$$f_1 = \min \sum_{h=1}^{H} \sum_{k=1}^{K} T_k y_{kh} \tag{1}$$

Included among these:

$$T_K = T_{kw} + T_{kp} \tag{2}$$

$$T_{kw} = L_k / V_w \tag{3}$$

$$T_{kp} = Z_k * V_p \tag{4}$$

Constraints:

$$\sum_{K=1}^{K} X_{ik} = 1, i = 1,2,3......, N \tag{5}$$

$$\sum_{K=1}^{H} y_{kh} = 1, k = 1,2,3,......K \tag{6}$$

$$\sum_{i=1}^{N} X_{ik} \le C, k = 1,2,3,......, K \tag{7}$$

$$X_{ik} = \begin{cases} 1, \text{Whether or not order i is picked in lot k} \\ 0\text{，if not} \end{cases} \tag{8}$$

$$T_k^{end} = \sum_{k=1}^{k} X_{ik} T_k^{start} + \sum_{k=1}^{k} X_{ik} T_k \tag{9}$$

$$T_k^{start} = \sum_{k=1}^{k} y_{kh} T_{k'h} \tag{10}$$

$$T_{k'h} = \max_{k' \in K'} \left\{ y_{k'h} T_{k'}^{end} \right\}, K' = \{1, 2, 3, ..., K-1\} \tag{11}$$

$$y_{kh} = \begin{cases} 1, T_{kh} \le T_{k'h'} \\ 0, \text{if not} \end{cases} \tag{12}$$

The objective function (1) represents the minimization of the picking operation time. Constraint (5) indicates that each order can be assigned to only one batch. Constraint (6) equation states that each batch can be assigned to only one picker. Constraint (7) states that the number of picks per batch is limited by the capacity of the picking cart. Constraint (8) denotes the range of values of the decision variable X_{ik}, which takes the value of 1 or 0. Constraint (9) denotes the completion time of the first k batches. Constraint (10) indicates that the start time of each batch is the completion time of the previous batch. Constraints (11) and (12) are assignment limits for batches, indicating that batch k is only assigned to the earliest person who completed the previous batch of picking.

3 Algorithm Design

3.1 Order Lane Similarity

It is known that the formula for calculating the similarity of order lanes is [11]

$$S_{ij}^{0} = \frac{I_i \cap I_j}{I_i \cup I_j} \tag{13}$$

3.2 Lane similarity metric considering regional information

In this paper, for the dual-zone type e-commerce warehouse order batching problem, based on the traditional order lane similarity, a comprehensive lane similarity measure considering regional information is proposed. In a dual-area warehouse, for two orders involving A and B areas at the same time, when calculating the order lane similarity, the percentage of goods contained in the same area in the same lane between the two orders is calculated separately, which is conducive to dividing the orders with high lane similarity in the same area into the same batch compared to the traditional way of calculating the order lane similarity, and reduces the number of alleys that have to pass through the two areas AB, to more effectively reduce the walking distance of the picker, shorten the picking operation time, and improve the picking efficiency.

Therefore, this paper defines the comprehensive lane similarity between two orders based on the traditional order lane similarity, taking into account the regional information and utilizing the weighting coefficient λ ($0 \le \lambda \le 1$). The specific formula is

$$S = \lambda S_A + (1 - \lambda) S_B \tag{14}$$

Where S is the composite lane similarity of the two orders AB area, S_A is the lane similarity of the two inter-order items in the A area, S_B is the lane similarity of the two inter-order items in the B area, λ represents the weight coefficient of the order lane similarity of the A area, and the λ takes a different value, and the results of the inter-order similarity calculation are also different. When $\lambda > 0.5$, focus on the similarity of inter-order A area; when $\lambda = 0.5$, the weight of similarity between inter-order A and B areas is the same; when $\lambda < 0.5$, focus on the similarity of inter-order B area.

