

## The Effect of Warehouse Layout Design on Order Picking Efficiency

Hyun Kim\* · Yun-Su Hur\*\* · Suk-Tae Bae†

\* Department of Logistics System Engineering, Korea Maritime University, Busan 606-791, Korea

\*\* Researcher, Busan Development Institute, Busan 608-711, Korea

† College of Port & Logistics, Tongmyung University, Busan 608-711, Korea

**Abstract :** *In this paper the order picking problem in warehouses is considered, a topic which has received considerable attention from the international academic body in recent years. The order picking problem deals with the retrieval of order items from prespecified locations in the warehouse, and its objective is usually the minimization of travel time or travel distance. Hence, a well-thought order picking policy in combination with an appropriate storage policy will enhance warehouse efficiency and reduce operational costs. This paper starts with a literature overview summarizing approaches to routing order pickers, assigning stock-keeping units to pick locations and designing warehouse layouts. Since the layout design might affect both storage and routing policies, the three factors are interdependent with respect to order picking performance. To test these interdependencies, a simulation experiment was set up, involving two types of warehouse layout, four types of storage policy, five well-known heuristics and five sizes of order picking list. Our results illustrate that from the point of view of order picking distance minimization it is recommended to equip the warehouse with a third cross aisle, although this comes at the cost of a certain space loss. Additionally, we propose a set of most appropriate matches between order picking heuristics and storage policies. Finally, we give some directions for further research and recommend an integrated approach involving all factors that affect warehouse efficiency.*

**Key words :** *Order picking, Pick-to-part, Routing policy, Storage policy, Travel distance, Warehouse layout design*

### 1. Introduction

A major function of a warehouse can be simply described that keeping the products and picking the correct product as quickly as possible when it gets the order from customer. According to this description, warehouse productivity is usually decided by performance of how quickly picking the correct product. Therefore, order picking system is regarded as a main performance in the warehouse and has received attention from warehouse manager and company to cut down the operation cost and increase its efficiency.

Moreover, globalization has influenced on markets and products. In terms of market expansion, there is much bigger group of customers who each have different requirements of their products. Thus, the products have been diversified to satisfy customer's various needs and the product's life cycle becomes shorter since the various needs influences producing new product (trends of the product or improvement of the technology may make product life shorter as well). To satisfy the various customers' needs, one of firm's strategies is to keep the assembly part of product in their warehouse and combine the parts to make complete product later. For corresponding short life of product which means those

products require reduced customer delivery time, company should reduce the time for picking and delivering. Both situations need well managed order picking system to response those situations.

The objective of order picking problem is usually to minimize either travel time or travel distance. Generally, if the travel time or distance is reduced, the cost of order picking performance will be reduced. This paper takes into account the objective of minimizing travel distance in the chapter of experiment of combining factors.

Order picking performance arises in the warehouse. Depending on layout of warehouse, order picking efficiency can be good or bad. Hence, the layout design of the picking area is often mentioned as a major factor affecting order picking efficiency. Besides, the layout design determines the number of aisle and shape of storage space which influence the travel length in the warehouse. The layout design could be so call physical condition, then how to travel between the rack and aisle and how decide where the products are stored can be a policy for treating the product. In summary, as shown in Figure 1, the layout design can affect both storage policy and routing policy and those three factors are interdependent to order picking performance.

\* Hyun Kim, hyunkim@gncnet.co.kr 010-3891-6402

\*\* logiyun@bdi.re.kr 017-518-5508

† Corresponding author : Suk-Tae Bae, stbae@tu.ac.kr 011-9508-3379

The aim of this term paper is to address the order picking problem through studying of prior researches and experiment how travel distance can be changed under the different combination of affecting factors. In the literature review part, previous researches have been summarized in terms of objective, considered factors and approaches to obtain the optimal result. Based on those researches which have achieved significant result, several alternatives of layout design and routing and storage policies are chosen for testing and it calculates the travel distance by heuristic approach. Lastly, testing result and conclusion of this term paper are finalized at the end of this paper.

