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Research on Picking Strategy of Automatic Picking System Based on Orthogonal Test

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ABSTRACT

Three factors of the distance between adjacent picking machines, the picking time of single goods and the speed of conveyor belt in the automatic picking system is selected. Selecting three levels, and the orthogonal experiments were respective carried out for three different picking modes to analyze the influence extent of different factors on the total picking time. The optimal combination can be obtained by analyzing the analysis table of orthogonal experiment. Through the analysis of three different picking methods, it is found that the left-to-right picking method has a lower total picking time and is an excellent picking method. It is also pointed out that the series-parallel hybrid picking method has some limitations and is not suitable for the scenario where orders are concentrated on certain types of goods. But the picking speed efficiency is obviously faster than the other two in suitable scenarios such as when the level of different types of goods is basically the same or the number of items is large.In this paper, the combination of operation parameters in automatic picking system is studied, which has certain significance on how to improve the efficiency of automatic picking system in distribution center.

Key words: Automatic picking system; Orthogonal experiment; Strategy; Efficiency

INTRODUCTION

Generally speaking, the picking machine is placed on the side of the conveyor belt according to the number of types of the needed goods, and each picking machine can only store the same kind of goods in the buffer area, but it can change the location. In order picking system, each sorter sends the goods to the conveying system according to the demand of the order, and the goods are conveyed to the sorting and packaging operation desk by the conveyor belt. Generally, the automatic picking system carries on the batch to the order, and picks the next batch of order only after one batch of goods has been finished. The same batch of orders adopt the sequential picking strategy, that is, to start the next order picking after the previous order picking, or to select different orders at the same time, but one finished order space must be reserved on the conveyor belt to ensure that the goods on the conveyor belt are placed separately according to different orders.

Regarding the research on the picking strategy of the automatic picking system, Jewkes et al. [1,2] analyzed the previous work data in 2004, and used a dynamic programming algorithm to carry out a new cargo allocation for the goods in the manual picking work area, so that the shipment amount of each picking area was roughly consistent, and finally achieved the effect of reducing the picking time. Wu yingying et al. [3] studied the work flow of partition automatic picking in 2012 and divided the order processing time into confluent time and delay time to establish the picking time model of parallel and serial modes. Finally, taboo search method, dynamic programming method, dynamic clustering method, genetic algorithm, greedy algorithm and other methods were used to optimize the mathematical model. Lu shaoping [4] studied the effects of the number of picking areas, the order of items and the capacity of each location on the picking efficiency of the automatic picking system in 2012, and analyzed the relationship between the action sequence of the baffle and the time of picking a batch of orders. Based on this, in order to reduce the total picking time as the objective function, the volume of picking space, the number of picking zones and the order of picking location are taken as the influencing factors, and the CV time model and the optimal solution is obtained. Among them, the similarity coefficient is introduced to establish the allocation model.

Rosenblatt & Roll [5-7] took the displacement, picking time, picking cost and warehousing utilization of goods needed to complete picking as reference factors in 2013, and planned the warehousing layout of distribution centers in order to solve the problem of reducing costs and improving efficiency. Zhang Xupeng [8] studied the module partitioning method of automatic drug sorting system in 2012, designed the module partitioning method based on functional analysis, put forward a variety of module partitioning methods of different combinational order, and analyzed the feasibility of this method. Xiao Jiwei and others [9] studied the combination of a typewriter and horizontal sorter in 2008. The optimization model was established with the total sorting cost as the objective function, and the effects of different combinations on the sorting time and cost were studied. Hausman,et al. [10,11] conducted research in 2015 on the influence of three different storage methods, namely random, dedicated and class based, on the movement distance required by the access machine for picking an order in the ABC turnover based system. Chin-chia Jane and yih-wenn Laih[12] were to make the work amount of each picker in each picker area roughly consistent in 2005, improve the clustering model of the picker system, and adopt the improved heuristic algorithm to minimize the total picker time. Liu Debao et al. [13] proposed a series-parallel hybrid picking strategy in 2015, which can reduce the overall picking time and improve the efficiency of the automatic picking system. In this kind of picking method, the goods of an order are sorted in batches on the picking system. First, the goods that can be picked at the same time are selected, then the empty picking is carried out, and finally the remaining goods are sorted in turn. This kind of picking method improves the efficiency of picking. Wang Yanyan and others [14] deeply analyzed the overall selection process of parallel automatic sorting system in 2013. Through analysis, it is judged that the delay of the sorter will affect the overall sorting efficiency. On this basis, this paper establishes a virtual window-based picking time model to study whether the quantity of goods needed to be discharged from warehouse can be split and the effect of the split on picking efficiency. Finally, a model of total picking time is established under the condition of mass shipment. The objective is to find the shortest picking time. The heuristic adaptive genetic algorithm is used to find the optimal solution.

For the automatic picking system, if the picking strategy and the location are determined, the main reason is that the operating parameters of the system will affect the picking operation time. This paper chooses the operation parameters of the picking machine of the automatic picking system, which include the time t'(s), the speed v(m/s) of the conveyor belt and the distance l(m) between the adjacent picking machines. In this chapter, we mainly analyze the influence of these three factors on the picking efficiency.

