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Selecting between Pick-and-sort System and Carousel System Based on Order Clustering and Genetic Algorithm

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Abstract

A method is presented to select the suitable order picking system between pick-and-sort system, a type of semi-automated put system, and carousel system, a type of parts-to-picker system, for different types of customer orders, mainly determined by density and quantity. As policies of batching and zoning are essentially order clustering, the customer order sheet can be divided into unit grids. Then the time formulation for each system can be derived according to the logical movements in a unit grid and time sequence relationship among all unit grids. Genetic algorithm is adopted to search the optimal order picking time. Subtraction value ΔT *of order picking time between two kinds of system is used as the criteria to select more suitable system. In the experimental study, not only the suitability of each system with the hypothetic value of parameters can be got, but also the effect of some key factors on suitability is finally discussed.*

Key words: *selecting, pick-and-sort system, carousel system, order cluster, genetic algorithm*

1. Introduction

Order picking is the most important process in distribution centers because it consumes the most labor, determines the level of service experienced by the downstream customers. There are many order picking systems in practice to deal with the orders to complete order picking. According to the taxonomies of logical movement and mechanization level, we can get the classification of order picking systems [1], as illustrated in Figure 1.

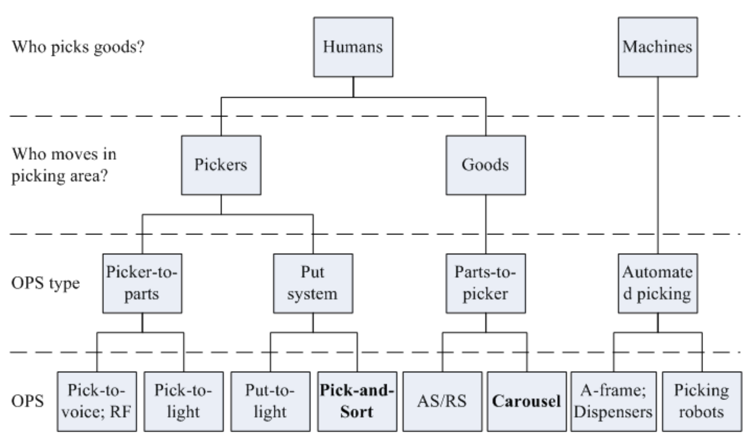

Figure 1. Classification of order picking systems

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As higher mechanization can be used in put system and parts-to-picker system, these two systems are employed more and more widely, especially the pick-and-sort system and carousel system. In pick-and-sort system, pickers in the picking bay retrieve the amount of each single item resulting from a wave of multiple orders and put them on a takeaway conveyor connecting the forward picking area with the sorting area [1]. The conveyor operates in a closed loop with automatic divert mechanisms and accumulation lanes (e.g. a tilt-tray or cross-belt sorting conveyor). A computerized system then determines the destination bay for each item; each destination bay refers to an individual customer order. A carousel system is an automated warehousing system consisting of a large number of shelves or drawers rotating in a closed loop in either direction [2]. In carousel system, the stock keeping units (SKUs) in the carousel are moved simultaneously by automatic device to the picking bay, where the pickers select the required amount of each item.

It makes sense to select the right order picking system for given orders. However, there are not many literatures about order picking system selection. The order picking systems are chosen on the basis of insights and experience. In this paper, a selecting method is presented to select the proper system between pick-and-sort system and carousel system from the standpoint of order picking time.

2. Problem analysis

2.1Oder picking time composition

For most order picking systems, the overall order picking time in a typical distribution center can be broken up into components as shown in Table 1.

Table 1. The composition of order picking time

Activity	%Order picking time
Traveling	55%
Searching	15%
Picking	10%
Other activities	20%

In both pick-and-sort system and carousel system, the searching time usually occurs with picking time simultaneously so it is negligible [11]. Therefore, the overall order picking time t can be defined as the composition of traveling time t_T, picking time t_E including searching time, and other time t_O.

In order to let the selection process confirm to the practical application, three main policies which are batching, zoning and storage assignment [3] are employed to get the optimal order picking time for either pick-and-sort system or carousel system.