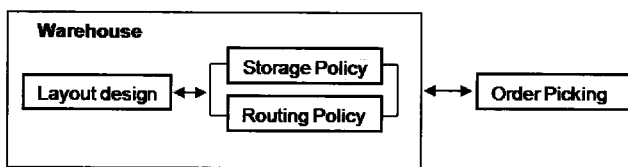


Fig. 1 Relationship of order picking and warehouse system factors

## 2. Literature review

Since order picking has received considerable attention from long time ago, there are many researches which tried to find way to improve order picking efficiency.

As stated, this paper considers layout design and routing and storage policy as the main affecting factors on order picking efficiency. Hence, reviewing past researches is focusing on those factors.

Order picking system can be classified as given in Figure 2. This activity can be implemented by either human or machine. However, running by machine meaning of automatization is known as expensive system, so not many firms adopt this system. Therefore, human order picking system is often employed as a majority system. Among three types of performance that order picker is involved in, picker-to-parts system where the order picker walks or drives along the aisles to pick items are most common(De Koster,2004). There are two types of picker-to-parts system : low-level picking and high-level picking. In low-level system, the order picker picks requested items from storage racks or bins through traveling along the storage aisles. On the other side, high level picking system employs lifting truck or crane picker to perform the pick in the high storage racks. Since high level picking system can be studied by same way of low level picking system and low level system takes more work portion in order picking activity, low-level

picking system is mainly concerned. Consequently, many researches have focused low-level picker-to-parts order picking problem which is influenced by other factors rather than the other picking systems(Hwang et al.,2004).

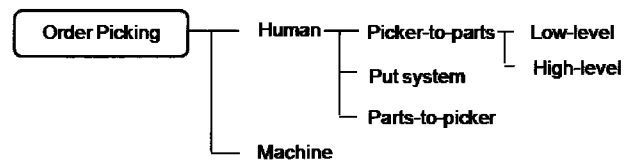


Fig. 2 Classification of order picking (De Koster, 2006(De Koster, 2004))

### 2.1 Warehouse layout

The warehouse layout is usually regarded rectangular shape with a certain number of aisles. Figure 3 shows typical warehouse layouts. The issue here is of finding a good aisle configuration minimizing order picking travel time. For this, the location of input/output (or depot), the total length of the picking aisles and the number of aisle and cross aisle has to be considered. Layout 1 is the layout without within cross aisle and layout 2 is the layout with one cross aisle at the middle of picking area. When the cross aisle is added in the layout design, it may reduce the storage capacity or need more financial investment to obtain enough space to store the product (usually the number of cross aisle increases, more warehouse space is needed). But it can offer more flexible travel space to picker which means order picking efficiency can be improved. This is the layout argument whether choosing economical investment or high order picking efficiency.

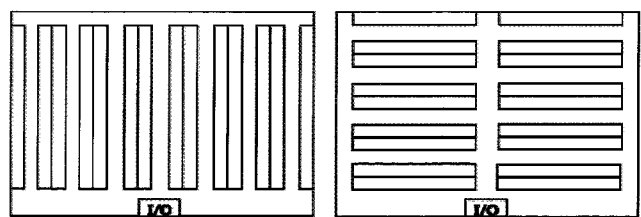


Fig. 3 Basic rectangular warehouse layouts

### 2.2 Storage

Large storage area increases the travel distance and reduces picking efficiency. In other words, storage efficiency is tradeoff with picking efficiency. Usually it is known that storage policy impacts the order-picking throughput time. Here the basic policies of storage are presented which are random-based, dedicated-based and class-based storage.

- Random-based storage: This is the easiest and

rational method. Every incoming product is randomly assigned in the available storage location that all eligible empty locations with equal probability (Petersen, 1997) or preferences. Thus, this storage policy maximizes space utilization, unfortunately which increases travel distance.

- **Dedicated-based storage:** This policy stores each product at a fixed location. Contrast to the random storage, the space utilization is lowest among all storage policies.

