Sensitivity Analysis in Finding Shortest Path for Order Picker with Limited Picking Capacity

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Abstract. The success of any warehouse management is normally contributed by the success of order picking process. In any warehouse operation, order picking contributes more than half percentage of the total warehouse operating costs. Layout of warehouse, storage allocation, number of order pickers and various routing methods contribute to significant impact on the order picking process. All of these variables need to be considered in ensuring smooth and fast order picking process. We test the variation of each variable in finding the optimal route for each order picker, using a modified Dynamic Programming method. Real data set of a warehouse operation is used for the study. The results show a reduced of total distance by 11.6% by choosing the shortest path based on the number of order pickers and an increase by 48% using batch picking method. The shortest distances for each OP with limited capacity are also discussed thoroughly in this paper.

1. Introduction

Order picking is a process of retrieving goods from specified storage locations based on the customer orders and can constitute more that 50 percent of total warehouse operation cost [1]. Therefore, order picking is a benchmark and the highest priority in measuring the performance and productivity improvement of any warehouse management [2]. The order picking success is also very much related to the internal layout design of a warehouse, storage assignment methods, routing methods, order batching and zoning. Research on this area is growing rapidly and yet the areas are hardly been explored. Many research outputs also agree that these four methods help to reduce the travel distance of order picker. In the order picking process, it consists many subprocesses; including clustering and scheduling orders from customers, assigning stocks, release order, order picked up and disposal from the warehouse [2], [3]. [4] stated that the most common objective of order picking is to maximize service level, subject to resource constraints such as labor, machines and capital. Once a customer request or placed an order, the demands need to be satisfied within a targeted time.
The layout of warehouse can affect the management of orders in fulfilling the demand. However, order retrieval time depends on the travelling distance in the warehouse, item searching, item lifting/discharging from the shelves and the equipment used [5], [6]. Thus, to improve the quality of order picking, it is pinnacle to reduce the travel time involved. According to [7],[8],[9], proper routing in order picking can efficiently help to reduce between 17% and 34% in travelling distance. The number of reductions depends on the methods that are used.

Previously, the study of finding shortest path in a case study of car manufacturing company is tested using two methods; The Dijkstra’s Algorithm (DA) and the Dynamic Programming (DP) Method [10]. Based on the findings, the DP method did produce better results compared to the Dijkstra’s algorithm. This may be due to the inflexibility of choosing path in the Dijkstra’s algorithm. Under the algorithm, it is assumed that the picker moves only on the stored location to pick an item which is not rational in a real situation. On the other hand, DP did provide shortest path by considering all possible paths. In DP, the picker will follow the path that has already organized in the warehouse. In this case, all impossible solution can be eliminated. Furthermore, the problem is solved stage by stage. In this study, the same DP method is modified to find the shortest path and distances for the order pickers in a manufacturing company. The main objective of this study is to make sure that all the items in every node is visited and picked. Other objective is to make sure the results obtained is the best shortest path and distance given for each order picker (OP).

This study consists of two parts (Part A and B). There are two analysis done in Part A (i. Finding Shortest Path based on picking by items and ii: Finding Shortest Path based on Order Picker (OP). In Part B the focus is on Finding Shortest Path based on single order picking. The real data is obtained from a selected car manufacturing company. In this study, the layout plan of Zone 1 of the company’s warehouse is as shown in Figure 1. All the parts is numbered according to the company’s system and number of items left are also indicated. In this Zone 1, there are 4 aisles in total and each OP needs to collect items in these aisles according to the customers’ demand. The demand needs to be completed within designated time as all orders must be completed within a day.

![Figure 1. Layout Plan for Zone 1 in EPMB](image-url)
2. Methodology
In this study, Dynamic Programming Model by [3] is used to find the shortest distance for the OP to complete an order. The objective of using this model is to find the best shortest path solution with each OP has equal number of items to be picked. This model is then adjusted to suit the situation in the study, and it is hoped to provide better solutions for any warehouse with similar background problem.

The procedure starts with an OP brings an order form or number of items need to be collected. The OP will start at the collection point O. From O the OP will determine his next destination, j for his next pick up. The distance from O to k is the next shortest distance with an item to be picked. While in j, each OP can only pick at most 25 items at a time. Say, the total items need to be picked are 90 items, then the OP needs to go back to O and come back to j to pick the balance of 65 until all items are collected. Once the condition is satisfied, next, the OP can move to the next node, \( j + 1 \). Complication arises when the number of items to be picked is more than 25.

