Abstract: It has been recently shown that a reduction in distribution cost is needed to both ensure lower prices and a higher quality of products. The expansion of the Internet mail order system requires warehouses to handle many types of commodities in small quantities. Picking operations in the warehouses are dependent on individuals who can respond flexibly. Therefore, shipment work has become a labor-intensive operation. Particularly, the walking time for commodity picking accounts for over half of the total shipping time. In this study, we propose a commodity location method to reduce the manual picking travel distance for a warehouse that handles many types and small quantities of commodities. We focus on the order quantity using ABC analysis to determine the commodity location. Furthermore, we conduct a comparative study with three kinds of location methods, two kinds of class-based methods, and random location. Our experimental results suggest that the proposed method can reduce the traveling time for manual picking.

Keywords: Warehouse, Class-based storage, Commodity location

1. Introduction

Presently, many companies try to reduce storage and distribution costs related to their warehouses [1]-[4]. In the past, the main role of the warehouse was to store many supplies [2][5]. However, warehouses have now changed to physical distribution centers that distribute several products with efficiency. Many parts of a warehouse’s functions have been automated, and work efficiency improved using information technology. It has been identified that order picking is one of the activity remaining to be automated in almost all medium- or small-sized warehouses [1]-[3]. Automation and robots are rarely used for picking in such warehouses. Therefore, order picking is the most labor-intensive and costly activity in those warehouses. The cost of order picking generally accounts for as much as 54% of the total shipping operating expenses [2]. The picking operation can be divided into multiple work processes, including “travel,” “picking commodities,” and “confirming commodities.” According to an operation time analysis, traveling time occupies over half of the working time (approximately 52%) in order picking [1][2]. To reduce the traveling time, the picker needs to memorize a commodity location, and choose the shorter route for picking all orders. Furthermore, the layout of a warehouse can change with new items or replacement of major seasonal items. Therefore, it is difficult to satisfy these requirements even for expert workers. Fig.1 shows the outline of the picking support system. One of the methods for improving picking work efficiency is to locate the commodities in appropriate racks [1][6]. In previous studies, it has been revealed that a class-based location is useful for improving picking work efficiency [1][2][7]. The class-based location is available as a standard type of rack layout, which has picking aisles with cross-aisles; and front, back, and intermediate aisles [1][7]. However, the efficiency for a unique layout that has no front and back (or side) aisles is not yet clear. The unique layouts are often seen in medium- or small-sized warehouses in Japan. Therefore, it is important to improve picking work efficiency for the warehouses that have a unique type of rack layout.

In this paper, we develop a commodity location method for the picking support system used in medium- or small-sized warehouses that have the unique layout mentioned above. We tested the method with actual order data for seven months, and evaluated the usefulness of our proposed location method. The remainder of this paper is organized as follows: in Chapter 2, we describe the details of the warehouse and work model used in this study. In Chapter 3, the details of the proposed method using ABC analysis [2][5] are described. In Chapter 4, we describe the experiment and evaluation of the proposed method. The experiment aims to investigate the usefulness of the proposed method. In our previous study, we compared the travel distance between the proposed method and the commodity location (original location) based on general warehouse knowledge [2][3], and

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revealed the efficiency of our class-based method [8]. In this paper, we compare the travel distance between the proposed method and the other class-based location methods. Chapter 5 discusses the conclusions of this study.

2. Warehouse simulation model

2.1 Warehouse Layout The target of consideration of this study is the medium- or small-sized warehouse. The target warehouses have less automated facilities, such as a robotized picking system, and therefore, handle various items and small lot sizes. Therefore, almost all the work is labor-intensive, particularly in a manual picking operation. Fig. 1 shows three kinds of storage rack layouts. Fig. 2(a) and (b) show a typical rack layout that has picking aisles with front and back cross-aisles. The pick aisles are two-sided and sufficient for two-way travel. Class-based location is available to a typical rack layout, as shown in Fig. 2(a) and 2(b). Class-based location is available to a typical rack layout, as shown in Fig. 2(a) and 2(b). Fig. 2(c) shows the warehouse rack layout considered in this study. It is a typical layout for a medium- or small-sized warehouse. Two storage zones are located opposite to each other with the cross-aisle in the center of the layout. Both zones have the same layout. The width of all aisles is wide enough for two handcarts to pass each other. The depot (shipping place) is placed just outside the entrance door. This layout has no front and back (or side) aisles, and worker must go back to the cross-aisle from the pick aisles. Therefore, appropriate traveling root and commodity arrangement are considered different from a typical layout. This unique layout is often seen in medium- or small-sized warehouses in Japan, especially in other purpose facilities, such as the renovation and conversion of a school building into a warehouse. This unique layout can stock more commodities than a typical rack layout, as shown in Fig. 2(a) and 2(b), because it can use floor space on both side ends. Therefore, the layout in Fig. 2(c) is applied to most medium- and small-sized warehouses.