- **Class-based storage :** The main idea of this policy is that dividing products and locations into a certain classes, group or item basis, can be improved picker's productivity.

Based above three main storage policies, some ideas for better storage policy added a product characteristic related rule or existed theories. Newly derivative storage policies are as follows;

- **Closest open location storage:** It assumes that the picker is able to choose the location for storage themselves. Hence, the performance result arises that the racks located near depot are usually full and gradually emptier towards the back (de Koster et al., 2006). Its performance is similar when the random storage implements with picker's preference.

- **Full-turnover storage:** Product turnover is the key decision factor. Often requested product is located at the easiest accessible locations which are near the depot. On the other hands, slow moving products are located somewhere towards the back of the warehouse (de Koster et al., 2006).

As we can see from 'closest open location' and 'full-turnover storages', the main concept of this is how classify the product location according to a certain criterion. The criterions to decide the classification practically refer from Pareto's law (ABC method). Similarly, COI (cube-per-order index) rule which is defined as the ratio of the item's total required space to the number of trips required to satisfy its demand per period has been proposed by Heskett(1963). These rules often combined with above basic storage policies. Caron et al.(2000a, 2000b) usually adopts COI based ABC curves storage policy for their studies. Hwang et al.(2004) also assumed storage policy with COI rule. Figure 4 is the storage location planning/strategies based on above policies. Manzini et al.(2007) used across-aisle and within-aisle location planning in their recent study. Hwang et al.(2004) compared three of storage location planning, i.e. across, within and perimeter. Incidentally, assumption behind of all storage policies is that product location information should be known in advance for picking accuracy.

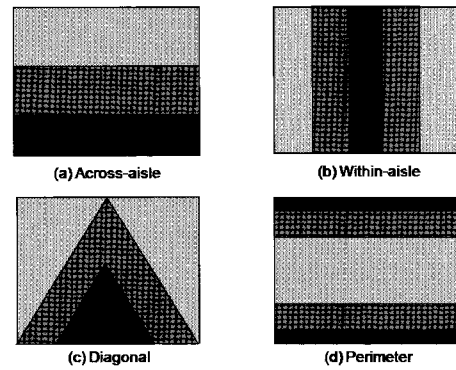


Fig. 4 Type of storage location planning frequency

## 2.2 Routing

To determine the optimal sequence of visits to pick up a number of requested items as quickly as possible, some of routing strategies (see figure 5) which mainly used in many researches are presented below.

- **S-Shape(=traversal):** A picker departs from the depot, traverses each aisle fully by entering it from one cross aisle and exiting it at the other cross aisle, and completes at the depot.

- **Return:** A picker enters picking aisles containing picks from the front cross aisle only, performs the pick, and then returns to the front cross aisle.

- **Midpoint:** The main idea is dividing each length of each picking aisle into two equal parts at its midpoint. A picker enters a picking aisle from across aisle and traverses only up to its midpoint to perform the picks in that section of the aisle and returns to the same cross aisle. Depending on the items to be picked in an aisle, a picker may have to enter the same picking aisle gain from the other cross aisle.

- **Largest Gap:** It is similar to the midpoint strategy except that a picker enters an aisle as far as the largest gap within an aisle. The gap represents the separation between any two adjacent picks, between the first pick and the front aisle, or between the last pick and the back aisle. If the largest gap is between two adjacent picks, the order picker performs a return route from both ends of the aisle.

- **Composite/Combined :** The aisles with picks are entirely traversed or entered and left at the same end.

- **Optimal :** This is similar concept of composite / combined. However it often uses dynamic approach to find optimal route.

Routing problem is usually solved by heuristic in practice since optimal routing solutions have some limitations such as inadequacy in many different layout cases, inconvenience for picker's movement and neglecting congestion in the aisle.