The first step in initialization of the model is by fixing the starting node (collection point), O. All corresponding nodes from O are identified. The distances between each node are known and the number of items to be collected are identified from the order note. All weights of other precedence edges are labelled as infinity (\( \infty \)). The list of visited node is updated. Next, in step 2, initiates the whole network involved in the study. The route is expanded to the entire network for each iteration. The expansion involves connecting between two nodes with the shortest path. In this expansion, the current path is then compared with other adjacent nodes using the algorithm. In the end, the path with the shortest distance is updated and each OP will have the optimum number of items to be picked. The iterations stop until all nodes with an item are visited.

Stage 1: Initialization Stage Steps:
1. Let \( N \) be set of all nodes. Identify the starting node, \( O \). Let \( a \) denote the total distance from \( O \) to node \( a \). Thus, \( (a) = 0 \).
2. Let \( w_j \) be total items to be picked where \( w_j \leq 25 \). For every order picker, maximum number to be picked at one time is \( K \). Under this situation, \( K = 25 \). For each node \( j \) adjacent from O, then, \( x_j = 1 \) or \( x_j = 0 \). If there is an item to be picked at the current node, thus \( x_j = 1 \), else skip the node and go to the next consecutive node.
3. Let \( p(i) \) denotes the predecessor of \( i \). Thus, \( p(i) = 0 \).
4. For each other node \( l \) such that \( l \neq 0 \) and \( l \) is not adjacent from \( O \), let \( (l) = \infty \).
5. Let \( S \) denotes the set of visited nodes. Then, \( S = \{0\} \).

Stage 2: Iteration Stage Steps:
1. Determine the node \( j \) that minimizes \( q(j) \) in \( S \).
2. Let the weight (distance) from any node \( i \) to \( j \) be denoted by \( w \).
3. Let the item to be picked from node \( i \) to \( j \) be denoted by \( V \). For every pick, \( V \) must not exceed \( K \). Thus, need to check whether \( w_j + V_i \leq 25 \).
4. For each \( x_j = 1 \)and \( w_j + V_i \leq 25 \), then \( n = (i) + a \). Compare \( (j) \) and \( n \). If \( n \) is the least of the two and \( w_j + V_i \leq 25 \) then update \( (j) \) such that \( q(j) = n, w_j + w_{j+1} \) and \( V_{j+1} \)
5. Else, if \( w_j + V_i > 25 \), stay at current \( (i) \) and repeat steps 1 to 4. However, the distance \( a \) is added for every movement from \( O \) to current node.
6. If \( S = N \), then all nodes have been visited, thus stop and obtain the total distance. Otherwise, repeat step 1 to 5 of Stage 2.

3. Results and Discussion
The analysis will be divided into two (2) parts. Part A is using Batch Order Picking with the first scenario; i) based on picked items, ii) based on the order picker; and Part B is using Single Order Picking.

3.1. Batch Picking
3.1.1. Finding Shortest Path based on picking by items. In the company, there are seven OPs per shift for picking a Brand A car parts. In Figure 2, 13 orders were selected at random to determine the routing and shortest path for each OP from initial point (depot) to end point (packaging point). This is based on daily order made in the selected company. With the total items of 1540, seven OPs were appointed to collect the items at preferred nodes. In Part A, few limitations are taken into consideration for each OP. Firstly, for every trip, the maximum number of items to be picked are 25 items per OP. Therefore, seven OPs are able to pick only 220 items per trip. Thus, each OP needs to complete at most 9 trips to complete all the 1540 items. Summary of the calculation is as shown in Table 1.

Table 1. Summary of calculations on total number of orders, items and its assignment to OPs

|                                |       |
|--------------------------------|-------|
| Total number of orders         | 13    |
| Total number of items          | 1540  |
| Number of OPs                  | 7     |
| Maximum number of items for each picker | 25    |
| Total items to be picked per OP|       |
|                                | $\frac{1540}{7} = 220$ |
| Total trips for each OP        | $\frac{220}{25} = 8.8 \approx 9$ |

The colour denotes the order for each customer. For instance, order No.1 wanted item PJ D48(30 items) and PJ D73(60 items). Therefore, in Figure 1, the layout plan of zone 1 were coloured the same as order No.1.

Figure 2. Details breakdown of items for 13 orders made by customers of the company
In this situation, based on the information gathered, a simulation test was done, and the following limitations are anticipated:

1. Maximum number to be picked by each OP that is 220 items per OP.
2. Some of the items need to be collected together with other items to fit in the number of pickers.