2.2 Work Model In this paper, we assumed, as a work model, that one picker works at a single site exclusively. They pick order items using the total picking method that involves collecting items together from multiple customer orders. This model uses a general type handcart for the transportation of the shipping commodities. Therefore, carrying means are determined as the volume of a container that can be mounted onto the handcart. If the amount of the order commodity is larger than the container volume, the picker must return to the depot and unload the picked commodities.

3. Determination of Commodity Location

3.1 Location Determination Method The shipping quantity of each commodity is generally different due to various factors such as the consumption degree or popularity of each commodity. The shipping quantity and order frequency of each commodity significantly influence the traveling distance of the picker. From this factor, it is assumed that locating the commodities based on the shipping quantity priority is useful for shortening this distance. Therefore, we propose a location determining method focused on the shipping quantities. The proposed method locates the commodities near the entrance in the order of the shipping quantity in all orders for an arbitrary period. Our proposed method is a class-based method using ABC analysis [2][5]. The proposed method consists of four steps. First, we input all of the order reception data for an arbitrary period. Sec-
Table 1: An example of order reception data

| Sales slip number | Customer code | Commodity code | Shipment quantity | Order receipt date |
|-------------------|---------------|----------------|------------------|-------------------|
| Order 1           | 358844        | YGNVU          | Sm90             | 500               | 20XX0101         |
| Order 2           | 358844        | YGNVU          | Oj29             | 10000             | 20XX0101         |
| Order 3           | 149060        | MRGCI          | Xd87             | 10                | 20XX0211         |
| Order 4           | 052620        | XLWWRU         | Cq25             | 10                | 20XX0523         |
| Order 5           | 634711        | HHKTH          | Hn21             | 90                | 20XX0729         |

Table 2: Commodity records sorted by quantity composition rate

| Commodity code | Shipping quantity | Quantity composition rate [%] | Cumulative value of composition rate [%] |
|----------------|-------------------|-------------------------------|----------------------------------------|
| Hx92           | 317620            | 11.0                          | 11.0                                   |
| Lo35           | 287220            | 9.9                           | 20.9                                   |
| Wv68           | 245710            | 8.5                           | 29.4                                   |
| Nw94           | 234350            | 8.1                           | 37.5                                   |
| Ck84           | 162925            | 5.6                           | 43.2                                   |
| Oj29           | 162875            | 5.6                           | 48.8                                   |
| Iz20           | 94680             | 3.3                           | 52.1                                   |
| Xy05           | 30                | 0.0                           | 100                                    |

3.2 Order Data Format

Table 1 lists an example of order reception data (raw data). The data have five basic records. Orders from the same customer have the same customer code. In this study, we use three types of records: commodity code, shipment quantity, and order receipt date. We convert the order reception data to a total picking slip in four steps. First, we read the raw data, and divide the original receipt orders by each different order receipt date. Second, we divide orders for one day equally into three work units based on our field survey at the target type warehouse. Third, we find the total orders of each unit by commodity code. Finally, we add one more record, the “commodity location number,” for every commodity sequentially. The commodity location number is the same as the rack number, such as 1 to n, for storing one type of commodity by one rack. Subsequently, three picking slips are generated for a day.

3.3 Commodity Classification Process

For determining the commodity location adaptively, we use ABC analysis. Fig. 3 shows the flow of ABC analysis in our proposed method. ABC analysis is a management method focused on the importance of a certain object as a share of the whole set of objects [2][5]. In the proposed method, we use a shipping quantity of each commodity for calculating the importance of a commodity among the whole set of commodities. Thus, the importance of a commodity is represented as the “quantity composition rate” of each commodity. This rate refers to the occupation rate of the shipping quantity of each commodity among a whole set of commodities. The actual procedure of ABC analysis in the proposed method follows four steps:

(a) The quantity composition ratio of each commodity was calculated using equation (1), where \( O_i \) is the quantity composition ratio of each commodity. The valuable \( A_i \) is the shipping quantity of the commodity \( i \), and \( A_t \) is the quantity of the whole set of commodities.

\[
O_i = \frac{A_i}{A_t} \times 100 \quad (1)
\]

(b) We sort all the commodities in descending order based on the calculation result of the preceding process (a). The cumulative value of the composition ratio at each rank is then calculated using equation (2), where \( CO_i \) is the cumulative quantity of the composition ratio of the commodity \( i \), and \( t \) is the total number of the commodities.

\[
CO_i = \sum_{i=1}^{t} O_i \quad (2)
\]

