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# Performance Analysis of Picking Path Strategies in Chevron Layout Warehouse

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**Abstract:** Order picking is the part with the highest proportion of operation cost and time in the warehouse. The characteristics of small-batch and multi-frequency current orders reduce the applicability of the traditional layout in the warehouse. Besides this, the improvement of the layout will also affect the picking path, such as the Chevron warehouse layout, and at present, there is a lack of research on order picking with multiple picking locations under non-traditional layouts. In order to minimize the order picking cost and time, and expand the research in this field, this paper selects the Chevron layout to design and describe the warehouse layout, constructs the picking walking distance model of Return-type, S-type and Mixed-type path strategies in the random storage Chevron layout warehouse, and uses the Cuckoo Search (CS) algorithm to solve the picking walking distance generated by the Mixed-type path. Compared with the existing single-command order picking research, the order picking problem of multi picking locations is more suitable for the reality of e-commerce warehouses. Moreover, numerical experiments are carried out on the above three path strategies to study the impact of different walking paths on the picking walking distance, and the performance of different path strategies is evaluated by comparing the order picking walking distance with the different number of locations to be picked. The results show that, among the three path strategies, the Mixed-type path strategy is better than the Return-type path strategy, and the average optimization proportion is higher than 20%. When the number of locations to be picked is less than 36, the Mixed-type path is better than the S-type path. With the increase of the number of locations to be picked, the Mixed-type path is gradually worse than the S-type path. When the number of locations to be picked is less than 5, the Return-type path is better than the S-type path. With the increase of the number of locations to be picked in the order, the S-type path is gradually better than the Return-type path.

**Keywords:** Chevron layout; picking travel path; Return-type path; S-type path; Mixed-type path



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## 1. Introduction

Warehousing is an indispensable link in logistics and the supply chain [1]. With the further development of e-commerce, small-batch, multi-frequency and high timeliness have gradually become the main demand characteristics of customers. Under this background, the traditional layout warehouse is unsustainable. Meanwhile, in the overall operating cost of the warehouse distribution center, picking activities account for 50–75% [2–7], which is the highest part [8]. In terms of time cost, the time spent on walking in the warehouse also accounts for more than 50% in picking activities [4,9,10]. Based on this, for e-commerce warehouses with small-batch, multiple varieties and high operation intensity, it is found that the warehouse layout, storage strategy, picking path and other factors affect their warehouse picking efficiency [8]. At the same time, it is supplemented by the intelligent algorithm to study the optimal planning and decision making of picking travel paths when the internal storage layout is certain, and effectively improve the overall operational efficiency of the distribution center.

The existing research results mainly include two aspects: one is the comparative research on the existing picking path strategy, and the other is the optimization research on the picking path strategy by combining other warehousing system strategies or intelligent optimization algorithms, of which the latter is more prominent. Pansart et al. [7] and Hong et al. [11] respectively proposed the application of mixed integer programming to optimize order batching to realize the optimization of order picking path. Dijkstra et al. [12] and Liu et al. [13] comprehensively considered the impact of location allocation on picking paths. Lu et al. [14] studied the warehouse picking strategy based on the dynamic picking path optimization algorithm. Through simulation, it was found that the algorithm is better than the static and heuristic picking path optimization algorithm under certain conditions. Bódis et al. [15] used Bacterial Memory algorithm and Simulated Annealing algorithm to solve the order picking problem in the unit picking warehouse. The simulation results show that the former has a more obvious optimization effect on the picking walking path problem than the latter. Zhou et al. [16] applied the intelligent algorithm to the picking path optimization of Fishbone layout, and simulated the model through data mining. Masae et al. [17] proposed four heuristic paths based on Euclidean distance and dynamic programming process under Leaf warehouse layout.

Žulj et al. [18] proposed a picking path strategy combined with priority constraints based on practical cases and analyzed the sensitivity of the parameters to propose the best priority constraints. Scholz et al. [19] proposed a variable neighborhood descent algorithm for various neighborhood structures of batch processing and sorting problems. Moons et al. [20] used a single optimization framework to solve the order picking problem and the vehicle routing problem with a time window and release date at the same time. Pferschy et al. [21], from the perspective of commodity similarity in orders, through the example verification under four different order scale scenarios, found that the average walking distance of picking in batches is saved by 34.7% compared to that in no-batches. Weidinger et al. [22] increased the distribution range of goods in the warehouse, thus shortening the walking distance of the picking operation. Liu et al. [23] aimed at the path optimization problem in the traditional two zone warehouse, and found that the Ant Colony algorithm can effectively reduce the walking distance and time. Based on the Fishbone layout, they proposed a multi-population genetic algorithm with an evolutionary reversal operator and proved the superiority of the algorithm results by comparing them with other traditional algorithms [24]. Giannikas et al. [25] proposed an intervention picking strategy considering new orders and operation interruption to improve the response-ability of the picking system. Moons et al. [26] proposed a memory travel algorithm to solve the comprehensive picking vehicle routing problem. Liu et al. [27] studied the order picking path optimization problem based on Flying-V layout, and found that the use of Ant Colony algorithm can greatly reduce the picking time and improve the picking efficiency. Öztürkoğlu [28] proposed a double objective mathematical model which can better shorten the picking walking distance than other models. Chae et al. [29] proposed a double row layout model and compared the existing literature with the proposed model. The results show that the new model has better performance and a shorter picking time. Masae et al. [30] proposed an optimal order picker routing strategy for conventional warehouses with double partitions and arbitrary starting and ending points. Masae et al. [31] and Çelik et al. [32] proposed the best order picking strategy by using dynamic programming and the heuristic algorithm respectively based on the concept of graph theory. Alipour et al. [33] proposed a new heuristic algorithm for multi-picking vehicles to solve the online order batch processing problem. Shavaki et al. [34] comprehensively considered the constraints such as warehouse storage, online order batching, robot scheduling, and route selection, and proposed a rule-based heuristic path algorithm.

It can be seen from the above literature that the existing research on warehouse picking paths mostly focuses on traditional layouts, while the research on picking paths under non-traditional layouts focuses on Fishbone layout and V-shaped layout, and the research on other non-traditional layouts is relatively lacking. The improvement of warehouse layout provides more path choices for picking walking. Based on this, this paper selects Chevron layout in non-traditional layout as the research object to study the optimization of picking walking path. The Chevron layout was first proposed by Öztürkoğlu et al. [35]. Since the left and right parts of Chevron layout are symmetrical about the central picking channel, the diagonal angles of the right and left parts are 135° and 45° respectively. Meanwhile, Öztürkoğlu et al. [35] concluded that the Chevron layout design is the best design for many industrial applications for theory and practice. Therefore, based on the previous research results and literature research conclusions, the main contributions of this paper are:

1. For Chevron layout, models of picking walking distance generated by order picking using Return-type, S-type and Mixed-type path strategies under random storage are constructed.
2. The influence of different walking paths on picking walking distance is studied.
3. The performances of different path strategies are evaluated by comparing the order picking walking distance with the different number of locations to be picked.

The structure of the rest of this paper is as follows: The next section describes the problems studied in this paper, and constructs the walking distance models of the three picking paths. Section 3 explores the comparison and selection of three path strategies in a Chevron layout warehouse through numerical experiments. Section 4 summarizes the full text and prospects the follow-up research.

## 2. Problem Description and Model Construction

### 2.1. Problem Description

Figure 1 presents the Chevron warehouse layout.