In this paper, the orthogonal test method will be used to analyze the influence of these three factors on the picking efficiency in three different picking methods, that is, different parameters will be set and substituted into the total picking time model. The following work will be done and the results will be carried out in order to do these:

1. The influence degree of these three factors on picking efficiency is analyzed and compared, and the primary and secondary factors affecting picking efficiency are determined[15].
2. The influence law of different parameters on the total picking operation time is analyzed and compared, and the influence of each factor level is determined by quantitative analysis based on range analysis method[16].
3. In the different collocation designs of each factor and its reference value, the more optimized scheme combination design is sought[17].

BASIC AUTOMATIC PICKING MODE AND OPERATION TIME MODEL

In this paper, three common picking methods are studied, which are right-to-left sequential picking, left-to-right sequential picking and series-parallel hybrid picking.

2.1 Picking time model of right-to-left sequential picking

The right-to-left sequential picking method is to pick all the goods required in the order from right to left according to the position in the picking channel [18]. According to the goods that need to be selected in the order, the system start from the first goods that need to be delivered on the right of the automatic picker. At this time, the starting time of the left goods can be determined. Because the quantity of goods required is greater than 1, all goods are not selected at the same time, and there is a certain time difference to ensure that there is no overlap of goods and the same kind of goods scattered on the conveyor belt. After all the goods are picked, the state of the goods on the conveyor belt is arranged from right to left in the order of picking channel. After one order is finished, the next order will be picked.

Let the quantity of a batch order be M, the number of the kinds of goods that need to be selected for this batch order be Λ, and the number of pickers be N_0 The picker is sorted from left to right, numbered $1-N$, in the mode of right-to-left picker, it can be known that the picking time of the jth item in the order is determined by the end of picking time of the item on the right side of the jth item, then the starting picking time of the picker j in order i is[13]:

$$t_{i\_j}^{s}=\begin{cases}0, & j=N\\ t_{i\_j+1}^{s}+(a_{ij+1}-1)\times t', & 1\le j<N\end{cases} \quad (1)$$

In formula (1), t' indicates the time required for picking a piece of goods by the picking machine, and $t_{i\_j+1}^{s}$ indicates the starting picking time of picking machine $j+1$ in order i.

At the end of any picking machine, the time required for the picking machine to start and complete the ejection of all the goods corresponding to the picking machine is added, that is:

$$t_{i\_j}^{e}=t_{i\_j}^{s}+a_{ij}\times t' \quad (2)$$

If S is the left-most part of order that needs to be picked, the time of picking completion of goods S can be obtained by recursion of Formula (1), (2):

$$t_{i\_s}^{e}=\sum_{j=1}^{N}a_{ij}\times t'-\left(\sum_{j=1}^{N}\lambda_{ij}-1\right)\times t') \quad (3)$$

In formula (3), λ_{ij} is the decision variable, $\lambda_{ij}=\begin{cases}1, & a_{ij}>0\\ 0, & a_{ij}=0\end{cases}$, a_{ij} is used to represent the demand for goods stored in sorter j in order i.

Assuming that t_{d_i} is the time when the left-most part of order i needs to be picked out and the goods are shipped out of the picking area after the picking is completed, that is, the time when the last part of the order moves from its location to the right side of all the picking channels, then:

$$t_{d\_i}=[N-\min_{j\in(1,N),\lambda_{ij}\neq 0}(\lambda_{ij}\times j)+1]\times l/v \quad (4)$$

l denotes the distance between two adjacent picking channels in the picking system, and v denotes the running speed of the conveyor belt.

From formula (2), (3), (4), it can be deduced that the total picking operation time t_i of order i is :

$$\begin{aligned}t_i &= \sum_{j=1}^{N}a_{ij}\times t'-(\sum_{j=1}^{N}\lambda_{ij}-1)\times t'\\ &+(N-\min_{j\in(1,N),\lambda_{ij}\neq 0}(\lambda_{ij}\times j)+1)\times l/v+\Delta t\end{aligned} \quad (5)$$

In addition, in order to ensure that there is no confusion between the two orders and the distance between them is small, it is necessary to introduce Δt as the interval between picking two orders.

To sum up, the total picking time of a batch of orders is T:

$$\begin{aligned}T=\sum_{i=1}^{M}t_i &= \sum_{i=1}^{M}\sum_{j=1}^{N}a_{ij}\times t'-\sum_{i=1}^{M}(\sum_{j=1}^{N}\lambda_{ij}-1)\times t'\\ &+\sum_{i=1}^{M}[(N-\min_{j\in(1,N),\lambda_{ij}\neq 0}(\lambda_{ij}\times j)+1)\times l/v]+(\sum_{i}i-1)\times\Delta t\end{aligned} \quad (6)$$

2.2 Picking Time Model of Left-to-Right Sequential Serial Picking

Contrary to the left-to-right picking method, left-to-right sequential picking is the goods are picked one by one from left to right in the order in which they are placed in the automatic picking system. According to the order, the goods that need to be picked in the system start from the first goods to be delivered from the warehouse at the left of the automatic picker. After each picker selects a number of goods, and there is space on the conveyor belt, the system starts to pick the goods on the right side [19]. In this picking method, after finishing an order, the position of the goods on the conveyor belt is opposite to the number of the picking machine. The left-to-right picking method is equivalent to leaving space for the location of goods in each order [20], so different orders can be picked at the same time.