3.3 Heuristic seed algorithm design for solving order batching

In this paper, a heuristic seed algorithm is chosen to optimize orders in batches. The basic steps of the algorithm are as follows:

Step 1 Select the orders whose goods are only in zone A, and generate the order set O_A;

Step 2 Determine the seed orders. When the order pool contains more than one order, randomly select an order as the seed order; otherwise, go to Step 5. Meanwhile, remove the order from the order collection;

Step 3 Order Lane similarity calculation. Calculate the lane similarity with the seed order O_i one by one among the orders to be batched according to the formula, use Formula (13) when calculating orders only in Zone A and only in Zone B, and use Formula (14) when calculating orders in both AB zones, and sort the orders from highest to lowest according to the size of the similarity;

Step 4 Order Merging. Select the order with the highest similarity to the seed order O_i to join the batch, order merging And after if the picking car capacity constraint is reached, then the picking batch is generated and returned to Step 2 if the capacity constraint is not satisfied, then the orders in the sequential post-postponement Step 3 sorting will be added to the batch to meet the constraints of the order, and if no order meets the conditions, then the picking batch will be generated and output directly, and deleted from the order collection, and turn to Step 2;

Step 5 Only one order remains in the order collection, and the picking batch is generated directly.

Step 6 Selects the order whose merchandise is only in zone B, generates the order collection O_B, and performs Steps 2 through 5;

Step 7 Selects an order whose merchandise is in both zone A and zone B, generates the order collection O_{AB}, and performs Steps 2 through 5;

Step 8 Calculate the total picking time of all batches output according to the objective function;

Step 9 End

4 Simulation experiments and results analysis

To evaluate the effectiveness of the model and the algorithm, this paper chooses to analyze 345 orders arriving in an e-commerce warehouse during the period of 14:00-

16:00 on a certain day. The length and width of the warehouse picking space is 1m, the width of the aisle is 1.5 m, the width of the channel is 2.5 m, and the capacity of the picking car is 9. There are 8 picking employees, the walking speed of the picking staff is 50 m/min, the speed of picking goods is 5 seconds/pc, and the S-picking path strategy is used for picking. This paper uses MATLAB software to write a heuristic seed algorithm to implement the program, and after running, the batch results of 345 orders are shown in Table 1.

Table 1. Order batching results

Batch	Order Number								
1	12	15	94	106	182	222	257	286	309
2	44	71	143	144	172	225	243	272	326
3	30	88	118	135	153	242	279	298	339
…	…	…	…	…	…	…	…	…	…
39	190	261	325	328	335	338			

1) Comparative analysis of experimental results

In this part, based on the above research to determine the batch mode, the value of λ is taken as 0.5, and the experimental results of the three batch modes are shown in Table 2 to determine the optimization effect of this paper.

Table 2. Comparative Analysis

Evaluation indicators	Comprehensive lane similarity batching approach considering regional information	Lane similarity batching approach without considering regional information	First-come-first-served batch approach
Picking operation time (min)	222	255	318
Picking travel distance (m)	4899	6208	8765

From Table 2, it can be concluded that the optimized order batching method can reduce the total picking time by 33 minutes, with an optimization degree of 12.94%, compared with the lane similarity batching method that does not consider the regional information; it reduces the total picking distance by 3,866 meters, with an optimization degree of 21.09%; and compared with the first-come-first-served batching method, it can reduce the total picking time by 96 minutes, with an optimization degree of 30.19%; and reduces the total picking distance by 3,866 meters, with an optimization level of 44.11%.