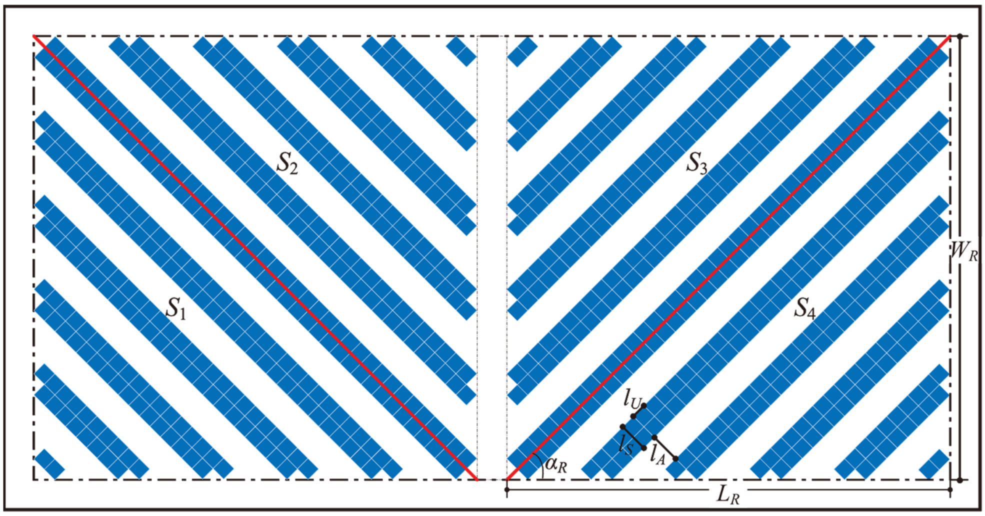


**Figure 1.** Chevron warehouse layout.

The parameter setting in the warehousing picking system is an important factor affecting the picking walking path, and the same is true under the Chevron layout. The Chevron warehouse layout is developed from the traditional layout, which is symmetrical, and the angle of the shelves on the left and right sides of the central main aisle is variable. According to Öztürkoğlu et al. [35], when the shelf angles in the right half-warehouse and the left half-warehouse are 45° and 135° in the Chevron layout (without considering the main picking channel and surrounding picking channels), the picking process has the shortest walking distance. At the same time, based on the previous research results, it is also proven that under the Chevron warehouse layout, the shelf angle has no significant influence on the effective storage area utilization rate. Therefore, when the shelf angles in the right half-warehouse and the left half-warehouse are 45° and 135°, three picking path strategies of S-type, Return-type and Mixed-type are studied. In order to ensure the accuracy of the model, with reference to the research assumptions of Gue et al. [36] and Öztürkoğlu et al. [35] and the actual warehouse operation, the relevant assumptions are as follows: (1) The warehouse has only one I/O (input/output) point and is located below the central main channel. (2) The picker starts from the I/O point and finally returns to the I/O point after finishing the picking operation. (3) The shelf is composed of unit storage locations with equal length and width, and the shelf height is not considered. (4) During the picking operation, there is no shortage of goods in the storage location, and the picking operator or equipment can complete each batch of picking list at one time. (5) This is regardless of the division, reorganization or batch of orders. (6) The picker walks along the centerline of the picking channel, and the picking task of the shelves on both sides can be completed from the centerline of the channel. (7) The length and width of the right half of the warehouse are equal, the width of the shelf and the picking channel are equal, and the width of the unit storage location is half of the shelf width.

At the same time, as shown in Table A1 in Appendix A, the relevant symbols are explained as follows: $L_R$ and $W_R$ are the length and width of the right half of the warehouse (excluding the width of the surrounding aisles and the main aisle in the middle), and $L_R = W_R$. $l_S$, $l_A$, $l_U$ represent the width of shelves, aisles, and unit storage locations respectively, and $l_U = 0.5l_S = 0.5l_A$. $\alpha_R$ is the angle of the right half of the shelf and the picking channel, and $\alpha_R = 45°$. $S_i(i = 1, 2, 3, 4)$ indicates the four picking areas divided into the warehouse by the warehouse diagonal and the central main aisle.

According to Chevron layout settings and model condition assumptions, the objective function of picking walking distance with multi locations to be picked is as Equation (1). In the research of Öztürkoğlu et al. [35], it takes Chevron layout as a new design scheme of single-command order picking operation, but does not study the picking walking path with multiple picking locations. Compared with it, Equation (1) is an extension of Öztürkoğlu et al. [35].

$$D = \min(d_{01}x_{01} + \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij} + d_{n0}x_{n0}), \tag{1}$$

s.t.

$$\sum_{i=1}^{n} x_{ij} = 1, j = 1, 2, 3, \ldots, n, \tag{1a}$$

$$\sum_{j=1}^{n} x_{ij} = 1, i = 1, 2, 3, \ldots, n, \tag{1b}$$

$$\sum_{i,j \in K} x_{ij} \leq |K| - 1, K \subset V, \tag{1c}$$

$$x_{ij} = 0,\ 1. \tag{1d}$$

Among them, $D$ is the total distance traveled to complete a picking task. Equation (1a,b) indicate that all the locations to be picked are picked and only picked once during the picking process. $x_{01}$, $x_{n0}$ represents the path starting from the I/O point to the picking location 1 and returning from the picking location $n$ to the I/O point, and $x_{01} = 1$, $x_{n0} = 1$. Equation (1c) avoids incomplete picking, where $K$ represents the number of items to be picked. $d_{ij}(1 \leq i, j \leq n, i \neq j)$ is the shortest distance between cargo location $i$ and cargo location $j$, $x_{ij}(1 \leq i, j \leq n, i \neq j)$ is whether to choose the walking path from cargo location $i$ to cargo location $j$, and:

$$x_{ij} = \begin{cases} 1, \text{ the path from } i \text{ to } j \text{ is passed} \\ 0, \text{ the path from } i \text{ to } j \text{ is not passed} \end{cases}, i, j = 1, 2, 3, \cdots, n.$$

The optimization problem of the picking walking path in the warehouse picking system under the Chevron layout is an NP-hard problem, and its goal is to minimize the total walking distance of the picking operation. In order to facilitate the model description, the storage locations in the warehouse picking system under Chevron layout are coordinately processed, and we set the coordinate of any position to be picked as $(s, x, y, z)$. Among them, $s$ is the serial number of the area, $s = 1, 2, 3, 4$. $x$ is the picking channel where the goods to be picked located, and $x = 1, 2, \cdots, u$. $y$ is the side of the goods to be picked in the picking channel. If the goods to be picked are on the upper side of the picking channel, $y = 0$, otherwise, $y = 1$. $z$ is the location of the goods to be picked on the $y$ side of the channel $x$, and increases from near I/O point to far I/O point in sequence, and $z = 1, 2, 3, \cdots, v$. For example, the coordinate of the location to be picked $(1, 2, 0, 3)$ indicates that the location to be picked is on the third location from the lower left to the upper right in the lower side of the second channel in $S_1$ area. Here, set the coordinate of I/O point is $(0, 0, 0, 0)$ and the code number is 0.

First, solve $d_{01}$, the distance between the I/O point and the first location to be picked, and $d_{n0}$, the distance between the last location to be picked and the I/O point. Set the coordinate of the location to be picked as $(s_i, x_i, y_i, z_i)$, and then $d_{0i}$ can be divided into four parts:

1. ${d_{0i}}^{(1)}$, travel distance from I/O point to the main channel or surrounding channels;
2. ${d_{0i}}^{(2)}$, walking distance in the main channel or surrounding channels;
3. ${d_{0i}}^{(3)}$, travel distance from the main channel or surrounding channels to the channel to be picked;
4. ${d_{0i}}^{(4)}$, travel distance in the channel to be picked.