Before starting the sorting operation, space can be reserved for each order to generate a virtual container whose right side coincides with the leftmost end of the automatic picking system. When the first non-zero goods at the left end are picked, T=0, at this point, the displacement of the virtual container to the right is [13] :

$$l_s^1 = N_{1\_1} \times l - \frac{1}{2}(l - w_b) - t' \times v \quad (7)$$

N_{1_1} represents the picker position of the leftmost non-zero item in the first order. The starting time of the first order is:

$$t_1^s = l_s^1 / v \quad (8)$$

Similarly, when the second order starts to be picked, the displacement of the virtual container to the right is:

$$l_s^2 = N_{2\_1} \times l - \frac{1}{2}(l - w_b) - t' \times v \quad (9)$$

In addition, the virtual container length after picking the first order and the gap between the two orders are based on the leftmost end of the picker, and the overall moving distance of the conveyor belt is:

$$l_{sum}^2 = l_s^2 + l_{spa} + l_1 \quad (10)$$

Similarly, the starting time of the second order is:

$$t_2^s = l_{sum}^2 / v \quad (11)$$

According to the recursion of equations (8) and (11), it can be obtained that the starting time of any order i is:

$$t_i^s = l_{sum}^i / v \quad (12)$$

Among them $l_{sum}^i = l_s^i + \sum_{j=1}^{i-1}(l_{spa} + l_j), l_s^i = N_{i\_1} \times l - \frac{1}{2}(l - w_b) - t' \times v$

Assuming that there is a total of M orders, the starting picking time of the Mth order can be expressed as:

$$t_M^s = ((N_{M\_1} \times l - \frac{1}{2}(l - w_b) - t' \times v) + \sum_{j=1}^{M-1}(l_{spa} + l_j))/v \quad (13)$$

Therefore, when M orders are placed, the total picking operation time can be expressed as:

$$T = t_M^s + (L - l_s^M + l_M)/v - min(t_i^s) \quad (14)$$

The starting picking time of the last order M i s recorded as t_M^s, and the time required for the Mth order from the beginning to the end of picking can be expressed as（L-l_s^M+l_M）$/v$; the time required for a batch order to virtual run from the left to the right of the picking system to the first item can be expressed as $min(t_i^s)$. Because there may be a situation, that is, the first goods that need to be picked in the first order is located on the right side of the picking system, while the first goods that need to be picked in the next order is located on the left side. When the first virtual container reserved has not been picked, the following order has begun to be picked, that is, the first goods that need to be picked are not the first order. According to (13), then (14) can be transformed into:

$$T = (l_s^M + \sum_{j=1}^{M-1}(l_{spa} + l_j))/v + (L - l_s^M + l_M)/v - \min(t_i^s)$$
$$= (L + (M-1) \times l_{sp} + \sum_{j=1}^{M} l_j)/v - min(t_i^s) \quad (15)$$

Formula (15) can be converted into:

$$T = (L + (M-1) \times l_{spa} + \sum_{i=1}^{M}(w_b + l') \times (\sum_{j=1}^{N} a_{ij} - 1))/v - min(t_i^s) \quad (16)$$

Simplification can obtain the total picking time as follows:

$$T = (L + (M-1) \times l_{spa})/v + \sum_{i=1}^{M}(\sum_{j=1}^{N} a_{ij} - 1) \times t' - min(t_i^s) \quad (17)$$

2.3 Series-parallel Hybrid Picking Method and Total Picking Time Model

When using string parallel mixed picking method to pick M orders, it needs to preprocess the orders first. Judge whether order i can conduct parallel picking. If so, the automatic picking system will first select the goods that can be conducted parallel picking. For the remaining goods, judge whether the space between adjacent different items of the first batch of selected goods is allowed for interleaved picking. If so, conduct the selection of the second batch of goods [21]. If neither do them are selected through the two judgements, the goods will be selected in the order from left to right at the end, and the next order will be selected after an order is selected and the products are exported to the picking area [22].

If the number of non-zero goods sorts in order i is s, then it is $1 \leq s \leq N$, and the corresponding number of all goods that need to be selected is set as U, and it is arranged in the order from smallest to largest [13]. The following will be performed according to the string parallel mixed picking operation:

Step 1: determine the first batch of goods that can be used for parallel picking. Assuming that there are two adjacent non-zero items $f_k \in U$、$f_{k-1} \in U$ and $f_k > f_{k-1}$ in the automatic picking system, where f_k can conduct the first batch of picking, the condition for whether f_{k-1} can conduct the first batch of parallel picking at the same time is:

$$\lambda_{f_{k-1}f_k}=\frac{(f_k-f_{k-1}-1)\times l}{v}-(a_{if_k}-1)\times t' \quad (18)$$

In formula (18), l is the distance between two adjacent pickers in the automatic picking system; v is the speed of the conveyor; t' is a goods has chosen machine at any time; a_{ij} represents the quantity of goods j required in order i.

For the judging condition of equation (18), if $\lambda_{f_{k-1}f_k}\geqslant 0$, then f_{k-1} can perform the first batch of parallel picking with f_k. If $\lambda_{f_{k-1}f_k}<0$, then it is judged that f_{k-1} cannot be selected in the first batch. Repeat the above judgment function until it is determined that all the goods in U can be selected in the first batch at the same time in parallel, and these goods are formed into a new set, $U_1, U_1\in U$.

