Research on Picking Route Optimization of Multi-zone Warehouse Based on Traveling Salesman Problem and Simulated Annealing Algorithm

Wanqing Peng, Siqi Guo, Haoxuan Li*
College of Mathematics, Sichuan University, Chengdu, Sichuan 610065, PR China
hxli.scu@gmail.com

Abstract. The improvement of the national economy has led to the rapid development of e-commerce business, which has caused an explosive growth of warehouse orders. Picking is the core operation of the warehouse, which occupies a lot of time and capital costs. Therefore, optimizing the picking path has become an urgent problem for e-commerce companies to solve. This article calculates the distance matrix based on the characteristics of multi-zone warehouses, establishes a Traveling Salesman Problem (TSP) model to process 49 combined orders, and solves the model through the simulated annealing algorithm. In addition, add review stations at different locations to analyze the impact on delivery time. Finally, the optimal picking path, the optimal distribution method of orders, and the time it takes to deliver are obtained. The results indicate that the TSP model combined with the simulated annealing algorithm can optimize the picking path, adding a review station close to the center of the warehouse can reduce the time of delivery, and the model is universal applicability.

1. Introduction
Nowadays, the e-commerce industry is booming, and orders from modern e-commerce enterprises are accumulating during peak sales periods. E-commerce orders have the characteristics of small batches, high frequency, and individualization. Simultaneously, customers' requirements for order response time are gradually increasing, resulting in huge logistics service pressures for e-commerce companies and high logistics costs [1]. Logistics services are mainly divided into two parts: warehousing and transportation. Among them, the workload of warehousing picking accounts for 60%, and the cost of picking movement accounts for about 90% of the overall warehousing cost. Scientific and reasonable planning of the picking path can reduce its moving costs, which is an effective method and means to solve the low efficiency and high cost of picking operations [2-4]. We calculates the distance matrix by constructing a simulated warehouse, and then studies the complex picking problem of multi-person, multi-orders, and multi-review stations by building a Traveling Salesman Problem (TSP) model. Finally, the optimal picking path is obtained through the simulated annealing algorithm, and a novel algorithm is proposed for the first time, which builds a time test function following the shortest waste road principle. Besides, comparing the impact of adding review stations in different locations on the delivery time can reduce the internal operating costs of the enterprise and improve the delivery efficiency of the enterprise [5-7]. It should be pointed out that this article takes the widely used multi-zone warehouse as the research object, which can provide a reference for the optimization of the picking path of most companies in the market.
The simulated warehouse is a multi-zone warehouse with 13 review stations and 3000 cargo compartments. The warehouse compartment number is S00101-S20015, and the 13 review stations are numbered FH01-FH13, respectively. For the convenience of marking, arrange all the cargo compartment numbers in ascending order, record their serial numbers as 1-3000, and record the serial numbers of review stations FH01-FH13 as 3001-3013. In addition, for small and medium-sized goods warehouses, the number of goods ordered by a single customer is small, hence we combine multiple individual orders with a small number of goods into a combined order for research.

2. Construction of the Distance Matrix
The warehouse contains 4 rows of shelves, of which there are 25 sets of shelves in each row, two shelves in each group, a total of 50 shelves, and each shelf contains 15 cargo boxes for a total of 3000 cargo boxes. The horizontal distance between two adjacent sets of shelves is 1500mm, the vertical distance between two adjacent rows of shelves is 2000mm, the length and width of the cargo box are both 800mm, and the length and width of the inspection station are both 1000mm. The warehouse structure is shown in Fig.1. The construction of the distance matrix and subsequent modeling are based on the warehouse shown in Fig.1, and the size of the pick-up truck and the height of the shelf and the review station is not considered.