2.2 Batching and zoning using order cluster

Essentially, both batching and zoning are cluster methods about customer order sheet. Batching is clustering multiple individual orders (or SKUs) into one batch as one single tour; zoning is clustering multiple SKUs (or orders) into one zone assigned with one picker. With the zoning and batching, the customer order sheet can be gridded into many blocks. We assume that the order sheet can be divided into M*N grids which means M rows and N columns. We use (m,n) to index the grid of row m and column n where 1≤ m≤ M, 1≤ n≤

N, and let $i \in \{1, 2, ..., I\}$ be the index for $Order_i$ and $j \in \{1, 2, ..., J\}$ be the index for SKU_j.

Particularly, in pick-and-sort system, one zone includes many waves of orders and there is only one SKU in one batch. Therefore, the grid (m, n) in pick-and-sort system is called the mth wave of orders and nth SKU; however, in carousel system, it is called the mth batch of orders and the nth zone of SKU_s.

For either pick-and-sort system or carousel system, synchronized zoning is the proper zoning policy [4], as shown in Figure 2.

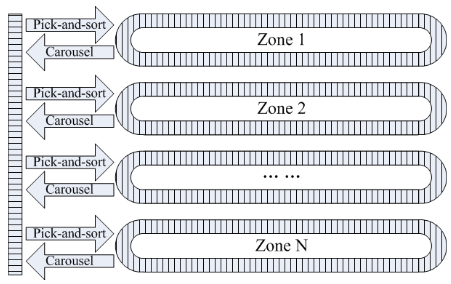

Figure 2. A typical layout with synchronized zoning

2.3 Storage assignment using COI

The concept of cube-per-order index (COI) is employed to optimize the sequence in each grid to get the shortest travel distance. The index COI for an item is defined as the ratio of its space requirement and order frequency [9]. Orders in pick-and-sort system or SKU_s in carousel system are sorted by the COI in ascending order and allocated to pick locations in non-decreasing order of distance from the I/O point [5]. The concept of COI for SKU_s in each zone or Orders in each wave is defined as Eq. (1).

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

Where

P_k: COI for $SKU_j (k = j)$

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

A_{hk}: The 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 SKU_s in one wave).

For pick-and-sort 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 fair comparison, we also set the storage space devoted to SKU_j $C_k(k=i)$ as 1.

3. Problem Modeling

3.1Time Model of Pick-and-sort System

In pick-and-sort system, as the conveyor operates in a closed loop, the SKU_s can be put on the conveyor item by item with a reasonable distance between them (*e.g.*, length of tilt-tray). So it is not necessary to wait for the tilt-tray to go back to the beginning of the system to start a new picking tour, as shown in Figure.3. A pick-and-sort system typically works with pick waves, where all of the orders in a pick wave are completely sorted before releasing the following pick wave [10].

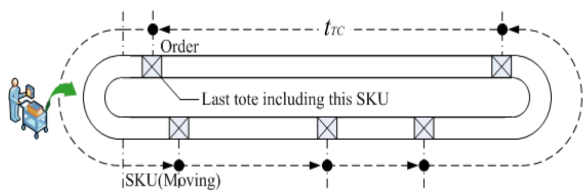

Figure 3. The schematic of pick-and-sort system in one zone

When item arrives at the destination bay, it will be put into the tote by tilt-tray but won't stop. So the picking time t_E is 0 and the order picking is equal to traveling time. In order to get the minimum order picking time, we make the assumption according to practical application as follows.

1) As mentioned above, totes corresponding to orders are allocated to pick locations in ascending sequence of COI. It means that the order with smaller COI value will be put nearer to the in/out (I/O) point, and vice versa.

2) In each wave of orders, the *SKUs* are assigned in the descending sequence of maximal pick location in this wave. It means that the SKU with greater maximal pick location will be put on the conveyor earlier, and vice versa.

3) For one SKU, the items will be distributed to the farthest pick location firstly and then to the nearer one piece by piece.

Therefore, in one zone, the cumulative time of one SKU is determined by the quantity of the previous SKUs (including itself) and the pick location it will go to, as illustrated in Figure 4.