Then:

$$d_{0i} = {d_{0i}}^{(1)} + {d_{0i}}^{(2)} + {d_{0i}}^{(3)} + {d_{0i}}^{(4)}, \tag{2}$$

where:

$${d_{0i}}^{(1)} = \begin{cases} \frac{1}{\sqrt{2}} l_A, & s_i = 1 \text{ or } 4 \\ l_A, & s_i = 2 \text{ or } 3 \end{cases}, \tag{3}$$

$${d_{0i}}^{(2)} = \begin{cases} \frac{(x_i - 0.5)\cdot(l_A + l_S)}{\sin \alpha_R} - \frac{0.5 l_A}{\tan \alpha_R}, & s_i = 1 \text{ or } 4 \\ \frac{(x_i - 0.5)\cdot(l_A + l_S)}{\cos \alpha_R} - 0.5 l_A \cdot \tan \alpha_R, & s_i = 2 \text{ or } 3 \end{cases}, \tag{4}$$

$${d_{0i}}^{(3)} = \begin{cases} \frac{0.5 l_A}{\sin \alpha_R}, & s_i = 1 \text{ or } 4 \\ \frac{0.5 l_A}{\cos \alpha_R}, & s_i = 2 \text{ or } 3 \end{cases}, \tag{5}$$

$${d_{0i}}^{(4)} = \begin{cases} (z_i - 0.5)\cdot l_U + \frac{y_i \cdot 0.5(l_A + l_S)}{\tan \alpha_R} + \frac{(y_i - 1)\cdot 0.5 l_A}{\tan \alpha_R}, & s_i = 1 \text{ or } 4 \\ (z_i - 0.5)\cdot l_U + \frac{(1 - y_i)\cdot 0.5(l_A + l_S)}{\tan(90 - \alpha_R)} - \frac{y_i \cdot 0.5 l_A}{\tan(90 - \alpha_R)}, & s_i = 2 \text{ or } 3 \end{cases}. \tag{6}$$

At the same time, the length of the picking channel $x_i$ can be obtained as:

$$\phi_i = \begin{cases} \left[L_R - \frac{(x_i - 0.5)\cdot(l_A + l_S)}{\sin \alpha_R}\right] / \cos \alpha_R, & s_i = 1 \text{ or } 4 \\ [W_R - (x_i - 0.5)\cdot(l_A + l_S)/\cos \alpha_R] / \sin \alpha_R, & s_i = 2 \text{ or } 3 \end{cases}. \tag{7}$$

The remaining distance in picking channel $x_i$ except ${d_{0i}}^{(4)}$ is:

$$\varphi_i = \phi_i - {d_{0i}}^{(4)}. \tag{8}$$

### 2.2. Return-Type Picking Path Model

Return-type picking path strategy is one of the most commonly used picking path methods in warehouse picking. During the picking operation, the picking personnel enter from one end of the picking channel, first pick the items required by the order on one side along the direction of the picking channel, return the same way after completing the picking operation of the items to be picked farthest from the channel, and then pick the items to be picked on the other side until they return to the main aisle and enter the next picking channel. Figure 2 shows the Return-type picking path under the Chevron layout.

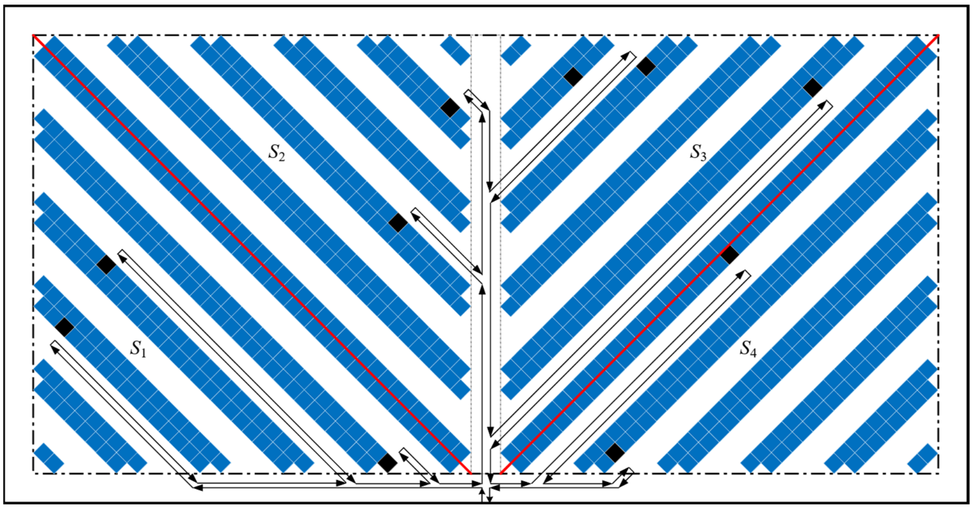


**Figure 2.** Return-type picking path in Chevron layout warehouse.

As shown in Figure 2, when using the Return-type path strategy to select goods, Equation (1) turns into:

$$D = d_{01} + \sum_{i=1}^{n-1} d_{ij} + d_{n0}, j = i + 1, \quad (9)$$

where $d_{ij}$ needs to be discussed according to the situation, as follows:

1. When two locations $i$ and $j$ to be picked are located in the same picking channel, $s_i = s_j$, $x_i = x_j$, there are:

$$d_{ij} = |z_i - z_j| l_U. \quad (10)$$

2. When two locations $i$ and $j$ to be picked are located in the same area and different picking channels, $s_i = s_j$, $x_i \neq x_j$, there are:

$$d_{ij} = \left| {d_{0i}}^{(2)} - {d_{0j}}^{(2)} \right| + {d_{0i}}^{(3)} + {d_{0j}}^{(3)} + {d_{0i}}^{(4)} + {d_{0j}}^{(4)}. \quad (11)$$

3. When two locations $i$ and $j$ to be picked are located in different picking areas, $s_i \neq s_j$, there are:

(1) The two locations $i$ and $j$ to be picked are located in $S_2$ and $S_3$ respectively, and $d_{ij}$ is the same as Equation (11).

(2) The two locations $i$ and $j$ to be picked are located in different areas and in addition to the above condition, there are:

$$d_{ij} = {d_{0i}}^{(2)} + {d_{0j}}^{(2)} + {d_{0i}}^{(3)} + {d_{0j}}^{(3)} + {d_{0i}}^{(4)} + {d_{0j}}^{(4)} + l_A. \quad (12)$$

### *2.3. S-Type Picking Path Model*

The S-type picking path strategy is also one of the main path strategies used for warehouse picking. In the picking process, the picking personnel enter from one end of the picking channel, complete the picking of goods on the shelves on both sides of the channel, leave from the other end of the picking channel, and repeat the above process until all picking tasks are completed. Among them, if the picking channel of the final location to be picked is the even number of picking channels, the S-type path strategy is adopted to return to the I/O point after completing the picking task. If the picking channel of the final location to be picked is the odd number of picking channels, the Return-type path strategy is adopted to return to the I/O point after completing the picking task. Figure 3 shows the S-type picking walking path under the Chevron layout.

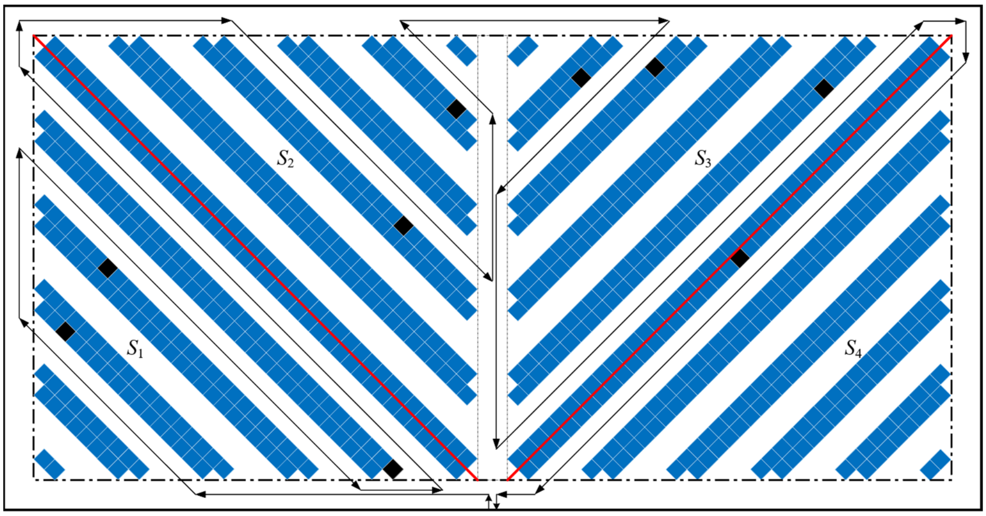


**Figure 3.** S-type picking path in Chevron layout warehouse.

As shown in Figure 3, when picking with S-type path strategy, Equation (1) turns into:

$$D = d_{01} + \sum_{i=1}^{n-1} d_{ij} + d_{n0}, j = i + 1. \quad (13)$$

At the same time, about $d_{ij}$, there are:

1. When two locations $i$ and $j$ to be picked are located in the same picking channel, $s_i = s_j$, $x_i = x_j$, $d_{ij}$ is the same as Equation (10).
2. When two locations $i$ and $j$ to be picked are located in the same area and different picking channels, $s_i = s_j$, $x_i \neq x_j$, there are:
   (1) When $i$ is an even number, $d_{ij}$ is the same as Equation (11).
   (2) When $i$ is an odd number and $s_i = 1$ or 4, there are:

$$d_{ij} = \frac{|x_i - x_j|(l_A + l_S)}{\cos \alpha_R} + \varphi_i + \varphi_j + \frac{l_A}{\cos \alpha_R}. \quad (14)$$

   (3) When $i$ is an odd number and $s_i = 2$ or 3, there are:

$$d_{ij} = \frac{|x_i - x_j|(l_A + l_S)}{\sin \alpha_R} + \varphi_i + \varphi_j + \frac{l_A}{\sin \alpha_R}. \quad (15)$$

3. When two locations $i$ and $j$ to be picked are located in different picking areas, there are:

(1) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_4$ respectively, and $i$ is an even number, $d_{ij}$ is the same as Equation (12). When $i$ is an odd number, there are:

$$d_{ij} = \varphi_i + \frac{l_A}{\cos \alpha_R} + 2L_R + 3l_A + \varphi_j + 2W_R - (\phi_i + \phi_j + \frac{l_A}{\cos \alpha_R}) \sin \alpha_R. \quad (16)$$

(2) When the two locations $i$ and $j$ to be picked are located in $S_2$ and $S_3$ respectively, and $i$ is an even number, $d_{ij}$ is the same as Equation (11). When $i$ is an odd number, there are:

$$d_{ij} = \left( \varphi_i + \varphi_j + \frac{l_A}{\sin \alpha_R} \right) \cdot \cos \alpha_R + l_A + \varphi_i + \varphi_j + \frac{l_A}{\sin \alpha_R}. \quad (17)$$

(3) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_3$ areas or $S_3$ and $S_4$ areas respectively, and $i$ is an even number, $d_{ij}$ is the same as Equation (12). When $i$ is an odd number, there are:

$$\begin{array}{c} d_{ij} = W_R - \left(\phi_i + \frac{0.5l_A}{\cos\alpha_R}\right)\sin\alpha_R + \frac{0.5l_A}{\cos\alpha_R} + \varphi_i + l_A + \\ L_R - \left(\varphi_j + \frac{0.5l_A}{\sin\alpha_R}\right)\cdot\cos\alpha_R + \frac{0.5l_A}{\sin\alpha_R} + \varphi_j \end{array}. \tag{18}$$

(4) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_3$ areas or $S_2$ and $S_4$ areas respectively, and $i$ is an even number, $d_{ij}$ is the same as Equation (12). When $i$ is an odd number, there are:

$$\begin{array}{c} d_{ij} = W_R - (\phi_i + \frac{0.5l_A}{\cos\alpha_R})\sin\alpha_R + \frac{0.5l_A}{\cos\alpha_R} + \varphi_i + 2l_A + \\ L_R + (\phi_j + \frac{0.5l_A}{\sin\alpha_R})\cos\alpha_R + \frac{0.5l_A}{\sin\alpha_R} + \varphi_j \end{array}. \tag{19}$$

### *2.4. Mixed-Type Picking Path Model*

Mixed-type picking path is mainly the combination of Return-type path and S-type path to optimize the overall picking walking distance. Figure 4 shows the Mixed-type picking walking path under the Chevron layout.

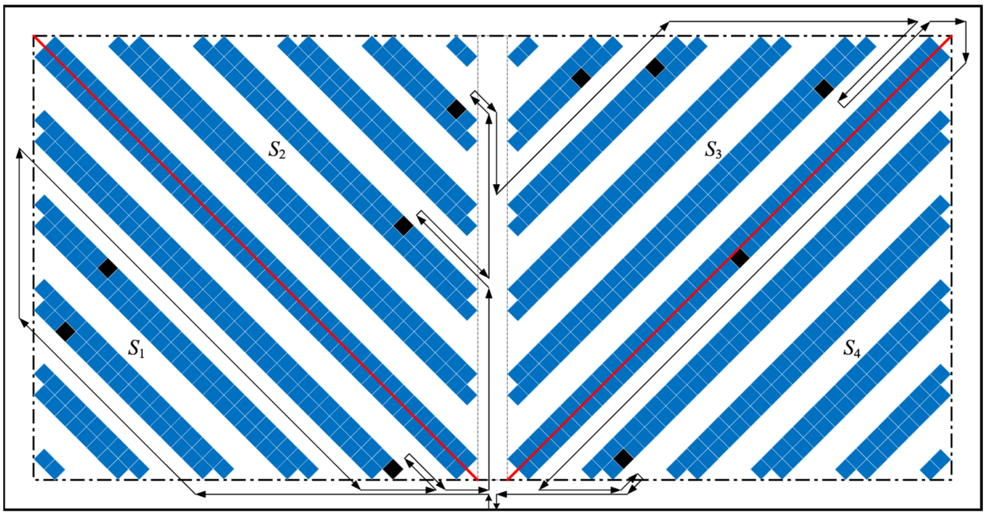


**Figure 4.** Mixed-type picking path in Chevron layout warehouse.

As shown in Figure 4, when Mixed-type path strategy is used for picking, Equation (1) turns into:

$$D = \min(d_{01} + \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij} + d_{n0}). \tag{20}$$

At the same time, about $d_{ij}$, there are:

1. When two locations $i$ and $j$ to be picked are located in the same picking channel, $s_i = s_j$, $x_i = x_j$, $d_{ij}$ is the same as Equation (10);
2. When two locations $i$ and $j$ to be picked are located in the same area and different picking channels, $s_i = s_j$, $x_i \neq x_j$, there are:
   (1) When $s_i$ =1 or 4, $d_{ij} = \min$ (Equation (11), Equation (14));
   (2) When $s_i$ =2 or 3, $d_{ij} = \min$ (Equation (11), Equation (15)).
3. When two locations $i$ and $j$ to be picked are located in different picking areas, there are:

(1) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_4$ respectively, there are:

- When $i$ is odd, and S-type path is adopted, $d_{ij}$ is the same as Equation (16);

- When $i$ is even, and S-type path is adopted, $d_{ij}$ is the same as Equation (12);
- Through the main channel and the rear picking channel, enter the picking channel $x_j$ where the location $j$ to be picked is located from the right picking channel to complete the picking operation, then:

$$d_{ij} = d_{0i} - {d_{0i}}^{(1)} + 3l_A + 2W_R + L_R - (\phi_j + \frac{0.5l_A}{\cos \alpha_R}) \sin \alpha_R + \frac{0.5l_A}{\cos \alpha_R} + \varphi_j; \quad (21)$$

- Through the bottom picking channel and the right picking channel, the right picking channel enters the picking channel $x_j$ where the location $j$ to be picked is located to complete the picking operation, then:

$$d_{ij} = {d_{0i}}^{(2)} + {d_{0i}}^{(3)} + {d_{0i}}^{(4)} + 2l_A + W_R + (\phi_j + \frac{0.5l_A}{\cos \alpha_R}) \sin \alpha_R + \frac{0.5l_A}{\cos \alpha_R} + \varphi_j. \quad (22)$$

Therefore, $d_{ij} = \min(\text{Equation}(12), \text{ Equation}(16), \text{ Equation}(21), \text{ Equation}(22))$.

(2) When the two locations $i$ and $j$ to be picked are located in $S_2$ and $S_3$ respectively, there are:

- When $i$ is odd, and S-type path is adopted, $d_{ij}$ is the same as Equation (17);
- When $i$ is even, and S-type path is adopted, $d_{ij}$ is the same as Equation (11);
- Through the main channel and the rear picking channel, enter the picking channel $x_j$ where the location $j$ to be picked is located from the right picking channel to complete the picking operation, then:

$$d_{ij} = {d_{0i}}^{(3)} + {d_{0i}}^{(4)} + WR - {d_{0i}}^{(2)} + l_A + \left(\varphi_j + \frac{0.5l_A}{\sin \alpha_R}\right) \cdot \cos \alpha_R + \frac{0.5l_A}{\sin \alpha_R} + \varphi_j; \quad (23)$$

- Through the bottom picking channel, the right picking channel, and the rear picking channel, enter the picking channel $x_j$ where the location $j$ to be picked is located to complete the picking operation, then:

$$d_{ij} = d_{0i} - {d_{0i}}^{(1)} + 3l_A + 2W_R + L_R - \left(\varphi_j + \frac{0.5l_A}{\sin \alpha_R}\right) \cdot \cos \alpha_R + \frac{0.5l_A}{\sin \alpha_R} + \varphi_j. \quad (24)$$

Therefore, $d_{ij} = \min \left(\text{Equation (11)}, \text{ Equation (17)}, \text{ Equation (23)}, \text{ Equation (24)}\right)$.