Figure 3: Flow of ABC analysis
3.4 Determination of the Commodity Location

The commodity location is determined by referring to the results of the ABC analysis. Fig. 4 shows an image of the commodity location using the proposed method. The determination process has three steps. First, preserve the number of racks required to store the commodities in each rank, and the preserved racks are allocated near the entrance with the calculated priority ranks (i.e., from the rank A to rank C). We used Manhattan distance to determine the proximity between the entrance and each rack. Next, commodities belonging to rank A are located at the nearest preserved racks, and commodities belonging to rank B are located at the next nearest preserved racks as shown in Fig. 4. In the areas for rank A and B, the commodity that has the greatest shipping quantity is located on the nearest rack in each rank area. Commodities are then located on the next nearest racks in descending order based on shipping quantity. After the location process, we overwrite the location records to the property of each commodity. Finally, the determination of the commodity location process is finished.

4. Experiment

4.1 Experiment Procedure

Fig. 5 shows the outline of this experiment. To confirm the shortening effect of the proposed method for picker travel distance, we compared the picker travel distances between the two types of typical class-based location methods and the proposed method. Furthermore, we compared the picker travel distances of a commodity location method that located commodities in a random manner with the proposed method. Ten random values for location were generated, and we used the average value of the random locations for the comparison index.

4.2 Data Used

The data used was seven months’ actual business data from the Research and Development (R&D) partner company. The number of original order receptions were 22,467, and 502 types of commodities were included in the data. Working days were 210 days for 7
months, with 106 order receptions for a day on average. This is the same data as the data of reference [8].

4.3 Rack Layout and Routing Method Fig. 6 shows the rack layout in this experiment. This layout is the same layout as reference [8] In this model, each rack stores one type of item, and the items can be replenished at any time. The number of shelves is the minimum value calculated from the number of varieties of items. The commodity location number is the same as the rack number, such as 1 to 502 for storing one type of commodity by one rack. The commodity size contains only one size.

\[ N_p = N_p + 1 \]

\[ C_{SP} = C_{SP} + Q_{SP} \]

\[ C_{SP} \geq I_{max} \]

\[ C_{SP} = C_{SP} - I_{max} \]

\[ C_{PR} = C_{PR} + 1 \]

\[ (\text{add type RN}) \]

\[ N_x = N_x + 1 \]

Figure 8: Flow chart of unloading process

Figure 9: Pareto chart of data used

(a) Proposed method

(b) Within-aisle

(c) Across-aisle

Figure 10: Commodity locations in each class-based method
sion of the commodity size was set to length 40 mm × width 40 mm × height 70 mm.

In this experiment, we applied a basic method for picker routing as the same of the reference [8]. Fig. 7 shows an image of the routing method used in this simulation. The picker walks a U-shaped line along the right rack in one stroke writing manner. In our warehouse model, the picker uses a general type of handcart for the manual picking operation, and the picker manages the picking work of one zone exclusively. Therefore, when an order item quantity exceeds the capacity of the handcart, it is necessary to unload the pick items at the depot. We define the unload process as one node named “RN: Return Node.” The coordinates of the RN have the same coordinates as the entrance node, because the depot is set outside of the entrance. The volume of the container that can be mounted on the handcart determines the capacity of the handcart. The container size was set to length 780 mm × width 470 mm × height 503 mm based on our survey on the general types of containers. Fig. 8 shows the flowchart of the unloading process. The picked item quantity for one work period is counted. When the item quantity exceeds the capacity of the handcart (\(C_{NP} \geq L_{max}\)), we add one return node (\(C_{RN} = C_{RN} + 1\)). This process is repeated until the number of items for all nodes (racks) are picked (\(N_p = N_l\)).

### 4.4 Commodity Location of Proposed method and Comparisons

Fig 9 shows the Pareto chart calculated from the used data. The top 17 commodities occupied approximately 70% of the entire shipping quantity, and occupancy was increased up to approximately 90% by adding the next 38 commodities. Thus, the top 17 commodities were set to rank A, the next 38 commodities were set to rank B, and the other 439 commodities were set to rank C. Commodities were located on the basis of this classification.

Fig 10(a) shows the commodity location by the proposed method. Ranked commodities were located based on Manhattan distance as mentioned in section 3.4. Fig. 10(b) and 10(c) shows the typical type locations based on class-based method. The class-based location shown in Fig. 10(b) is called the “within-aisle storage” [1]. Each aisle contained the commodities with same rank in this location. In this paper, commodities belonging to rank A are located at the nearest right and left aisles situated opposite to each other with the current aisle in the center. Among the same rank, commodities were located to the rack nearest to the depot in the order of the quantity composition rate. The commodities belonging to rank B were located in the same way as the commodities belonging to rank A. The commodities belonging to rank C were located to the empty racks with the smallest number in the order of the quantity composition rate. The class-based location shown in Fig. 10(c) is called the “across-aisle storage” [1]. The commodities belonging to rank A are located at the nearest rack to the center-aisle. After placement of rank A commodities, the commodities belonging to rank B were located on the racks that are the next closest columns from the center-aisle. The previous study had revealed that the “across-aisle storage” is close to optimal for the return routing policy.