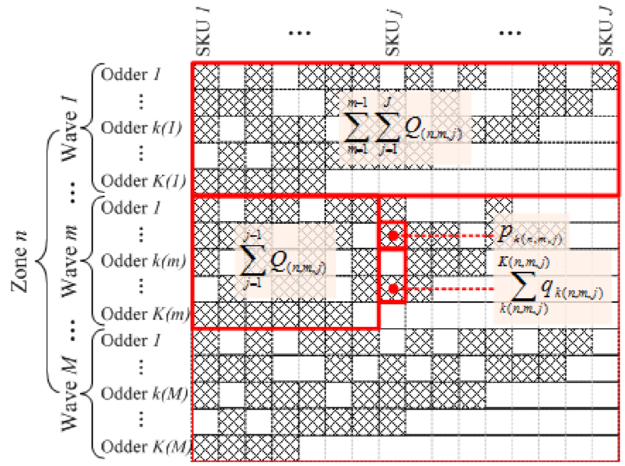

Figure 4. The cumulative time for pick-and-sort system in one zone

The cumulative time formulation of pick-and-sort system in one zone can be expressed as Eq. (2).

$$T_{(n,m,j,k)} = T_{TC(n,m,j,k)} = \left(\begin{array}{l} \sum_{m=1}^{m-1}\sum_{j=1}^{J} Q_{(n,m,j)} + \sum_{j=1}^{j-1} Q_{(n,m,j)} \\ + \sum_{k(n,m,j)}^{K(n,m,j)} q_{k(n,m,j)} + p_{k(n,m,j)} \end{array} \right) \times \frac{L_0}{v_C} \tag{2}$$

Where

$T_{(n,m,j,k)}$: Cumulative order picking time of SKU_j in kth pick location of mth wave in nth zone;

$T_{TC(n,m,j,k)}$: Cumulative traveling time of SKU_j in kth pick location of mth wave in nth zone;

$Q_{(n,m,j)}$: Items quantity of jth SKU in mth wave of orders in nth zone;

$q_{k(n,m,j)}$: Items quantity of jth SKU in kth pick location of mth wave in nth zone;

$p_{k(n,m,j)}$: Number of kth pick location of jth SKU in mth wave in nth zone;

$k(n,m,j)$: Index of kth pick location of jth SKU in mth wave in nth zone;

$K(n,m,j)$: Index of the last pick location of jth SKU in mth wave in nth zone;

L_0: Length of each tilt-tray;

v_C: transporting velocity of takeaway conveyor.

If m=1, then we set $\sum_{m=1}^{m-1}\sum_{j=1}^{J} Q_{(n,m,j)}$ =0; if j=1, then we set $\sum_{j=1}^{j-1} Q_{(n,m,j)}$ =0.

As the zoning policy employed in pick-and-sort system is synchronized zoning, the order picking time of each zone is independent. So the time for entire pick-and-sort system can be expressed as Eq. (3).

$$\max_{1\le n\le N}\left\{\max_{1\le m\le M,1\le j\le J,1\le k\le K}\left\{T_{(n,m,j,k)}\right\}\right\} \quad (3)$$

3.2 Time Model of Carousel System

For the carousel is bidirectional, we implement carousel with Nearest Item (NI) heuristic, where the next item to be picked is always the nearest one as exhibited in Figure 5. Bartholdi and Platzman have proved that the travel time under the NI heuristic is never greater than one rotation of the carousel, so we use NI heuristic as the movement policy of carousel system.

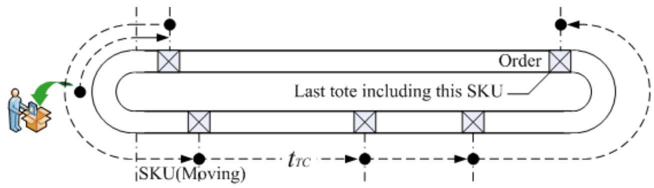

Figure 5. The schematic of carousel system in one zone

The independent order picking time in grid (m,n) for carousel system can be expressed as Eq. (4).

$$t_{(m,n)}=\sum_{k=1}^{Z_{N(n)}}\left(t_{TC(m,k)}+t_{E(m,k)}\right)=\sum_{k=1}^{Z_{N(n)}}\min\left\{\begin{array}{c}\dfrac{\left|P_{(m,k)}-P_{(m,k-1)}\right|\times L_1}{v_C},\\[2ex] \dfrac{\left(Z_{N(n)}-\left|P_{(m,k)}-P_{(m,k-1)}\right|\right)\times L_1}{v_C}\end{array}\right\}+t_{E_0}\times F_{(m,n)} \quad (4)$$

