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Manual Order Picking Route Optimization in Distribution Warehouse of Chain Furniture Retail Enterprise

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Abstract

Due to the effects of the COVID-19 pandemic and the rise of online shopping, the offline sales of IKEA Fuzhou have been declining since 2020. Because the cost of distribution warehouse is a major expense for offline chain furniture retailers, and the picking process is a key activity in distribution warehouse operations. To reduce the cost of distribution warehouse and alleviate the survival pressure of the offline chain furniture retailers, this paper focuses on optimizing the picking route of the IKEA Fuzhou distribution warehouse. It starts by creating a two-dimensional coordinate system for the storage location of the distribution warehouse using the traditional S-type picking strategy to calculate the distance and time of the sorting route. Then, the problem of optimizing the picking route is then transformed into the travelling salesman problem (TSP), and picking route optimization model is developed using a genetic algorithm to analyze the sorting efficiency and picking route optimization. Results show that the order-picking route using the genetic algorithm strategy is significantly better than the traditional S-type picking strategy, which can improve overall sorting efficiency and operations, reduce costs, and increase efficiency. Thus, this establishes an implementation process for the order-picking path based on genetic algorithm optimization to improve overall sorting efficiency and operations, reduce costs, increase efficiency, and alleviate the survival pressure of pandemic-affected enterprises.

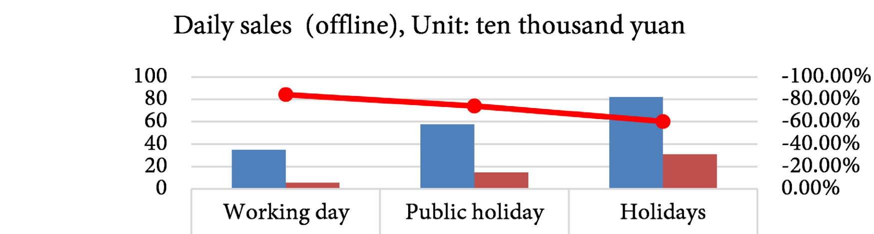
Keywords

S-Shaped Picking Strategy, Picking Route, Traveling Salesman Problem, Genetic Algorithm

1. Introduction

IKEA is a typical enterprise in the chain retail furniture industry, it is a comprehensive unit that integrates warehousing, distribution, and sales functions where it acts both as a retail store and a logistics distribution center. IKEA's Fuzhou branch in China was established in 2017, its total floor area covers 112,000 sqm. with four floors in the commercial section. The first underground floor is a commercial parking lot, and the first above-ground floor is a 15,000-square-meter external leasing area. The plan is to introduce 60 merchants covering entertainment, dining, children's playgrounds, and upstream and downstream brands related to the IKEA industry chain. Its second and third floors span the 40,000 sqm. Standard is found in all IKEA stores, with the second floor serving as the self-service area for goods and home goods and the third floor as both the furniture display area (home model room) and the restaurant. With the rapid development of Internet technology since the beginning of the 21st century, e-commerce has emerged and transformed what was originally a purely offline business model. The rapid development of e-commerce has also led to the formation of a large-scale online furniture sales model, squeezing the market share of traditional chain furniture retail enterprises [1]. Additionally, compared to the efficiency and cost of e-commerce logistics and distribution, the logistics and distribution of traditional chain furniture retail enterprises appear relatively backward and bead high logistics costs, thus putting more pressure on the logistics and distribution level of traditional chain furniture retail enterprises [2]. For IKEA Fuzhou, in addition to being affected by the rise of online shopping malls, the COVID-19 pandemic has also affected its performance since it opened in 2020, and its offline store's sales have been declining. As shown in **Figure 1**, IKEA Fuzhou's daily sales have decreased significantly with the largest decline happening on weekdays, dropping from an average of 350,000 CNY in 2020, to an average of 55,000 CNY in 2022, representing a decrease of 84.29%. The decline seen during public holidays and festivals is relatively lower, which is at 74.14% and 62.20%, respectively. This sharp decline in sales has led to a sudden increase in pressure for the company to survive, which makes cost control a top priority.

In any logistics system, the warehousing operation represents a significant



	Working day	Public holiday	Holidays
2020	35	58	82
2022	5.5	15	31
Growth rate	-84.29%	-74.14%	-60.20%

Figure 1. Average daily turnover of IKEA offline stores in Fuzhou in 2020 and 2022.

proportion of the total cost. Among all warehousing activities, the order-picking process is the most crucial [3]. This study found that the order-picking route planning at IKEA Fuzhou was entirely dependent on the personal experience of the order pickers. When the number of picking order items is small and the distribution of order items is centralized, subjective experience-based order-picking route planning can be effective.

However, when there are many items to be picked and are scattered across the warehouse, the absence of a scientific order-picking route plan results in order pickers taking longer routes, which lowers the efficiency of the picking process. Furthermore, the composition of the order-picking workforce at IKEA Fuzhou's logistics department is mainly divided into two categories: regular employees and short-term, contract-based employees hired through manpower outsourcing companies. During peak periods, the ratio of regular employees to contract employees is typically around 1:3. Contract employees receive minimal training before starting work and lack experience in order picking. The lack of a scientific order-picking route plan, coupled with the absence of experience among contract employees, result in order pickers frequently backtracking, which leads to longer order-picking routes and lower picking efficiency. Picking operations in a distribution warehouse generally consume 30% - 40% of the warehouse's total operation time [4] [5], while their cost covers over 50% - 70% of the overall cost [6] [7]. Consequently, optimizing the sorting efficiency and operation of chain furniture retail companies' distribution warehouses can help improve their outdated delivery operations and enhance logistics efficiency. This may also provide better control of logistics costs and increased market competitiveness for said companies. These ultimately reduce the logistics costs and ease physical enterprises' pressure to survive during the pandemic.

This paper will focus on establishing a feasible sorting route optimization model to help the warehouse reduce costs and increase efficiency, ultimately enhancing its market competitiveness. This paper first establishes a two-dimensional coordinate system for the storage locations in the distribution warehouse based on the traditional S-shaped picking strategy [8]. The two-dimensional coordinate system was used to calculate the distance and time of sorting routes. The picking route optimization problem was transformed into the TSP, and a picking route optimization model was established. Owing to the genetic algorithm has been widely used in solving the TSP [9] [10] [11], and it has better convergence than the traditional algorithm, such as exhaustive algorithm or heuristic algorithm [12]. Thus, a genetic algorithm was used for the picking route optimization and sorting efficiency analysis. The distance and time of the picking strategy generated by the genetic algorithm were compared with those of the traditional S-shaped picking strategy. Finally, following the results of the comparative analysis, an implementation process for the order-picking route based on the genetic algorithm optimization was established. Then this order-picking route information is fed back to the warehouse management system (WMS), and the WMS then sends the original order information and picking list summary to the personal digital assistant (PDA) held by the picker, and finally completes the entire picking process. In this way, the original method of planning the order-picking route by the picker's personal experience is optimized to improve the picking efficiency.

2. Literature Review

Research on manual picking efficiency in warehouses mainly focuses on applying and improving heuristic algorithms in picking paths. The picking paths are optimized through algorithms to improve warehouse sorting efficiency. The main algorithms include genetic algorithm (GA), ant colony algorithm (ACO), simulated annealing (SA), particle swarm optimization algorithm (PSO), and improved and hybrid algorithms based on these algorithms. In addition, when studying the warehouse picking route optimization problem, it is generally converted into the traveling salesman problem (TSP) for solution [13].

In the research on picking path optimization, Li *et al.* [14] believe that genetic algorithm is the mainstream of current path planning research. Therefore, Yu [15] used genetic algorithms to optimize the path that pickers in e-commerce distribution centers walk during the picking process, reducing the useless paths of manual labor and picking equipment and the risk of goods explosion during e-commerce sales. Cui [16] used EIQ analysis to optimize the warehouse layout, and then the genetic algorithm was used to optimize the picking path. The analysis result shows that the picking time after the optimization is significantly reduced, improving the company's picking efficiency. In addition to the traditional genetic algorithm, Zhou *et al.* [17] proposed two partheno genetic algorithms, PGA and IPGA, and compared them with the particle swarm optimization algorithm (PSO) and the invasive weed optimization algorithm (IWO) to solve the multiple traveling salesman problem (MTSP). The results show that IPGA has better advantages in solving MTSP. Okonji *et al.* [18] analyzed four algorithms: the ant colony algorithm, the Dijkstra algorithm, the Bellman-Ford algorithm, and the Suurballe algorithm, and believed that mixing the algorithms can improve the performance of the algorithm and facilitate the solution of more complex path optimization problems. Sebo and Busa [19] studied a dual-zone warehouse. Then, they found that the results of the genetic algorithm are greatly affected by the population size, reproduction operator, and number of generations, and the improved genetic algorithm has more advantages than simple heuristic algorithms and experienced picking employees when dealing with path optimization picking problems.

In addition to being affected by the picking path, picking efficiency is also affected by order batching. Only one target variable needs to be considered when considering order batch optimization or path optimization, which makes it easier to obtain the target result. However, considering both simultaneously will increase the difficulty of solving the target result. Sun *et al.* [20] designed the double nested improved genetic algorithm to solve the joint optimization problem of order batching and picking path. Wang [21] considered the impact of picker congestion on picking efficiency and established an order batch optimization model using seed algorithm and ant colony algorithm as the primary solution tools. Yan *et al.* [22] constructed an online order batch planning model for minimum picking path. Then, they proposed a method based on a genetic algorithm and k-means clustering algorithm to handle picking path planning and order batching, respectively, to solve the online order batch planning model.

According to the literature's research content, the genetic algorithm has been widely used in warehousing manual picking path optimization research. Therefore, the genetic algorithm is used for path optimization in this paper.

3. Current Status of Fuzhou IKEA Distribution Warehouse

3.1. Overview of Fuzhou IKEA Distribution Warehouse

Fuzhou IKEA, established in 2017, operates as a hybrid commercial and logistics distribution center that does warehousing, distribution, and sales functions. As a sales-focused establishment, the company's storage and distribution unit encompasses a complete distribution warehouse and serves as a product display platform for consumers. Its distinctive features require that the logistics and distribution model adopted follows an online order logistics distribution.

The distribution warehouse on the second floor of the shopping mall can be classified as a semi-open warehouse divided into two distinct areas. The first area is located in the mall's furniture self-service area, where the merchandise on the lower shelves is made available for consumers to take on their own. The second area is separated by partition walls from the furniture self-service area, and is the main workspace for warehouse staff, prohibiting access from consumers. The storage of goods on the warehouse shelves follows a typical upper storage and lower retrieval warehouse model. The upper floors of the shelves are reserved for goods storage units, while the lower floors are utilized for the goods picking units. The distinction between the goods storage and picking units is illustrated in **Figure 2**.

During the picking stage, manual picking using forklifts is the primary method used during picking operations. By combining manual labor with hand trucks, workers select and transport goods from various shelves to hand trucks before delivering them to the logistics center for checking and then handing them over to the partner for shipment. In terms of picking areas, the picking work of the branch's employees mainly focus on both the furniture self-pickup area and the non-self-pickup area, as shown in **Figure 3**.

3.2. Picking Process of Fuzhou IKEA Distribution Warehouse

The picking process of the Fuzhou IKEA distribution center is generally divided into five stages, namely the order generation, order allocation, goods picking, goods checking, and goods delivery stages (**Figure 4**).