(3) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_2$ areas or $S_3$ and $S_4$ areas respectively, there are:

- When $i$ is even, and S-type path is adopted, $d_{ij}$ is the same as Equation (12);
- When $i$ is odd, and S-type path is adopted, $d_{ij}$ is the same as Equation (18).

Therefore, $d_{ij} = \min \left(\text{Equation (12)}, \text{ Equation (18)}\right)$.

(4) When the two locations $i$ and $j$ to be picked are located in $S_1$ and $S_3$ areas or $S_2$ and $S_4$ areas respectively, there are:

- When $i$ is odd, and S-type path is adopted, $d_{ij}$ is the same as Equation (19);
- When $i$ is even, and S-type path is adopted, $d_{ij}$ is the same as Equation (12);
- Through the left picking channel, the rear picking channel and the main picking channel, enter the picking channel $x_j$ where the location of the goods $j$ to be picked is located to complete the picking operation, then:

$$\begin{aligned} d_{ij} = W_R - (\phi_i + \tfrac{0.5l_A}{\cos \alpha_R}) \sin \alpha_R + \tfrac{0.5l_A}{\cos \alpha_R} + \varphi_i + 2l_A + \\ L_R + W_R - {d_{0j}}^{(2)} + {d_{0j}}^{(3)} + {d_{0j}}^{(4)} \end{aligned} \quad (25)$$

Therefore, $d_{ij} = \min \left(\text{Equation (12)}, \text{ Equation (19)}, \text{ Equation (25)}\right)$.

Due to the random storage in the warehouse, there are different schemes for the path selection between any two locations to be picked. The above is the solution process of the walking distance between any two locations to be picked in the Chevron warehouse layout with the random storage strategy.

## 3. Results and Analysis

After the model construction of picking travel distance of Return-type, S-type, and Mixed-type path in the storage system under Chevron layout, it can be found that the picking travel distance of Return-type and S-type path is easy to be obtained, and the picking travel distance of Mixed-type path needs to be solved by relevant algorithms. According to the research conclusions of Zhou et al. [16], the CS algorithm has a good effect on solving the picking walking distance under the Fishbone layout. At the same time, Chevron layout and Fishbone layout are improved warehouse layouts developed from the traditional layout. Therefore, the CS algorithm is used to solve the Mixed-type path picking walking distance under Chevron layout. The relevant principles of the CS algorithm have been described in detail by Zhou et al. [16], which will not be repeated here. The algorithm flow is shown in Figure 5. At the same time, the symbols used in the CS algorithm are as follows: $n$ is the number of host nests, $p_a$ is the probability of being discovered by the host, that is, the probability of a new solution, $nd - 1$ is the number of locations to be picked in the warehouse, and $N\_iter$ is the maximum number of iterations in the solution process.

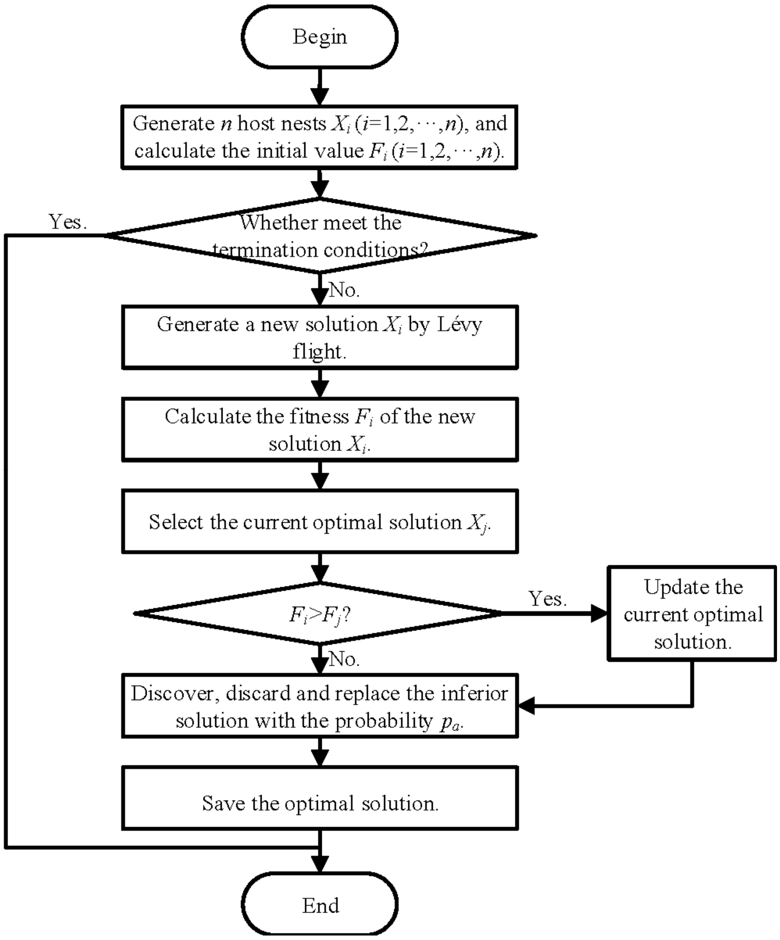


**Figure 5.** CS algorithm for warehouse picking.

### 3.1. Results

To calculate the walking distance of picking operation under the three path strategies, $l_A = l_S = 10$ and $W_R = L_R = 210/\sqrt{2}$ in Chevron layout warehouse is set, and the CS algorithm is used to solve the walking distance of Mixed-type path picking. The parameter used is: $n = 100, Pa = 0.25, N\_iter = 500$. In the actual warehouse picking operation, orders arrive at random and unpredictable. At the same time, the locations of goods stored in the warehouse will also affect the actual picking travel distance. Therefore, we randomly generate the coordinates of 100 locations to be picked in the Chevron layout warehouse, and randomly select 10 orders including 10, 20, 30 and 40 locations to be picked to solve the walking distance of the picking operation. Take one order as an example, for example, Tables 1–4 show the location coordinates and code numbers of a single order when it contains 10, 20, 30 and 40 locations to be picked respectively, and solve the walking distance of the single order picking operation, where the coordinate of I/O point is $(0,0,0,0)$, and the code number is 0. All numerical tests are implemented by MATLAB 2020a on a computer with Intel(R) Core(TM) i3-4160 CPU.

