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# 창고의 복도형 오더 피킹 시스템의 'Golden Zone' 운영과 경로 최적화 알고리즘 효과 비교

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# An Evaluation of Routing Methods and the Golden Zone Effect in the Warehouses Order Picking System

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ABSTRACT

Order picking in automotive service parts warehouses is considered to be the most labor-intensive operation. Such warehouses contain hundreds of thousands of items, but normally 20% of products contribute to about 80% of turnover according to Pareto's 80-20 principle. Therefore most fast moving items are located near an outbound area which is called the "Golden Zone". Order picking routing efficiency is related to productivity and labor cost. However, most companies use simple methods. In this paper, we describe a series of computational experiments over a set of test cases where, we compared various previously existing routing heuristics to an optimal algorithm. We focus on examining the influence of the golden zone on the performance and selection of routing methods. The results obtained show that the optimal routing method increases the productivity at least 17.2%, and all the routing methods have better performance as the pick up rate from the golden zone increases.

**Key words** : Golden zone, Order picking, S-shape, Mid-Point, Largest gap, Warehouse layout

요 약

자동차 보수용 부품 창고 운영에서 오더 피킹 작업은 대부분 노동력에 의존하는 작업이다. 자동차 보수용 부품 창고는 수십만 품목을 저정하고 있는데, 일반적으로 파레토의 80대 20의 법칙과 같이 저장된 품목의 20%가 80%의 물동량을 일으키고 있다. 이를 효율적으로 운영하기 위하여 고순환 품목은 불출장 근처에 배치하여 운영 효율을 높이게 되는데, 불출장 근처의 고순환 품목 저장 공간을 Golden Zone이라 한다. 오더 피킹 경로를 효율적으로 결정하는 것은 생산성 및 인건비와 직접적인 연관 관계가 있다. 하지만 많은 기업에서는 단순한 방법론을 적용하고 있는 것이 현실이다. 본 연구에서는 기존의 오더 피킹 휴리스틱 및 경로 최적화 알고리즘을 현실적으로 적용하면 어떤 효과를 얻을 수 있는지 여러 가지 상황에 대한 시뮬레이션 실험을 진행하였다. 특히 Golden Zone 운영이 오더 피킹 작업의 생산성에 미치는 영향을 각 경로 최적화 알고리즘과 같이 비교 분석하였다. 분석 결과 최적화 알고리즘은 가장 단순한 방법론 대비 최소 17.2%의 개선 효과 기대할 수 있으며 Golden Zone 운영은 어떤 경로 최적화 알고리즘을 적용하더라도 효과적임을 확인하였다.

**주요어** : 창고 운영 최적화, 오더 피킹 최적화, 창고 내 재고 배치, 작업자 할당, 경로 최적화

## 1. Introduction

In warehouse and distribution centers, products are stored in specified locations and have to be picked on the basis of customer orders. Order picking is the retrieval of a number of items from warehouse storage locations to satisfy a certain amount of customer orders. It has

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long been considered as the most labor-intensive and costly activity for most warehouses. Order picking cost is estimated to be as much as 55% of the total warehouse operating expense(De Koster et al., 2006). Therefore, efficiency of order picking is critical for logistics operations, as more companies attempt to cut costs and improve warehouse performance.

There is ample room to improve order picking efficiency. Researches have focused on variety of areas, such as layout design, storage assignment methods, routing methods, batching and zoning. Layout design concerns two sub-problems: facility layout problem and internal layout design. Facility layout problem deals with the problems of where to locate various departments(receiving, picking, storage, etc.). Internal layout design concerns the number of blocks added, and the number, length and width of aisles within each block. Storage assignment methods are rules based on which products are assigned to storage locations. The objective of routing methods is to find the order and its route to pick items on the pick list. Batching is the method of grouping a set of orders into some sub-sets, so each sub-set orders can be picked in a single tour. Order batching is considered as an NP-hard problem, and often solved by heuristics. Zoning methods provide the rules to divide the order picking area into several zones. Order picker is only responsible to pick items in his assigned zone. Researches on storage assignment(like forward-reserve allocation, family grouping, and dynamic storage) and routing appear to have matured in the last decade. However, inter-relationships among routing methods, storage assignment methods, and zoning methods have hardly been explored. And there is a gap between academic research and practice.

