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A Selecting Method between Picker-to-parts System and Put System Based on Order Cluster

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Abstract

This study proposes a systemic method to selecting between two basic types of order picking system picker-to-parts system and put system for different types of customer orders such as wholesaler orders, retailer orders and consumer orders. In essence, order batching and picking area zoning are cluster method about customer order sheet, so the customer order sheet can be gridded into many unit blocks. After the picking time formulation for each system in one-dimensional unit blocks is defined according to the logical movements, the time sequence models for two-dimensional systems are established by filling curves to link the one-dimensional unit blocks to form tow-dimensional system. In consideration of "U" shaped dual tour, the subtraction value between picker-to-parts system and put system is used as the criteria to select the suitable system. Genetic algorithm is adopted to find the optimal value for each system. Through the experimental study, the proposed method is proved to be able to get the suitability of picker-to-parts system and put system for given orders with the hypothetic value of parameters, and some key factors such as zone number, batch size, wave size, dual tour and setup time have significant effect on suitability of each system for different orders.

Keywords: *Order picking system, selecting method, picker-to-parts system, put system*

1. Introduction

Picker-to-parts system and put system are the two basic manual systems according to the classification of order picking systems presented by Koster et al [1]. Each system is suitable for certain types of applications. However, we could not find literatures directly addressing this issue. At present, they are usually chosen on the basis of insights and experiences.

Picker-to-parts system is the most widely used order picking system [2]. In zoned picker-to-parts system, a picker visits the parts with order container(s). The picker picks the parts at picking locations then put the parts into the containers. After picking the last item in the picking tour, the container(s) are delivered to the end of the picking zone for the picker in next zone to continue. The delivery can be by the picker manually or by powered conveyor [3]. To limit the scope of the study, we assume that the totes are delivered manually. The schematic of picker-to-parts system is shown in Figure 1.

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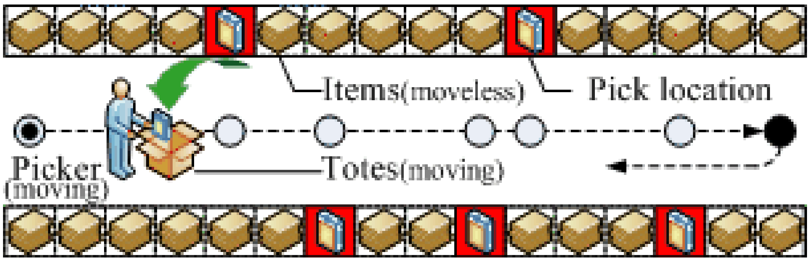


Figure 1. The Schematic of Picker-to-Parts System

Put system consists of a retrieval and a distribution process. Items have to be retrieved firstly. Then, the pickers carry the pre-picked items in some carrier (such as a bin) and travel to the pick locations. They distribute the items over customer orders ("put" the items into customer totes). When finishing distributing the last item in one picking tour, the pickers will go back to get next task. Figure 2 illustrates the schematic of put system. It seems that the productivity of put system is greater than that of picker-to-parts system because the pickers needn't to travel to the end of the picking zone. Put system not only needs the process of restocking totes like restocking items in picker-to-parts system, but also requires extra labor and time between adjacent two waves of orders to take away the full totes after picking. Picker-to-parts system can save the extra labor and time.

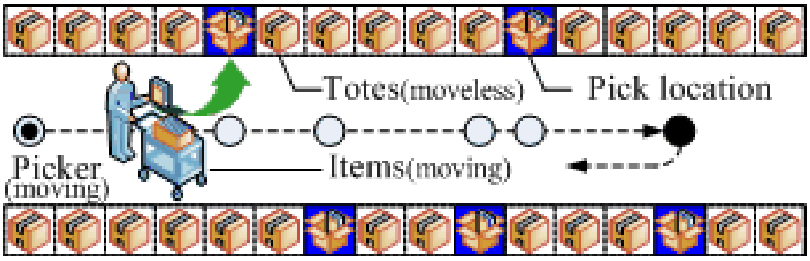


Figure 2. The Schematic of Put System

In many cases, the suitable system can be chosen easily according to some distinguishing feature of the SKUs and orders such as the dynamic nature, number, picking style and assistive technology.

1) If the SKUs are static and the orders are dynamic, picker-to-parts system is often used; while if the SKUs vary with static orders, such as a DC support stores, put system is likely to be always better.
2) If the number of SKUs is large but that of orders is small, picker-to-parts system might be a good choice; otherwise, the travel times of pickers will also be large. In a similar way, if the number of orders is large with a few SKUs, put system would like to be used.
3) In the case of pallet picking or case picking, the picker-to-parts system doesn't need the retrieval process comparing with put system; and the items are picked just in the reserved storage area. On this occasion, picker-to-parts system is the better choice.
4) When employed paper-based list, voice headset or RF to guide the pickers to find the pick locations [4], the instructions occur in origin rather than destination, so search time from origin to destination will take place. In picker-to-parts system, the items are always stored in the same location so that the pickers can gradually get familiar with the SKUs to reduce the searching time. But in put system, the advantage of familiarity can't be used because the locations of totes are changed between waves. So with the assistive technologies providing instructions in origin but not in destination, the probability of employing picker-to-parts system is

bigger.

In this paper we address a common situation in practice with several assumptions as below.

1) Both SKUs and orders are static, and meanwhile the number of SKUs and orders are more or less the same.
2) We only concentrate on the systems for piece picking in forward picking area. As illustrated in Figure 3 and Figure 4, picker-to-parts system and put system require almost the same area and process. Under the circumstance, the items are retrieved from reserved storage area to buffer area firstly, and then order picking is completed in the forward picking area.

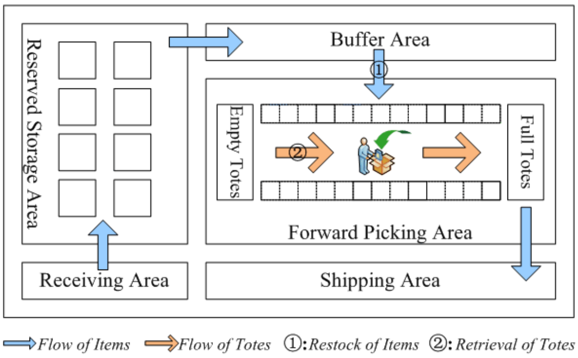


Figure 3. The Typical Process of Picker-to-Parts System in a Distribution Center

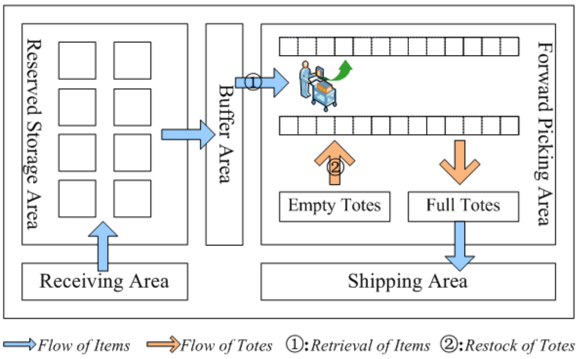


Figure 4. The Typical Process of Put System In A Distribution Center

3) There is no bottleneck in the process of restocking according to practical experience in both picker-to-parts system and put system. In picker-to-parts system, pickers retrieve empty totes, pick items and deliver the full totes while replenishers restock the items into the system. In put system, pickers retrieve the items from buffer area while the replenishers restock the empty totes and take away the full totes.
4) In put system, setup time exits between adjacent waves and is in proportion to the number of totes visited in the last tour of previous wave. It means that after pickers finishing a wave of orders, the replenishers have to spend some time to take away the full totes and setup the empty totes for next wave; and the time vary as the quantity of visited totes in previous wave.