Therefore, heuristics methods are preferred. Roodbergen and Koster(2001) described a number of heuristics to determine order picking routes. Rarson (1997) also approached space utilization and material handling problem by using heuristics. Manzini et al.(2007) proposed new integrated approach which considered less than unit load order picking system. Caron et al.(2000a) presented a simulation approach to efficient layout design under the objective of minimizing travel distance. Recently, the best routing heuristic known is the combined heuristic (Roodbergen, 2001). This method combines two basis methods of either traversing a visited aisle from one end to the other or entering and leaving the aisle from the same aisle's end (but optimal routing often outperforms with certain storage planning).

Each routing method can outperform when it combines with suitable storage policy. For instance, the largest gap method often outperforms the midpoint method (Hall, 1993). As a more example result, Hwang et al.(2004) found that return policy with across-aisle strategy, traversal policy with within-aisle strategy and midpoint policy with perimeter strategy led the best order picking performance in their study.

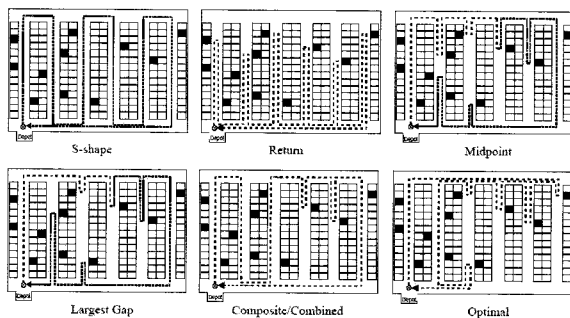


Fig. 5 Types of routing policy (Roodbergen, 2001)

Many of order picking related researches considered single-block warehouses since multiple-block warehouses can be applied for this method with some modification. However, Vaughan and Petersen (1999) considered multiple-block warehouses method from earlier and Caron et al.(2000b) considered 2-block warehouses with one middle cross aisle.

Lastly, Hsieh and Tsai (2006) recently developed the warehouse design database with basis of the minimum overall traveling distance, the cross aisle quantity, warehouse layout, storage assignment, picking route planning(Z-pick and return policy), picking density and order combination type. It seems order picking problem is more complicated in terms of factors being considered in practical situation.

### 3. Experiment of combining factors

As described in the literature review part, there are significant routing and storage policy to consider for testing. Thus, from this chapter, it shows testing performance under several different combinations of warehouse system factors. The objective of this experiment is to calculate minimum order picking travel distance under several different management situations. The assumption for experiment can be summarized as follows:

- Size and the number of aisle of order picking area are fixed.
- Single-block warehouse is considered.
- Depot is located at the middle of front.
- Lot size is not considered but 5 sequent increased order picking size is considered.
- All requested products should be picked.

Table 1 shows factors being combined for experiment. Two types of layout, four types of storage location planning and six types of routing policies are used for this experiment, which are total 200 performances to calculate a travel distance. Initial data for the numerical calculation is shown in Table 2.

Table 1 Parameters for combination

Warehouse layout	Storage planning	Routing policy	Size of Picking
layout 1	Across	S-Shape	12
layout 2	Within	Return	24
	Diagonal	Midpoint	36
	Perimeter	Largest Gap	48
		Composite	52

Table 2 Initial data

	layout 1	layout 2
Total picking area width (m)	22.2	21
Total picking area length (m)	20	22.2
Picking aisle width(m)	1.5	1.5
Cross aisle width(m)	3	3
Cell width(m)	1	1
Cell depth(m)	1.1	1.1
Number of aisle	6	6
Number of cross aisle	2	3

Referring from Figure 3, layout 1 is a normal vertical rack design while layout 2 has one more cross aisle at the middle of picking area. It is expected to show the effect of cross aisle on order picking efficiency.

Concerning routing matter, optimal routing policy has not been considered in this experiment since it may need spending more time to establish the dynamic programming. This paper only cares 5 well known routing policies with their basic concept (i.e. heuristic) of searching shortest travel route.