Although optimal routing methods have been found long time ago, they are seldom used in practice. Most warehouses still choose simple routing heuristics such as S-shape, largest gap and midpoint heuristic for practical operation. The main reason for this may be due to the difficulty in implementing the optimal procedure. Normally, the simpler, the better. Heuristics intend to generate aisle by aisle picking route, based on simple rules which may lead to less mistakes and less aisles changing. Moreover, there are many other ways to improve order picking efficiency besides new developments and innovations in technology. Innovations in technology have led to more automatic order picking. The use of mobile terminals results in accurate up-to-date stock information, on-line control of progress and pick-error reduction.

In this paper, we consider the traditional order picking system and we studied the effect of implementing several heuristics. We focus on examining the influence of golden zone on selecting routing methods and present a practical case study.

The remainder of this paper is organized as follows. In the next section, we briefly introduce order picking process in a practical warehouse system and highlight the concept of Golden zone. Section 3 reviews five most well known routing methods. Section 4 and 5 compare the performance of routing methods. Section 6 gives conclusion.

## 2. Order picking in Auto Service Parts Warehouse

Auto parts warehouses provide aftermarket auto collision replacement auto parts and accessories to auto dealers as well as wholesale market dealers. Such warehouses serve as the hub of distribution activities, an efficiently managed warehouse is critical to achieving success in customer satisfaction, cost control, optimal sales and operations fulfillment.

Generally, auto service parts warehouses store 200 thousands to 400 thousands products. In this study, we analyzed the warehouses of an automotive service parts company(called Beta hereafter to preserve its desire for anonymity). There are about 200 thousands products stored in the warehouse. According to the statistic data of the company, only 20 thousands products are frequently picked and they contribute to about 80% of the warehouse turnover. This is also consistent with Pareto’s principle of 80-20 rule.

Fig. 1 shows that although most frequently picked items only take a small part of the total products stored in the warehouse, they contribute to the largest part of annual turnover. These frequently picked items are stored

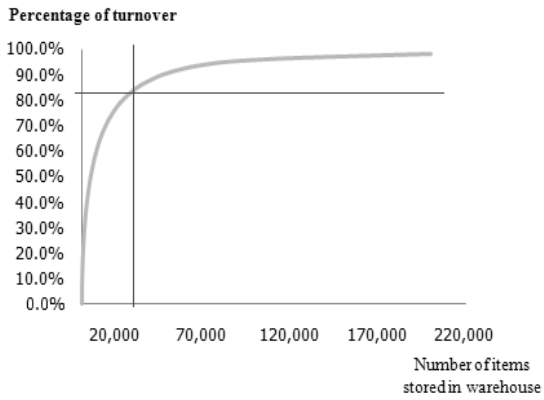


**Fig. 1.** Pareto's relationship between number of items and the percentage of annual turnover, based on statistic data from Beta company

in the outbound area close to the depot which is called "Golden zone". Order pickers are provided with personal digital assistants(PDA) which could help them search stock locations and visualize job status in real time.

In this study, we concentrate on finding out a practical useful heuristic and evaluating whether order picking performance can be improved by applying golden zone concept into storage assignment rules.

## 3 Routing Methods

In this paper, we compare the performance of four most commonly used routing heuristics to the optimal algorithm on different storage assignment bases and suggest one heuristic with the shortest order picking time. Followings are the main routing methods studied in academia. Fig. 2 illustrates an example of five routing methods.

### 3.1 S-shape heuristic

S-shape heuristic is one of the simplest routing methods. Basically, order picker travels aisle by aisle, goes through the entire aisle containing at least one pick and skips aisles with nothing to be picked. Fig. 2 (a).

### 3.2 Midpoint heuristic

The midpoint heuristic essentially divides the warehouse by centerline. An order picker enters and leaves the aisle from the same side, and is only allowed to go as far as centerline to pick items. The order picker travel through the first subaisle containing picks to start the route and travel through the last subaisle to get back to the depot. Fig. 2 (b).

### 3.3 Largest gap heuristic

The largest gap heuristic is similar to midpoint heuristic. We first calculate the distance between front cross aisle and the nearest pick item, the gap between each two adjacent picks and the distance between back cross aisle and the nearest pick item. Then choose the largest gap. The order picker enters and leaves the aisle from the same side, leave the largest gap empty. In this way, items are picked either from both sides of the subaisle or from one side of the subaisle. Fig. 2 (c).