Based on the previous info in Part A.i, the maximum number of items to be picked by each OP is fixed to 220 items. Therefore, to fit in the total of 220 items per OP, some of the items need to be collected with other items. Say, total item for PJ D07 is 180 items. Thus, the OPs need to collect another 40 items from PJ D08. The balance of PJ D08 will be collected by the second OP. Table 2 shows the joining number of items to be collected by OP.

**Table 2. Summary of assignment for each OP based on picking by batch (items)**

| Item Number       | Balance Item | Order Picker (OP) | Legend |
|-------------------|--------------|-------------------|--------|
| PJ D07 (180) + PJ D08 (40) = 220 | PJ D08 = 140 | OP 1              | ←      |
| PJ D08 (140) + PJ D48 (80) = 220 | PJ D48 = 100 | OP 2              | ←      |
| PJ D48 (100) + PJ D73 (120) = 220 | NONE        | OP 3              | ←      |
| PJ D74 (180) + PJ D75 (40) = 220 | PJ D75 = 110 | OP 4              | ←      |
| PJ D75 (110) + PJ D76 (110) = 220 | PJ D76 = 40  | OP 5              | ←      |
| PJ D76 (40) + PJ D95 (180) = 220 | PJ D95 = 20  | OP 6              | ←      |
| PJ D95 (20) + PJ D96 (200) = 220 | NONE        | OP 7              | ←      |

Overall, the number of OPs and the number of maximum items can be picked per OP are still maintained. The shortest path for every OP is as in Figure 3. For instance, OP 1 will go to node 8 to pick 180 items then go to node 3 to pick another 40 items to complete his job. In this situation, the shortest path for OP 1 is via path $C \rightarrow 8 \rightarrow 3$ with the total distance of 770.82cm. Noted that the items can be reached from both subaisle B and subaisle C. Thus, OP 1 can save the distance of travelling through one subaisles instead of two subaisles. The lists of shortest path and respective distance are in Table 3.

**Figure 3. Optimal Shortest path for each OP based on picking by batch (items)**
Table 3. Detail of optimal Shortest path based on picking by batch (items)

| Order Picker (OP) | Route                                      | Total Distance (cm) |
|------------------|--------------------------------------------|---------------------|
| OP 1             | Node C→ Node 8 → Node 3                    | 770.82              |
| OP 2             | Node B → Node 3→ Node 5                    | 603.48              |
| OP 3             | Node B→ Node 5→Node 7→Node 2              | 1138.76             |
| OP 4             | Node A→Node 1→Node A→Node B→Node C→Node 10| 1929.52             |
| OP 5             | Node C→Node 7→Node 10                     | 850.82              |
| OP 6             | Node 7→Node F→Node G→Node H→Node 11      | 1767.55             |
| OP 7             | Node D→Node 11→Node 12                    | 917.73              |

3.1.2. Finding Shortest Path based on Order Picker (OP). Next, a shortest path for picking by items based on the number of OP. In this situation, the following limitations are considered.

1. Maximum number to be picked by each OP is 220 items per OP.
2. The second OP will continue to pick right after the first OP completed his job.

Using the information gathered from the 13 orders, a simulation was done to test on the OP and the item to be picked. In this situation, the capacity and volume to be picked for each OP is considered. As mentioned earlier, all the seven OPs need to complete 9 trips in order to complete picking all the items. Firstly, the total number of orders based on each order note are recorded in Figure 3 based on the colours as in Figure 2. Next, Figure 4 represents the network of 4 aisles including the total number of items at each node. All the item codes were transferred into nodes. There are 12 nodes altogether and the first OP will start at A as the initial point. Later, the second OP will continue at the next node where the first order picker finished the job. As in node 2, the number 60 denotes number of items need to be picked based on order number 1 by the OP. Finally, the seventh OP will pick the final items and end the job at node D.

For each aisle, the total number of items are as follow; Row A: 300 items, Row B: 510 items, Row C: 330 items and Row D: 400 items. In this situation, the OP is assumed to pick all the items by batch and gathered them at the packaging point. Once arrived, the item will then be organized per order note. As a result, the seven OPs will pick all the items according to Table 4.
Figure 4: Sample of optimal Routing network of 4 aisles for Zone 1