The order generation stage at the distribution warehouse can be broadly divided into two sources: offline and online orders. Both sources involve consumers

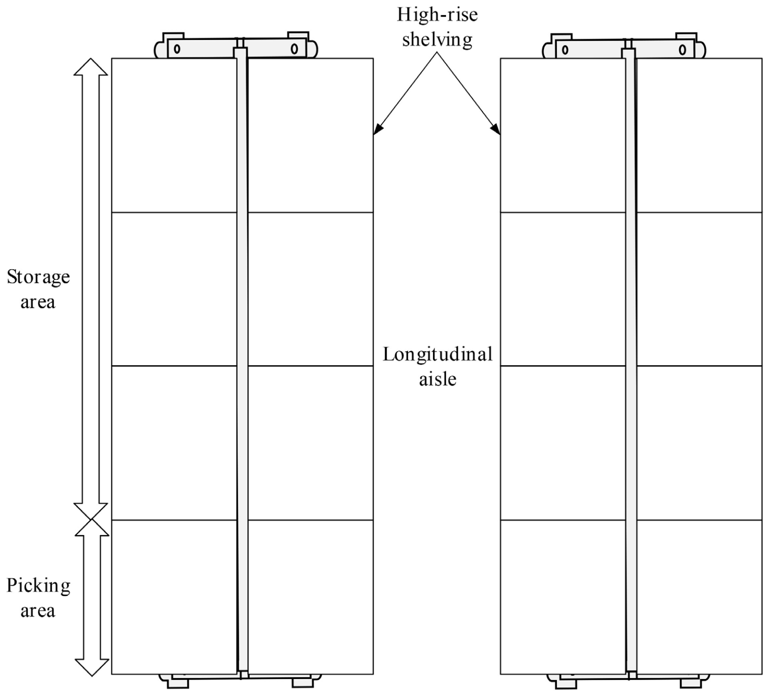


Figure 2. Distribution of IKEA distribution warehouse shelf picking and storage unit.

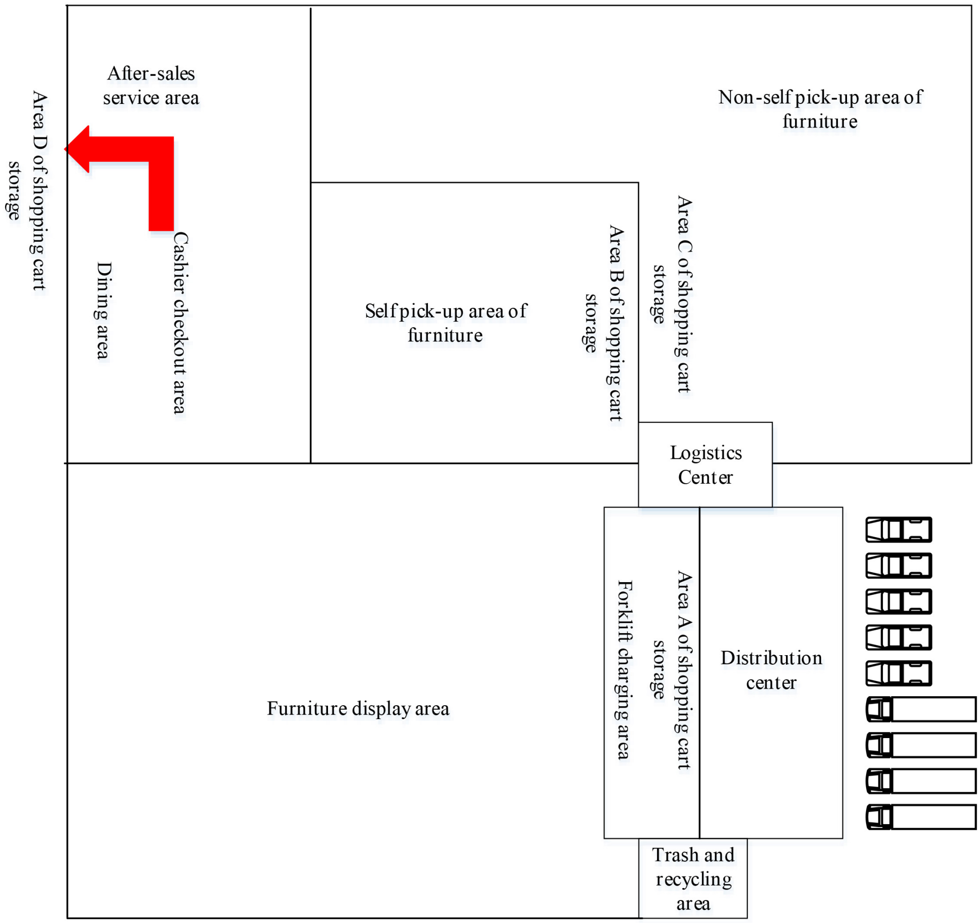


Figure 3. Layout of operations on the second floor of Fuzhou IKEA.

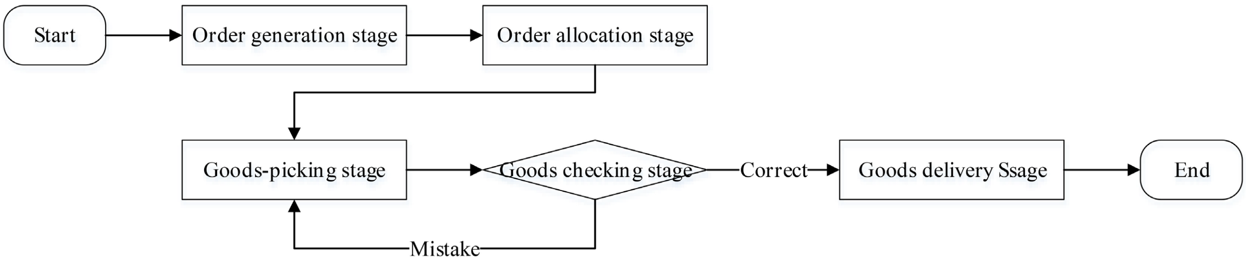


Figure 4. Picking process of distribution warehouse.

submitting their product needs and making payments, and the corresponding order information is automatically synchronized to the store's logistics center. Unlike offline orders, online orders are uniquely identified inside of the logistics center. Additionally, regardless of whether the order is offline or online, the order information transferred to the logistics center is labeled with the latest delivery time, allowing workers to reasonably arrange the order of picking. The selected order content includes information such as the name, the SKU (stock keeping unit), pick-up location, weight, quantity, and if it is a special heavy item prompt or not.

During the order allocation stage, those assigned to picking tasks at the branch's distribution center area are always composed of a minimum of three employees during each time period of operational hours, only increasing to five or eight employees during peak picking periods (including one designated supervisor and the remaining staff comprised of internal and long-term part-time employees). After the generation of a product order, picking personnel use PDA to access information regarding the items to be picked. The allocation of orders generally follows the principle of proximity, meaning that if multiple employees are available simultaneously, the distribution of employees assigned to pick items is based on the distance of the collective items waiting to be selected from each employee.

Upon receiving the picking task, the picking personnel at the distribution warehouse log in to the PDA with their personal accounts, select and click the corresponding order, and officially enter the goods picking stage. By then, the order task is in an exclusive state, and others cannot select the task again. The order will also disappear on the task list to avoid duplicate picking. During the overall picking process, the employees usually start by picking up a trolley from the trolley storage area and then proceed to the corresponding shelf number prompted on the PDA to scan and place the goods into the trolley. The employee repeats the process for each product, in order, until all goods are picked. Finally, the employee pushes the trolley back to the logistics center. After arriving at the logistics center, the picking personnel must complete the submission feedback of the picking task on the PDA. The system will then automatically print out the picking completion list. After the employee manually signs the list, the goods-picking process is officially completed.

After completing the goods-picking phase, the process then enters the goods checking stage, where the order information for the corresponding product is transmitted from the picking node to the order review node in the warehouse management system. The goods review personnel use their personal account to log in to the PDA and select the order to be reviewed and received, and then complete the scanning review operation for each item. After scanning all the goods, the goods review personnel confirm whether the goods picked were correct: if there are any missing or extra items, the picking personnel must re-pick the goods and return them to the logistics center. Once confirmed as correct, the goods review task is submitted and feedback is provided through the PDA. The system then automatically prints out a label with the customer's contact information and address to be attached to each piece of outer packaging indicating which customer the item belongs to, thus avoiding errors during delivery. Finally, the goods review personnel manually sign the previously printed picking list, completing the signature section and marking the end of the goods review phase.

After the goods have been checked, it goes to the goods delivery stage, and the verification personnel hand over the goods and the goods list to the third-party logistics company. The logistics company then checks the name and contents of the goods. Once confirmed, the personnel responsible from the logistics company sign the receipt. At this point, the entire picking and delivery process from IKEA's internal product order to the third-party logistics company is officially completed. An on-site investigation and analysis of the picking time of orders at the IKEA Fuzhou distribution warehouse revealed that the warehouse's picking orders can be divided based on the number of items to be picked, revealing three categories: less than 10, 10 - 20, and 20 - 50. For each category, the number of items to be picked for each product type is mainly only 1, with a few exceptions such as furniture that requires multiple components such as the wooden boards used to assemble a bedside table. **Table 1** displays the average time required from the generation of an order to the completion of item picking for the three categories of orders involved in the warehouse's daily picking operations.

4. Calculation of Sorting Route Distance and Time under Traditional S-Shaped Picking Strategy

During the order-picking process in warehouses, the picking route refers to the specific walking route taken by the warehouse staff to collect the ordered items. An appropriate picking route can significantly reduce redundant picking distances, shorten picking time, and improve picking efficiency. One common picking strategy is the traditional S-shaped picking strategy, also known as the

Table 1. Picking time for three types of orders.

	Kinds	Amount	Average
Order A	10	15 - 20	14 min
Order B	20	30 - 60	27 min
Order C	50	80 - 130	65 min

cross-type picking strategy. This strategy's picking route is well-suited for warehouses with intermediate partition racks and achieves the shortest route for picking goods, thus saving time [23] [24]. Warehouse staff start from the entrance, cross the aisle where the items to be picked is located, and while walking in said aisle, place all the required items into the picking equipment. After completing the picking in that aisle, they then move on to the next aisle and continue picking until all items have been picked. Finally, they return to the entrance, as shown in Figure 5.

4.1. Establishing Warehouse 2D Coordinates

To facilitate the calculation of the distribution route of the Fuzhou IKEA distribution warehouse and reduce unnecessary interference, the specific layout of the warehouse has been transformed and simplified without affecting its overall layout and real data. The simplified plan view of the distribution warehouse is shown in Figure 6. It can be seen that the warehouse is divided into four areas by the main aisle of the logistics center and the transverse passage 2. According to the characteristics of IKEA's goods and the rules for setting up shelves, having only one type of goods stored in a location is predominant, so it is assumed that only one type of goods is stored in a location. A coordinate system was established in the lower left corner of the warehouse floor plan whose location was determined according to the coding rules for the double-aisle warehouse, followed by the determination of the coordinates of the goods.