### 3.4 Combined heuristic

Roodbergen and De Koster presented the combined heuristic in 2001. They argued that routes with a clear pattern are more useful, since such routes will be easier for order pickers to locate. Combined heuristic generates such routes. It is actually a combination of S-shape heuristic and return heuristic. The route starts and ends at the depot. Order pickers either entirely travel through the pick aisle or enter and leave the aisle from the same side. And those choices are decision elements in their dynamic programming model. The subaisles which contain picks are visited exactly once. Fig. 2 (d).

### 3.5 Optimal algorithm

Ratliff and Rosenthal(1983) demonstrated a well known algorithm based on dynamic programming for finding a shortest order picking tour in a rectangular warehouse. However, in practice, most of warehouses perform order picking process by using simple heuristic methods.

The optimal routing policy is not well implemented due to following disadvantages. Firstly, an optimal algorithm is not appropriate for every warehouse layout. Optimal method uses dynamic programming to solve the problem. It prestores the possible arc configurations that connect aisles and picks which could generate optimum tour

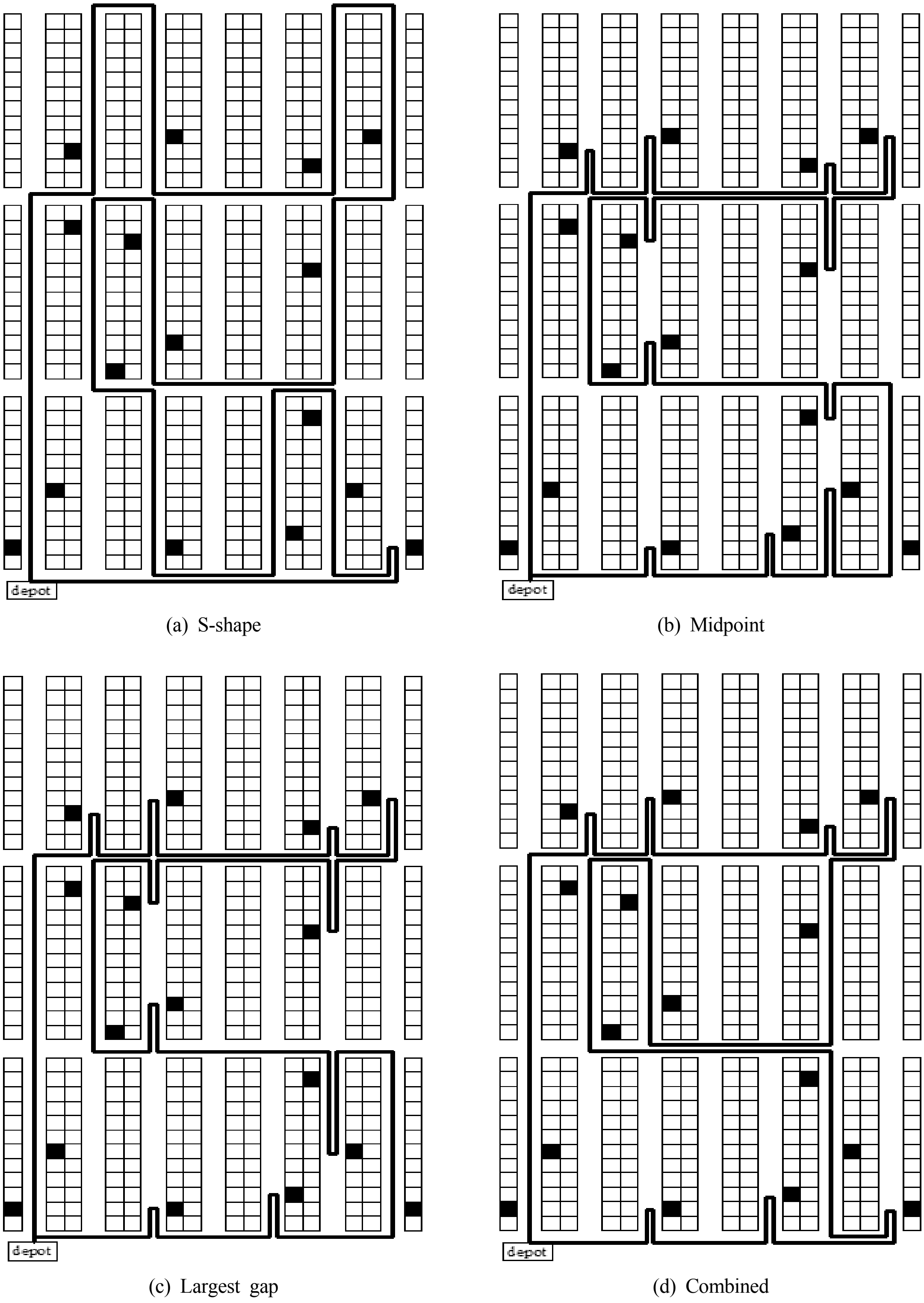


**Fig. 2.** Example routes for 5 routing methods

subgraph. It also denotes equivalence class as a node which contains information of how the aisle is connected to other aisles and picks. Appropriate combination of equivalent classes can generate the shortest route. For a basic rectangular warehouse with two cross aisles, only 7 equivalence classes are needed to generate the shortest route, while for a warehouse with three cross aisles, 25 equivalence classes are required(see K.J. Roodbergen et al., 2001). And the problem gets more complex as the number of picking aisles or cross aisles increase. Secondly, order pickers may find it illogical to travel as optimal routes and deviate from it(Gademann and Van de Veide, 2005). Like Fig. 3 shows, order pickers should travel back and forth between aisles and blocks, instead of visiting blocks and aisles in sequence. Once order pickers make mistakes, they will spend more time to get back to the right path. Thirdly, aisle congestion is not taken into account by optimal algorithm(De Koster et al., 2006).