5) The technology of light is employed in the both two systems. Employed the technology of light, the search time can be reduced sharply because the instructions occurring in destination rather than in origin can help pickers to find the objectives quickly. As no familiarity can be used, the difference of search time between picker-to-parts system and put system is negligible.
6) SKUs spread over in multiple zones in picker-to-parts system; and orders spread over in multiple zones in put system.

From the above, we can get the fair conditions to compare picker-to-parts system with put system. In this paper, we set the overall order picking time (or called overall throughput time) as the criterion to select the suitable system. It means that we choose the system which cost fewer time for given customer orders.

2. Problem Analysis

2.1. Order Picking Time

For either picker-to-parts system or put system, the overall order picking time in a typical distribution center can be broken up into components as shown in Table 1 [5].

Table 1. Typical Distribution of Order Picking Time

Activity	% of overall order picking time
Travel	50%
Search	20%
Pick	15%
Setup	10%
Other	5%

Travel is the movement of pickers from one pick location to another pick location. For manual order picking systems, the travel time is an increasing function of the travel distance [1]. The total travel distance is the product of average travel distance of each picking tour and number of travel times. The average travel distance can be reduced using the policy of storage assignment which puts the popular items in good locations; the number of travel times can be saved using batching policy which picks a set of orders in one single picking tour. It seems that zoning policy, which assigns pickers in his assigned zone to pick part of the order, can also reduce travel time in put system because the sum of travel distance in many small zones may be shorter than that in one big zone.

Search is the activity of pickers to find the items or totes in the storage locations after the pickers traveled to the destination. After the items or totes are found, the pick activity composed of extract and put will be taken place. Extract is activity of removing the items from storage locations, and put means moving items into the totes. In practice, under the instruction of light, the negligible search time usually occurs with pick time simultaneously.

Setup is the assistive activity to complete the preparation work to start or keep order picking. Because of parallelism, setup time in picker-to-parts system will be hidden. But in put system, setup time will appear and is proportional to the number of totes visited in the last tour of the each wave of orders. Therefore, we can reduce setup time by assigning the last tour to include the fewest totes.

Besides the above basic activities, order picking also includes some other activities such as documenting. For given orders, the time of other activities is constant. It makes no difference for the selection between different systems.

From the foregoing, the overall order picking time t can be defined as the composition of travel time t_T, pick time t_E including search time, and setup time t_O. And bathing, zoning and storage assignment are the three main policies that can help to get the optimal order picking time for either picker-to-parts system or put system so that the selection process can confirm to the practical application.

2.2. Order Cluster

Essentially, both order batching and picking area zoning are cluster methods about customer order sheet [6]. batching is clustering multiple individual orders into one batch which can be picked simultaneously on the same trip; zoning is clustering multiple SKUs into one zone within which a specific picker picks these SKUs. Through the zoning and batching, the customer order sheet can be gridded into many unite blocks. In this paper, the order sheet is divided into M*N grids which means M rows and N columns, as illustrated in Figure 5.

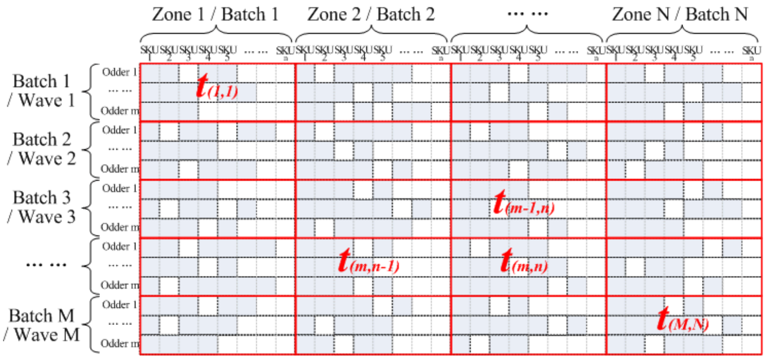


Figure 5. The Schematic of Order Cluster with Batching and Zoning

We use(m,n) to index the grid of row m and column n where $1 \le m \le M$, $1 \le n \le N$. Practically, in picker-to-parts system, the grid (m,n) is called the mth batch of orders and the nth zone of SKUs; however, in put system, it is called the mth wave of orders and nth batch of SKUs. One zone in put system may include many waves of orders.

By gridding the orders, we get a matrix of order clusters and SKU clusters. We define the variables of Order/SKU matrix as follows. Let:

$i \in \{1,2,...,I\}$ be the index for $Order_i$;

$j \in \{1,2,...,J\}$ be the index for SKU_j;

$x_i \in \{1,...,M\}$ be the cluster number of Orders;

$y_j \in \{1,...,N\}$ be the cluster number of SKUs;

$H_{(m,n)}, m \in \{1,...,M\}, n \in \{1,...,N\}$ be the set of cluster in the Order/SKU matrix.

These definitions of Order/SKU matrix are illustrated in Figure 6 [7].

$$\begin{array}{r|cccccc|}
 & \overbrace{y_1 \quad y_2 \quad \cdots}^{1} & \cdots & \overbrace{y_j}^{n} & \cdots & \overbrace{y_J}^{N} \\
 & sku_1\ sku_2\ \cdots & \cdots & sku_j & \cdots & sku_J \\
1 \begin{cases} x_1 & order_1 \\ x_2 & order_2 \\ \cdots & \cdots \end{cases} & \left\{ \begin{matrix} \\ H_{(1,1)} \\ \\ \end{matrix} \right\} & \cdots & & & \\
\cdots \quad \cdots \quad \cdots & \cdots & \cdots & & & \\
m \ \{ x_i \quad order_i & & & \{ H_{(m,n)} \} & & \\
\cdots \quad \cdots \quad \cdots & & & & \cdots & \cdots \\
M \ \{ x_I \quad order_I & & & & \cdots & \{ H_{(M,N)} \}
\end{array}$$

Figure 6. Definitions of Order/SKU Matrix

2.3. Storage Assignment

We use the concept of COI, which was introduced by Heskett [8], to optimize the sequence in each zone to get the shortest travel distance. The index COI for an item is defined as the ratio of its space requirement and order frequency. SKUs in picker-to-parts system or Orders in put system are sorted by the COI in ascending order and allocated to storage locations in non-decreasing order of distance from the I/O point [9]. We applied the concept of COI for SKUs in each zone or orders in each wave respectively.

$$COI_k = C_k \Big/ \sum_{1 \le h \le H} A_{hk} \tag{1}$$

Where

C_k: Space devoted to SKU_j ($k = j$) or $Order_i$ ($k = i$);

A_{hk}: Sum of visit frequency of SKU_j ($h = i$, $k = j$, H is the number of orders in one zone) or $Order_i$ ($h = j$, $k = i$, H is the number of SKUs in one wave).