Step 2: determine the first choose the distance between the adjacent items different goods will allow the rest of the goods have not been chosen to fill-in the picking, so need to request the amount of space between different items, are the first batch of goods were chosen f_t, f_{t-1}, and $f_t\in U_1$、, $f_{t-1}\in U_1$, $f_t>f_{t-1}$, then the goods f_{t-1} the first to be chosen goods with f_t last on the list to be chosen can be expressed as the distance between the goods:

$$\delta_{f_{t-1}f_t}=(f_t-f_{t-1}-1)\times l-(a_{if_t}-1)\times t'\times v \quad (19)$$

Step 3: to judge whether the unselected goods g can be selected by interpolation according to the distance obtained in the second step, $g\in U$ and $g\notin U_1$. When the second picking is carried out, it is still considered that if the g items are shipped, all of them will be sent out. Therefore, the space length of the $\delta_{f_{t-1}f_t}$ needs to be occupied by the quantity whose spacing is larger than g items. Then we can get the condition of whether the goods can be picked between f_t and f_{t-1}:

$$\xi=\delta_{f_{t-1}f_t}-[(a_{ig}\times t'\times v-(v\times t'-l)]-\theta(f_t,g)\times(f_t-g-1)\times l \quad (20)$$

Among them $\theta(f_t,g)=\begin{cases}1 & f_t>g\\ 0 & f_t<g\end{cases}$.

According to Formula (20), it is analyzed and judged one by one whether each unselected goods g can be selected by interpolation. The second batch of selected goods g is composed of aggregated U_2, $U_2\in U$.

Step 4: After the first batch of parallel picking goods has been completed and the second batch of all the goods that can be slotted and picked have been completed, the left-to-right sequential picking of all the goods that have not yet been selected in the order is carried out. Let , U_3, $U_3=U, U_1, U_2$ denote the set of goods h that have not been picked. Let the number of the left-most goods in the first batch of selected goods be f_1, $f_1\in U_1$. The end picking time of the goods f_1 can be obtained is:

$$t^e_{i\_f_1}=a_{if_1}\times t' \quad (21)$$

Suppose that the number of the leftmost goods in the unselected goods is h_1, $h_1\in U_3$. The starting picking time for goods h_1 can be obtained is:

$$t^s_{i\_h_1}=\max((t^e_{i_{f_1}}-\frac{(f_1-h_1)\times l}{v}+\Delta t),0) \quad (22)$$

So the end picking time of h_1 can be expressed as the beginning picking time plus the time needed for picking a_{ih_1}:

$$t^e_{i\_h_1}=t^s_{i\_h_1}+a_{ih_1}\times t' \quad (23)$$

The unpicked goods adjacent to the right side of h_1 are recorded as h_2, then the recurrence of (22) and (23) can tell the starting time of h_2:

$$t^s_{i\_h_2}=t^e_{i\_h_1}-\frac{(h_2-h_1)\times l}{v}+\Delta t \quad (24)$$

According to (23) recursion, the end picking time of h_2 is:

$$t^e_{i\_h_2}=t^s_{i\_h_2}+a_{ih_2}\times t' \quad (25)$$

Remember that after two rounds of picking, there are a total of P types of goods that have not been picked. That is, the cardinal number of the set U_3 is P. Let the right-most goods in U_3 be h_p, so the starting picking time of can h_p be obtained by recursion of formulas (21), (22), (23), (24), (25):

$$t^s_{i\_h_p}=t^s_{i\_h_1}+\sum_{p=1}^{P-1}a_{ih_p}\times t'+\frac{(h_p-h_1)\times l}{v}+(P-1)\times\Delta t \quad (26)$$

The time to finish picking h_p is:

$$t^e_{i\_h_p}=t^s_{i\_h_p}+a_{ih_p}\times t' \quad (27)$$

Step 5: according to formula (22), (26) and (27), it can be concluded that the time required to complete an order is [13] :

$$t_i = \max((t^e_{i\_f_1} - \frac{(f_1 - h_1)\times l}{v} + \Delta t),0) + \sum_{p=1}^{P} a_{ih_p} \times t' + \frac{(h_p - h_1)\times l}{v} + (P-1)\times \Delta t + \frac{(N - h_p)\times l}{v} \quad (28)$$

According to the above formula, the total time for M orders to be picked is:

$$T = \sum_{i=1}^{M} t_i \quad (29)$$

ORTHOGONAL EXPERIMENTAL DESIGN OF PICKING TIME MODEL FOR THREE PICKING MODES

Factor selection: picking time t'(s), conveyor belt speed v(m/s), distance l(m) between adjacent pickers.

Level: in this experiment, each factor adopts the same test level. In order to ensure the number of samples in the experiment, three levels of test level are selected.

According to the orthogonal experiment of parameter optimization standard, this experiment can select each column level is 3 single orthogonal table L_9(3^4). According to the results of this experiment and the actual investigation, the three-level test level value of the parameters was determined [23]. Thus, the factor level of orthogonal test can be obtained, as shown in table 1:

Table 1 factor level of orthogonal test

factors / level	Adjacent picker distance l(m)	Single cargo picking time t'(s)	Null columns (--)	Conveyor speed v (m/s)
1	0.3	1	(--)	1.0
2	0.4	0.8	(--)	1.2
3	0.6	0.5	(--)	1.5

The above data are obtained from the actual research in the enterprise. Due to the distance of adjacent picker, according to the transformation of the different directions on the width, the whole change is difficult, so according to the ideas of the orthogonal experiment put it in the first column, and the adjustment of the speed of conveyor belt only needs to change the system running parameters, and the change is the most simple and convenient, so put that in the last column. In addition, error columns are traditionally placed in the middle of the level table [24].