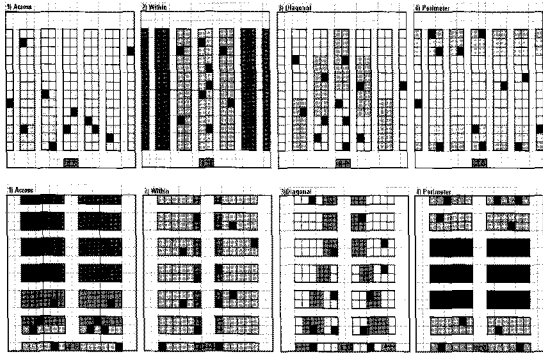


Fig. 6 Testing data: two-layout over storage policies (n=12)

Figure 6 is the example of graphical expression for the smallest order quantity case, n=12. Upper four cases are across, within, diagonal and perimeter storage location planning respectively for the layout 1 and bottom four are for the layout 2. For the calculation of travel distance, it is basically calculated by heuristic method that has been proposed in previous researches. However, this test adopted an improved Z-pick picking approach which is shown in Figure 7 below.

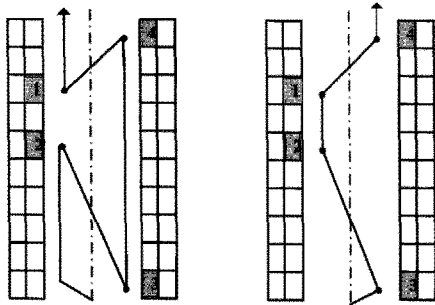


Fig. 7 Initial method of Z-pick picking (left) and improved method of z-pick picking (right)

For storage location planning, picking product location (that customer requested) generated by randomly. The portion of product storage area and product picking frequency are decided within range of simple ABC classification.

- A: space occupation 20%, picking frequency 50%,
- B: space occupation 30%, picking frequency 30%
- C: space occupation 50%, picking frequency 20%

Finally, the travel distance for 200 testing performance is

calculated by Microsoft office Excel.

#### 4. Results

The average expected travel distance over different 5 routing methods has been shown in Figure 8 (case of layout 1). According to the order size, we can see that travel distance is gradually increased (layout 2 also shows similar result).

From Figure 9, we can find that layout 2 has relatively shorter travel distance than layout 1 under same amount of picking products which means although cross aisle occupies more space (meaning that storage space is reduced), it gives picker more flexible travel route. However, as mentioned before, in economic point of view, company may think about the tradeoff between financial investment and picking efficiency.

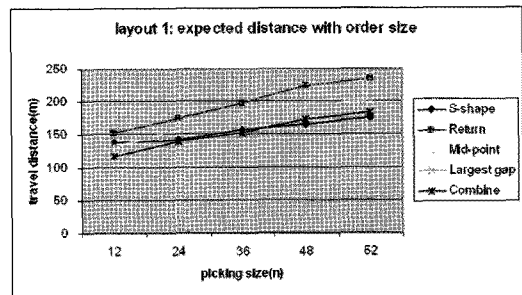


Fig. 8 Expected travel distance of layout 1

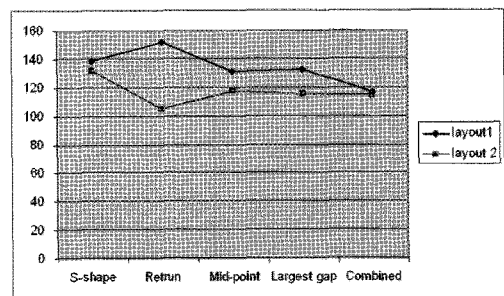


Fig. 9 Differences between two layouts (n=12)

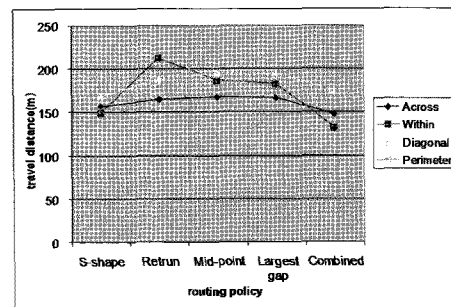


Fig. 10 Expected travel distance with storage planning over routing policy

Based on experiment result, we can figure out suitable match between routing policy and storage location planning (see Figure 10). Outperforming combination of storage and routing method can be summarized as given in Table 3. In this experiment, although across storage planning and s-shape routing policy works strangely well in most of case, this experiment carries quite similar result as shown in previous researches.