For picker-to-parts system, Bartholdi has proved in his book that in order to minimize total restocks over all SKUs in the forward picking area, the fraction of available storage space devoted to each SKU should be as Eq.(2) [10].

$$v_j = \frac{\sqrt{f_j}}{\sum_{1 \le j \le J} \sqrt{f_j}} \tag{2}$$

Where

f_j: Volume of SKU_j.

We define the storage space devoted to SKU_j as the ratio of v_j and average value $\overline{v_j}$. And the ratio is rounded to the nearest integer, as shown in Eq. (3). Specially, if v_j is too small to cause C_j to be zero, we set C_j as 1.

$$C_j = \left[v_j \times \frac{1}{\overline{v_j}} \right] \tag{3}$$

Where

$\overline{v_j}$: the average value of v_j, j = 1, …, n.

For put system, the storage space devoted to $Order_i$ C_k $(k = i)$ is practically set as 1 to manage the order picking work easily. In order to have the fair comparison conditions, we also set the storage space devoted to SKU_j C_k $(k = i)$ as 1. Therefore, the COI will vary inversely as the sum of visit frequency as shown in Eq.(4).

$$COI_k = 1 \Big/ \sum_{1 \le h \le H} A_{hk} \tag{4}$$

3. Problem Modeling

3.1. Order Picking Time Formulation in Unit Grid

Firstly, we establish the order picking time formulations by analyzing the logical movements in one-dimensional unit grid.

3.1.1. Formulation of Picker-to-Parts System

In picker-to-parts without powered conveyor, the pickers have to deliver the totes to the end of the picking zone and then come back to the start point to get the next task, as illustrated in Figure 7.

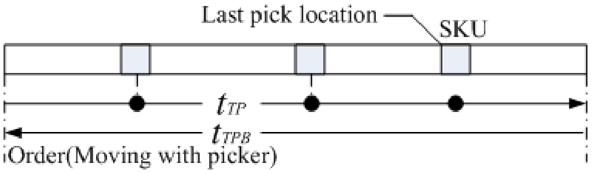


Figure 7. Logical Movement of Picker-to-Parts System in One Grid

The picking time in grid (m, n) for picker-to-parts system can be expressed as Eq. (5).

$$\begin{aligned} & t_{(m,n)} \\ & = t_{TP(m,n)} + t_{E(m,n)} + t_{TPB(m,n)} \\ & = \frac{\sum_{j=1}^{Z_{N(n)}} \left(C_j \times L_i\right)}{v_P} + t_{E_0} \times Q_{(m,n)} + \frac{\sum_{j=1}^{Z_{N(n)}} \left(C_j \times L_i\right)}{v_P} \\ & = 2 \times \frac{\sum_{j=1}^{Z_{N(n)}} \left(C_j \times L_i\right)}{v_P} + t_{E_0} \times Q_{(m,n)} \end{aligned} \tag{5}$$

Where

$t_{(m,n)}$: Picking time spent in mth batch and nth zone;

$t_{TP(m,n)}$: Travel time of picker in mth batch and nth zone;

$t_{TPB(m,n)}$: Travel back time from the end point to the start point in mth batch and nth zone;

$t_{E(m,n)}$: Extract time in mth batch and nth zone;

$Z_{N(n)}$: Quantity of SKUs in zone n;

L_j: Length of SKU_j;

C_j: Space devoted to SKU_j in the system;

$Q_{(m,n)}$: Quantity of items picked in mth batch and nth zone.

v_P: Walk velocity of pickers;

t_{E_0}: Unit time of extracting one item;

3.1.2. Formulation of Put System

In put system, as showed in Figure 8, after picking the last item into the tote corresponding to the order to complete the picking tour, the picker travels upstream to the start point of the picking zone to get another SKU or another bath of SKUs.

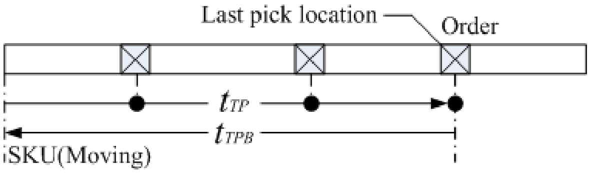


Figure 8. Logical Movement of Put System in One Grid

The picking time in grid (m , n) for put system can be expressed as Eq. (6).

$$\begin{aligned} & t_{(m,n)} \\ & = t_{TP(m,n)} + t_{E(m,n)} + t_{TPB(m,n)} \\ & = \frac{P_{(m,n)} \times L_0}{v_P} + t_{E_0} \times Q_{(m,n)} + \frac{P_{(m,n)} \times L_0}{v_P} \\ & = 2 \times \frac{P_{(m,n)} \times L_0}{v_P} + t_{E_0} \times Q_{(m,n)} \end{aligned} \tag{6}$$

Where

$t_{(m,n)}$: Picking time spent in mth wave and nth batch;

$t_{TP(m,n)}$:Travel time of picker in mth wave and nth batch;

$t_{TPB(m,n)}$: Travel back time from last pick location to start point in mth wave and nth batch;

$t_{E(m,n)}$: Extract time in mth wave and nth batch;

$P_{(m,n)}$: Last position of the totes that needed to be distributed in mth wave and nth batch;

L_0: Length of each tote;

v_P: Walk velocity of pickers;

t_{E_0}: Unit time of extracting one item;

$Q_{(m,n)}$: Quantity of items picked in mth wave and nth batch.

3.2. Time of 2-Dimensional System using Filling Curves

In fact, order picking systems are implemented in two-or-three dimensional spaced. We can map a general space into a one-dimensional system by using the concept of filling curve [7], which is a continuous mapping. A filling curve is a continuous mapping from one-dimensional unit grids into a higher dimensional space. For either picker-to-parts system or put system with synchronized zoning, we can design a typical layout as Figure 9.

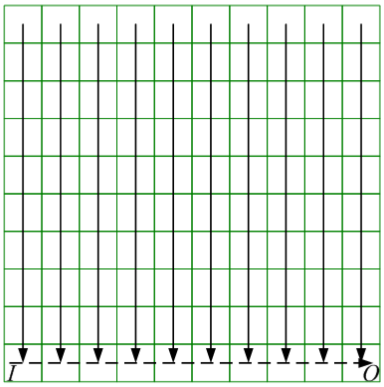


Figure 9. A Typical Filling Curve of Synchronized Zoning

Although picker-to-parts system can employ either progressive zoning policy or synchronized zoning policy, put system is usually implemented with the synchronized zoning policy which means the pickers will distribute the items to respective orders simultaneously. We establish time sequence models to combine the individual time of unit grids into the total time of entire system.