Firstly, the shortest walking distance of goods picked in different cargo boxes is defined by the folding line method. Based on the structure of the multi-zone warehouse, where the distance between the cargo box and the cargo box, the cargo box and the review station cannot be directly calculated by the Euclidean distance, so this chapter introduces the shortest polyline distance to calculate the distance between the two [8,9]. Assuming that the detour obstacle is a polyline, the horizontal and vertical offsets are both taken as d=750mm. The distance between the cargo box and the review station is simplified as the distance from the midpoint of the cargo box to the midpoint of the nearest edge to the review station. The schematic diagram of the walking route is shown in Fig.2. Secondly, the distance matrix is established based on the row and column of the cargo box to calculate the distance between the cargo box. Similarly, the distance between the cargo box and the review station is also calculated from the rows and columns of the two. The distance between the review stations is calculated by Manhattan distance, and finally a distance matrix of 3013*3013 is obtained.

3. Simulate Warehouse Picking Operations through TSP Model
Due to the huge number of orders for picking in modern warehouses, multi-person and multi-review stations are usually applied to improve the efficiency of operations. Therefore, this chapter explores the process of multi-person and multi-orders by opening four review stations FH01, FH03, FH10, and FH12 to provide the optimal picking path. The random number is generated by Monte Carlo method to assign the initial position of the picker stochastic as the initial parameter of the algorithm, and the optimal picking path of the order is calculated by the simulated annealing algorithm. In addition, the optimal
distribution of orders is achieved by following the shortest waste road principle, maximizing the efficiency of delivery and the utilization rate of the review station.

3.1. Set the initial location
Taking 9 pickers processing 49 combined orders as an example, the pickers are regarded as equivalent individuals, so the initial locations are randomly assigned. Initially, only 4 review stations FH01, FH03, FH10, and FH12 will be opened, which are set to serial numbers 1~4, respectively. Generate random numbers by Monte Carlo method and assign them to pickers 1-9 as their initial location.

Fig. 3 Warehouse picking operation flow chart

3.2. Assign tasks

3.2.1. Define the waste road function
In order to shorten the shortest picking path, waste roads need to be reduced. In other words, the sum of the distance from the initial review station to the first cargo box and the distance from the last cargo box to the return review station should be as short as possible, thus the waste function of the n-th order is defined:

\[ h(x)^{(n)} = x_{0i}^{(n)} + x_{i0}^{(n)} \]

where \( x_{0i}^{(n)} \) represents the distance between the first review station and the first cargo box in the n-th order and \( x_{i0}^{(n)} \) represents the distance between the first box and the final check box in the n-th order. Based on the shortest waste road principle, the most suitable orders are selected for 9 pickers from 49 orders to achieve the optimal distribution of orders.

3.2.2. The TSP Model
The value of \( x_{0i}^{(n)} \) and \( x_{i0}^{(n)} \) in the waste road function depends on the initial location, which is determined by Monte Carlo random assignment. To solve this problem, a TSP model can be established to obtain \( x_{0i}^{(n)} \), \( x_{i0}^{(n)} \), and the return review station of the optimal picking path as the initial position of the next order. Finally, the optimal path and total delivery time are obtained [10,12].

Assuming that all review stations are working normally, P pickers receive T orders from the initial review station, pick all the goods and then return to any review station to review and pack. Suppose A is the set of coordinates of all the goods in the T order, where the elements are different from each other. Assuming that the coordinates of any two points in the cargo box and the review station are \( W_i(x_i, y_i) \), \( W_j(x_j, y_j) \). \( x_{ij} \) represents the shortest walking distance between the two points, \( x_{0j} \) represents the shortest walking distance from the initial review station to the cargo box \( W_j \), and \( x_{i0} \) represents the shortest walking distance from the cargo box \( W_i \) to the nearest review, thus:

\[ x_{i0} = \min_{30015/23013} \{ x_{ij} \} \]
Then introduce parameter $a_{ij}$ ($i \in A \cup \{0\}, j \in A \cup \{0\}$):

$$a_{ij} = \begin{cases} 1, & \text{the order of picking is } W_i \text{ to } W_j \\ 0, & \text{the two are in no order} \end{cases}$$