The random manner location was generated ten times by use of a pseudo-random function. We calculate the average value of travel distance of the random locations, and compare the average distance with travel distances obtained by other methods.

### 4.5 Experimental Result

In this paper, we used travel distances derived in each method for the evaluation index. Table 3 compares the results of four methods. The shortening rate of travel distance of the proposed method to the comparison methods were calculated using equation (3),

\[
\text{Shortening rate} = \left(1 - \frac{T_d^{\text{proposed}}}{T_d^{\text{comparison}}}\right) \times 100
\]

where \(T_d\) means the travel distance of proposed and comparison method. The travel distances are decreased drastically by use of the class-based method, which are 47.1–49.3% shorter than that of the random manner in the mean value. These results revealed that the class-based method is very effective for shortening travel distance in the tar-
get rack layout as with the case of other rack layouts mentioned in the previous studies [1][8]. The main factor of the travel distance shortage is the difference in travel distance on the cross-aisle, because the simulation model in this experiment has a loading process. The picker returns to the depot through the cross-aisle for unloading the commodities when the container on the handcart is filled with commodities. The loading process tends to occur frequently at a rack that has the largest shipping order amount. The class-based method locates a large quantity of commodities near the entrance. Therefore, the return distance of the class-based locations is considered shorter than that of the random location.

Next, comparing the three kinds of class-based methods, the proposed method obtained the shortest travel distance for all months. Across-aisle method was obtained as the second best result. The difference of travel distance was 1488.7 meter in total (for seven months), and the shortening rate was 0.9% on average. The result of travel distance is close, but the proposed method decreases the travel distance in all months, and decreases in 347 out of 630 (approximately 55.1%) picking slips. The across-aisle storage is one of the optimal location methods for the return routing policy. Thus, these results suggest the usefulness of the proposed method under the conditions set in this paper.

In the within-aisle storage, the travel distance was longer than that of the other class-based method. The difference of travel distance was 6851.7 meter compared to the proposed method for seven months. The major difference between the proposed method and the within-aisle storage is location policy of high rank commodities. The proposed method located the high rank commodities to the nearest rack based on the Manhattan distance. On the other hands, high rank commodities may not be located to nearest neighbor rack by within-aisle storage method when the rack layout have many rows. In this experiment condition, the racks numbered 13–18 (or 1–6) are far from the entrance (depot) compared to racks numbered 28, 46, and 64. Furthermore, the pickers cannot move to next column when they return to center-aisle, because side aisles were not set in target layout. Therefore, travel distance of within-aisle method was longer than the other method.

Table 4 shows the correlation coefficients between the experimental result of proposed method and the comparison method. We calculated two types of correlation coefficients. The correlation coefficient calculated from the travel distances of both methods showed a strong correlation; the correlation coefficient of each method ranges from 0.982 to 0.999. These results suggested that the picking slip (or orders) is a basic factor in determining the travel distance of each method. In contrast, the trend of the correlation differs between travel distance and shortage rate of comparison method; within-aisle and random location methods have positive correlation, but across-aisle method have negative correlation. The shortening rate tends to rise as the traveling distance increases in the cases of within-aisle and random methods. The result shows the advantage of propose method to the within-aisle and random location method. In contrast, we exhibited the negative correlation in the calculated result of the correlation with the shortening rate of the across-aisle. From this result, it is assumed that the useful condition is slightly different between the proposed and the across-aisle method. However, more investigation will be needed to clearly identify factors influencing the differences in correlation.

5. Conclusion

In this study, we developed the commodity location method for the picking support system used in medium- or small-sized warehouses. The proposed location method uses ABC analysis to determine the relative importance of shipping commodities. To investigate the effect of the changed locations, we compared the travel distance with the other four kinds of location method. Our experiments provide the following conclusions:

(a) Experiment results reveal that the travel distance was decreased drastically compared to random location by the use of the class-based method. The shortening rate of each method ranges from 47.1% to 49.3% in the mean value.

(b) Comparing the three kinds of class-based methods, the proposed method obtained the shortest travel distance for all months.

For future work, we plan to investigate other factors for shortening travel distance and increasing the effectiveness of the proposed location method. In addition, we also plan to develop a picking support system with a travel route search method adapted to a medium- or small-sized warehouse.

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