3.2.1. Time Model of Picker-to-Parts System

In picker-to-parts system, we assume that the pickers in their assigned zones process the orders respectively, so the time sequence model is shown as Figure 10.

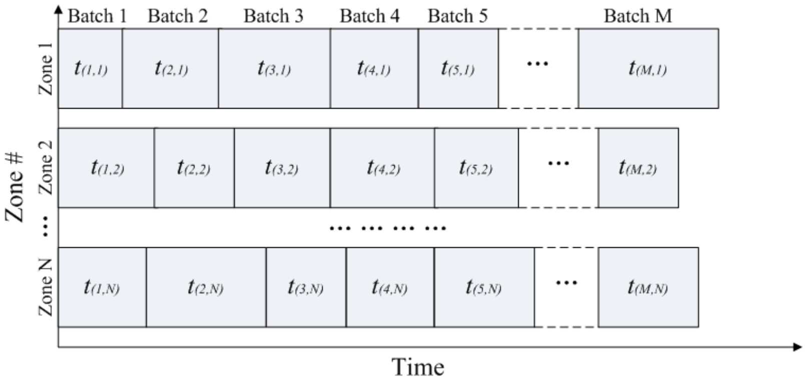


Figure 10. Time Sequence Model of Picker-To-Parts System with Synchronized Zoning

So the cumulative picking time for any (m , n) in picker-to-parts system can be expressed as Eq. (7).

$$T_{(m,n)} = T_{(m-1,n)} + t_{(m,n)} \tag{7}$$

In one wave, $T_{(m,n)}$ is determined by $T_{(m-1,n)}$. So we should set some initial formulations.

$$T_{(1,n)} = t_{(1,n)} \tag{8}$$

Then, the overall order picking time of picker-to-parts system is as Eq. (9).

$$\max_{1 \le n \le N} \left\{ T_{(M,n)} \right\} \tag{9}$$

3.2.2. Time Model of Put System

In put system, setup time t_O exits between two adjacent batches, as illustrated in Figure 11. One picking zone includes many waves of orders, and one wave includes many batches of SKUs.

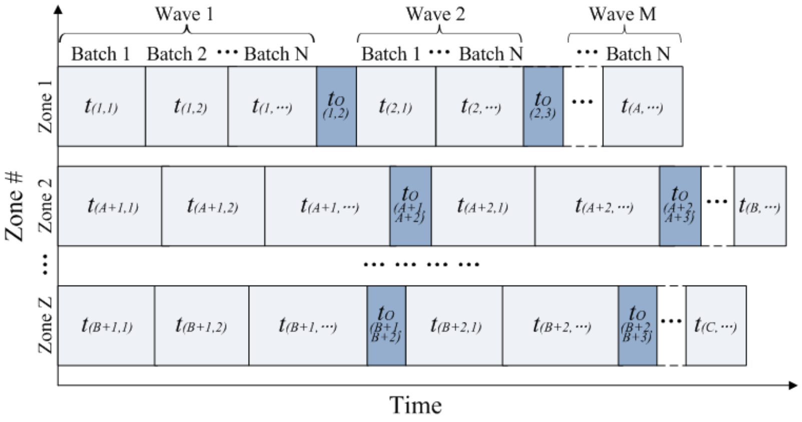


Figure 11. Time Sequence Model of Put System with Synchronized Zoning

The setup time $t_{O(m-1,m)}$ between two adjacent waves of orders is determined by the order frequency of the last batch of SKUs in the previous wave of orders, so we can assign the batch of SKUs which have the minimal order frequency as the last one to get the minimal setup time, as expressed in Eq. (10).

$$t_{O(m-1,m)} = t_{O_0} \times \min_{1 \le n \le N} \left\{ F_{(m-1,n)} \right\} \tag{10}$$

Where

$F_{(m-1,n)}$: the order frequency (the number of orders including the SKUs) of the nth batch of SKUs in the (m -1)th wave of orders;

Thus, the cumulative picking time for any (m , n) in put system can be expressed as Eq. (11).

$$T_{(m,n)} = T_{(m,n-1)} + t_{(m,n)} + t_{O(m-1,m)} \tag{11}$$

The initial formulation is set as Eq. (12).

$$T_{(m,1)} = t_{(m,1)} \tag{12}$$

As the waves of orders are independent, we can gain the respective order picking time of each wave $T_{(m,N)}$. If we divide the two-dimensional space into Z parallel zones with the index $z \in \{1,2,..,Z\}$, we can get the proximal mean cumulative time for each zone through the function as Eq. (13).

$$T_{\_Z} = f\left(T_{\_S}, Z\right) = f\left(\underset{1 \le m \le M}{sort}\left\{T_{(m,N)}\right\}, Z\right) \tag{13}$$

Where

$T_{\_S}$: Set of sorted $T_{(m,N)}$, $m=\{1,2,..,M\}$ with ascending order.

We propose an algorithm which can implement the function consuming very little time as the following steps.

Step1. Initialization.

Step1.1. Sort $T_{(m,N)}$, $m=\{1,2,..,M\}$ with descending order and assign them into $T_{\_S(s)}$, $s=\{1,2,..,M\}$.

Step1.2. Calculate the average value of $T_{\_S(s)}$, where $s=\{1,2,..,M\}$, and put it into $\overline{T}$.

Step1.3. Set $T_{\_Z(z)} = 0$, $z = \{1,2,..,Z\}$. Set $s = 1$ and $z = 1$.

Step2. Primary grouping. From 1 to Z (means for each $T_{\_Z(z)}$, $z = \{1,2,..,Z\}$), execute loop statement as follows until $s=M$.

Step2.1. If $T_{\_S(s)} \ge \overline{T}$, then remove $T_{\_S(s)}$ from $T_{\_S}$ into $T_{(z)}$. Reset $T_{\_S}$ with the rest of $T_{\_S}$. Break this loop and start next loop where $z = z + 1$.

Step2.2. If $T_{(z)} + T_{(s)} \le \overline{T}$, then remove $T_{\_S(s)}$ from $T_{\_S}$ into $T_{(z)}$. Reset $T_{\_S}$ with the rest of $T_{\_S}$.

Step2.3. If $T_{(z)} + T_{(s)} > \overline{T}$, then remove $T_{\_S(s)}$ from $T_{\_S}$ into $T_{\_temp}$. Reset $T_{\_S}$ with the rest of $T_{\_S}$.

Step3. Supplemental grouping. If $T_{\_temp}$ is not empty, then remove the smallest one from $T_{\_temp}$ into greatest one of $T_{(z)}$ until $T_{\_temp}$ becomes empty.

Then, the overall order picking time of put system is as Eq. (14).

$$\max_{1 \le z \le Z}\left\{T_{\_Z(z)}\right\} \tag{14}$$

3.3. The Effect of Dual Tour

Observe that in the simple one-dimensional rack, after visiting the last pick location at the end of a grid, a picker will revisit all the pick locations in the same grid on his or her return to the start point. This means the picker will visit the same location twice in the one-dimensional rack structure. The travel distance can be reduced if pick locations in one zone are arranged in a “U” shape as illustrated in Figure 12.