Table 3 Outperforming combination of storage and routing method

Preferred routing method	Storage planning
S-Shape	Within-aisle
Return	Across-aisle
Mid-point	Across/Perimeter-aisle
Large Gap	Across-aisle
Combined	Within-aisle

### 5. Conclusion and recommendations

This paper addressed the warehouse order picking problem and summarized the significant affecting factors on order picking efficiency through reviewing prior researches. As well known about this problem, many researchers have improved storage policy and routing algorithms in many ways. Several significant storage and routing policies are employed for testing combination of those policies and carried the result which is similar as previous researches'. From the experiment, we expected that it may help us to understand how those affecting factors work under different combination condition in the warehouse.

The algorithm of routing policy has been developed so well and it seems it might be too much for the picker who actually accomplishes order picking performance. Therefore, further studies, for the accuracy and more practical result of order picking problem, may need more study about following factors: picker's capacity, order batching, time parameter and congestion in aisle which are more realistic factors. Not many studies consider all the affecting factors putting together into one solution model since it is too complicated. However, some of very recent studies are trying to consider those factors all together in the warehouse management system to develop the database about this problem. Although this new attempt is difficult and time consuming job, once it figures out, it could help warehouse manager and company as a guideline to choose a suitable warehouse system.

design in manual picking systems: a simulation approach", *Integrated Manufacturing Systems*, Vol. 11, No. 2, pp. 94-104.

[2] Caron, F., Marchet, G., and Perego, A. (2000b), "Optimal layout in low-level picker-to-part systems", *International Journal of Production Research*, Vol. 38, No. 1, pp. 101-117.

[3] De Koster, R., Le-Duc, T., and Roodbergen, K.J. (2006), "Design and control of warehouse order picking: A literature review", *European Journal of Operational Research*, Inpress.

[4] Gu, J., Goetschalckx, M., and McGinnis, L.F. (2007), "Research on warehouse operation: A comprehensive review", *European Journal of Operational Research*, 177, pp. 1-21.

[5] Heskett, J.L. (1963), "Cube-per-order index - A key to warehouse stock location", *Transport and Distribution Management*, 3, pp. 27 - 31.

[6] Hsieh, L.F. and Tsai, L. (2006), "The optimum design of a warehouse system on order picking efficiency", *The International Journal of Advanced Manufacturing Technology*, 28, pp. 626-637.

[7] Hwang, H., Oh, Y.H., and Lee, Y.K. (2004), "An evaluation of routing policies for order-picking operations in low-level picker-to-part system", *International Journal of Production Research*, Vol.42, No.18, pp. 3873-3889.

[8] Larson, T.N., March, H., and Kusiak, A. (1997), "A heuristic approach to warehouse layout with class-based storage", *IIE Transactions*, 29, pp. 337-348.

[9] Manzini, R., Gamberi, M., Persona, A., and Regattieri, A. (2007), "Design of a class based storage picker to product order picking system". *Int J Adv Manuf Technol*, 32; pp. 811-821.

[10] Petersen, C.G. (1997), "An evaluation of order picking routing policies", *International Journal of Operations & Production Management*, 17 (11), pp. 1098 - 1111.

[11] Roodbergen, K.J. and De Koster, R. (2001), "Routing methods for warehouses with multiple cross aisles", *Int J Prod Res*, Vol. 39, No. 9, pp. 1865-1883.

[12] Vaughan, T.S. and Petersen, C.G. (1999), "The effect of warehouse cross aisles on order picking efficiency", *International Journal of Production Research*, 37 (4), pp. 881 - 897.

### References

[1] Caron, F., Marchet, G., and Perego, A. (2000a), "Layout

Received 22 Sep 2008  
 Revised 11 Sep 2009  
 Accepted 17 Sep 2009