4.1.1. Two-Dimensional Coordinates of Warehouse Location

As shown in Figure 6, the IKEA Fuzhou warehouse includes 16 aisles, a main aisle leading to the logistics center, and 3 transverse aisles. Assuming that the origin of the coordinate system is located at point o in the lower left corner, the X-axis extends to the right of o, and the Y-axis extends upward from o. Let $S(x_s, y_s)$

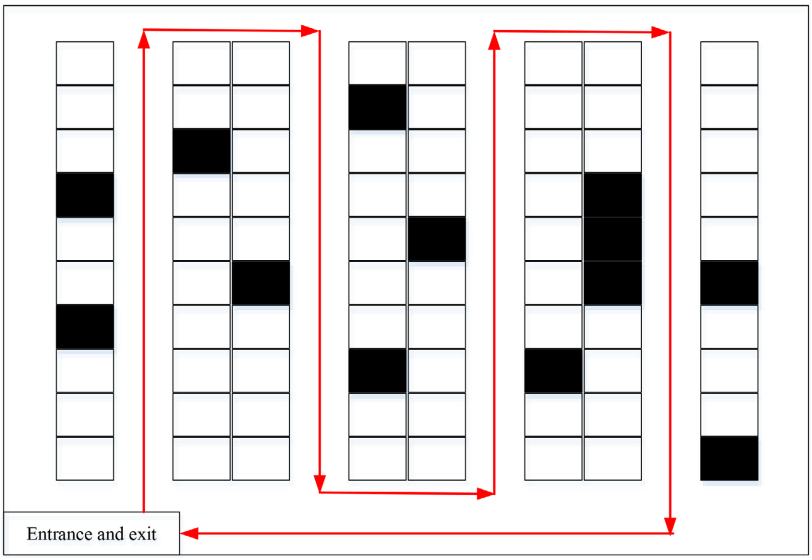


Figure 5. Strategy of S-type picking.

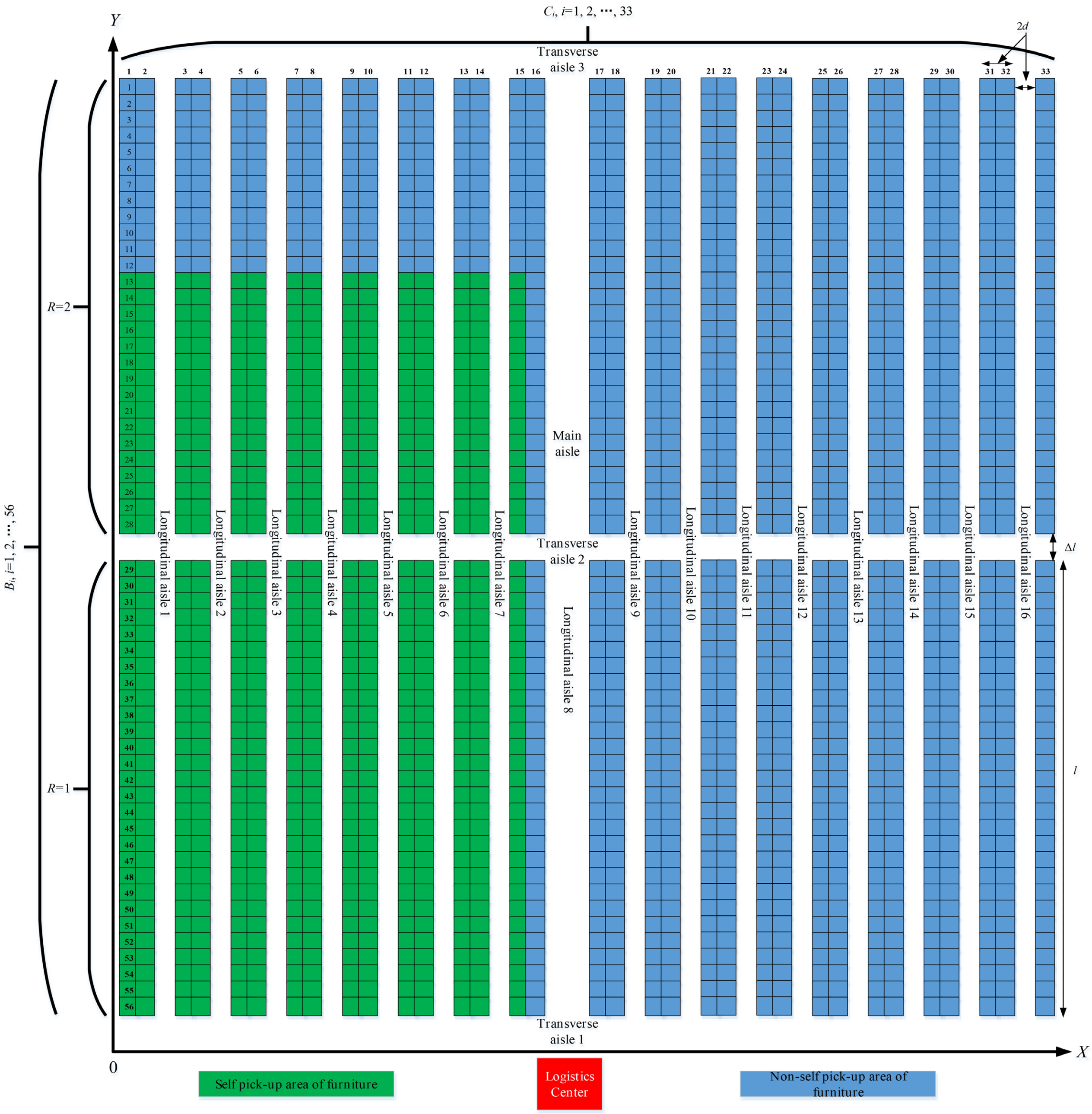


Figure 6. Schematic plan view of IKEA warehouse in Fuzhou.

denote the southwest corner of the store near the origin, with shelf spacing d and aisle spacing d_c. The warehouse location two-dimensional coordinate system is established [25], as shown in Equation (1) to Equation (6).

$$x = \begin{cases} x_s + \dfrac{C-1}{2} d + (C-1) d_c, & \text{if } C \text{ is an odd number} \\ x_s + \left(\dfrac{C}{2} - 1\right) d + C \times d_c, & \text{if } C \text{ is an even number} \end{cases}. \tag{1}$$

$$y = Y + y_s = (R-1)(l + \Delta l) + \frac{(B-1) l_B + (P-1) l_p + l_p}{2} + y_s. \tag{2}$$

$$y = Y + y_s = (R-1)(l+\Delta l) + \frac{(2P-1)l_p}{2} + y_s . \tag{3}$$

$$X_{12} = |x_1 - x_2| . \tag{4}$$

$$Y_{12} = \begin{cases} \min\{\Delta Y_1 + \Delta Y_2, 2l - (\Delta Y_1 + \Delta Y_2)\}, & \text{when } R_1 = R_2 \text{ and } \left[\frac{C_1}{2}\right] \neq \left[\frac{C_2}{2}\right] \\ |y_1 - y_2|, & \text{otherwise} \end{cases} . \tag{5}$$

$$\Delta Y_i = \frac{(2P-1)l_p}{2}, \quad i = 1,\ 2 . \tag{6}$$

First, Equation (1) represents the horizontal coordinate x of any storage location $W(x, y)$, where x_s is the horizontal coordinate of point $S(x_s, y_s)$, C is the number of shelf rows, d is the shelf width distance, and d_c is the width distance of each column of shelves. Second, Equation (2) represents the vertical coordinate y of any storage location $W(x, y)$, where Y is the vertical distance of the storage location $W(x, y)$ relative to point $S(x_s, y_s)$. The vertical coordinate y of the storage location $W(x, y)$ is the sum of Y and y_s, where y_s is the vertical coordinate of point $S(x_s, y_s)$. R represents the number of shelf rows in a double-deep warehouse, where $R = 1$ for the area close to the logistics center and $R = 2$ for the farther area. l is the length of the shelf, Δl is the distance between two rows of shelves, B represents the shelf, P represents the storage location, l_B is the length of each section of the shelf, and l_p is the length of each storage location within each section of the shelf. Because this paper assumes that each section of the shelf has only one storage location, $l_B = l_p$, Equation (2) can be simplified as Equation (3).

Finally, Equation (1) to Equation (3) were followed to generate the matrix of distances between the coordinates of the goods. Assuming that any two coordinates of the goods are $W_1(x_1, y_1)$ and $W_2(x_2, y_2)$, the shortest walking distance along the broken line between them is S_{12}. Due to the presence of the shelves, the actual picking process of the picker cannot calculate the picking distance S_{12} based on Euclidean distance. Hence, Manhattan distance was used to calculate the picking distance S_{12} [26]. Here, the picking distance S_{12} between $W_1(x_1, y_1)$ and $W_2(x_2, y_2)$ is $S_{12} = X_{12} + Y_{12}$, where X_{12} is the absolute value of the difference between the abscissae of $W_1(x_1, y_1)$ and $W_2(x_2, y_2)$, as shown in Equation (4), and Y_{12} as shown in Equation (5). ΔY_i in Equation (6) is the distance between the location $W_i(x_i, y_i)$ of the goods and the southern end of the shelf where it is located. If two goods are in the same area but not in the same aisle, circumnavigation happens, which takes the smaller value of circumnavigation in the northward and southward directions. In other cases, circumnavigation instead does not happen.

4.1.2. Distance Matrix of Picking Goods

The study assumes that the picking of goods starts from the starting point $W_0(x_0, y_0)$ and the picker selects all the goods required in the order to be picked once and returns to the starting point. Let W_1, W_2, …, W_n be the coordinates of all the items to be picked in one picking operation, where the coordinates of the item to be picked are $W_i(x_i, y_i)$, where $i = \{0, 1, 2, \ldots, n\}$. Let S_{ij} be the shortest distance between W_i and W_j, where the distance from i to j is equal to the distance from j to i, thus $S_{ij} = S_{ji}$, and $S_{i0} = S_{0j} = x_i + y_j$. The distance matrix of the items to be picked can be obtained as shown in Table 2.

4.2. Distance and Time of Order Picking Route

The warehouse picking orders at IKEA Fuzhou are generally divided into three categories based on the number of items to be picked: less than 10, 10 - 20, and 20 - 50. Most items to be picked in each category are single items, with only a few home furnishings requiring multiple pieces to be assembled. The distribution of storage locations for picking items is determined by the sales volume parameters for each type of item, known as Every Week Sales (EWS), which is generated from historical data. The EWS values for items located closer to the logistics center are generally higher, while those farther away have lower values.

To make numerical comparisons of the picking orders, three types of orders were analogously categorized, namely Order A, Order B, and Order C, with 10, 20, and 50 items to be picked, respectively. For the distribution of items, a normal distribution was used to randomly generate warehouse locations, with a mean of 16 (the position of the main aisle shelves) and a standard deviation of 10. Table 3 provides detailed information on the three picking orders.

4.2.1. Order Picking Route

The positions of each pending item in the two-dimensional coordinate system can be determined following the warehouse location distribution of the goods displayed in Order A, Order B, and Order C. Currently, the picking staff at the Fuzhou IKEA distribution warehouse mainly adopts the S-shaped picking strategy. Therefore, based on the principle of the S-shaped picking strategy, the picking routes for Order A, Order B, and Order C are plotted. The specific picking routes for each order are shown in Figures 7-9, respectively.

4.2.2. Calculation of Picking Order Distance and Time

The calculation of the X-axis coordinates of each pick-up item in pick-up Order A, Order B, and Order C is given in Equation (1). Based on the average measurement, the width of each shelf in the Fuzhou IKEA warehouse is $d_c = 1.24$ m, and the average width of each aisle is $d = 2d_c = 2.48$ m. As point S is located near the origin of the coordinate system, then $X_S = 0$. Point C represents the shelf

Table 2. Distance matrix of goods to be picked.