**Table 1.** Coordinates and code numbers with 10 locations to be picked.

| Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number |
|---|---|---|---|---|---|---|---|
| (0,0,0,0) | 0 | (4,4,0,8) | 3 | (3,3,1,9) | 6 | (2,3,1,19) | 9 |
| (4,1,0,20) | 1 | (2,1,0,13) | 4 | (2,1,0,26) | 7 | (2,1,0,20) | 10 |
| (3,1,1,13) | 2 | (3,2,0,6) | 5 | (3,4,0,7) | 8 | —— | —— |

**Table 2.** Coordinates and code numbers with 20 locations to be picked.

| Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number |
|---|---|---|---|---|---|---|---|
| (0,0,0,0) | 0 | (1,2,0,12) | 6 | (2,3,1,19) | 12 | (3,2,1,9) | 18 |
| (4,4,0,8) | 1 | (3,2,0,11) | 7 | (1,2,1,24) | 13 | (3,2,1,2) | 19 |
| (1,1,1,4) | 2 | (3,4,1,12) | 8 | (3,1,1,16) | 14 | (4,3,1,10) | 20 |
| (1,2,0,30) | 3 | (3,3,0,15) | 9 | (3,3,0,1) | 15 | —— | —— |
| (1,1,0,28) | 4 | (2,2,0,14) | 10 | (1,3,1,13) | 16 | —— | —— |
| (2,2,1,13) | 5 | (4,2,1,6) | 11 | (3,5,1,1) | 17 | —— | —— |

**Table 3.** Coordinates and code numbers with 30 locations to be picked.

| Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number |
|---|---|---|---|---|---|---|---|
| (0,0,0,0) | 0 | (2,1,0,20) | 8 | (1,1,0,39) | 16 | (2,1,0,13) | 24 |
| (3,2,1,1) | 1 | (1,1,1,4) | 9 | (1,2,0,24) | 17 | (3,2,0,11) | 25 |
| (3,2,0,23) | 2 | (3,3,0,1) | 10 | (4,2,0,30) | 18 | (4,1,0,7) | 26 |
| (3,3,1,23) | 3 | (4,5,0,5) | 11 | (4,1,0,5) | 19 | (1,1,1,14) | 27 |
| (2,3,1,19) | 4 | (4,1,1,18) | 12 | (1,2,1,19) | 20 | (2,1,0,14) | 28 |
| (4,4,1,1) | 5 | (3,2,1,2) | 13 | (3,2,1,3) | 21 | (3,4,0,7) | 29 |
| (2,1,0,25) | 6 | (2,2,1,3) | 14 | (2,2,1,6) | 22 | (1,1,1,13) | 30 |
| (2,4,0,7) | 7 | (4,1,1,32) | 15 | (3,1,1,5) | 23 | —— | —— |

**Table 4.** Coordinates and code numbers with 40 locations to be picked.

| Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number | Coordinate | Code Number |
|---|---|---|---|---|---|---|---|
| (0,0,0,0) | 0 | (1,2,0,12) | 11 | (1,1,1,1) | 22 | (2,3,0,4) | 33 |
| (3,4,1,10) | 1 | (2,4,0,7) | 12 | (3,4,0,7) | 23 | (2,2,0,14) | 34 |
| (4,4,1,2) | 2 | (3,4,1,12) | 13 | (1,2,0,30) | 24 | (1,2,1,20) | 35 |
| (3,3,1,17) | 3 | (2,1,0,14) | 14 | (4,4,0,8) | 25 | (3,3,1,11) | 36 |
| (3,2,0,23) | 4 | (4,1,0,24) | 15 | (4,2,1,6) | 26 | (4,1,0,5) | 37 |
| (3,2,1,1) | 5 | (4,2,1,20) | 16 | (2,2,1,13) | 27 | (1,1,0,5) | 38 |
| (3,3,0,1) | 6 | (3,1,1,5) | 17 | (1,1,1,14) | 28 | (2,2,1,4) | 39 |
| (4,1,1,22) | 7 | (3,3,0,6) | 18 | (1,4,0,12) | 29 | (3,3,0,15) | 40 |
| (4,2,0,23) | 8 | (1,3,1,11) | 19 | (4,1,0,20) | 30 | —— | —— |
| (4,1,1,32) | 9 | (1,2,0,24) | 20 | (3,2,0,17) | 31 | —— | —— |
| (4,2,0,28) | 10 | (3,1,1,34) | 21 | (3,4,1,13) | 32 | —— | —— |

When the number of goods to be picked in a single order is 10, the walking distance generated by the Return-type path strategy and the S-type path strategy is 1566.188 and 1444.7666, respectively. Using the CS algorithm, the optimal walking distance of the Mixed-type path strategy is 1404.9747, and the sequence of the optimal picking operation is: 0→3→1→2→5→6→9→8→7→10→4→0. Figure 6 is the convergence curve of the CS algorithm for solving the walking distance of Mixed-type path when the number of goods to be picked contained in a single order is 10.

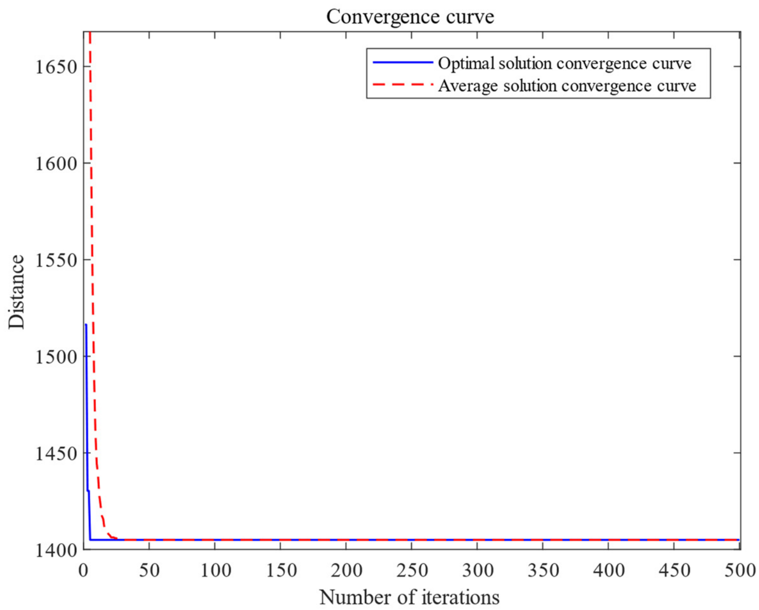


**Figure 6.** Optimization results of the Mixed-type path with CS algorithm when the number of locations to be picked is 10.

When the number of goods to be picked in a single order is 20, the walking distance generated by the Return-type path strategy and the S-type path strategy is 2596.9596 and 2184.5763, respectively. Using the CS algorithm, the optimal walking distance of the Mixed-type path strategy is 2116.9596, and the sequence of the optimal picking operation is: 0→1→20→11→14→5→10→19→18→7→9→15→17→8→12→4→2→3→13→6→16→0. Figure 7 is the convergence curve of the CS algorithm for solving the walking distance of Mixed-type path when the number of goods to be picked contained in a single order is 20.

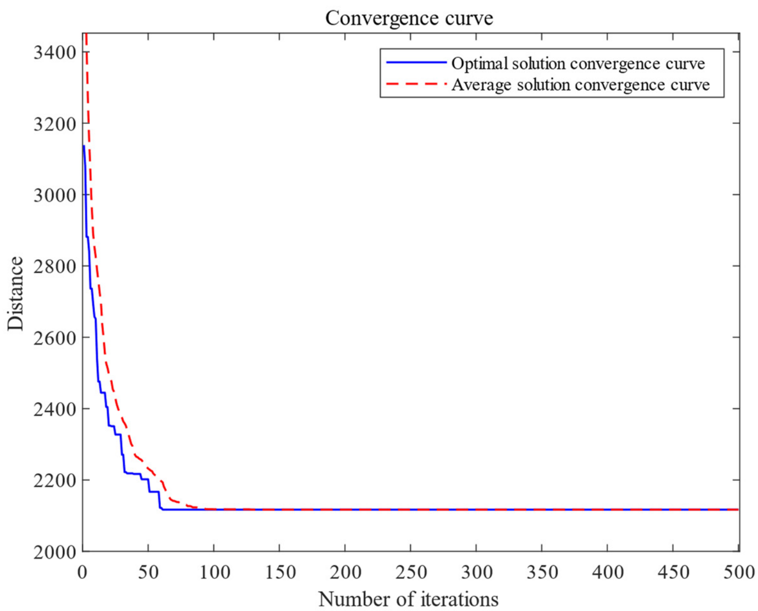


**Figure 7.** Optimization results of the Mixed-type path with CS algorithm when the number of locations to be picked is 20.

When the number of goods to be picked in a single order is 30, the walking distance generated by the Return-type path strategy and the S-type path strategy is 3184.5332 and 2349.4722, respectively. Using the CS algorithm, the optimal walking distance of the Mixed-type path strategy is 2045.452, and the sequence of the optimal picking operation is: 0→27→30→9→20→17→4→16→6→8→28→24→23→14→22→10→29→7→3→1→13 →21→25→2→18→5→11→15→12→26→19→0. Figure 8 is the convergence curve of the CS algorithm for solving the walking distance of Mixed-type path when the number of goods to be picked contained in a single order is 30.