In our research, we use branch and bound algorithm as an alternative way to find the optimal route. The basic principle of the method is to break up the set of all tours into smaller and smaller subsets and to calculate the lower bound of each possible tour and find the optimal one therein. The algorithm can significantly reduce the searching time for an optimal route. However, it also has disadvantages. One is that the computational time required increases dramatically with the number of cities, and eventually becomes prohibitive. Another is that it only guarantees a very good solution to the problem; the globally optimum solution could be missed This occurs since a node of a tree has only one chance to be extended, when the node is not good enough to be branched, it will be dropped off.

In order to interpret the algorithm, some notations need to be defined. Let the cities be indexed by $i=1, \cdots, n$. The cost for going from city $i$ to city $j$ is $c_{ij}$. Let $C=[c_{ij}]$ be a cost matrix. $C$ will first be the original

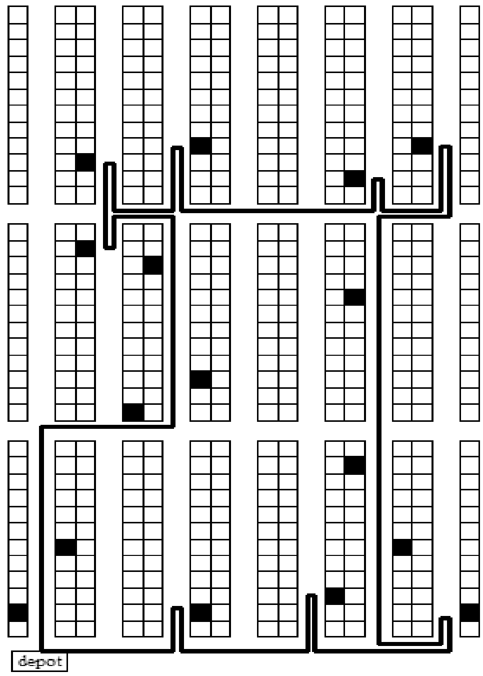


**Fig. 3.** Optimal routs

cost matrix of the problem but will undergo various forms as the algorithm proceeds. $X$ , $Y$ , $\overline{Y}$ are nodes of the tree. Nodes represent subsets of tours. $v_k v_l$ means the vector from city $k$ to city $l$. A tour, $t$, can be constructed as a set of n ordered city pairs, e.g.,

$$t = [(i_1,i_2)(i_2,i_3)\cdots(i_{n-1},i_n)(i_n,i_1)],$$

which form a circular route going to each city once and only once. Let $w(t)$ denotes the cost of a tour $t$, under a matrix $C$, then $w(t)$ is the sum of the matrix elements picked out by $t$:

$$w(t) = \sum_{(i,j)\in t} C_{ij}$$

Also, let

$X$, $Y$, $\overline{Y}$ = nodes of the tree;

$X'$, $X''$ = the medium node, its cost matrix is just the cost matrix of the new node before reduction;

$t_x$= a lower bound on the cost of the tours of $X$, i.e., $w(t) > t_x$ for the tour $t$ of $X$;

$d_{ij}$ = sum of the smallest element in row $i$ and the smallest element in column $j$ of the cost matrix excluding $c_{ij}(c_{ij}=0)$;

$d_{kl}$ = the maximum number of $d_{ij}$s, the variable is used to find <k,l>, from where the tree branches.