	W_0	W_1	$\cdots$	W_n
W_0	S_{00}	S_{01}	$\cdots$	S_{0n}
W_1	S_{10}	S_{11}	$\cdots$	S_{1n}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
W_n	S_{n0}	S_{n1}	$\cdots$	S_{nn}

Table 3. Picking Order *A*, Order *B*, and Order *C* (10, 20, 50 kinds of goods to be picked).

Order	ID	Quantity	Storage location	Location coordinates	Order	ID	Quantity	Storage location	Location coordinates
Order *A*	1	1	06-22-00	W_7	Order *C*	11	4	10-47-00	W_{13}
	2	1	08-31-00	W_6		12	1	11-12-00	W_{26}
	3	3	08-49-00	W_5		13	1	11-40-00	W_{15}
	4	1	09-17-00	W_8		14	2	11-46-00	W_{14}
	5	4	10-11-00	W_9		15	1	12-19-00	W_{29}
	6	1	15-53-00	W_4		16	10	12-50-00	W_{12}
	7	2	18-07-00	W_{10}		17	1	13-15-00	W_{30}
	8	2	19-38-00	W_2		18	1	13-19-00	W_{28}
	9	1	19-41-00	W_3		19	2	13-28-00	W_{27}
	10	1	25-36-00	W_1		20	1	15-49-00	W_{11}
Order *B*	1	1	03-12-00	W_{11}		21	1	15-53-00	W_{10}
	2	1	06-23-00	W_{12}		22	1	16-42-00	W_{46}
	3	3	08-31-00	W_8		23	10	16-48-00	W_{47}
	4	1	08-41-00	W_{10}		24	1	16-49-00	W_{19}
	5	4	09-17-00	W_{13}		25	1	17-14-00	W_{31}
	6	1	09-44-00	W_9		26	1	17-29-00	W_{43}
	7	2	10-11-00	W_{14}		27	10	17-41-00	W_{44}
	8	2	11-40-00	W_7		28	1	17-42-00	W_{45}
	9	5	15-53-00	W_6		29	1	17-48-00	W_{48}
	10	1	16-42-00	W_{19}		30	8	17-51-00	W_{50}
	11	1	16-49-00	W_{20}		31	1	18-07-00	W_{32}
	12	1	17-14-00	W_{15}		32	2	19-38-00	W_9
	13	1	18-07-00	W_{16}		33	1	20-47-00	W_8
	14	2	19-38-00	W_4		34	1	21-10-00	W_{33}
	15	1	19-41-00	W_5		35	2	22-14-00	W_{35}
	16	1	20-47-00	W_3		36	1	22-17-00	W_{34}
	17	10	25-04-00	W_{17}		37	1	25-04-00	W_{36}
	18	1	25-05-00	W_{18}		38	10	25-05-00	W_{37}
	19	1	25-36-00	W_2		39	1	25-36-00	W_7
	20	1	26-43-00	W_1		40	1	26-10-00	W_{38}
Order *C*	1	1	03-12-00	W_{21}		41	2	26-39-00	W_6
	2	1	04-16-00	W_{22}		42	1	26-43-00	W_5
	3	3	04-20-00	W_{23}		43	4	27-43-00	W_4
	4	1	07-32-00	W_{20}		44	4	28-39-00	W_3
	5	4	07-37-00	W_{19}		45	1	29-07-00	W_{39}
	6	1	08-49-00	W_{18}		46	2	29-18-00	W_{40}
	7	2	09-17-00	W_{25}		47	1	30-16-00	W_{41}
	8	2	09-21-00	W_{24}		48	1	32-16-00	W_{42}
	9	1	09-41-00	W_{16}		49	1	33-45-00	W_2
	10	1	09-44-00	W_{17}		50	1	33-49-00	W_1

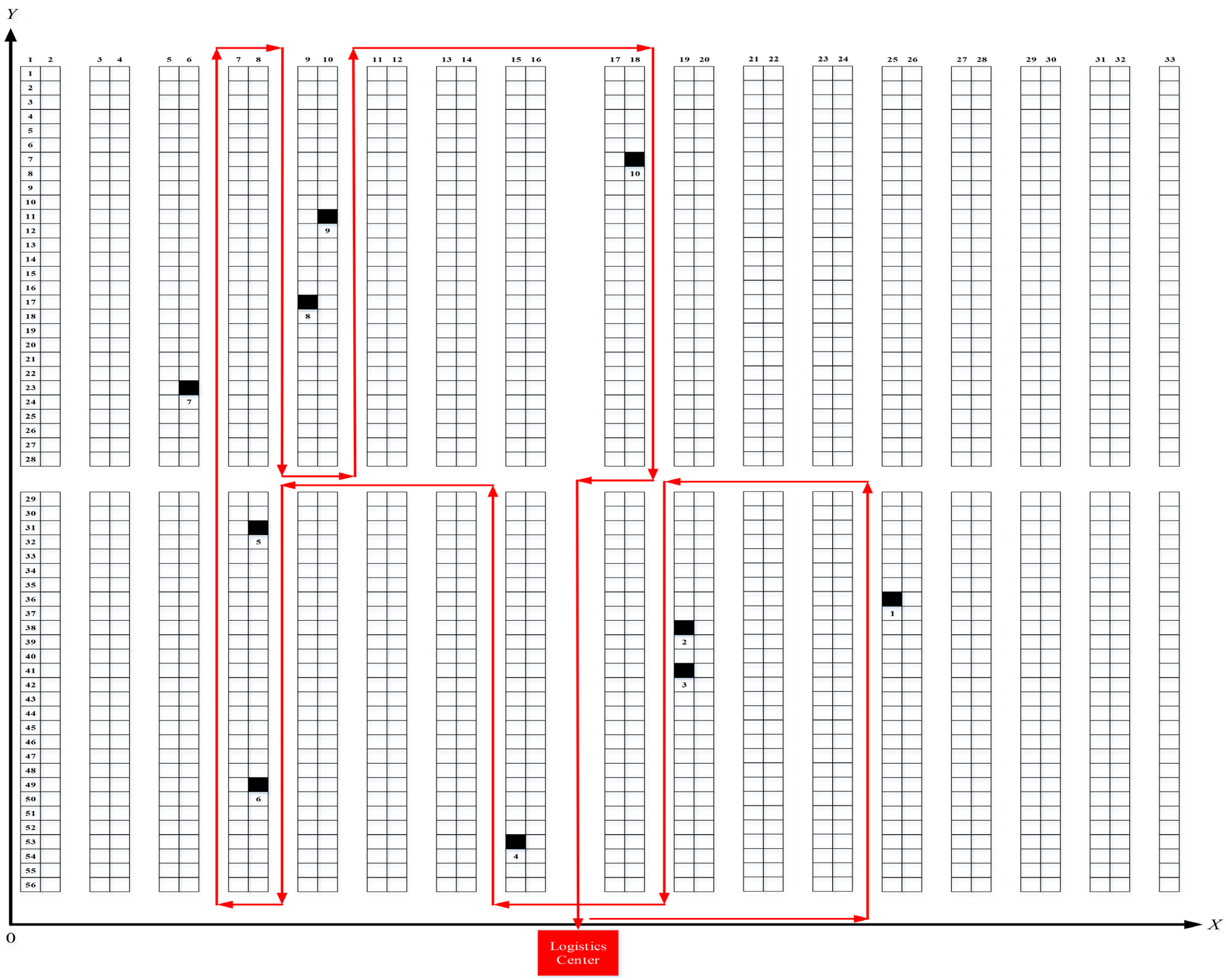


Figure 7. Picking path of Order A under S-type picking strategy (10 kinds of goods to be picked).

number where the item is located and can be obtained from the first two digits of the item's storage location in the order. Therefore, the calculation formula for the horizontal coordinates of each point in the warehouse can be rewritten as Equation (7).

$$x = 2.48 \times (C - 1). \tag{7}$$

The calculation formula for the ordinate of each point is given in Equation (3). Because point S is close to the origin, this yield $Y_S = 0$. The value of R is either 1 or 2 depending on the aisle where the item is located; $R = 1$ for the aisle closer to the logistics center, and $R = 2$ for the aisle further away. The total length of each aisle is $l = 28 \times 0.84$ m, while the width of the central aisle is $\Delta l = 2 \times 0.84$ m. Because the values for B and P can be directly obtained from the item storage location code, this yields $l_B = l_P = 0.84$ m. Therefore, the calculation formula for the ordinate of each point in the warehouse can be converted to Equation (8). In the next step, the warehouse storage location data for the three orders were entered to obtain the corresponding horizontal and vertical coordinate data, as shown in **Tables 4-6**.

Figure 8. Picking path of Order B under S-type picking strategy (20 kinds of goods to be picked).

Table 4. Storage location coordinates of Order A.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = P$	X coordinate	Y coordinate
Order A	06-22-00	W_7	6	22	2	7	12.40	30.66
	08-31-00	W_6	8	31	1	26	17.36	21.42
	08-49-00	W_5	8	49	1	8	17.36	6.30
	09-17-00	W_8	9	17	2	12	19.84	34.86
	10-11-00	W_9	10	11	2	18	22.32	39.90
	15-53-00	W_4	15	53	1	4	34.72	2.94
	18-07-00	W_{10}	18	7	2	22	42.16	43.26
	19-38-00	W_2	19	38	1	19	44.64	15.54
	19-41-00	W_3	19	41	1	16	44.64	13.02
	25-36-00	W_1	25	36	1	21	59.52	17.22

Table 5. Storage location coordinates of Order B.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = P$	X coordinate	Y coordinate
Order B	03-12-00	W_{11}	3	12	2	17	4.96	39.06
	06-23-00	W_{12}	6	23	2	6	12.40	29.82
	08-31-00	W_{8}	8	31	1	26	17.36	21.42
	08-41-00	W_{10}	8	41	1	16	17.36	13.02
	09-17-00	W_{13}	9	17	2	12	19.84	34.86
	09-44-00	W_{9}	9	44	1	13	19.84	10.50
	10-11-00	W_{14}	10	11	2	18	22.32	39.90
	11-40-00	W_{7}	11	40	1	17	24.80	13.86
	15-53-00	W_{6}	15	53	1	4	34.72	2.94
	16-42-00	W_{19}	16	42	1	15	37.20	12.18
	16-49-00	W_{20}	16	19	1	8	37.20	6.30
	17-14-00	W_{15}	17	14	2	15	39.68	37.38
	18-07-00	W_{16}	18	7	2	22	42.16	43.26
	19-38-00	W_{4}	19	38	1	19	44.64	15.54
	19-41-00	W_{5}	19	41	1	16	44.64	13.02
	20-47-00	W_{3}	20	47	1	10	47.12	7.98
	25-04-00	W_{17}	25	4	2	25	59.52	45.78
	25-05-00	W_{18}	25	5	2	24	59.52	44.94
	25-36-00	W_{2}	25	36	1	21	59.52	17.22
	26-43-00	W_{1}	26	43	1	14	62.00	11.34

Table 6. Storage location coordinates of Order C.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = P$	X coordinate	Y coordinate
Order C	03-12-00	W_{21}	3	12	2	17	4.96	39.06
	04-16-00	W_{22}	4	16	2	13	7.44	35.70
	04-20-00	W_{23}	4	20	2	9	7.44	32.34
	07-32-00	W_{20}	7	32	1	25	14.88	20.58
	07-37-00	W_{19}	7	37	1	20	14.88	16.38
	08-49-00	W_{18}	8	49	1	8	17.36	6.30
	09-17-00	W_{25}	9	17	2	12	19.84	34.86
	09-21-00	W_{24}	9	21	2	8	19.84	31.50
	09-41-00	W_{16}	9	41	1	16	19.84	13.02
	09-44-00	W_{17}	9	44	1	13	19.84	10.50
	10-47-00	W_{13}	10	47	1	10	22.32	7.98
	11-12-00	W_{26}	11	12	2	17	24.80	39.06