Hence, $x_{ij} = x_{ji}$. Assuming that the shortest walking distance of all the cargo boxes in the list $T$ is $z$, then the TSP model is established as follows:

$$z = \min \sum_{i \in \{0\} \cup A} \left( \sum_{j \in A} a_{ij} \cdot x_{ij} + a_{i0} \cdot x_{i0} \right)$$

$$s.t. \begin{cases} \sum_{j \in \{0\} \cup A} a_{ij} = 1, & i \in \{0\} \cup A \\ \sum_{i \in \{0\} \cup A} a_{ij} = 1, & j \in \{0\} \cup A \\ \sum_{i \in D, j \in \bar{D}} a_{ij} \geq 1, & D \text{ is any subset of } A \\ a_{ij} \in \{0,1\}, & i \in A \cup \{0\}, j \in A \cup \{0\} \end{cases}$$

3.3. Estimate Time
Assume that the packing time at the review station is 30s, and the picker’s walking speed is $v=1.5m/s$. Suppose the total time is $t$, the walking time is $t_1$, the pick-up time is $t_2$ and the review packing time is $t_3$, thus:

$$t = t_1 + t_2 + t_3$$

Suppose $t_{2i}$ represents the time to pick up the goods from the $i$-th cargo box and $n$ is the number of off-shelf goods, and for any cargo box. If the quantity of goods removed from the shelves is less than 3 pieces, 5s is needed to complete the removal of each piece and 4s otherwise, thus:

$$t_{2i} = \begin{cases} 5n_i, & n < 3 \\ 4n_i, & n \geq 3 \end{cases}$$

Therefore, the delivery time of a fixed order can be obtained by solving the following model:

$$\begin{cases} t_1 = \frac{z}{v} \\ t_2 = \sum_{i \in A} t_{2i} \\ t_3 = 30 \end{cases}$$

3.4. Set time function
This section checks the working status of each picker in real-time by setting a time function, with $t=0$ as the starting point, and the checking interval is 50 seconds. At first, the total time required to process the first order is taken as the critical value. If the time at this moment is less than this value, it means that the picker is working at this time, otherwise, it means that it is idle. Therefore, the optimal order can be distributed from the remaining orders according to the shortest waste road principle, and the delivery time can be estimated. In the next inspection, update the critical value for the expected time it takes to process the existing total order, repeat the above process, and inspect 9 pickers in turn. When they are idle, they are automatically assigned new orders until all the orders are distributed, and the inspection process is ended. The time when the last picker returns to the review station is taken as the total delivery time.

4. Obtain the Optimal Path through Simulated Annealing Algorithm
This chapter discusses the problems of multi-person, multi-order, multi-review station, and solves the TSP model through the simulated annealing algorithm. The simulated annealing algorithm is a greedy algorithm, which is a random optimization algorithm based on Monte-Carlo iterative solution. This
algorithm escapes the trap of local optimal solution, and obtains the approximate optimal solution through iteration. Based on the above model, the optimal picking path and the optimal distribution method and delivery time of each order picker are obtained [13-15].

Tab.1 shows the optimal distribution method of 49 combined orders processed by 9 pickers, and the optimal picking path of the pickers can be obtained according to the TSP model. Take the No. 1 order T0019 assigned by No. 1 picker as an example to show the optimal picking path of No. 1 picker as shown in Fig. 4. FH12 is randomly assigned as its initial location, traverses the entire order according to the color path in Fig. 4, and finally returns to the nearest review station FH10.

Since more orders are processed through fewer review stations, and it takes an extra 30s to pack, queuing may occur when only 4 review stations are open. Therefore, the total order processing time includes picking time and queuing time. From Tab. 2, the shortest time for the picker to process all orders is 5197s, and the queuing time is indicated in parentheses.

From Tab. 3, the utilization rate of each review station is 1.7%, 7.5%, 13.3%, 5.8%, respectively. The low utilization rate of FH01 and FH12 is attributed to the fact that their location is far from the center of the warehouse, which leads to a longer waste distance when starting again. The higher utilization rate of FH03 and FH10 is due to their superior location. In this way, the goods can be placed in zones to reduce the distance of waste, thereby balancing the utilization rate of the review station and making full use of limited resources. The review station closer to the warehouse center should be opened first when there are fewer orders, so as to improve the efficiency of warehouse delivery.

| Picker number | Order number |
|--------------|-------------|
| 1            | T0019       |
| 2            | T0046       |
| 3            | T0047       |
| 4            | T0034       |
| 5            | T0048       |
| 6            | T0033       |
| 7            | T0017       |
| 8            | T0045       |
| 9            | T0023       |