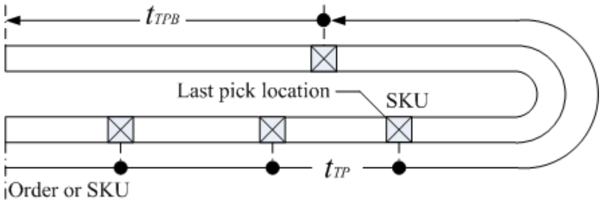


Figure 12. The Travel Back Time of Put System

The travel back time of picker-to-parts system, is expressed as (15).

$$t_{TPB(m,n)} = \min\left\{ \frac{\sum_{j=1}^{P_{(m,n)}} \left(C_j \times L_j\right)}{v_P}, \frac{\sum_{j=P_{(m,n)}}^{Z_{N(n)}} \left(C_j \times L_j\right)}{v_P} \right\} \tag{15}$$

The travel back time of put system, is expressed as (16).

$$t_{TPB(m,n)} = \min\left\{ \frac{P_{(m,n)} \times L_0}{v_P}, \frac{(W_{N(m)} - P_{(m,n)}) \times L_0}{v_P} \right\} \tag{16}$$

Where

$W_{N(m)}$: Quantity of orders(totes) in mth wave.

With the “U” shape two-dimensional unit, we can design another common layout with synchronized zoning as illustrated in Figure 13.

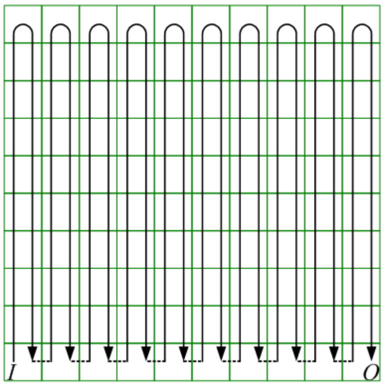


Figure 13. A Dual Filling Curve of Synchronized Zoning

4. Objective Function and Algorithm

4.1. Objective Function

With efficiency as the standard, it is obvious that we should select the order picking system that costs less time for given customer orders. Therefore, we define the subtraction value of optimal order picking time which is obtained by employing proper policies between picker-to-parts system and put system as Eq. (17).

$$\Delta T = \min\left\{ \max_{1 \le z \le Z} \left\{ T_{\_Z(z)} \right\} \right\} - \min\left\{ \max_{1 \le n \le N} \left\{ T_{(M,n)} \right\} \right\} \tag{17}$$

Where $\Delta T > 0$, select picker-to-parts system; otherwise, select put system. The greater ΔT is, the stronger necessity is to select picker-to-parts system and vice versa.

We can find that L_0 , v_P , t_{E_0} , t_{O_0} are parameters determined by the order picking systems, and $P_{(m,n)}$, $Q_{(m,n)}$, $Z_{N(n)}$, $W_{N(m)}$ are determined by order clustering. For given alternative order picking systems, the parameters are constants, so the way to find the optimal picking time is to search the optimal order clustering.

4.2. Optimization with Genetic Algorithm

In order to find the optimal order clustering, we adopt the genetic algorithm. In our case, we define the two sets of variables, and , for chromosome representation [7]. the encoding chromosome can be expressed as a vector of I+J integers with the value and , where N denotes the number of groups divided among the SKUs and M denotes the number of groups divided among the orders.

$$\text{Individual} \rightarrow (\underbrace{x_1, x_2, ..., x_I}_{Orders}, \underbrace{y_1, y_2, ..., y_J}_{SKUs}) .$$

The following steps are employed to search the optimal solution.

Step1: Initialization. Randomly generate a set of chromosomes to be the initial population. A chromosome will correspond to an Order/SKU matrix.

Step2: Evaluation. Evaluate the performance of a chromosome via the fitness function. In this case, the fitness function is the objective function in Eq.(17).

Step3: Selection. Select chromosomes from current generation to be copied into next generation by the Roulette rules. That is, the chromosome with the lower fitness function has a higher probability to be selected.

Step4: Crossover. Pick two chromosomes from the population after selection operation to be parent chromosomes. Set the position between x_I and y_1 as a crossover point within both the parents and interchange the genes after the crossover point of the paired chromosomes to produce two new children.

Step5: Mutation. Firstly, select a chromosome from the population after crossover operation to be a parent chromosome with a certain probability. Secondly, pick randomly an SKU or Order from this chromosome and move it to another cluster. This is equivalent to changing the position of the corresponding column or row in the Order/SKU matrix. In the chromosome representation, this is equivalent to assigning a random element of the chromosome to another valid value.

Step6: Replace. After each generation including selection, crossover and mutation, replace least-fit parents with their children which have lower value of fitness function.

Step7: Repeat step 2 to step 6 until the maximum generation limit is met.

5. Experimental Research

5.1. Input Analysis

5.1.1. Experimental Orders

In order to evaluate this method for selecting order picking system according to different orders, we generate three classical kinds of customer order sheets: wholesaler orders, retailer orders and consumer orders. For each kind customer order sheet, we suppose that there are popular SKUs and major customers corresponding to big Orders, so that we assume that both Orders and SKUs follow normal distribution. It means that either in Orders or SKUs, the density including quantity (Items/SKU and Items/Order) and frequency (Orders/SKU and SKUs/Order) follow normal distribution, as illustrated in Figure 14.

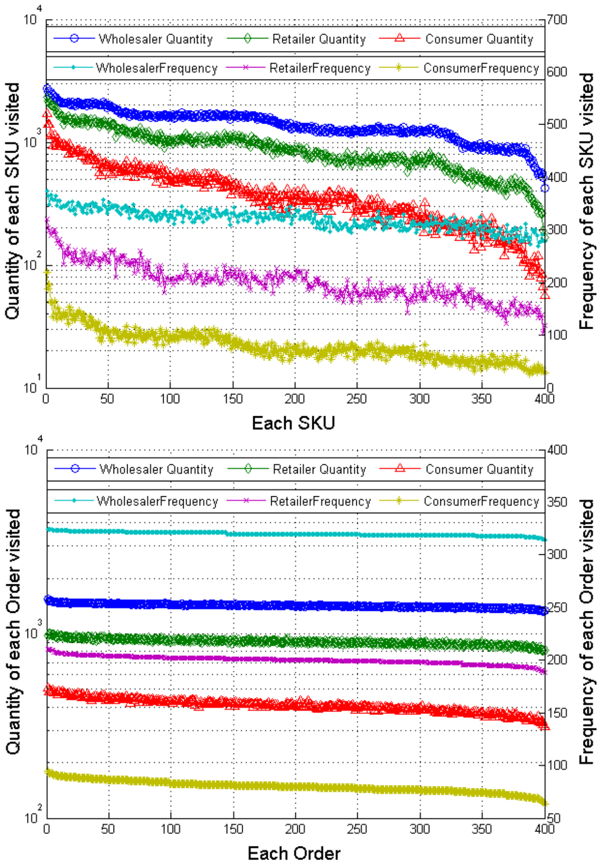


Figure 14. The Quantity and Frequency of Skus and Orders

The main elements of the orders are shown in Table 2.