Continued

11-40-00	W_{15}	11	40	1	17	24.80	13.86
11-46-00	W_{14}	11	46	1	11	24.80	8.82
12-19-00	W_{29}	12	19	2	10	27.28	33.18
12-50-00	W_{12}	12	50	1	7	27.28	5.46
13-15-00	W_{30}	13	15	2	14	29.76	36.54
13-19-00	W_{28}	13	19	2	10	29.76	33.18
13-28-00	W_{27}	13	28	2	1	29.76	25.62
15-49-00	W_{11}	15	49	1	8	34.72	6.30
15-53-00	W_{10}	15	53	1	4	34.72	2.94
16-42-00	W_{46}	16	42	1	15	37.20	12.18
16-48-00	W_{47}	16	48	1	9	37.20	7.14
16-49-00	W_{49}	16	49	1	8	37.20	6.30
17-14-00	W_{31}	17	14	2	15	39.68	37.38
17-29-00	W_{43}	17	29	1	28	39.68	23.10
17-41-00	W_{44}	17	41	1	16	39.68	13.02
17-42-00	W_{45}	17	42	1	15	39.68	12.18
17-48-00	W_{48}	17	48	1	9	39.68	7.14
17-51-00	W_{50}	17	51	1	6	39.68	4.62
18-07-00	W_{32}	18	7	2	22	42.16	43.26
19-38-00	W_9	19	38	1	19	44.64	15.54
20-47-00	W_8	20	47	1	10	47.12	7.98
21-10-00	W_{33}	21	10	2	19	49.60	40.74
22-14-00	W_{35}	22	14	2	15	52.08	37.38
22-17-00	W_{34}	22	17	2	12	52.08	34.86
25-04-00	W_{36}	25	4	2	25	59.52	45.78
25-05-00	W_{37}	25	5	2	24	59.52	44.94
25-36-00	W_7	25	36	1	21	59.52	17.22
26-10-00	W_{38}	26	10	2	19	62.00	40.74
26-39-00	W_6	26	39	1	18	62.00	14.70
26-43-00	W_5	26	43	1	14	62.00	11.34
27-43-00	W_4	27	43	1	14	64.48	11.34
28-39-00	W_3	28	39	1	18	66.96	14.70
29-07-00	W_{39}	29	7	2	22	69.44	43.26
29-18-00	W_{40}	29	18	2	11	69.44	34.02
30-16-00	W_{41}	30	16	2	13	71.92	35.70
32-16-00	W_{42}	32	16	2	13	76.88	35.70
33-45-00	W_2	33	45	1	12	79.36	9.66
33-49-00	W_1	33	49	1	8	79.36	6.30

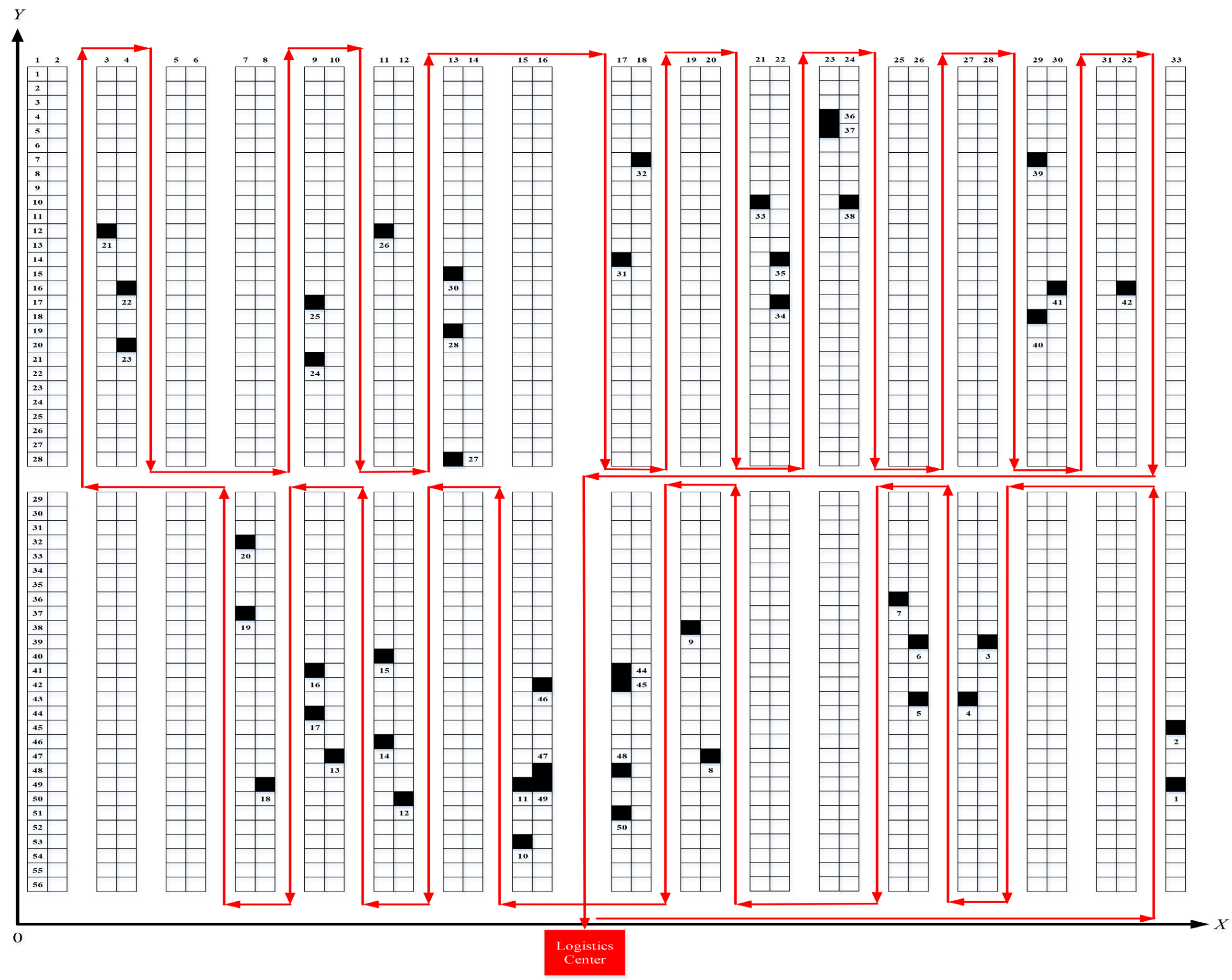


Figure 9. Picking path of Order C under S-type picking strategy (50 kinds of goods to be picked).

$$y = 25.2 \times (R-1) + 0.42 \times (2P-1). \tag{8}$$

After obtaining the coordinates of each item in the three orders, the distance between adjacent coordinates was calculated under the *S*-shaped picking strategy. The picking starts from the logistics center where all the items are picked up in sequence, and then returns to the logistics center. As the logistics center is located near the 16th shelf (X-axis of item 16 is 37.2) at the bottom of the Y-axis, the coordinates of the logistics center are set as (37.2, 0).

ΔY_i is the distance between item *i*'s coordinate and the southernmost end of the nearest shelf. Because $B = P$ and $l_B = l_P = 0.84$ m can be directly obtained from the position of the item, the total picking distance for Orders A, B, and C can be calculated by substituting the three sets of order data into Equation (4), Equation (5), and Equation (6), respectively, and the results are shown in Tables 7-9. Results show that the picking distance for Order A (10 items) is 283.08 m, the picking distance for Order B (20 items) is 497.16 m, and the picking distance for Order C (50 items) is 927.56 m.

Table 7. Total picking distance for Order *A* under the S-shaped picking strategy.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = P$	X coordinate	Y coordinate	ΔY_i	Distance from X-axis-X	Distance from Y-axis-Y	Picking distance $X + Y$
	Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	22.32	17.22	39.54
	25-36-00	W_1	25	36	1	21	59.52	17.22	17.22	14.88	14.28	29.16
	19-38-00	W_2	19	38	1	19	44.64	15.54	15.54	0.00	2.52	2.52
	19-41-00	W_3	19	41	1	16	44.64	13.02	13.02	9.92	15.96	25.88
	15-53-00	W_4	15	53	1	4	34.72	2.94	2.94	17.36	9.24	26.60
	08-49-00	W_5	8	49	1	8	17.36	6.30	6.30	0.00	15.12	15.12
Order A	08-31-00	W_6	8	31	1	26	17.36	21.42	21.42	4.96	9.24	14.20
	06-22-00	W_7	6	22	2	7	12.40	30.66	5.46	7.44	15.12	22.56
	09-17-00	W_8	9	17	2	12	19.84	34.86	9.66	2.48	22.68	25.16
	10-11-00	W_9	10	11	2	18	22.32	39.90	14.70	19.84	14.28	34.12
	18-07-00	W_{10}	18	7	2	22	42.16	43.26	18.06	4.96	43.26	48.22
	Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	-	-	-
						Total picking distance for Order A						283.08

Table 8. Total picking distance for Order *B* under the S-shaped picking strategy.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = P$	X coordinate	Y coordinate	ΔY_i	Distance from X-axis-X	Distance from Y-axis-Y	Picking distance $X + Y$
	Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	24.80	11.34	36.14
	26-43-00	W_1	26	43	1	14	62.00	11.34	11.34	2.48	18.48	20.96
	25-36-00	W_2	25	36	1	21	59.52	17.22	17.22	12.40	21.84	34.24
	20-47-00	W_3	20	47	1	10	47.12	7.98	7.98	2.48	23.52	26.00
	19-38-00	W_4	19	38	1	19	44.64	15.54	15.54	0.00	2.52	2.52
	19-41-00	W_5	19	41	1	16	44.64	13.02	13.02	9.92	15.96	25.88
	15-53-00	W_6	15	53	1	4	34.72	2.94	2.94	9.92	16.80	26.72
	11-40-00	W_7	11	40	1	17	24.80	13.86	13.86	7.44	11.76	19.20
	08-31-00	W_8	8	31	1	26	17.36	21.42	21.42	2.48	15.12	17.60
	09-44-00	W_9	9	44	1	13	19.84	10.50	10.50	2.48	23.52	26.00
	08-41-00	W_{10}	8	41	1	16	17.36	13.02	13.02	12.40	26.04	38.44
Order B	03-12-00	W_{11}	3	12	2	17	4.96	39.06	13.86	7.44	18.48	25.92
	06-23-00	W_{12}	6	23	2	6	12.40	29.82	4.62	7.44	14.28	21.72
	09-17-00	W_{13}	9	17	2	12	19.84	34.86	9.66	2.48	22.68	25.16
	10-11-00	W_{14}	10	11	2	18	22.32	39.90	14.70	17.36	20.16	37.52
	17-14-00	W_{15}	17	14	2	15	39.68	37.38	12.18	2.48	16.80	19.28
	18-07-00	W_{16}	18	7	2	22	42.16	43.26	18.06	17.36	8.40	25.76
	25-04-00	W_{17}	25	4	2	25	59.52	45.78	20.58	0.00	0.84	0.84
	25-05-00	W_{18}	25	5	2	24	59.52	44.94	19.74	22.32	32.76	55.08
	16-42-00	W_{19}	16	42	1	15	37.20	12.18	12.18	0.00	5.88	5.88
	16-49-00	W_{20}	16	19	1	8	37.20	6.30	6.30	0.00	6.30	6.30
	Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	-	-	-
						Total picking distance for Order B						497.16

Table 9. Total picking distance for Order C under the S-shaped picking strategy.