Where

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

$t_{TC(m,k)}$: Traveling time of bin to go to the picking bay in mth batch and kth tour;

$t_{E(m,k)}$: Extracting time of picker in mth batch and kth tour;

$Z_{N(n)}$: Number of *SKUs* in nth zone;

$P_{(m,k)}$: Location of the *SKUs* that needed to be picked in mth batch and kth tour;

$F_{(m,n)}$: Quantity of *SKUs* in mth batch and nth zone;

v_C: Transporting velocity of carousel;

t_{E_0}: Unit time of extracting one kind of SKU;

L_1: Length of each SKU.

In Carousel system, we assume that the pickers in their assigned zones process the orders respectively, so the time sequence [6] model is shown as Figure 6.

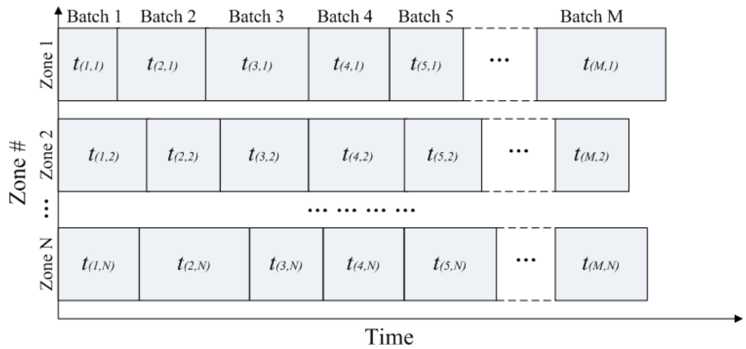

Figure 6. Time model of carousel system

So the cumulative picking time for any (m, n) in carousel system can be expressed as Eq. (5).

$$T_{(m,n)} = T_{(m-1,n)} + t_{(m,n)} \tag{5}$$

In one zone, $T_{(m,n)}$ is determined by $T_{(m-1,n)}$. So if m=1, then we set $T_{(m-1,n)}$=0.

Then, the overall order picking time of carousel system is as Eq. (6).

$$\max_{1\le n\le N}\left\{T_{(M,n)}\right\} \tag{6}$$

4. Objective function and algorithm

4.1Objective 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 pick-and-sort system and carousel system as (7).

$$\Delta T = \min\left\{\max_{1\le n\le N}\left\{T_{(M,n)}\right\}\right\} - \min\left\{\max_{1\le n\le N}\left\{\max_{1\le m\le M,1\le j\le J,1\le k\le K}\left\{T_{(n,m,j,k)}\right\}\right\}\right\} \tag{7}$$

If Δ T>0, select pick-and-sort system, otherwise, select carousel system. The greater Δ T, the stronger necessity is to select pick-and-sort system and vice versa.

From the expression of minimized order picking time, we can find that the parameters of L_0, L_1, v_C, t_{E_0} are determined by the order picking systems and $Q_{(n,m,j)}$, $Z_{N(n)}$, $F_{(m,n)}$, $P_{(m,k)}$ are determined by the combination of orders and SKUs. For certain order picking system, the parameters are constants, so the way to find the minimized order picking time is to search the optimal combination of orders and SKUs.

4.2 Optimization with genetic algorithm

In order to find the optimal combination of orders and SKUs, we adopt the genetic algorithm. In our case, we define the two sets of variables x_i, $i \in \{1,2,...,I\}$ and y_j, $j \in \{1,2,...,J\}$ for chromosome representation [7]. We define individual to be a vector of

I+J integers with the value $x_i \in \{1,...,M\}$ and $y_j \in \{1,...,N\}$, where M represents the number of groups divided among the orders and N represents the number of groups divided among the SKUs.

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

The following steps are employed to find the optimal value of x_i, y_j

Step1: Initialization. Randomly generate a set of individuals as the initial population. Each individual will correspond to a different Order/SKU matrix.