Table 2. Elements of General Orders

Elements	Value
Orders number	400
SKUs number	400
Densities[1]	20%, 50%, 80%
Quantities[2]	1～10
L_j[3]	0.5m
L_0	0.5m

[1]: the ratio of visited SKUs to the total SKUs in all order lines.
[2]: the range of quantity of each visited SKU in each order.
[3]: in order to compare fairly, we assume the length of each SKU is same as that of each tote.

5.1.2. Parameters of System

Since the parameters of order picking system will have a significant impact on the picking time, we set most parameters as the same value so that we can get the fair comparison, as shown in Table 3.

Table 3. Parameters of Order Picking System

Parameters	Unit	Picker-to-parts	Put
v_P	m/s	1	1
t_{E_0}	s	1	1
t_{O_0}	s	0	10
Clusters of Orders M		400,200,133,100,80[1]	40,20,10,5[2]
Clusters of SKUs N		2,3,4,5[3]	400,200,133,100,80[4]
Zone number		2,3,4,5	2,3,4,5

[1]:M = Orders number / batch size. We set batch size which means the quantity of orders in each batch as 1, 2, 3, 4 and 5.

[2]:M = Orders number / wave size. We set wave size which means the quantity of orders in each wave as 10, 20, 40 and 80.

[3]:N = zone number.

[4]:N = SKUs number / batch size. We set batch size which means the quantity of SKUs in each batch as 1, 2, 3, 4 and 5.

5.1.3. Parameters of Algorithm

By testing a set of values, we choose the better value of parameters for the genetic algorithm in this paper, as shown in Table 4.

Table 4. Parameters of Genetic Algorithm

Parameters	Value
Population	10
Generations	100
Crossover probability	0.8
Mutation probability	0.01

5.2. Output analysis

5.2.1 Suitability Analysis

After setting the parameters and inputting the experimental orders, we can get the subtraction value ΔT between picker-to-parts system and put system for different types of orders, as shown in Table 5. With the hypothetic value of each parameter, we can get the suitability of the two systems for each experimental order by comparing the delta order picking time ΔT with 0.

Table 5. Subtraction Value ΔT

Order	Tour	Wave size	10				20				40				80			
		Zone / Batch	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
Wholesaler	Single	1	-890	7610	-900	-730	-180	10710	-400	-420	450	46150	35020	-260	71670	48340	107300	-100
		2	2170	8540	1090	670	2160	11210	970	660	2310	42410	32470	690	65650	44570	96400	720
		3	1770	8480	850	330	1710	9990	680	80	2770	39630	30650	40	61360	41980	91660	30
		4	5110	9970	2630	1780	5150	12390	2630	1710	5190	41970	32340	1740	65270	44060	93020	1760
		5	6600	10970	2960	2450	6610	13510	2970	2390	6690	42170	32660	2390	66130	44890	92600	2380
	ua	1	1280	7620	610	0	880	10210	460	-100	1030	40980	31560	-120	64090	43210	95640	-70
		2	2420	8090	1040	690	2220	10630	930	590	2300	39900	30320	620	61650	41920	90500	660

		3	2140	7460	860	630	1560	9830	710	380	1470	38000	29300	390	58700	39970	88120	340
		4	5340	9570	2490	1820	5200	12540	2600	1740	5230	40900	31380	1770	62750	42770	89700	1830
		5	6590	10770	3290	2220	6600	13200	3290	2310	6750	41270	32020	2330	64570	43630	90240	2380
Retailer	Single	1	-8500	-1130	-4430	-3550	-4360	4680	-2210	-1930	-2010	30400	23540	-1070	48820	33390	74960	-610
		2	-360	3250	-300	-348	130	6200	-70	-77	570	26830	21020	71	42740	29300	64140	192
		3	630	3470	230	201	220	6180	180	-53	420	25290	19760	73	40430	27520	60120	12
		4	2240	4520	890	814	2140	7180	1130	705	2210	25880	20070	715	40670	28000	59450	722
		5	3360	4790	1710	1033	3030	7530	1530	924	3180	25800	20420	942	41110	28170	59100	1086
	Dual	1	230	3240	0	-5	170	6340	130	-62	340	26990	20880	-43	42320	28810	64030	-18
		2	1080	3730	400	303	850	6110	400	322	920	24710	19440	205	39030	26940	58390	218
		3	1220	3400	547	500	520	5870	565	150	590	23470	18376	250	37320	25980	55716	122
		4	2600	4060	1151	777	2360	6870	1206	711	2520	24920	19392	762	38310	26520	56762	699
		5	3210	4680	1677	1276	3000	7220	1574	1259	3050	24820	19345	1186	39070	26880	56775	1173
Consumer	Single	1	-31310	-20691	-15635	-12498	-19680	-9492	-9600	-7678	-10670	9580	8204	-4389	22960	16360	41183	-2352
		2	-8020	-5195	-3913	-3217	-4680	-418	-2130	-1859	-2400	11530	9420	-991	20180	14492	33080	-533
		3	-2910	-1949	-1404	-1319	-1890	1269	-803	-694	-940	10291	9137	-467	18950	13348	29748	-209
		4	-890	-584	-409	-429	-520	1799	-89	-197	-20	10249	8980	-55	17880	12986	28490	71
		5	688	-196	3	-27	40	2202	171	25	482	10687	8794	93	17913	12626	26700	174
	Dual	1	-8220	-5391	-3996	-3464	-2980	663	-1517	-1149	-640	13025	10502	-335	21520	15482	34112	-113
		2	-760	-565	-200	-223	-150	2206	-187	-9	90	10576	8887	13	18170	12976	28097	37
		3	374	-8	145	106	131	2180	195	6	98	10318	8136	-25	16933	12065	26226	56
		4	1027	173	373	273	525	2163	249	178	530	9860	8104	180	16400	12017	25217	236
		5	1391	373	463	289	606	2300	432	238	651	9660	8142	238	16430	11788	24999	247

From Table 5, we can notice that the suitability is influenced by batch size, wave size, number of zones and type of travel tour. But the principle between the suitability and the influence factors doesn’t seem obvious because there are some singular values with some combinations of number of waves and number of zones. In fact, in picker-to-parts system, the relationship between order picking time and number of zones seems like hyperbolic type; in put system, the order picking time is proportion to the ratio of number of waves and number of zones, as illustrated in Figure 15.