Order	Storage location	Location coordinates	Shelf number (C)	Location No. (B)	R	$B = F$	X coordinate	Y coordinate	ΔY_i	Distance from X-axis (X)	Distance from Y-axis (Y)	Picking distance ($X + Y$)
Order C	Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	42.16	6.30	48.46
	33-49-00	W_1	33	49	1	8	79.36	6.30	6.30	0.00	3.36	3.36
	33-45-00	W_2	33	45	1	12	79.36	9.66	9.66	12.40	22.68	35.08
	28-39-00	W_3	28	39	1	18	66.96	14.70	14.70	2.48	21.00	23.48
	27-43-00	W_4	27	43	1	14	64.48	11.34	11.34	2.48	22.68	25.16
	26-43-00	W_5	26	43	1	14	62.00	11.34	11.34	0.00	3.36	3.36
	26-39-00	W_6	26	39	1	18	62.00	14.70	14.70	2.48	15.12	17.60
	25-36-00	W_7	25	36	1	21	59.52	17.22	17.22	12.40	21.84	34.24
	20-47-00	W_8	20	47	1	10	47.12	7.98	7.98	2.48	23.52	26.00
	19-38-00	W_9	19	38	1	19	44.64	15.54	15.54	9.92	18.48	28.40
	15-53-00	W_{10}	15	53	1	4	34.72	2.94	2.94	0.00	3.36	3.36
	15-49-00	W_{11}	15	49	1	8	34.72	6.30	6.30	7.44	11.76	19.20
	12-50-00	W_{12}	12	50	1	7	27.28	5.46	5.46	4.96	13.44	18.40
	10-47-00	W_{13}	10	47	1	10	22.32	7.98	7.98	2.48	16.80	19.28
	11-46-00	W_{14}	11	46	1	11	24.80	8.82	8.82	0.00	5.04	5.04
	11-40-00	W_{15}	11	40	1	17	24.80	13.86	13.86	4.96	20.16	25.12
	09-41-00	W_{16}	9	41	1	16	19.84	13.02	13.02	0.00	2.52	2.52
	09-44-00	W_{17}	9	44	1	13	19.84	10.50	10.50	2.48	16.80	19.28
	08-49-00	W_{18}	8	49	1	8	17.36	6.30	6.30	2.48	22.68	25.16
	07-37-00	W_{19}	7	37	1	20	14.88	16.38	16.38	0.00	4.20	4.20
	07-32-00	W_{20}	7	32	1	25	14.88	20.58	20.58	9.92	18.48	28.40
	03-12-00	W_{21}	3	12	2	17	4.96	39.06	13.86	2.48	22.68	25.16
	04-16-00	W_{22}	4	16	2	13	7.44	35.70	10.50	0.00	3.36	3.36
	04-20-00	W_{23}	4	20	2	9	7.44	32.34	7.14	12.40	13.44	25.84
	09-21-00	W_{24}	9	21	2	8	19.84	31.50	6.30	0.00	3.36	3.36
	09-17-00	W_{25}	9	17	2	12	19.84	34.86	9.66	4.96	23.52	28.48
	11-12-00	W_{26}	11	12	2	17	24.80	39.06	13.86	4.96	14.28	19.24
	13-28-00	W_{27}	13	28	2	1	29.76	25.62	0.42	0.00	7.56	7.56
	13-19-00	W_{28}	13	19	2	10	29.76	33.18	7.98	2.48	15.96	18.44
	12-19-00	W_{29}	12	19	2	10	27.28	33.18	7.98	2.48	19.32	21.80
	13-15-00	W_{30}	13	15	2	14	29.76	36.54	11.34	9.92	23.52	33.44
	17-14-00	W_{31}	17	14	2	15	39.68	37.38	12.18	2.48	16.80	19.28
	18-07-00	W_{32}	18	7	2	22	42.16	43.26	18.06	7.44	13.44	20.88
	21-10-00	W_{33}	21	10	2	19	49.60	40.74	15.54	2.48	21.84	24.32
	22-17-00	W_{34}	22	17	2	12	52.08	34.86	9.66	0.00	2.52	2.52

Continued

22-14-00	W_{35}	22	14	2	15	52.08	37.38	12.18	7.44	14.28	21.72
25-04-00	W_{36}	25	4	2	25	59.52	45.78	20.58	0.00	0.84	0.84
25-05-00	W_{37}	25	5	2	24	59.52	44.94	19.74	2.48	11.76	14.24
26-10-00	W_{38}	26	10	2	19	62.00	40.74	15.54	7.44	13.44	20.88
29-07-00	W_{39}	29	7	2	22	69.44	43.26	18.06	0.00	9.24	9.24
29-18-00	W_{40}	29	18	2	11	69.44	34.02	8.82	2.48	19.32	21.80
30-16-00	W_{41}	30	16	2	13	71.92	35.70	10.50	4.96	21.00	25.96
32-16-00	W_{42}	32	16	2	13	76.88	35.70	10.50	37.20	12.60	49.80
17-29-00	W_{43}	17	29	1	28	39.68	23.10	23.10	0.00	10.08	10.08
17-41-00	W_{44}	17	41	1	16	39.68	13.02	13.02	0.00	0.84	0.84
17-42-00	W_{45}	17	42	1	15	39.68	12.18	12.18	2.48	22.68	25.16
16-42-00	W_{46}	16	42	1	15	37.20	12.18	12.18	0.00	5.04	5.04
16-48-00	W_{47}	16	48	1	9	37.20	7.14	7.14	2.48	14.28	16.76
17-48-00	W_{48}	17	48	1	9	39.68	7.14	7.14	2.48	13.44	15.92
16-49-00	W_{49}	16	49	1	8	37.20	6.30	6.30	2.48	10.92	13.40
17-51-00	W_{50}	17	51	1	6	39.68	4.62	4.62	2.48	4.62	7.10
Logistics center	W_0	16	-	1	-	37.20	0.00	0.00	-	-	-
				Total picking distance for Order C							927.56

This study's field investigation found that the order of picking-time of the employees can be mainly divided into the following parts: receiving and confirming the picking task, the initialization time (T_i) for starting the picking, the picking route time (T_d), the scanning time (T_s) for a single item after the employee reaches the corresponding item to be picked (the average scanning time for each item is 3 secs), the picking time (T_t) for picking up and placing each item onto the cart (the average time for each item to be picked up and placed onto the cart is 15 secs), and the final time (T_e) for confirming the completion of the picking task, and the generating and signing of the printout form after returning to the logistics center.

Following the field study results, the average walking speed of Ikea employees is 1.4 m/s. Assuming the total picking distance of the order is S, and the picking distances of Order A, Order B, and Order C are S_a, S_b, and S_c respectively, as calculated from the picking distances in **Tables 7-9**, S_a = 283.08 m, S_b = 497.16 m, and S_c = 927.56 m. Assuming the total number of items is N, and the number of items in Order A, Order B, and Order C are N_a, N_b, and N_c respectively, as shown in **Table 3**, N_a = 17 items, N_b = 41 items, and N_c = 115 items. Moreover, $T_i = 10s$, $T_d = S \times 1.4s$, $T_s = N \times 3s$, and $T_t = N \times 15s$, and $T_e = 20s$.

In summary, the total picking time for an order can be obtained using the following equation: $T = T_i + T_d + T_s + T_t + T_e = 10 + 1.4S + 3N + 15N + 20 = (1.4S + 18N + 30)s$ secs. By substituting this formula with the specific values for orders A, B, and C, the picking times for each order can be calculated and are presented in detail in Table 10. According to the table, the total picking times for Order *A*, Order *B*, and Order *C* under the *S*-shaped picking strategy are 12.21 mins, 24.4 mins, and 56.64 mins, respectively. The analysis results in Table 10 have a negligible deviation from the average picking times for the three types of orders presented in Table 1, indicating the applicability of the traditional S-shaped picking strategy distance and time calculation formula in the overall order picking process at the IKEA Fuzhou distribution warehouse.

5. Analysis of Picking Routes and Efficiency in Genetic Algorithm-Based Optimization

5.1. Assumptions and Parameter Settings for Problem Model

This paper takes the IKEA distribution center in Fuzhou as the research object for order picking. To facilitate the calculation of the distribution route of the distribution center and reduce unnecessary interference factors, the specific layout of the warehouse was simplified through transformation without affecting the overall layout and real data. The simplified warehouse was divided into four areas by the main aisle and the transverse passage of the logistics center, and can be regarded as a double-area warehouse as a whole. The warehouse is divided into three aisles, 16 lanes, 32 rows of shelves with 56 storage locations each, ultimately reaching a total of 1848 storage locations with each storage location storing one kind of goods.

The S-shaped picking strategy and Manhattan distance were employed to compute the picking distance and time between any two points of goods. As for the order data, as shown in Table 3, there were 10 orders of type *A* with 20 items to be picked, 20 orders of type *B* with 50 items to be picked, and 50 orders of type *C* with varying numbers of items to be picked. These three sets of order data were incorporated into the model, and a genetic algorithm was utilized to determine the picking distance and time for each respective order.

To establish the model for optimizing the picking route of goods in the IKEA Fuzhou distribution warehouse, the following assumptions were made:

1) Assumption 1: The inventory in the picking area of the warehouse is sufficient in meeting the picking requirements of the orders, and there is no shortage of goods.

2) Assumption 2: Each picking location of each shelf can only store one type of item.

Table 10. Total picking time of Order *A*, Order *B*, and Order *C* under S-type picking strategy.

	T_i	T_d	T_s	T_t	T_e	Total picking time (T/s)	Total picking time (T/min)
Order *A*	10.00	396.31	51.00	255.00	20.00	732.31	12.21
Order *B*	10.00	696.02	123.00	615.00	20.00	1464.02	24.40
Order *C*	10.00	1298.58	345.00	1725.00	20.00	3398.58	56.64

3) Assumption 3: The shortest linear walking distance between two picking locations with coordinates $W_i\,(x_i, y_i)$ and $W_j\,(x_j, y_j)$ is denoted as S_{ij}, and the distance between goods was calculated based on the Manhattan distance.

4) Assumption 4: In the same picking aisle, pickers can select goods from both left and right sides of the shelves.

5) Assumption 5: The distance traveled by the picker during the picking process was calculated based on the midpoint of the coordinates of the picking locations that need to be visited.

6) Assumption 6: To reduce the complexity of the model, the width distance of the main aisle was assumed to be equal to that of the other aisles.

The model parameters are shown in Table 11.

Table 11. Description table of main parameters.