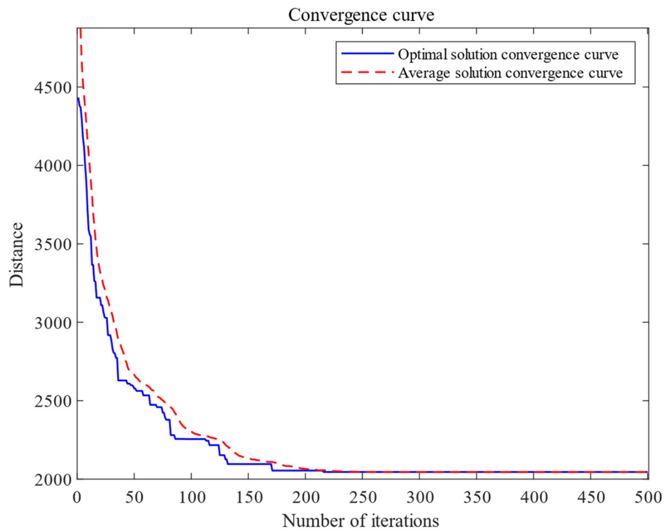


**Figure 8.** Optimization results of the Mixed-type path with CS algorithm when the number of locations to be picked is 30.

When the number of goods to be picked in a single order is 40, the walking distance generated by the Return-type path strategy and the S-type strategy is 3450.2439 and 2551.0408, respectively. Using the CS algorithm, the optimal walking distance of the Mixed-type path strategy is 2641.3099, and the sequence of picking operation is as follows: 0→14→17→5→21→25→2→10→8→16→26→37→30→7→15→9→4→31→6→18→36→ 40→3→1→13→32→23→12→33→39→27→34→24→20→35→11→19→29→22→28→38→0. Figure 9 is the convergence curve of the CS algorithm for solving the walking distance of Mixed-type path when the number of goods to be picked contained in a single order is 40.

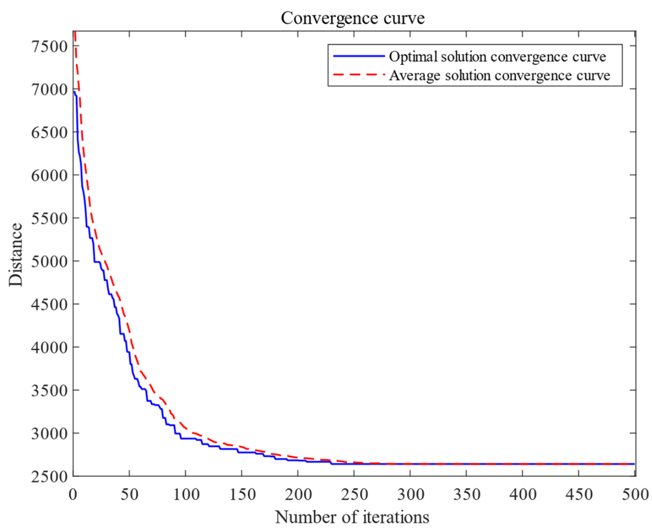


**Figure 9.** Optimization results of the Mixed-type path with CS algorithm when the number of locations to be picked is 40.

### *3.2. Analysis*

Tables 5–7 are the summary of the walking distance and results generated by the three path strategies of S-type, Return-type and Mixed-type for single and 10 orders containing 10, 20, 30 and 40 locations to be picked respectively in the Chevron layout warehouse.

**Table 5.** Results of the single order.

| Number of Locations | Path Strategy | CPU Running Time | Distance | Optimized Proportion | | |
|---|---|---|---|---|---|---|
| | | | | to S-Type | to Return-Type | to Mixed-Type |
| 10 | S-type | 0.123962 | 1444.7666 | 0.00% | 7.75% | −2.83% |
| | Return-type | 0.106539 | 1566.188 | −8.40% | 0.00% | −11.47% |
| | Mixed-type | 2.835667 | 1404.9747 | 2.75% | 10.29% | 0.00% |
| 20 | S-type | 0.151300 | 2184.5763 | 0.00% | 15.88% | −3.19% |
| | Return-type | 0.121123 | 2596.9596 | −18.88% | 0.00% | −22.67% |
| | Mixed-type | 3.034014 | 2116.9596 | 3.10% | 18.48% | 0.00% |
| 30 | S-type | 0.156416 | 2349.4722 | 0.00% | 26.22% | −14.86% |
| | Return-type | 0.133849 | 3184.5332 | −35.54% | 0.00% | −55.69% |
| | Mixed-type | 3.615413 | 2045.452 | 12.94% | 35.77% | 0.00% |
| 40 | S-type | 0.143845 | 2551.0408 | 0.00% | 26.06% | 3.42% |
| | Return-type | 0.150478 | 3450.2439 | −35.25% | 0.00% | −30.63% |
| | Mixed-type | 4.792556 | 1623.9958 | 36.10% | 45.44% | 0.00% |

**Table 6.** Results of 10 orders.

| Orders | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 10 | S-type | 1444.7666 | 1878.7615 | 1787.4012 | 1278.5534 | 1296.4823 |
| | Return-type | 1566.188 | 1746.3961 | 1938.8225 | 1295.4773 | 1659.2641 |
| | Mixed-type | 1404.9747 | 1572.9646 | 1665.8936 | 1125.4773 | 1146.7946 |
| 20 | S-type | 2184.5763 | 2026.188 | 1998.7615 | 2274.6804 | 2335.0788 |
| | Return type | 2596.9596 | 2417.1068 | 2134.8276 | 2605.0967 | 3020.3911 |
| | Mixed-type | 2116.9596 | 1728.9266 | 1723.9697 | 2204.2388 | 2380.452 |
| 30 | S-type | 2349.4722 | 2379.0738 | 2516.3961 | 2447.6093 | 2603.32 |
| | Return-type | 3184.5332 | 3197.6703 | 2951.8124 | 3161.8124 | 3344.0916 |
| | Mixed-type | 2045.452 | 2545.9545 | 2313.7794 | 2547.6703 | 2653.7363 |
| 40 | S-type | 2551.0408 | 2923.6753 | 2630.8936 | 2430.7895 | 2801.6043 |
| | Return-type | 3450.2439 | 3981.51 | 3562.5231 | 3596.1017 | 3902.3759 |
| | Mixed-type | 2641.3099 | 2996.518 | 2628.6322 | 2609.8454 | 2990.1576 |
| **Orders** | | **6** | **7** | **8** | **9** | **10** |
| 10 | S-type | 1788.32 | 1416.5433 | 1308.0509 | 1610.1829 | 1543.6575 |
| | Return-type | 1936.9596 | 1364.6804 | 1576.6905 | 1556.2489 | 1499.6194 |
| | Mixed-type | 1461.9596 | 1112.0027 | 1120.3301 | 1496.2489 | 1146.188 |
| 20 | S-type | 1992.5052 | 2018.9697 | 2244.8276 | 2075.0788 | 1912.9037 |
| | Return type | 2571.2489 | 2577.8175 | 2667.8175 | 2205.5382 | 2184.6804 |
| | Mixed-type | 1861.1627 | 2009.2819 | 2134.0307 | 1643.3631 | 1712.254 |
| 30 | S-type | 2364.325 | 2451.7514 | 2615.1829 | 2435.8936 | 2553.4672 |
| | Return-type | 2916.1017 | 3231.9596 | 2748.6753 | 3503.381 | 3311.8124 |
| | Mixed-type | 2329.0307 | 2613.5281 | 2360.3911 | 2483.2338 | 2376.9165 |
| 40 | S-type | 2801.6043 | 2283.3631 | 2738.8225 | 2754.6804 | 2683.1118 |
| | Return-type | 3912.3759 | 2955.3911 | 3455.0967 | 3900.0967 | 3854.386 |
| | Mixed-type | 2839.5942 | 2302.2109 | 2729.6982 | 2778.8835 | 2839.4901 |