The orthogonal test design scheme can be obtained as shown in table 2:

Table 2 orthogonal test design scheme

factors / level	Adjacent picker distance l(m) A	Single cargo picking time t'(s) B	Null columns (--) (--)	Conveyor speed v (m/s) C	Test plan
1	1	1	1	1	A1B1C1
2	1	2	2	2	A1B2C2
3	1	3	3	3	A1B3C3
4	2	1	2	3	A2B1C3
5	2	2	3	1	A2B2C1
6	2	3	1	2	A2B3C2
7	3	1	3	2	A3B1C2
8	3	2	1	3	A3B2C3
9	3	3	2	1	A3B3C1

This paper selects the complete order data of a certain period of a working day in the T distribution center for orthogonal test simulation analysis of the above three selection strategies. This batch of 25 orders, there are 81 types of goods, 3668 pieces of goods. MATLAB 2016a was used for calculation. 81 picker channels were set in the test.

ORTHOGONAL TEST OF SORTING METHOD

4.1 Orthogonal Test Analysis of Right-to-Left Picking Method

The results of orthogonal experiments of right-to-left sequential sorting strategy are shown in Table 3. The top of the table is the orthogonal test table with four factors (including empty columns) and the experimental data. The second half is the range analysis of the experimental results.

The sum of picking time values at the same level for each column factor is calculated and recorded in the corresponding column under the orthogonal table. In T_{ij}, i is the horizontal number, j is the column number, $\overline{T}$ represents the average value, R_J is the range [25].

Table 3 Orthogonal test results and analysis of right-to-left selection methods

factors / level	Adjacent picker distance l(m)	Single cargo picking time t'(s)	Null columns (--)	Conveyor speed v (m/s)	Total picking time T(s)
1	(1)0.3	(1)1	(1)0	(1)1	5179.00
2	(1)0.3	(2)0.8	(2)0	(2)1.2	4369.50
3	(1)0.3	(3)0.5	(3)0	(3)1.5	3206.50
4	(2)0.4	(1)1	(2)0	(3)1.5	5110.67
5	(2)0.4	(2)0.8	(3)0	(1)1	4677.00
6	(2)0.4	(3)0.5	(1)0	(2)1.2	3479.83
7	(3)0.6	(1)1	(3)0	(2)1.2	5589.00
8	(3)0.6	(2)0.8	(1)0	(3)1.5	4677.00
9	(3)0.6	(3)0.5	(2)0	(1)1	4026.50
$T_{(1)j}$	12755.00	15878.67	13335.83	13882.50	
$T_{(2)j}$	13267.50	13723.50	13506.67	13438.33	$\sum_{i=1}^{9} Ti$
$T_{(3)j}$	14292.50	10712.83	13472.50	12994.17	=40315.00
$\overline{T}_{(1)j}$	4251.67	5292.89	4445.28	4627.50	
$\overline{T}_{(2)j}$	4422.50	4574.50	4502.22	4479.44	
$\overline{T}_{(3)j}$	4764.17	3570.94	4490.83	4331.39	
R_J	512.50	1721.94	56.94	296.11	
Optimal combination	l(1)	t'(3)	(--)	v (3)	
Primary and Secondary Factor Sorting	$t' > l > v$				
Optimal combination	l(1)、t'(3)、v (3)				

According to the size of $\bar{T}$ value to determine the priority level of factor j, according to table 3, we can get:

$\bar{T}_{(1)1}<\bar{T}_{(2)1}<\bar{T}_{(3)1}$
$\bar{T}_{(3)2}<\bar{T}_{(2)2}<\bar{T}_{(1)1}$
$\bar{T}_{(1)3}<\bar{T}_{(3)3}<\bar{T}_{(2)3}$
$\bar{T}_{(3)4}<\bar{T}_{(2)4}<\bar{T}_{(1)4}$

So ' $t'(3)=0.5$, $l(1)=0.3$, $v(3)=1.5$ are the optimal levels of the three factors, and the combination of these three parameters is the optimal combination scheme in this experiment.

R_j indicates the variation of the experimental results when the level of the *Jth* factor changes. Therefore, the larger the representation factor R_j, the greater the impact of this factor on the experimental results [26], the greater the impact on improving the efficiency of the automatic sorting system. According to table 3, we can get the value of $R_2 > R_1 > R_3$, so the influence of three factors is ranked as $t' > l > v$.

4.2 Orthogonal Test Analysis of Left -to- Right Picking Method

Orthogonal test results and analysis of left-to-right selection methods are shown in Table 4.