2) Experimental results based on different similarity weight coefficients

Analysis λ take values from 0-1 by 0.1 steps to take different values, statistics for each case of order picking operation time, the experimental results are shown in Table 3

Table 3. Experimental results under different weight coefficients

λ	Picking operation time (min)	Percentage reduction relative to a batch approach that does not take into account the similarity of regional information lanes	Percentage reduction relative to the first-come-first-served batch approach
0	242	5.10%	23.90%
0.1	235	7.64%	26.10%
0.2	233	8.63%	26.73%
0.3	232	9.02%	27.04%
0.4	228	10.59%	28.30%
0.5	222	12.94%	30.19%
0.6	229	10.20%	27.99%
0.7	229	10.20%	27.99%

0.8	231	9.41%	27.36%
0.9	235	7.64%	26.10%
1	242	5.10%	23.90%

From the experimental results, it can be seen that as the weighting coefficients change, the order-picking operation time also changes. When λ is taken to 0.5, the picking operation time of the order is the shortest and the reduction percentage is the largest. Therefore, for this batch of orders, λ is optimized most effectively when the value is 0.5.

5 Conclusion

In this paper, for the dual-zone type e-commerce warehouse order batch picking problem, the establishment of the model to minimize the order picking operation time as the goal, the design of the integrated lane similarity seed algorithm considering the regional information, through the selection of appropriate weight coefficients, and the traditional lane similarity batch method and the warehouse of the original method of comparison, found that this paper, batch method can significantly shorten the order picking operation time, improve the efficiency of picking.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China under Grant (72101082); and the National Science Foundation of Hebei Province under Grant (F2021208011).

Bibliography

1. Scholz, André, Schubert D, W? Scher G. Order picking with multiple pickers and due dates – Simultaneous solution of Order Batching, Batch Assignment and Sequencing, and Picker Routing Problems[J]. European Journal of Operational Research, 2016:461-478. DOI: 10. 1016/j. ejor.2017.04.038.
2. Yanli Wang. Research on Optimization of Picking Operations in Distribution Centers [D]. Jilin University,2017. DOI: CNKI: CDMD:2.1017.148567.
3. Nicolas L, Yannick F, Ramzi H. Order batching in an automated warehouse with several vertical lift modules: Optimization and experiments with real data[J]. Post-Print, 2018. DOI.org/10.1016/j.ejor.2017.12.037
4. Jinlong ZHAO, Zhongzhong JIANG, Mingzhong WAN et al. Optimization of Goods-to-Person Order Picking Considering Delivery Deadlines [J/OL]. Chinese Journal of Management Science:1-12[2023-09-12]. https://doi.org/10.16381/j.cnki.issn1003-207x.2022.1049.
5. Aboelfotoh A, Singh M, Suer G. Order Batching Optimization for Warehouses with Cluster-Picking[J]. Procedia Manufacturing, 2019, 39:1464-1473. DOI: 10. 1016/j. promfg. 2020.01. 302.

6. A C A V, B J E B. Order batching using an approximation for the distance traveled by pickers[J]. European Journal of Operational Research, 2020, 284(2):460-484. DOI: 10. 1016/j. ejor.2020.01.022.
7. K Xiao, Y Xie, HW Wang, et al. Order batching heuristic seeding algorithm based on composite similarity [J]. Journal of Systems Engineering, 2020. DOI: 10. 13383/j. cnki. jse. 2020. 06. 007.
8. Xin Qin, Jiandao Zhao, Nan Ren. Research on order batching strategy based on clustering algorithm [J]. Manufacturing automation, 2021, 43(01): 134-137. https://kns.cnki.net/kcms/detail/detail.aspx? Fil-Name = JXGY202101030&DbName = CJFQ2021
9. Wei Zou, Hongluan Zhao, Xiaojun Li et al. Study on optimization of "Goods-to-Person" order batch picking operation [J]. Logistical science and technology,2022,45(11):27-33. DOI: 10.13714/j.cnki.1002-3100.2022.11.005.
10. Xiaolin Hu, Ling Xu. Research on order batching problem under dynamic parallel partition picking system[J]. Logistics Technology, 2019, 38(5):9. DOI: 10.3969/j. issn.1005-152X.2019.05.018.
11. Xuping Wang, Jun Zhang, Jun Ma. A batching model and algorithm for online order batching in e-commerce considering completion deadline [J]. Management Science, 2014, 27(6):11. DOI: 10.3969/j.issn.1672-0334.2014.06.009.