![Fig. 4 The optimal picking path for order T0019 processed by No. 1 picker](image)
Tab.2 Picking time and queue time for pickers to process orders

| Picker Number | Time | Total time |
|---------------|------|------------|
| 1             | 710  | 869 863 841 1019 | 5167(+30) |
| 2             | 776  | 995 893 881 919 | 4464      |
| 3             | 1031 | 905 1004 843 782 | 4566      |
| 4             | 930  | 810 911(+3) 728 809 742 | 4934      |
| 5             | 931  | 726 722 818 763 873 | 4835      |
| 6             | 715(+55) | 919 935 812 905 | 4341      |
| 7             | 1030 | 962 907 764 947 | 4610      |
| 8             | 911  | 923 956 906 916 | 4612      |
| 9             | 713(+27) | 853 715 818 777 787 | 4690      |

Tab.3 Utilization rate of four review stations

| Review station | FH01 | FH03 | FH10 | FH12 |
|----------------|------|------|------|------|
| Utilization rate | 1.7% | 7.5% | 13.3% | 5.8% |

5. The Impact on the Delivery Time after Adding a Review Station

The warehouse opens different review stations according to the order quantity to balance efficiency and benefits. Multi-review stations will improve delivery efficiency and at the same time will bring cost increases. The following chapter compares the impact of adding review stations at different locations on the delivery time, and provides a highly efficient delivery plan for warehouse operations.

5.1. Establishment of Model

This section follows the previous method, adding a review station to update the model based on the above model, and number the review stations FH01, FH03, FH10 and FH12 as 1~4, respectively. The random number is simulated by the Monte Carlo method and assigned to 1-9 pickers in turn as their initial review stations. Assume that review stations FH02, FH04, FH05, FH06...FH13 are added in sequence, and their numbers are set to 5. The updated model is solved in turn through the TSP model and the simulated annealing algorithm to obtain the shortest delivery time. For the shortest delivery time, a vertical comparison is made before and after the addition of review stations, and a horizontal comparison is made between the addition of review stations in different locations, so as to evaluate the impact of different numbers and locations of review stations on the total delivery time of combined orders.

5.2. Analysis of Result

Open the remaining 9 review stations in turn, and calculate the shortest delivery time for 9 pickers to process 49 combined orders according to Chapter 4, respectively.

Chapter 4 points out that the shortest time to process all orders is 5197s when only four review stations are open. From Tab.4, the longitudinal comparison shows that after adding FH04, FH02, FH05, FH07, FH08, FH09 or FH13, the time consumption is reduced to a certain extent, but after adding FH06, FH11, the time consumption increases instead. From Fig.5, the horizontal comparison shows that when FH07 is added, the total delivery time is the shortest. Therefore, it is concluded that when the number of review stations is small, increasing the number has positive marginal utility for improving the efficiency of warehouse picking. To a certain extent, adding review station can alleviate the queuing problem of pickers when reviewing and packing, reducing waiting time, but may increase the walking distance of pickers. Practically, to evaluate the impact of adding a review station, both effects must be considered. Only by opening the review station that is most suitable for the size of the warehouse and the placement of goods can the efficiency of warehouse picking operations be maximized.
Tab. 4 The impact of adding different review stations on the delivery time

| Additional review station | Delivery time | Comparison of delivery time |
|---------------------------|---------------|-----------------------------|
| FH04                      | 5154          | —                           |
| FH02                      | 5063          | —                           |
| FH05                      | 5193          | —                           |
| FH06                      | 5341          | +                           |
| FH07                      | 4931          | —                           |
| FH08                      | 5016          | —                           |
| FH09                      | 5007          | —                           |
| FH11                      | 5286          | +                           |
| FH13                      | 5129          | —                           |