If each element in the row(column) of the cost matrix is subtracted by the smallest element of that row (column), the matrix will have at least one zero in each row(column). This process is called *reducing the row (column)*. A *reduced matrix* is obtained by first reducing the rows, then columns. If $w(t)$ is the cost of a tour $t$ under original cost matrix, $w'(t)$ the cost under the reduced matrix, and $h$ the sum of constants used in the reducing process, then

$$w(t) = w'(t) + h$$

Since a reduced matrix has only non-negative elements, $h$ constitutes a lower bound on the cost under the original cost matrix.

The process for solving traveling sales man problem using branch and bound method is as follows:

(1) Set cost matrix for ordered items.

(2) Allocate buffering area, initialize set $Z$ = NULL, $Z$ will be used to save the nodes with smaller bounds.

(3) Set root node $X$, the cost matrix of $X$ is the reduced form of original cost matrix $C$. Let $t_x$ be the lower bound of $X$, $t_x=h_c$. Here $h_c$is the sum of reduced value of cost matrix $C$. Save $X$ and its lower bound into $Z$.

(4) Calculate $d_{kl}$ using the cost matrix of $X$ by the following equation

$$d_{kl} = \max_{S=\{c_{ij}=0\}} \{d_{ij} \mid d_{ij} = \min_{0 \le k < n, k \ne j} \{c_{ik}\} + \min_{0 \le k < n, k \ne i} \{c_{kj}\}\}$$

The tour from city $k$ to city $l$, $v_k v_l$ is selected as a new branch of the tree.

(5) Let $X'' = X$, set the element in the cost matrix of $X''$, $c''_{kl} = \infty$. The cost matrix of $\overline{Y}$ is the reduced form of the cost matrix of $X''$. The lower bound of $\overline{Y}$, $t_{\overline{Y}} = d_{kl} + t_x$. Save $\overline{Y}$ and its lower bound into Z.

(6) Let $X' = X$, delete row $k$ and column $l$. Find $p$ = starting city and $m$ = ending city of the path containing $v_k v_l$, set $c_{mp} = \infty$. The cost matrix of $Y$ which contains path $v_k v_l$ is the reduced form of the cost matrix of $X'$. The lower bound of $Y$, $t_Y = t_X + t_{X'}$. Save $Y$ and its lower bound into $Z$.

(7) Choose the node with the smallest lower bound from $Z$ and set it to be $X$.

(8) If $X$ is $2 \times 2$ matrix, the path from root node to $X$ and the two node left in $X$ will be the optimal route, and its bound will be the smallest route length.

(9) If $X$ is not $2 \times 2$ matrix, go to step 4.

## 4 Experimental Design

In order to make the experiment a better representation of practical problem. We design the warehouse layout as a small simulation of Beta Company's auto service parts warehouse.

According to the practical data, the probability of cells being picked in golden zone is 0.521 per order and the probability of cells being visited outside golden zone is 0.012 per order. Items stored in golden zone contribute to about 80% of total turnovers. The following assumptions are made. The warehouse contains 3 blocks, 4 cross aisles and 7 pick aisles. Each pick aisle contains 12 cells. Products are stored in the cells on both side of the pick aisle. Cross aisles are only used by order pickers to change aisles when they travel in the warehouse. The depot is placed on lower left corner of the warehouse. Golden zone is the lower bound area which is closest to the depot. It has the bottom 4 cells of each pick aisle in the block which is closest to the depot, accounting for about 11% of the warehouse's total area. The width of pick aisles is fairly narrow, so order pickers can travel through the middle of the pick aisles and reach items from both sides. The length of pick aisle is 12 meters. Cross aisle width is 2 meters.