**Table 7.** Summary of optimization proportion.

| Group | Mixed-Type to S-Type | | | | Mixed-Type to Return-Type | | | |
|---|---|---|---|---|---|---|---|---|
| | **10** | **20** | **30** | **40** | **10** | **20** | **30** | **40** |
| <0% | 0 | 1 | 5 | 8 | 0 | 0 | 0 | 0 |
| 0–10% | 3 | 5 | 4 | 2 | 2 | 0 | 0 | 0 |
| 10–20% | 5 | 3 | 1 | 0 | 4 | 3 | 3 | 0 |
| 20–30% | 2 | 1 | 0 | 0 | 3 | 7 | 6 | 10 |
| >30% | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| Total | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

According to the above results and Figure 10, the following results can be obtained with the Chevron layout: (1) Compared with the Return-type picking path strategy, the Mixed-type path strategy has better results. Compared with the S-type picking path strategy, the resulting advantage of the Mixed-type path strategy gradually decreases with the increase of the number of locations to be picked in the order. (2) Compared with the S-type picking path strategy, the Mixed-type path strategy has a higher optimization proportion of walking distance for the Return-type picking path strategy, and the average optimization proportion is higher than 20%. (3) With the increase of the number of goods to be picked, the number of iterations required by the CS algorithm to solve the walking distance of the Mixed-type path strategy also increases steadily. (4) When the number of goods to be picked in the order is small (less than 36), the result of the Mixed-type path is better than that of the S-type path. With the increase of the number of goods to be picked in the order, the advantage of the Mixed-type path is gradually weakened. When the number of goods to be picked in the order is greater than 36, the result of the S-type path is better than that of the Mixed-type path. (5) When the number of locations to be picked is small (less than 5), the result of the Return-type path is better than that of the S-type path. With the increase of the number of locations to be picked in the order (greater than 5), the result of the S-type path is gradually better than that of the Return-type path. To sum up, in the Chevron layout warehouse, the Mixed-type path strategy can produce better results than the Return-type picking path. Compared with the S-type picking path, with the increase of the number of locations to be picked in the order, the advantage of the Mixed-type path is gradually weakened and becomes gradually worse than the S-type path.

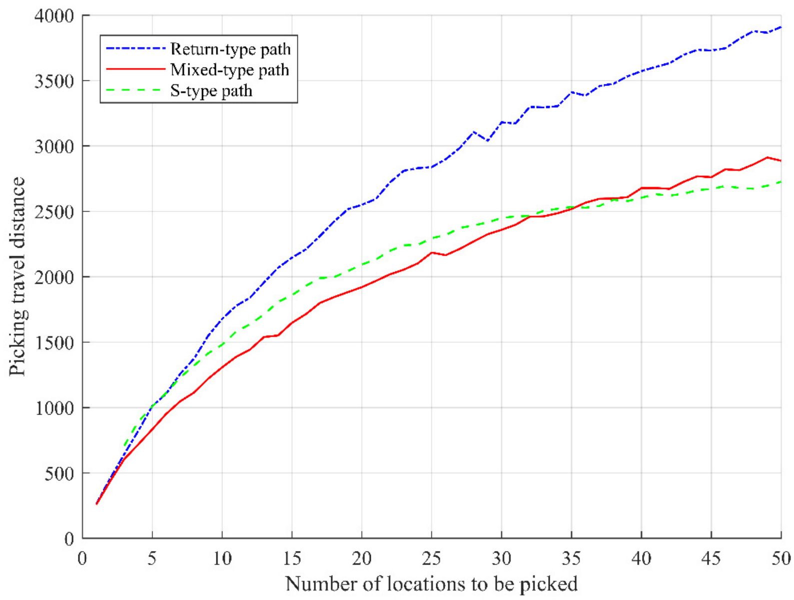


**Figure 10.** Comparison of results of different path strategies in chevron layout warehouse.

## 4. Conclusions

Based on the research of Öztürkoğlu et al. [35], this paper expands it, selects the Chevron layout to study the walking path with multi locations to be picked, and further supplements and improves this field based on single-command order picking of Öztürkoğlu et al. [35]. Compared with single-command order picking, the picking path problem with multi picking locations proposed in this paper is more suitable for the characteristics and requirements of orders in e-commerce warehouses. According to the characteristics of the Chevron warehouse layout, this paper takes the shelf angles in the right half-warehouse and the left half-warehouse of 45° and 135° to design and describe the warehouse layout, constructs the walking distance model of picking operation with the Return-type, S-type and Mixed-type path strategies in the random storage strategy, and introduces the CS algorithm to solve the picking travel distance generated by the Mixed-type path to compare and optimize the picking path in the Chevron layout storage center. In the process of solving the examples, 10 orders of 10, 20, 30 and 40 locations to be picked are randomly selected in the Chevron layout storage center for specific research. Through the comparative analysis of the solution results, it is found that the optimization proportion of the walking distance generated by the Mixed-type path strategy to the Return-type picking path strategy is higher, and the average optimization proportion is higher than 20%. Compared with the S-type picking path (Dukic et al. [37]), when the number of locations to be picked in the order is less than 36, the Mixed-type path result is better than the S-type path result. With the increase of the number of locations to be picked in the order, the advantage of the Mixed-type path result is gradually weakened and becomes worse than the S-type path result. When the number of locations to be picked is less than 5, the Return-type path result is better than the S-type path result. With the increase of the number of locations to be picked in the order, the S-type path result is gradually better than the Return-type path result.

The picking background of this paper is mainly based on the random storage strategy. In addition, there are many storage strategies, such as classified storage, category close storage, etc. In the follow-up research, it is necessary to study other storage strategies in the warehouse picking system. At the same time, this paper only applies one intelligent algorithm in the process of solving the walking distance of picking operation and does not improve and optimize its parameters. In the following research, it is necessary to study other intelligent algorithms and their corresponding improvements and parameter optimization.

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## Appendix A

The description of symbols is shown in Table A1.

**Table A1.** Description of symbols.

| Symbols | Description |
|---|---|
| $L_R$, $W_R$ | The length and width of the right half-warehouse (excluding the width of the surrounding aisles and the main aisle in the middle), and $L_R = W_R$. |
| $l_S$, $l_A$, $l_U$ | The width of shelves, aisles, and unit storage locations respectively, and $l_U = 0.5l_S = 0.5l_A$. |
| $\alpha_R$ | The angle of the shelf and the picking channel in the right half − warehouse, and $\alpha_R = 45°$. |
| $S_i$ | The four picking areas divided into the warehouse by the warehouse diagonal and the central main aisle, $i = 1, 2, 3, 4$. |
| $D$ | The total distance traveled to complete a picking task. |
| $x_{01}$, $x_{n0}$ | The path starting from the I/O point to the picking location 1 and returning from the picking location $n$ to the I/O point, and $x_{01} = 1$, $x_{n0} = 1$. |
| $K$ | The number of items to be picked. |
| $d_{ij}$ | The shortest distance between cargo location $i$ and $j$, $1 \le i, j \le n, i \ne j$. |
| $x_{ij}$ | Whether to choose the walking path from cargo location $i$ to $j$, $1 \le i, j \le n, i \ne j$. |
| $(s, x, y, z)$ | The coordinate of any cargo location. |
| $s$ | The serial number of the area, and $s = 1, 2, 3, 4$. |
| $x$ | The picking channel where the goods to be picked located, and $x = 1, 2, \cdots, u$. |
| $y$ | The side of the goods to be picked in the picking channel, $y = 0$ or 1. |
| $z$ | The location of the goods to be picked on the $y$ side of the channel $x$, $z = 1, 2, 3, \cdots, v$. |
| $d_{01}$ | The distance between the I/O point and the first location to be picked. |
| $d_{n0}$ | The distance between the last location to be picked and the I/O point. |
| ${d_{0i}}^{(1)}$ | Travel distance from I/O point to the main channel or surrounding channels. |
| ${d_{0i}}^{(2)}$ | Walking distance in the main channel or surrounding channels. |
| ${d_{0i}}^{(3)}$ | Travel distance from the main channel or surrounding channels to the channel to be picked. |
| ${d_{0i}}^{(4)}$ | Travel distance in the channel to be picked. |
| $\phi_i$ | The length of the picking channel $x_i$. |
| $\varphi_i$ | The remaining distance in picking channel $x_i$ except ${d_{0i}}^{(4)}$. |

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