Fig. 5 Delivery time to add different review stations

6. Conclusion

Picking operations is an important part of logistics warehouse operations, and a reasonable selection of picking paths can reduce the operating costs of e-commerce companies and improve logistics efficiency. Constructing a multi-zone warehouse with 13 review stations and 3000 cargo boxes to discuss the problem of picking route optimization with multi-person, multi-orders and multi-review stations. In response to this problem, 9 pickers are set to process 49 combined orders, the distance matrix is calculated, the simulated annealing algorithm is designed according to the shortest waste road principle and the TSP model, and a time function is created to check the order processing of the pickers. Finally, this article obtains the optimal allocation method of orders, the processing and waiting time of each order, the optimal picking path of the order, the utilization rate of the review station, and the specific delivery time after adding the review station at different locations. In addition, through the analysis of the results, suggestions are made to improve warehouse delivery efficiency.

The algorithm above is highly feasible and applicable, and the opening of the central location review station can reduce the delivery time, so as to better meet customer needs and create a competitive advantage. Furthermore, the best-selling products can be identified by counting the number of times the pickers have picked them, and they can be placed in regions according to the degree of best-selling, thereby improving business processing efficiency and realizing rational use of space. Based on the universality of the simulated warehouse, the overall research ideas, the proposed algorithm and model have important reference significance for the optimization of the picking path of most companies in the market.
Acknowledgments
We would like to thank the reviewers and the handling editor for their helpful comments and suggestions.

References
[1] Poon T C , Choy K L , Chow H K H , et al. A RFID case-based logistics resource management system for managing order-picking operations in warehouses[J]. Expert systems with applications, 2009, 36(4):8277-8301.
[2] Zhang Y , Zhang Y . Research on the schedule algorithm of the order picking optimization problem in bend aisle warehouse[C] Seventh International Conference on Fuzzy Systems & Knowledge Discovery. IEEE, 2010.
[3] Wang P G , Qi X M , Zong X P , et al. Picking Route Optimization of Automated Warehouse Based on Improved Genetic Algorithms[J]. Applied Mechanics and Materials, 2013, 411-414:2694-2697.
[4] Henn S . Algorithms for On-line Order Batching in an Order-Picking Warehouse[J]. Computers & Operations Research, 2012, 39(11):2549-2563.
[5] Shuhua M , Yanzhu H . Research on the order picking optimization problem of the automated warehouse[C]. Control & Decision Conference. IEEE, 2009.
[6] Tang Q , Xie F . An Approach for Picking Optimization in Automated Warehouse[C]// Fifth International Conference on Natural Computation. IEEE Computer Society, 2009.
[7] Yang B , Li W , Wang J , et al. A Novel Path Planning Algorithm for Warehouse Robots Based on A Two-Dimensional Grid Model[J]. IEEE Access, 2020, PP(99):1-1.
[8] Ho Y C , Su T S , Shi Z B . Order-batching methods for an order-picking warehouse with two cross aisles - ScienceDirect[J]. Computers & Industrial Engineering, 2008, 55(2):321-347.
[9] Burinskiene, Aurelija. Order picking process at warehouses[J]. International Journal of Logistics Systems & Management, 2010, 6(2):162-178.
[10] Theys C , Br?Ysy O , Dullaert W , et al. Using a TSP heuristic for routing order pickers in warehouses[J]. European Journal of Operational Research, 2010, 200(3):755-763.
[11] Kabadi S N . New polynomially solvable classes and a new heuristic for the traveling salesman problem and its generalization[J]. Discrete Applied Mathematics, 2002, 119(1-2):149-167.
[12] Eisenstein D D . Analysis and optimal design of discrete order picking technologies along a line[J]. Naval Research Logistics, 2010, 55(4):350-362.
[13] Khairuddin R , Zainuddin Z M , Jiun G J . A simulated annealing approach for redesigning a warehouse network problem[J]. Journal of Physics Conference, 2017, 890(1):012109.
[14] Matusiak M , de Koster, René , Kroon L , et al. A fast simulated annealing method for batching precedence-constrained customer orders in a warehouse[J]. European Journal of Operational Research, 2014, 236(3):968-977.
[15] Octavia T , Angelica S . Perbandingan Algoritma Simulated Annealing dan Harmony Search dalam Penerapan Picking Order Sequence[J]. Jurnal Teknik Industri, 2018, 19(2):125.