**Table 1.** Experimental design factors

| Experiment factors | Factor levels |
|---|---|
| Routing methods | Branch and bound, Combined, Midpoint, Largest gap, S-shape |
| Number of picks per order(order quantity) | 10, 20 |
| Pick up rate from the golden zone | 85%, 65%, 50%, random |

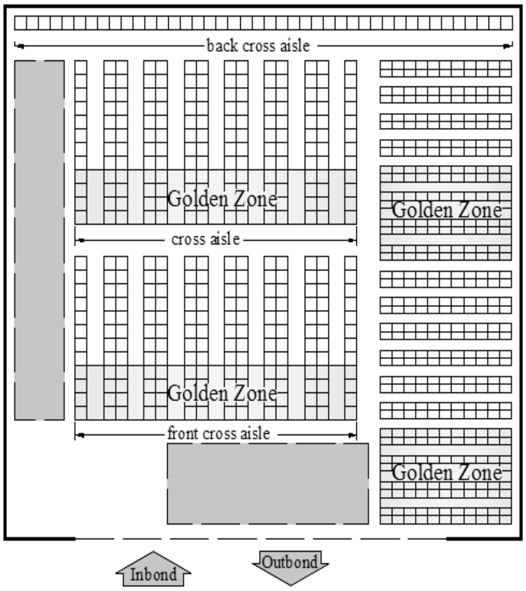


**Fig. 4.** Warehouse layout and golden zone concept

Centre distance between pick aisles is 2.5 meters. Fig. 4 illustrates the golden zone area in warehouse as an example. Average walking speed is 0.6 meters per second and no additional time is needed for changing aisles.

Since traveling takes up the most of time in order picking activity, we set route length as a basic factor to measure order picking efficiency. Orders are generated randomly and independently. We assume that order picker only picks one order at a time and that order does not exceed the vehicle's capacity. For each order, we calculate the route length separately using branch and bound method, S-shape heuristic, largest gap heuristic, midpoint heuristic and combined heuristic. 1000 random orders are examined and the performance of four routing heuristics is compared to the result of optimal method. Based on experience, one order usually contains 10~20 picks. We then, set the number of picks per order to 10 and 20 respectively, and set the probability of items being picked in golden zone to different values (see Table 1) to evaluate the influence of golden zone on routing methods selection. All the algorithms are programmed using C language. Average computational time is 0.81 second per thousand orders for heuristics on a 1.86 GHz computer. Yet calculation time for branch and bound method is unpredictable and varies greatly. For orders contain 10 picks, 0.171 second is required per order. For orders contain 20 picks, at least 18.375 second is required for a single route. For the four routing heuristics used in this study, the warehouse size and the order size can be extended to realistic level without causing much additional calculating time. However, for branch and bound method, when the order size is raised to 30, computational error will frequently occur due to the memory limits. The results of experiment are presented in the next section.

## 5 Results

The mean route length for five routing methods(Optimal, S-shape, Largest gap, Midpoint, and Combined) is shown in Table 2 and Table 3. By varying order quantity and the pick up rate from the golden zone, we have 8 different configurations for each routing method. Branch and bound method could always generate the shortest order picking route. Therefore, it is set to be the benchmark. Combined heuristic has the best performance over all configurations, followed by midpoint heuristic and largest gap heuristic. Routes generated by midpoint heuristic are on average, 3.94% longer than those generated by combined heuristic. S-shape heuristic always generates longest route and it is more than 20% longer than the optimal route.

In the reference experiment, items are chosen randomly

**Table 2.** Experiment results for the cases with 10 picks per order(unit of route length: m)

| | Route length | Percentage difference | Route length | Percentage difference | Route length | Percentage difference | Route length | Percentage difference |
|---|---|---|---|---|---|---|---|---|
| Golden zone contribution | 80% | | 65% | | 50% | | Random (Reference) | |
| Optimal | 114.26 | - | 130.14 | - | 135.31 | - | 140.90 | - |
| Combined | 117.34 | 2.7% | 141.13 | 8.4% | 145.36 | 7.4% | 155.23 | 10.2% |
| Midpoint | 125.96 | 10.2% | 143.84 | 10.5% | 149.15 | 10.2% | 161.52 | 14.6% |
| Largest gap | 132.52 | 16.0% | 149.10 | 14.6% | 154.04 | 13.8% | 163.99 | 16.4% |
| S-shape | 139.51 | 22.1% | 152.79 | 17.4% | 158.57 | 17.2% | 172.12 | 22.2% |