Table 4 Orthogonal test results and analysis of selection methods from left to right

factors / level	Adjacent picker distance l(m)	Single cargo picking time t'(s)	Null columns (--)	Conveyor speed v (m/s)	Total picking time T(s)
1	(1)0.3	(1)1	(1)0	(1)1	5681.08
2	(1)0.3	(2)0.8	(2)0	(2)1.2	4568.86
3	(1)0.3	(3)0.5	(3)0	(3)1.5	2900.55
4	(2)0.4	(1)1	(2)0	(3)1.5	5681.08
5	(2)0.4	(2)0.8	(3)0	(1)1	4568.93
6	(2)0.4	(3)0.5	(1)0	(2)1.2	2900.60
7	(3)0.6	(1)1	(3)0	(2)1.2	5681.19
8	(3)0.6	(2)0.8	(1)0	(3)1.5	4568.95
9	(3)0.6	(3)0.5	(2)0	(1)1	2900.73
$T_{(1)j}$	13150.49	17043.35	13150.63	13150.73	
$T_{(2)j}$	13150.61	13706.74	13150.67	13150.65	$\sum_{i=1}^{9} Ti$ =39451.96
$T_{(3)j}$	13150.86	8701.88	13150.66	13150.58	
$\bar{T}_{(1)j}$	4383.50	5681.12	4383.54	4383.58	
$\bar{T}_{(2)j}$	4383.54	4568.91	4383.56	4383.55	
$\bar{T}_{(3)j}$	4383.62	2900.63	4383.55	4383.53	
R_J	0.13	2780.49	0.01	0.05	
Optimal combination	$l(1)$	$t'(3)$	(--)	v (3)	
Primary and Secondary Factor Sorting	$t' > l > v$				
Optimal combination	$l(1)$、$t'(3)$、v (3)				

4.3 Orthogonal Test Analysis of Series-Parallel Mixed Picking Method

Orthogonal test results and analysis of series-parallel mixed picking method are given in Table 5.

Table 5 Orthogonal test results and analysis of serial parallel mixed picking method

factors / level	Adjacent picker distance l(m)	Single cargo picking time t'(s)	Null columns (--)	Conveyor speed v (m/s)	Total picking time T(s)
1	(1)0.3	(1)1	(1)0	(1)1	7919.90
2	(1)0.3	(2)0.8	(2)0	(2)1.2	7621.50
3	(1)0.3	(3)0.5	(3)0	(3)1.5	6216.50
4	(2)0.4	(1)1	(2)0	(3)1.5	8179.00
5	(2)0.4	(2)0.8	(3)0	(1)1	5498.00
6	(2)0.4	(3)0.5	(1)0	(2)1.2	4541.50
7	(3)0.6	(1)1	(3)0	(2)1.2	5822.50
8	(3)0.6	(2)0.8	(1)0	(3)1.5	5696.80
9	(3)0.6	(3)0.5	(2)0	(1)1	3730.30
$T_{(1)j}$	21757.90	21921.40	18158.20	17148.20	$\sum_{i=1}^{9} Ti$ =55226.00
$T_{(2)j}$	18218.50	18816.30	19530.80	17985.50	
$T_{(3)j}$	15249.60	14488.30	17537.00	20092.30	
$\bar{T}_{(1)j}$	7252.63	7307.13	6052.73	5716.07	
$\bar{T}_{(2)j}$	6072.83	6272.10	6510.27	5995.17	
$\bar{T}_{(3)j}$	5083.20	4829.43	5845.67	6697.43	
R_J	2169.43	2477.70	664.60	981.37	
Optimal combination	l(3)	t'(3)	(--)	v (1)	
Primary and Secondary Factor Sorting	$t' > l > v$				
Optimal combination	l(3)、t'(3)、v (1)				

□

ANALYSIS OF PICKING STRATEGY RESULTS OF AUTOMATIC PICKING SYSTEM

5.1 Contrastive Analysis of Operating Parameters and Picking Mode

In order to observe the influence of factor change on different picking methods, the same influencing factor of three picking methods was put in the same polyline map for comparative analysis.

Fig. 1 Comparison of the influence of distance l(m) between adjacent sorters on the total sorting time of three sorting methods

As can be seen from Figure 1, under these three different picking modes, both sequential and serial hybrid picking are positively correlated with the distance of adjacent picking machines and the total picking time schedule, while only sequential and parallel hybrid picking is negatively correlated with them. This situation has also been analyzed in the previous part of the paper, because the series-parallel hybrid picking needs to be chose by interpolation, the access width is large comparatively, which is conducive to the selection of the second batch of picking goods. And the slope absolute value of the mixed picking method is the largest, so the distance between adjacent picking machines has a greater impact on the third picking method. As far as the overall picking time is concerned, the total picking time under the two sequential picking modes is not significantly different, and both of them belong to the low level. If we analyze the order, we will find that the delivery rate of the two types of goods with serial numbers 80 and 81 is several times higher than the rest, which will indeed affect the picking of slots. If the number of orders is on the same side, the picking time should be very different.

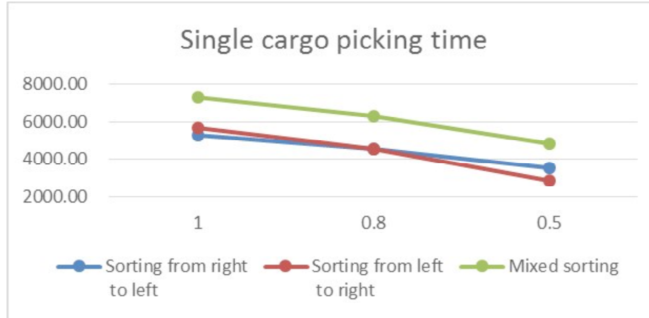

Fig.2 Comparison of the influence of single picking time on the total picking time of three picking methods

As can be seen in Figure 2, under these three different picking methods, the smaller the picking time of single goods, the lower the total picking time, and the greater the reduction. Here, at the same parameter level, the total picking time of the series-parallel hybrid picking method is still higher than that of the other two picking methods. When the single picking time is 0.5, the picking efficiency is the highest in the left-to-right picking mode. In fact, that can be understood from the picking principle of the left-to-right picking method. After the left-side picking is completed, the left-side picking moves to the right with vacancies. The picking speed is faster and the overall efficiency is improved naturally.