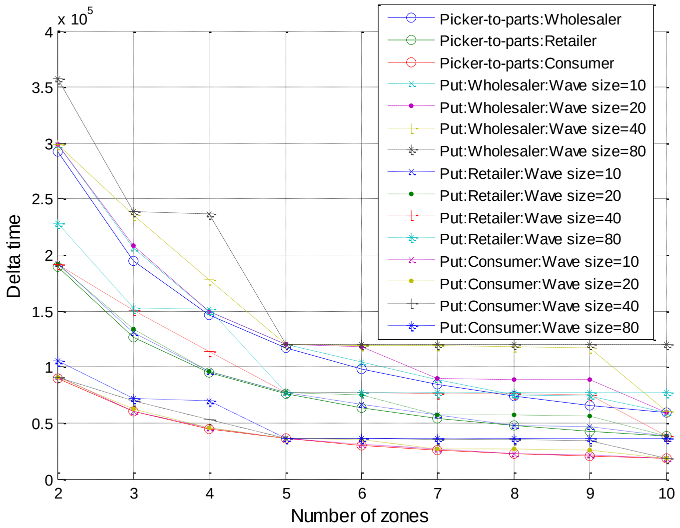


Figure 15. Order Picking Time of Different Systems for Different Orders

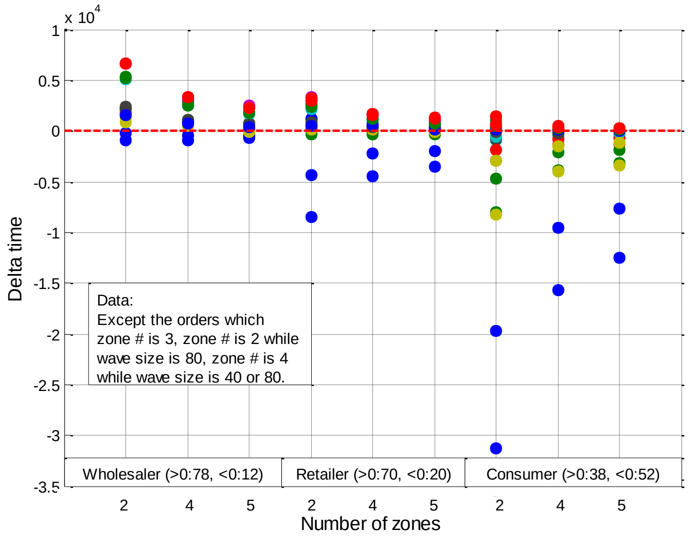
When the ratio of waves and zones is not an integer, the order picking time of put system will increase sharply because it is hard to distribute the waves into the zones equally. However, the distribution of SKUs into zones in picker-to-parts system is usually equal. Therefore, the probability of choosing put system is likely greater in this situation.

Practically, the number of waves is much greater than the number of zones in put system so the imbalance of distribution can be ignored. Also, the remainder of ratio can be distributed equally into the zones by distributing the orders not the waves. In order to matching the practical situation, we leave out the data when the ratio is not an integer during the analysis procedure as shown in Table 6.

Table 6. Ratio of Number of Waves and Number Of Zones

Zones # Wave size	2	3	4	5	6	7	8	9	10
10	20	13.3	10	8	6.7	5.7	5	4.4	4
20	10	6.7	5	4	3.3	2.9	2.5	2.2	2
40	5	3.3	2.5	2	1.7	1.4	1.3	1.1	1
80	2.5	1.7	1.3	1	0.8	0.7	0.6	0.6	0.5

Ignoring the singular values which the ratio of waves and zones is not integral, we can get the distribution of subtraction time ΔT relative to the type of orders as illustrated in Figure 16. Although each type of orders can be completed by either picker-to-parts system or put system with proper parameters, most ΔT for wholesaler and retailer order is greater than 0 and many ΔT for consumer order is less than 0. So in our case, picker-to-parts system trends to be employed for wholesaler and retailer order; however, put system is apt to be employed for consumer order.



Data:
Except the orders which zone # is 3, zone # is 2 while wave size is 80, zone # is 4 while wave size is 40 or 80.

Figure 16. Distribution of Delta Time Relative to Type Of Orders

5.2.2. Sensitivity Analysis

When we change the value of parameters, the order picking time of each system will change but the changing magnitude will be different, so the suitability may change. According to the simulation results, we can evaluate the effect of parameters on suitability.

(1) Zone number analysis

Figure 17 shows that as the number of zones increases, the probability of choosing put system for each kind of orders becomes bigger.

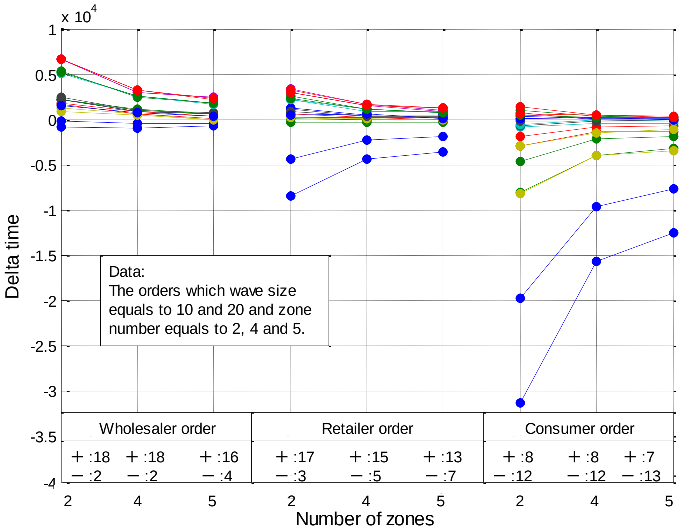


Figure 17. Sensitivity of Zone Number for Different Orders

(2) Batch size analysis

The influence of batching policy is shown in Figure 18. For any type of orders, the probability of choosing picker-to-parts system decreases progressively as the batch size becomes greater.

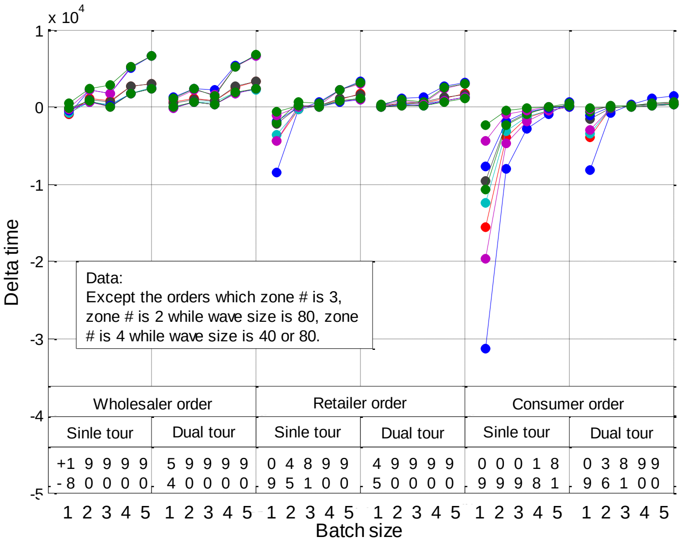


Figure 18. Sensitivity of Batch Size for Different Orders

(3) Wave size analysis

As illustrated in Figure 19, for consumer orders, the greater the wave size is, the greater the probability of choosing picker-to-parts system is. However, the impact of wave size on suitability for wholesaler and retailer orders is not significant.