Parameter	Explanation of parameter	Setting value/other instructions
R_i	Row number of warehouse, the first row is the lower row near the logistics center, and the second row is the upper row	$i = 1, 2$
C_i	Column number of warehouse, columns 1 - 33 from left to right	$i = 1, 2, \ldots, 33$
B_i	Shelf number of the warehouse, which is 1 - 56 from north to south	$i = 1, \ldots, 256$
P_i	Location number of the warehouse, because one shelf stores one kind of goods, thus $B = P$	$i = 1, 2, \ldots, 56$
l_B	Length of each section of the shelf	0.84 m
l_p	Length of each storage location within each section of the shelf	0.84 m
l	Length of the shelf	$l = 28 \times 0.84$ m
Δl	Distance between two rows of shelves	1.68 m
d	Shelf width distance	2.48 m
d_c	Width distance of each column of shelves	1.24 m
W_i	Coordinates of the item i	$W_i(x_i, y_i)$
S_{ij}	Distance from item i to item j, where $S_{ij} = S_{ji}$	$S_{ij} = X_{ij} + Y_{ij}$
X_i	Abscissa distance from item i to item j	
Y_i	Ordinate distance from item i to item j	
ΔY_i	Distance between item i's coordinate and the southernmost end of the nearest shelf	
T	Total picking time	$T = T_i + T_d + T_s + T_t + T_e$
T_i	Initialization time for starting the picking	$20s$
T_d	Picking route time	Determined by picking distance
T_s	Scanning time for a single item after the employee reaches the corresponding item to be picked	Determined by picking distance
T_t	Picking time for picking up and placing each item onto the cart	Determined by picking distance
T_e	Complete the picking task, print and sign to confirm the final time	$30s$
N_n	Quantity of chromosome population	Determined by order type
P_c	Crossover factor	Determined by order type
P_m	Mutation factor	Determined by order type
round	Maximum number of iterations	Determined by order type

5.2. Picking Route Optimization Model Based on Genetic Algorithm

To establish an optimized picking route model, the first step is to construct a two-dimensional coordinate distance matrix of goods and determine the coordinates of each item to be picked. Then, a distance matrix model is established between any two points by combining the Manhattan distance and the characteristics of the warehouse shelves. After completing the calculation of the distance between any two goods locations, because the optimization of the warehouse picking route is equivalent to the TSP [27] [28], an adapted TSP model was established for warehouse picking route optimization to facilitate problem-solving.

This study assumes that the picker starts from the logistics center $W_0(37.2, 0)$, traverses all the locations of the items in a picking order, and returns to the logistics center. Let $W_1, W_2, \ldots, W_n$ denote the coordinates of all the items in a picking order, where no two coordinates are identical. The coordinates of the i^{th} item are denoted as $W_i(x_i, y_i)$, where $i = \{0, 1, 2, \ldots, n\}$. Let S_{ij} denote the shortest distance between W_i and W_j, and introduce parameter X_{ij}, where $i = \{0, 1, 2, ..., n\}$ and $j = \{0, 1, 2, ..., n\}$, which is defined as shown in Equation (9).

$$x_{ij} = \begin{cases} 1, \text{ Picking storage location } W_i \text{ and} \\ \quad \text{storage location } W_j \text{ sequentially} \\ 0, \text{ No contiguous order between storage location } W_i \text{ and} \\ \quad \text{storage location } W \end{cases}. \tag{9}$$

Table 2 shows the distance matrix between the pickup locations and entrances at this point. Therefore, to minimize the pickup route, the mathematical model is established as shown in Equation (10) to Equation (14).

$$\min\ Z = \sum_i \sum_j s_{ij} x_{ij}. \tag{10}$$

$$\sum_{i=0}^{n} x_{ij} = 1,\ i = 1, 2, \cdots, n. \tag{11}$$

$$\sum_{j=0}^{n} x_{ij} = 1,\ j = 1, 2, \cdots, n. \tag{12}$$

$$\sum_{i \in D, j \in D} x_{ij} \ge 1,\ D \text{ is the any subset of the set of items waiting to be picked}. \tag{13}$$

$$x_{ij} \in \{0, 1\},\ i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, n. \tag{14}$$

Equation (10) represents the minimization of the total route length taken by a picker who starts from the logistics center, passes through n pick-up locations, and returns to the logistics center. Equation (11) and Equation (12) indicate that the pick route must pass through each location only once. Equation (13) implies that the pick route must form a complete cycle after visiting all the pick-up locations. Finally, Equation (14) represents a constraint on the 0 - 1 variables.

5.3. Genetic Algorithm Solution for the Model

5.3.1. Overall Solution Approach of the Algorithm

The steps of the genetic algorithm include parameter setting, population initialization, fitness function calculation, selection, crossover, mutation, termination criteria, and outputting the results [10] [29] [30]. The parameter setting of the algorithm is explained as the steps progress after population initialization. Additionally, in terms of software and hardware configuration, the processor used for program execution was i5-8300h, the software version used was Python: 3.8.5, and the compilation environment used was sublime text: 4126. The solution steps are explained as follows:

Step 1. Population Initialization: The first step is to encode the order data using a real-value encoding method, and input the coordinates of the items to be picked into the system. The order of the item coordinates was used as the chromosome solution encoding. The generation of the initial population begins after encoding the orders. A randomly generated chromosome population with a quantity of N_n and a length of 11/21/51 was used herein, and was generated by a random uniform distribution method. The specific population quantity must be modified and improved based on the characteristics of the data for Orders *A*, *B*, and *C*.

Step 2. Fitness function: The goal of the algorithm is to calculate the picking distance and time. The picking time was mainly determined by the picking distance and other factors. Therefore, the fitness function should be consistent with the model established in Section 2 of this chapter *i.e.*, the shorter the picking distance of a chromosome, the higher its fitness, and the better its performance, which can be preserved in subsequent evolution as the basis for the next generation.

Step 3. Genetic operators: Three genetic operators were used:

1) Selection: After initializing the population with 20 chromosomes of length 11 for Order *A*, the next step is to select a certain number of chromosomes for reproduction based on their fitness. Tournament selection was used herein, which involves randomly selecting a few chromosomes from the population and comparing their fitness values. The chromosome with the highest fitness value is then selected for reproduction. This process is repeated until the desired number of chromosomes is selected for reproduction.

2) Crossover: In the crossover process, two parent chromosomes are selected from the selected population, and their genetic information are combined to produce offspring chromosomes. The commonly used single-point crossover method cannot be used for the TSP because it may lead to the offspring chromosomes having duplicate genes, resulting in the incomplete delivery of goods. Therefore, this paper used the partially mapped crossover (PMX) method which first selects two random cut points to slice the parent chromosomes, with the genetic information between these cut points thereafter swapped between the two parent chromosomes. Next, the offspring chromosomes with duplicate genes are identified, and the corresponding genetic information is swapped between the parents. This process is repeated until there are no more duplicate genes in the offspring chromosomes [31].

3) Mutation: Mutation is a genetic operator that introduces diversity into the population. In this paper, the mutation operator randomly selects two genes from a chromosome and swaps their positions to create a new chromosome. The probability of mutation is typically set to a low value to maintain the population's diversity. However, the actual mutation probability must be determined through multiple trials based on the specific order data.

Step 4. Setting of termination conditions: This step is based on the program running iterative operation until the results show no significant decrease, thereby terminating the model and output either its optimal or suboptimal solution. Based on the characteristics of the orders, termination conditions are set for Orders A, B, and C to end the iterative operation when the number of iterations reaches 50, 200, and 800, respectively, thereafter outputting the optimization results.

5.3.2. Genetic Algorithm Solution Result

After either reaching or exceeding 100 experimental runs, this paper set the parameters of the population size (N_n), the maximum number of iterations ($round$), and the mutation factor (P_m) for Order A, Order B, and Order C as shown in Table 12.

Through a comprehensive analysis of the program's execution, it was determined that the algorithm yielded optimal results for the data associated with Order A. Notably, the algorithm displayed remarkable stability in output results during multiple runs. Moreover, given the limited number of items to be picked, the population size and mutation factor had only a marginal impact on the algorithm's final outcome.

Interestingly, the optimal route could be selected in a relatively modest number of iterations, usually around 20. In contrast, the data corresponding to Order B demonstrated a relatively consistent output during multiple runs. However, the algorithm required a larger number of iterations to reach the optimal solution when the population size was close to the number of items to be picked. The impact of the mutation factor was also more pronounced, with the algorithm generally struggling to iterate to the optimal solution range when $P_m = 0.1$, but more stable when $P_m = 0.8$.

Finally, for Order C, output results demonstrated greater instability. As the number of items to be picked increased to 50, the algorithm exhibited signs of fatigue, with a tendency to fall into a locally optimal solution. This was coupled with a prolonged execution time, averaging approximately 9 secs, compared to the 1.35 secs and 1.75 secs for orders A and B, respectively. However, the role of the mutation factor was further highlighted, given its ability to effectively prevent the algorithm from falling into a locally optimal solution.

5.4. Results Analysis

5.4.1. Optimal Picking Order

Figures 10-12 show the pick sequence obtained by the genetic algorithm and the

Table 12. Parameter settings of orders.

	N_n	*round*	P_m
Order A	20	50	0.6
Order B	40	200	0.8
Order C	80	800	0.9

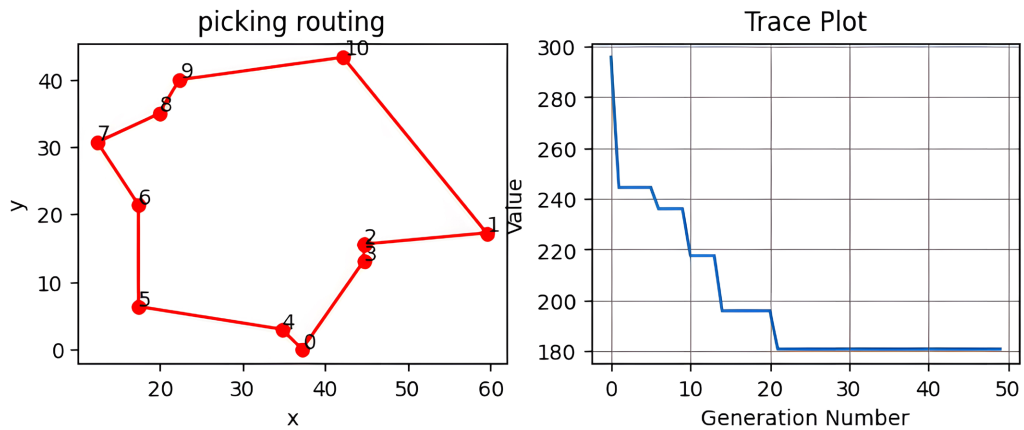


Figure 10. Picking routing and algorithm convergence process of Order A.

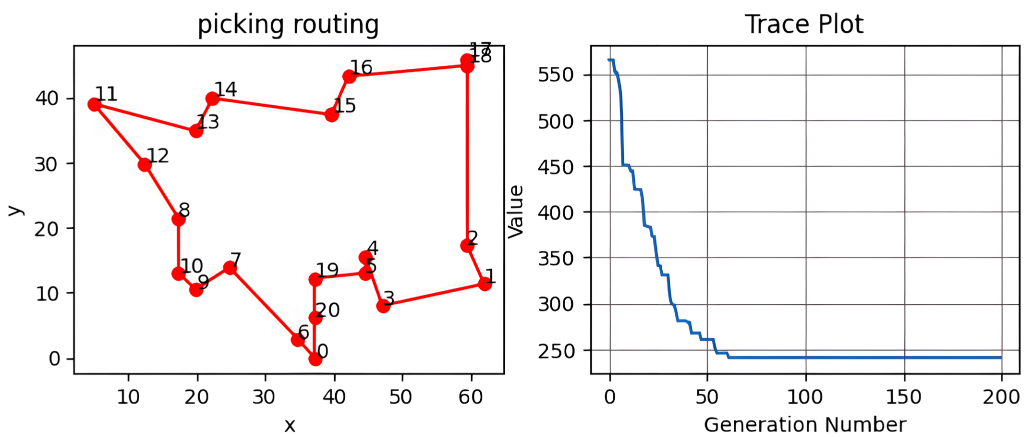


Figure 11. Picking routing and algorithm convergence process of Order B.