Step2: Evaluation. Evaluate the fitness function value of each individual in that population. In this case, we set the objective function as the fitness function.

Step3: Selection. Use the Roulette rules to select the best-fit individuals for reproduction. That is, the individual with the lowest fitness function is assigned a higher probability of being a parent in next generation.

Step4: Crossover. Pick two individuals from the population after selection operation to be parents. Both parents are cut at the splice point between x_I and y_1. The front portions of each parent are combined with the end portion of the other parent.

Step5: Mutation. Only one individual from the population after crossover operation is picked to be a parent. Starting from this individual, we randomly pick an SKU or Order 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 individual to another valid value.

Step6: Replace. After each generation including selection, crossover and mutation, replace least-fit parents with their children if a lower fitness function is discovered.

Step7: Repeat from step 2 until the maximum generation limit is met. In our case, we terminate the genetic algorithm when generation number meets the upper bound.

5. Experimental study

5.1Input data

In order to test the suitability between different systems and different orders, we create 6 different kinds of orders with different quantities and densities following normal distribution, as shown in Figure 7.

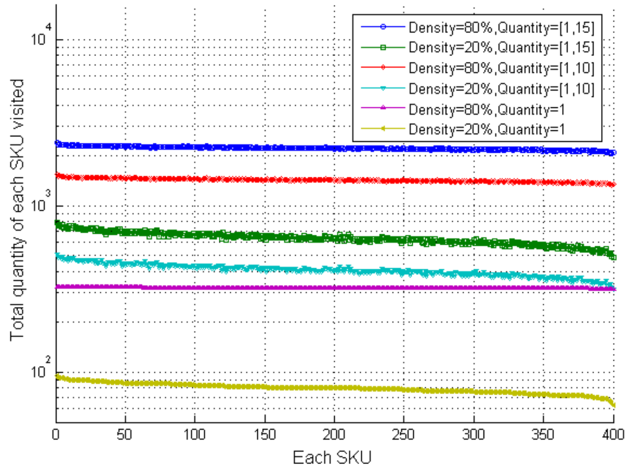

Figure 7. Experimental orders with different quantities and densities following normal distribution

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

Table 2. Elements of experimental orders

Elements	*Value*
Orders number	400
SKUs number	400
Densities[1]	20%, 80%
Quantities[2]	1, 1～10, 1～15
L_0	0.5m
L_1	0.5m

1: the ratio of visited *SKUs* to the total *SKUs* of all order lines.
2: the range of quantity of each visited SKU in each order.

As the parameters of order picking system will have significant influence on order picking time, we set the proper value of each parameter of the two systems, as shown in Table 3, to get fair comparison.

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

Table 3. Parameters of picker-to-parts system

Parameters	Unit	*Pick-and-sort*	*Carousel*
v_C	m/s	2	2
t_{E_0}	s		1
M		40,20,10,8	400
N		2,3,4,5,6	2,3,4,5,6

Table 4. Parameters of genetic algorithm

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

5.2 Output analysis

By inputting the experimental orders with the assumed value of parameters in our case, we can get the subtraction value Δ T, as shown in Table 5.

Table 5. Subtraction value ΔT for each order

	N / M	2	3	4	5	6	# of ΔT>0
D=20% Q=1	40	33133	22900	17698	14757	11983	20
	20	33133	22457	17696	14754	11982	
	10	33131	22458	16581	14752	9994	
	8	33127	21671	17692	12453	10978	
D=80% Q=1	40	69082	46223	35562	28817	21599	20
	20	69079	44622	35560	28814	21585	
	10	69074	44613	30783	28810	13588	
	8	69072	41419	35552	19237	17592	
D=20% Q=[1,10]	40	16630	11750	9445	8152.7	4207.2	17
	20	16627	9889	9443	8151.7	4161	
	10	16622	9807	3909	8146.5	-5985	
	8	16623	5619	9439	-3523	-857	
D=80% Q=[1,10]	40	13966	8045	8004	6768	-5534	13
	20	13964	1034	8001	6766	-5397	
	10	13959	906	-12769	6762	-40878	
	8	13956	-13214	7993	-35427	-23248	
D=20% Q=[1,15]	40	5366	4167	3813	3647	-1295	13
	20	5366	904	3812	3647	-1149	
	10	5366	1243	-4717	3641	-16725	
	8	5362	-5188	3805	-14388	-8968	
D=80% Q=[1,15]	40	-25567	-19275	-11762	-9046	-25011	0
	20	-25567	-30445	-11765	-9046	-24754	
	10	-25577	-30133	-44247	-9052	-80196	
	8	-25577	-52280	-11771	-74521	-52626	