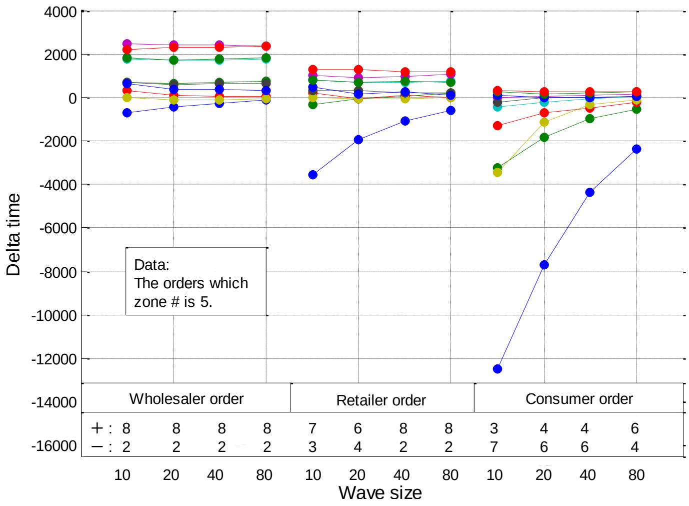


Figure 19. Sensitivity of Wave Size for Different Orders

(4)Dual tour analysis

As illustrated in Figure 20, dual tour policy will cause the bigger probability of choosing picker-to-parts system.

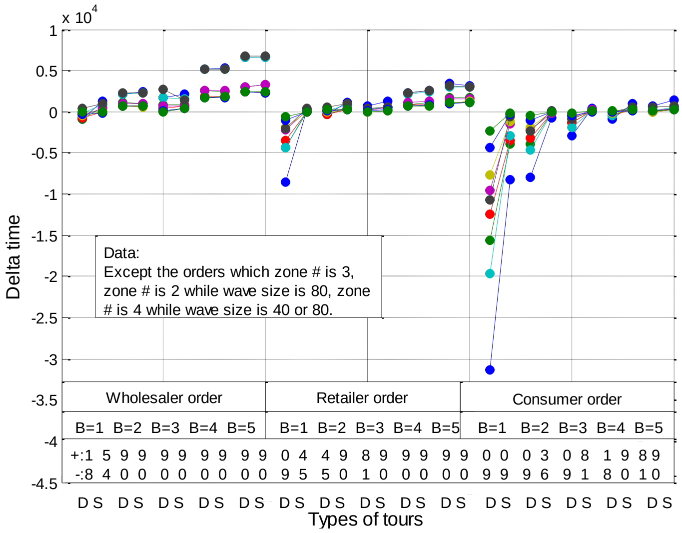
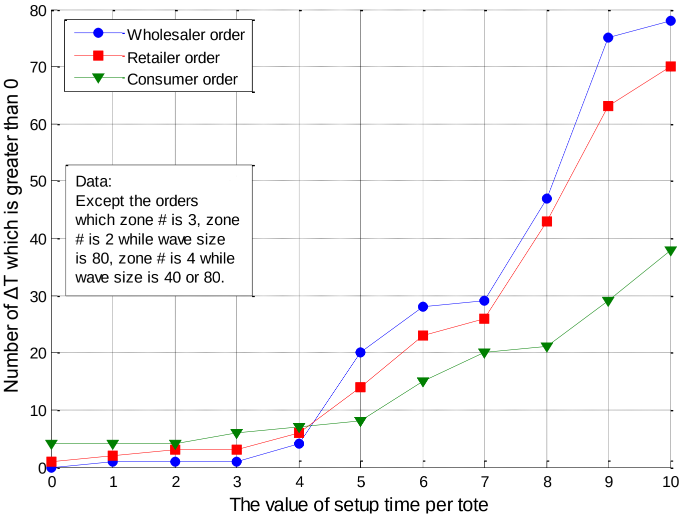


Figure 20. Sensitivity of Dual Tour for Different Orders

(5)Setup time analysis

Comparing the variation trend when setup time changes from 0 to 10 seconds per tote, we can find that the probability of choosing picker-to-parts system for each kind of orders becomes bigger as the setup time increases, as illustrated in Figure 21. Shown as the slope of each curve, setup time have biggest impact on suitability for wholesaler orders but least influence for consumer orders; and it falls in between for retailer orders.



Data:
Except the orders which zone # is 3, zone # is 2 while wave size is 80, zone # is 4 while wave size is 40 or 80.

Figure 21. Sensitivity of setup time for different orders

6. Conclusion and Further Research

Through the experimental study, we can find that this systemic method can not only get suitability of each system for given orders, but also can get sensitivity of the main parameters such as zone number, batch size, wave size, tour type and setup time. Roughly speaking, for both wholesaler orders and retailer orders, picker-to-parts system has the greater probability of being employed; and put system seems more suitable for consumer order. Some factors including zone number, batch size, wave size, dual tour and setup time have significant impact on the suitability of choosing the proper system for different orders.

Finally, it needs some time to develop and run the program. If we could find some metrics or theorems by testing a lot of experimental and practical customer order, then we can use a short time to select the proper system just by glancing over the orders. The potential theorems can be described with number, visited frequency and distribution of orders and SKUs, quality and length of item and container, and so on.

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References

[1] R.D. Koster, T. Le-Duc and K. J. Roodbergen, “Design and Control of Warehouse Order Picking: a Literature Review”, European Journal of Operational Research, vol.182, no.2, **(2007)**, pp.481-501.

[2] F. Dallari, G. Marchet and M. Melacini, “Design of Order Picking System”, Int J Adv Manuf Technol, vol.42, no.1, **(2009)**, pp.1-12.

[3] R.D. Koster, “How to Assess a Warehouse Operation in a Single Tour”, Technology Report, RSM Erasmus University, the Netherlands, **(2004)**.

[4] C.G. Petersen and G. Asse, “A Comparison of Picking, Storage and Routing Policies in Manual Order Picking”, Int. J. Production Economics, vol. 92,no.1, **(2004)**,pp.11-19.

[5] J.A. Tompkins, J.A. White, Y.A. Bozer, E.H. Frazelle and J.M.A. Tanchoco, Editor, Facilities Planning, John Wiley & Sons, New York, **(2003)**.

[6] P.J. Parikh and R.D. Meller, “Selection between Batch and Zone Order Picking Strategies in a Distribution Center”, Transportation Research Part E**(2008)**, Vol.44,No.5, pp.696-719.

[7] W. Hua and C. Zhou, “Clusters and Filling-curve-based Storage Assignment in a Circuit Board Assembly Kitting Area”, IIE Transactions, vol.40, no.6, **(2008)**,pp.569-585.

[8] J.L. Heskett, “Putting the Cube-per-order Index to Work in Warehouse Layout”, Transportation and Distribution Management, vol.4,no.8, **(1964)**, pp.23-30.

[9] B.I. Kim, S.S. Heragu, R.J. Graves and A.S.Onge, “Clustering-based Order-picking Sequence Algorithm for

an Automated Warehouse", International Journal of Production Research, vol.41,no.15, **(2003)**, pp.3445-3460.

[10] J.J. Batholdi and S.T. Hackman, Editor, Warehouse & Distribution Science, Georgia Institute of Technology, Atlanta, http://www2.isye.gatech.edu/~jjb/wh/book/editions/history.html, **(2008)**.

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