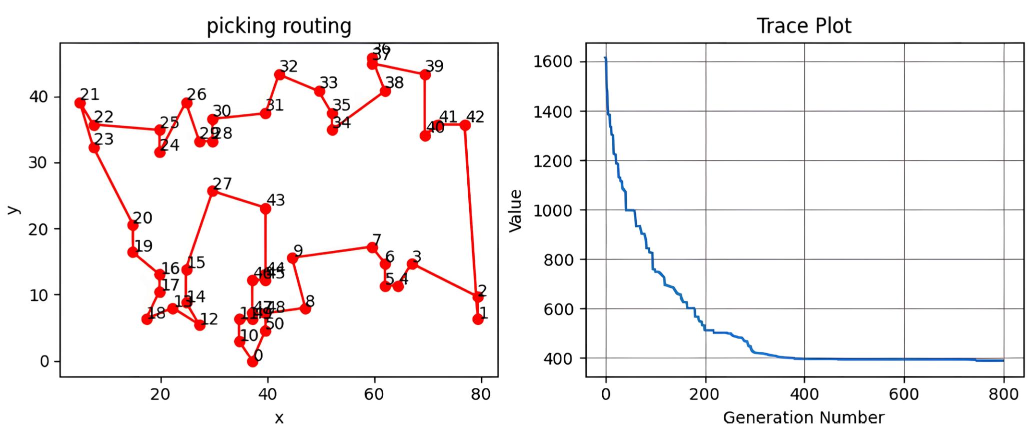


Figure 12. Picking routing and algorithm convergence process of Order C.

algorithm convergence process for Order A, Order B, and Order C, respectively. **Figure 10** shows that for Order A, the shortest pick distance output by the program is 180.76 m, and the optimal pick sequence is [0-6-3-2-1-4-5-7-10-8-9-0]. **Figure 11** shows that for Order B, the shortest pick distance output by the program is 240.92 m, and the optimal sequence is [0-20-19-5-4-3-1-2-18-17-16-15-14-13-11-12-8-10-9-7-6]. **Figure 12** shows that for Order C, the shortest pick distance output by the program is 389.56 m, with an average pick distance of 410 m, and an optimal pick sequence of [0-10-12-18-16-17-13-14-15-19-20-23-22-21-24-25-26-30-28-29-27-43-31-32-33-34-35-38-37-36-39-40-41-42-2-1-3-4-5-6 -7-9-8-44-45-46-47-11-49-48-50-0]. In the pick sequence, the digits represent the coordinates of the goods W_i, where $i = \{0, 1, \ldots, 10, 20, 50\}$.

Based on the pick-up distances obtained for all Orders using genetic algorithm, we can calculate the pick-up time using Equation. (4), Equation (5), and Equation (6). Results are shown in **Table 13**.

5.4.2. Picking Efficiency Analysis

Based on the traditional S-type picking strategy and the genetic algorithm-based optimization of the picking distance and time results of Orders A, B, and C, the data are summarized in **Table 14** and the comparison results between both are shown in **Figure 13**.

As shown in **Table 14** and **Figure 13**, when the original traditional S-shaped picking strategy is adopted for all Orders, their respective picking distances are 283.08, 497.16, and 927.56 m. When the picking routes generated by genetic algorithms are used, the lowest picking times for the three orders can be reduced to 180.76, 240.92, and 389.56 m, with reduction rates of 36.15%, 51.54%, and 58%, respectively. The data indicates that the reduction in picking distance increases as the number of picking types increases, thus demonstrating the effectiveness of genetic algorithms in optimizing order picking routes in the IKEA

Table 13. Total picking time of Order A, Order B, and Order C under GA picking strategy.

	T_i	T_d	T_s	T_t	T_e	Total picking time (T/s)	Total picking time (T/min)
Order A	10.00	253.06	51.00	255.00	20.00	589.06	9.82
Order B	10.00	337.29	123.00	615.00	20.00	1105.29	18.42
Order C	10.00	545.38	345.00	1725.00	20.00	2645.38	44.09

Table 14. Picking distance and time of S-Shaped and GA picking strategies.

	Picking distance (unit: meter)			Picking time (unit: minute)		
	Order A	Order B	Order C	Order A	Order B	Order C
S-type picking strategy	283.08	497.16	927.56	12.21	24.40	56.64
GA picking strategies	180.76	240.92	389.56	9.82	18.42	44.09
Difference analysis	−36.15%	−51.54%	−58.00%	−19.56%	−24.50%	−22.16%

branch's distribution center. Overall, the picking distance of the three orders using genetic algorithms can be reduced by an average of 48.56%.

For picking time, according to Table 14 and Figure 13, compared to the traditional S-shaped picking strategy, Order *A*, Order *B*, and Order *C* can save 19.56%, 24.5%, and 22.16% of their picking time, respectively, when using the genetic algorithm picking strategy. The less significant reduction in picking time compared to picking distance is that employee picking time is influenced by multiple factors, including initialization time, the number of items, walking time, and end-of-picking tasks such as item handover and signing, making it less straightforward to reduce the picking time. Overall, the picking time of the three orders can be reduced by an average of 22.08%.

Based on the aforementioned data analysis, a scientific picking process can be constructed by using the order picking route generated by the genetic algorithm to enhance the efficiency of the picking process (Figure 14). Figure 14, unlike

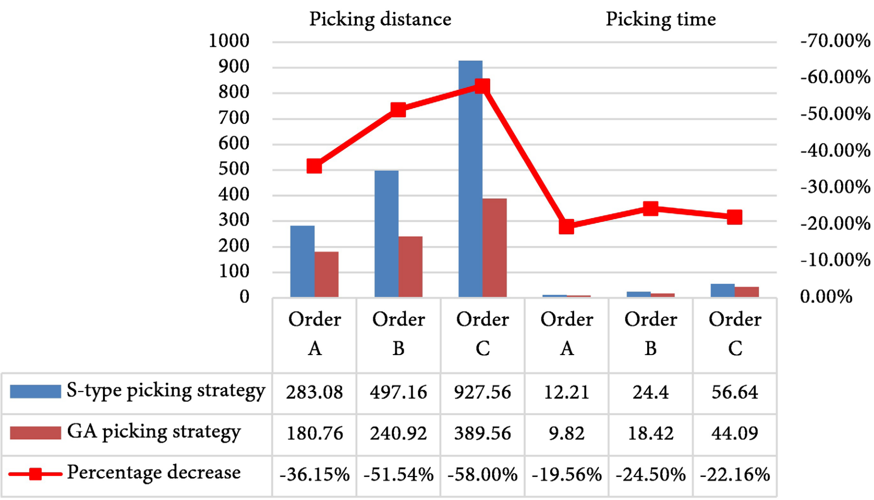


Figure 13. Comparison of picking distance and time between S-Shaped and GA Picking Strategie.

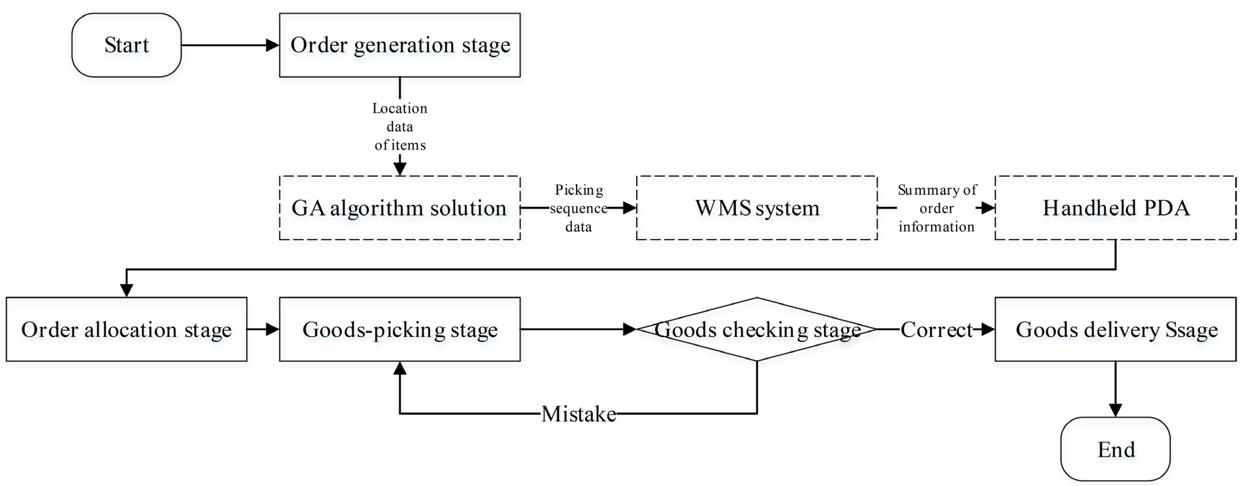


Figure 14. Algorithmic solution to the picking process for picking orders.

Figure 4 integrates the algorithm to determine the picking sequence and opens the information port of the WMS in the IKEA Fuzhou warehouse. Upon the generation of an order, the location information of the corresponding goods on the shelves is automatically generated and connected to the solution program of the genetic algorithm model. During program execution and output of the picking sequence of the order items, the information is fed back into the WMS system. Subsequently, the WMS system consolidates the original order information with the picking sequence and transmits it to the PDA held by the picker for order allocation, item picking, checking, and delivery, thereby completing the entire picking process. Integrating genetic algorithms into warehouse management systems can effectively improve picking efficiency. However, in practical applications, it is also necessary to establish a reasonable and standardized data management system to avoid incomplete and inaccurate order data. In addition, the genetic algorithm model needs to be updated regularly to optimize the picking performance of the warehouse management system.

6. Conclusions

The survival space of offline physical enterprises has been gradually compressed through the development of e-commerce. Moreover, due to the pandemic, the survival pressure of physical enterprises has further deepened. In terms of warehouse operations, finding ways to further reduce costs and increase efficiency is the main problem faced by all physical enterprises. In the case of IKEA Fuzhou, the planning of picking routes is entirely dependent on the personal experience of the picking staff. However, when dealing with a large variety of items to be picked for an order or when the distribution of items is uneven, there is a tendency for staff to take detours or follow overlapping routes, which adversely affects the efficiency of the picking process.

This paper addresses the issue of warehouse efficiency and operation optimization at the distribution center of the IKEA Home Furnishing Company's Fuzhou branch. Specifically, a genetic algorithm-based model for optimizing the picking route was proposed herein. The model was compared to the conventional S-shaped picking strategy in terms of its superiority and feasibility. Results show that the proposed genetic algorithm-based model significantly reduces the picking distance and time for orders with 10, 20, and 50 types of goods compared to the conventional S-shaped picking strategy. Specifically, the genetic algorithm reduces picking distance by 36.15%, 51.54%, and 58.00%, and shortens picking time by 16.44%, 20.26%, and 17.83%, respectively. The proposed scientific picking implementation process based on the genetic algorithm is capable of shortening the picking time and improving the efficiency of goods sorting. However, the genetic algorithm may also encounter local optima issues when dealing with a large variety of order goods. To address this, future and succeeding studies can consider using a mixed algorithm approach that combines the genetic algorithm with other algorithms, such as simulated annealing, to enhance the algorithm's performance.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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