By observing whether Δ T is greater than 0 or not, we can select the suitable system for given orders. If Δ T>0, then the pick-and-sort system is suitable; and if Δ T<0, we should select carousel system.

According to the total number of Δ T which is greater than 0 for one order with various combinations of waves and zones number, we can get the overall trend about the suitability as follows.

1) The higher the density is, the bigger probability is to select carousel system; and it is trend to select pick-and-sort system when density is low.

2) The greater the quantity is, the bigger probability is to select carousel system; and it is trend to select pick-and-sort system when quantity is small.

In fact, the mail order is the typical order with low density and small quantity. Pick-and-sort system is widely used in mail order companies [8].

The number of zones and waves also has significant effect on suitability, as shown in Figure 8 and Figure 9.In our case, Figure. 8 illustrates that the greater the zones number is, the bigger probability is to select carousel system and vice versa; Figure 9 shows that the greater the waves number is, the bigger probability is to select pick-and-sort system and vice versa.

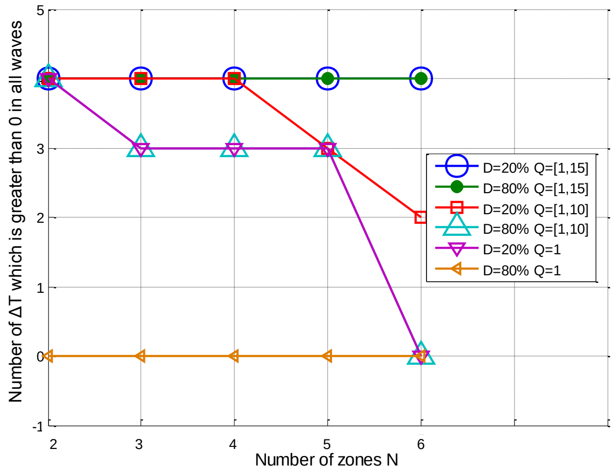

Figure 8. Effect of zones number on suitability

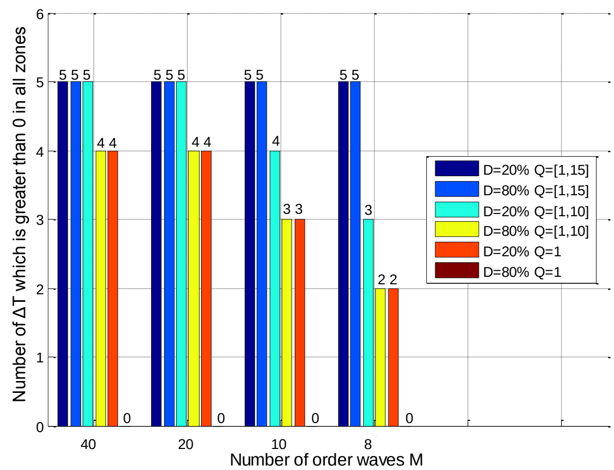

Figure 9. Effect of waves number on suitability

6. Conclusion and Further Research

Through the experimental study, we can find that this method can not only get suitability of the two systems for given orders, but also can get influence of the main operational factors such as zones number and waves number. Roughly speaking, for the orders with higher density and greater quantity, carousel system has the bigger probability of being employed; and pick-and-sort system seems more suitable for orders with lower density and less quantity. Under the hypotheses presented in this paper, number of zones has more significant influence on carousel system; and the bigger number of waves is, the stronger trend is to select pick-and-sort system.

However, this method requires some time to develop and run the program. It makes sense if some theorems or metrics can be found by testing plenty of experimental and practical orders so that we can select the proper system just by glancing over the orders in a short time. The potential theorems can be described with number of orders and SKUs, density, quantity, length of item and container, distribution of order and SKUs and so on.

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