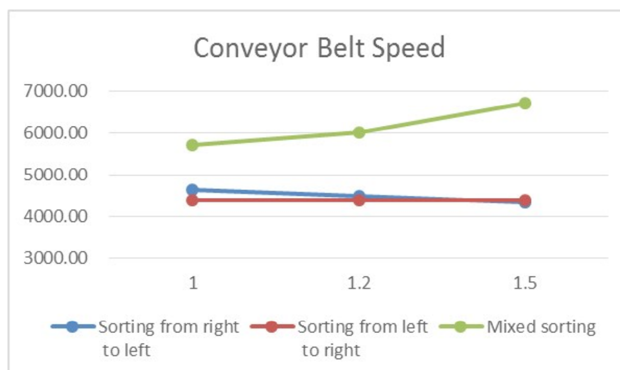

Fig. 3 Comparison of the influence of conveyor belt speed on the total picking time of three picking modes

From Figure 3, it can be seen that under these three different picking modes, the series-parallel hybrid picking mode is most affected by the conveyor belt, and the influence is positively correlated. The reduction of conveyor belt speed can greatly improve the picking efficiency under this picking mode. For the left-to-right and right-to-left picking methods, the improvement of conveyor belt speed does not significantly reduce the picking time.

In summary, under the right-to-left sequential picking mode, the overall picking time is on the low side, which is the best picking mode for this period of order in this case. The left-to-right sequential picking method is greatly influenced by the picking time of a single cargo. Under this strategy, the influence of the other two factors can be neglected. Series-parallel hybrid picking is not suitable for the order picking during this period, because the overall time is high. But it still can be seen that single picking machine picking time and picking machine width have greater impact on it.

5.2 Analyzing the scene that the series and parallel hybrid picking approach suitable for

According to the theory of picking, the serial-parallel hybrid picking method is actually a more efficient way of picking, but in the previous analysis, it is found that the situation is just the opposite. When it is affected by the same influence factor and at the same level, the total picking time of the other two sequential serial picking methods is lower than its. According to the thought analysis of the mixed picking method, the probability of the goods can be picked by insertion is low. Therefore, this section considers and studies on which scenario is suitable for this picking method, in order to find the appropriate application scenario. This paper will improve from the following aspects:

The first case is that the shipment level of each item in the order is basic. In this test, the demand for the top picking items is reduced only by choosing the ones with the highest picking quantity. The intuitive diagrams are shown in Fig. 4, 5 and 6.

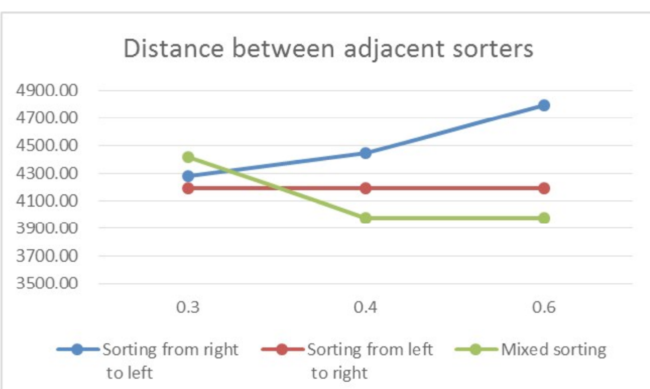

Fig. 4 Comparison of the influence of distance (m) between adjacent sorters on the total sorting time of three sorting methods

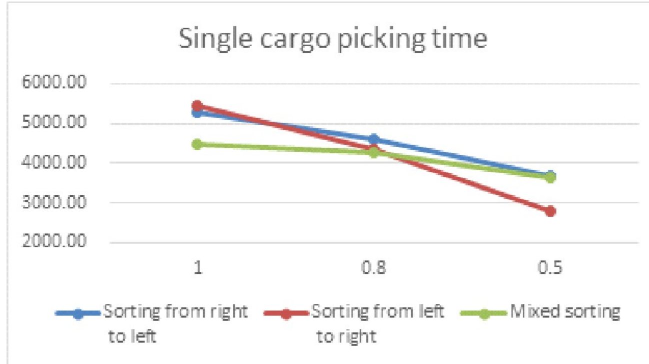

Fig.5 Comparison of the influence of single picking time on the total picking time of three picking methods

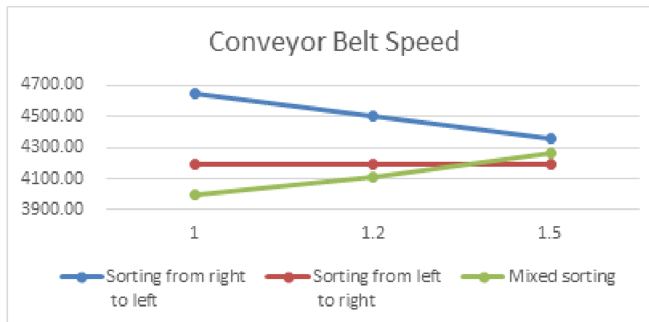

Fig.6 Comparison of the influence of conveyor belt speed on the total picking time of three picking modes

In this case, after a small change in order, we can see that the total picking time of the series-parallel hybrid picking method is no longer a very larger part. In Figure 4, when the width of a single picking machine is 0.4 meters and 0.6 meters, when the picking time of a single cargo is 1 and 0.8 in Figure 5, when the speed of the conveyor belt is 1 in Figure 6, the total picking time is shorter than that of the other two methods. Generally speaking, in this case, the series-parallel hybrid picking method is better than the right-to-left picking method, slightly better than the left-to-right picking method. It can be inferred that the series-parallel hybrid picking scheme is more appropriate if the difference of each goods in the order is almost small according to the delivery volume.