**Table 3.** Experiment results for the cases with 20 picks per order(unit of route length: m)

| | Route length | Percentage difference | Route length | Percentage difference | Route length | Percentage difference | Route length | Percentage difference |
|---|---|---|---|---|---|---|---|---|
| Golden zone contribution | 80% | | 65% | | 50% | | Random (Reference) | |
| Optimal | 140.52 | - | 155.86 | - | 175.11 | - | 198.68 | - |
| Combined | 157.97 | 12.4% | 181.74 | 16.6% | 198.12 | 13.1% | 220.94 | 11.2% |
| Midpoint | 166.10 | 18.2% | 189.12 | 21.3% | 204.73 | 16.9% | 227.74 | 14.6% |
| Largest gap | 174.89 | 24.5% | 197.64 | 26.8% | 212.79 | 21.5% | 231.79 | 16.7% |
| S-shape | 182.21 | 29.7% | 209.04 | 34.1% | 226.96 | 29.6% | 250.25 | 26.0% |

all over the warehouse, including the golden zone area. As the pick up rate from the golden zone increases, the route length decreases significantly for both order quantity of 10 picks and order quantity of 20 picks. If 80% picks in the order are chosen from golden zone, the route length will be reduced by 20%~27%, compared to the situation in the reference experiment. Even if the pick up rate from the golden zone is 50%, the route length will also decrease by 6%~10%. From this result, we can see that the concept of golden zone is very important. By increasing its contribution rate to orders, the route length will be greatly shortened. This is logical due to following reasons. The pick up rate from the golden zone increase means that products that are stored near the depot will be picked more frequently and products that are stored far from the depot will be picked less frequently. In this case, order pickers could collect most of the items near the depot without travelling far back to the warehouse, so that the travel distance is reduced. Although the order picking performance is improved by incorporating the golden zone concept into storage assignment rules, combined heuristic still generated shortest route length, except for optimal method, and S-shape heuristic still had longest route. Therefore, it seems that the frequency of items being picked in golden zone does not have a significant impact on selecting routing method, but on route length.

As order quantity increases from 10 to 20, the route length generated by each routing method also tends to be 19%~40% longer. When the order quantity is 10, the difference between combined heuristic and optimal method is dropping from 10.2% to 2.7% as the pick up rate from the golden zone is increasing to 80%. By incorporating the golden zone, the difference between optimal method and Midpoint heuristic decreased by 4% on average. For Largest gap heuristic and S-shape heuristic, the difference also decreased by about 2% and 3% in 10 picks order cases and about 7% and 5%

in 20 picks order cases. It indicates that the difference between optimal method and heuristics is smaller, when more picks in the order are stored in golden zone.

## 6 Conclusions

This study compared the performance of four commonly used heuristics to the optimal method using branch and bound algorithm. We designed the warehouse layout and golden zone area based on real statistic data from Beta Company'sauto service part warehouse. The golden zone concept has been introduced in this study. By changing the frequency of items being picked in golden zone, we set the pick up rate from the golden zone to 3 levels as 80%, 65%, and 50%. And we also assumed the case when the orders are chosen in random all over the warehouse without special concern of golden zone area as the reference case.

The study shows that applying the golden zone concept into storage assignment rules is quite important. In spite of the routing method implemented in the warehouse, the average route length would be much shortened as the pick up rate from the golden zone increase from 50% to 80%. However, we found that although the percentage of items being picked in golden zone had significant influence on route length, it did not affect the selection of routing methods. Combined heuristic has better performance in all situations we considered. Midpoint heuristic is the second best heuristic and S-shape heuristic always has longest route. Therefore, we suggest that products stored in the area near the depot which is so called "Golden zone" should be selected carefully. Golden zone area should be selected carefully to take full advantage of it by storing most frequently ordered products. We also recommend combined heuristic and midpoint heuristic, because both are easy to implement in the warehouse system and have superior performance than S-shape heuristic.

We compared order picking time based on the route length, assuming that the order quantity does not exceed vehicle's capacity. Future research could be more practical by taking vehicle's capacity and aisle congestion into consideration. To cut total cost and improve overall warehouse performance, it may be necessary to examine the interaction effects of batching and zoning activities. Multi objective decision making in order picking process might be an interesting direction.

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