The second case is that there are many kinds of zero-item goods in the order. In this experiment, the quantity of goods shipped with random modification in the order was changed to 0.

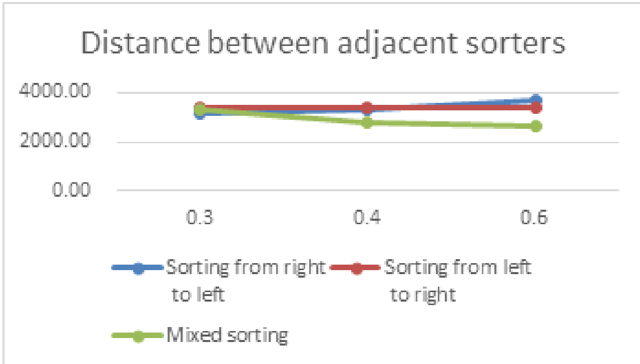

Fig.7 Comparison of the influence of distance (m) between adjacent sorters on the total sorting time of three sorting methods

Fig.8 Comparison of the influence of single picking time on the total picking time of three picking methods

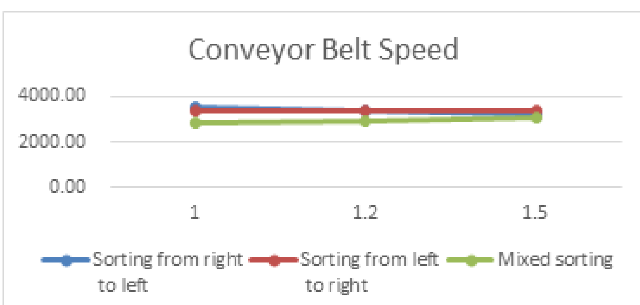

Fig.9 Comparison of the influence of conveyor belt speed on the total picking time of three picking modes

In this case, after a small part of the change, we can see that the total picking time of the series-parallel hybrid picking method is generally smaller in three different picking methods. It can be seen intuitively that only when the adjacent picking machine is 0.3 in Fig. 7 and when the picking time of single goods is 0.5 in Fig. 8, the time of the hybrid picking method is slightly longer than that of the left-right picking method. In the other cases, it is the method with the shortest total picking time has obvious advantages in picking efficiency.

In summary, it can be seen that the series-parallel hybrid picking method is also an excellent picking method, but it needs to play the greatest advantage in the suitable application scenario. Therefore, if the order situation is more suitable for the slot picking, that is, if the difference between the various goods in the order is almost small according to the quantity of delivery, or when the types of goods in the order need to be out of storage are less, The combined picking scheme has obvious advantages and the total picking time is the shortest. The second sequential picking method from left to right is suitable for various scenarios. In many scenarios, it is found that the total picking time is relatively shorter, which is an optimization strategy. The third kind of series-parallel mixed picking method is suitable for the case of many kinds of goods, similar shipments of different kinds of goods, and less types of goods that need to be picked on the picking machine in the order. However, according to the idea of serial-parallel hybrid picking, we can know that the distribution of goods location will have a very direct and significant impact on the types of the first and second batches of picking goods, and in the appropriate application scenarios, the advantages of picking efficiency are obvious, so this kind of picking method is very worthy of in-depth study, If the operating parameters of the picking machine and the allocation of cargo space are reasonable, it will be a very good way of picking.

CONCLUSION

In order to improve the operation efficiency of automatic sorting system in distribution center and reduce the time of sorting process, this paper mainly chooses a basic ejection sorting machine as the research object, and studies the sorting mode and the setting of operation parameters of the basic automatic sorting system. Based on the analysis of the operation thought and mode, the operation time mode and the operation time under three different picking modes, using the orthogonal test and range analysis method, the influence and degree of the three influencing factors on the picking efficiency in the automatic picking system, namely, the distance between adjacent picking machines, the picking time of single goods and the speed of conveyor belt, are analyzed. The efficiency of the automatic picking system of multi-factor parameters at different levels under different picking modes is analyzed. And the optimal parameter combination is found. At present, the general research is the influence of the parameter level on the picking efficiency without changing other parameters. This paper analyses the influence of multi-factor parameters on the picking efficiency of automatic picking system under different picking modes and different levels. According to the influence law of different factors under different picking strategies, the influence of each factor is determined by using the method of differential analysis, and the optimal combination scheme is found by studying different parameters matching different picking methods. At the same time, it is found that the series-parallel hybrid picking method has not achieved the desired effect. By analyzing the picking theory and steps of the method, we can find out the applicable order situation, and compare the picking time with the other two picking methods to determine whether it is more efficient.

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