Table 4: Details of Shortest path for seven OPs – indicating items and nodes

| Balance of item to be picked | Order picker (OP) | Total Item in a current row | Total number of item (to be picked) | Node | Item | Node | Item | Node | Item | Maximum picked in a trip =220 | Balance of item in a row |
|-----------------------------|-----------------|---------------------------|-----------------------------------|------|------|------|------|------|------|-----------------------------|------------------------|
| 0                           | 1 A=300         | 300                       | 1                                 | 180  | 2    | 40   | 0    | 0    | 0    | Complete 80                 |                        |
| A=80                        | 2 B=510         | 590                       | 2                                 | 80   | 7    | 140  | 0    | 0    | 0    | Complete 370                |                        |
| B=370                       | 3 B=370         | 370                       | 7                                 | 10   | 6    | 90   | 5    | 90   | 4    | Complete 150                |                        |
| B=150                       | 4 C=330         | 480                       | 4                                 | 60   | 3    | 90   | 8    | 70   | 0    | Complete 260                |                        |
| C=260                       | 5 D=400         | 660                       | 8                                 | 20   | 9    | 90   | 10   | 110  | 0    | Complete 440                |                        |
| D=440                       | 6 D=440         | 440                       | 10                                | 40   | 12   | 180  | 0    | 0    | 0    | Complete 220                |                        |
| D=220                       | 7 D=220         | 220                       | 12                                | 40   | 11   | 180  | 0    | 0    | 0    | Complete 0                  |                        |

Based on Table 4, each order picker will have to walk minimum distance with maximum number of items. As for the first OP (OP 1), he will start at node 1 and collect all the 180 items for three different order notes. Next, he continues to node 2 and collect another 40 items to complete his maximum number to be picked of 220 items per OP. Total distance for OP 1 is 1211.35cm. Noted that each trip the OP 1 only able to pick 25 quantities, therefore the OP 1 needs to travel back and forth up to 8.8 times to complete his cycle. Then, OP 2 will continue at node 2 and picked the balance of 80 items before he can proceed to node 7. The total distance for OP 2 is 964.17cm and the same procedures follow for the next 5 order pickers, and the results are summarized in Table 5.

Table 5: Details of Optimal Shortest path for each OP

| Order Picker (OP) | Route | Total Distance (cm) | Legend |
|-------------------|-------|---------------------|--------|
| OP 1              | Node 1 → Node 2 | 1211.35 | →         |
| OP 2              | Node 2 → Node 7 | 964.17 | →         |
| OP 3              | Node 7 → Node 6 → Node 5 → Node 4 | 300 | →         |
| OP 4              | Node 4 → Node 6 → Node 8 | 1275.3 | →         |
| OP 5              | Node 8 → Node 9 → Node 10 | 440 | →         |
| OP 6              | Node 10 → Node 12 | 1211.45 | →         |
| OP 7              | Node 12 → Node 11 | 917.73 | →         |
3.2 Finding Shortest Path based on Single Order. In Part B, this study is finding shortest path based on number of orders in Daily Order. In this study, there is no limitation on number of items to be picked by each OP. However, some of the OP needs to collect more than 220 items per picker. Thus, some OP will collect more than two order forms. Hence, number of items to be collected will range between 180 and 260 items.

Under this situation, the OP will need to pick according to the order form. Say, OP 1 will pick 260 items based on order number two (Order Number: KS3541217). On the other hand, OP 3 will have to pick item based on three order forms (KS3541216, KS3541219, KS3541224). Total number of items for OP 3 are 210 items. The list of OPs is in Table 6 and the shortest path for each OP is in Figure 5 respectively. The paragraph text follows on from the subsubsection heading but should not be in italic.

Table 6. Order Number for Respective OPs

| Order Picker (OP) | Order Number                  | Total Item |
|------------------|-------------------------------|------------|
| OP 1             | KS3541216                     | 260        |
| OP 2             | KS3541226                     | 230        |
| OP 3             | KS3541216, KS3541219, KS3541224 | 90+90+30 = 210 |
| OP 4             | KS3541218, KS3541222, KS3541227 | 60+90+75 = 225 |
| OP 5             | KS3541223, KS3541225, KS3541228 | 90+90+60 = 240 |
| OP 6             | KS3541220                     | 180        |
| OP 7             | KS3541221                     | 195        |

Basically, in this situation, it is assumed the OP can pick the items on both sides except row D. As can be seen in Figure 5, OP 7 may collect the items between subaisles B and C. Thus, the shortest path for OP 7 is C → 9 → 7 with the total distance of 710.82cm. This path is shorter than compared to that the OP need to go through path B → 5 → F → G → 10 with the total distance of 1768.65cm. Summary of the total path using this system is as shown in Table 7.
Table 7. Summary of shortest path for OP based on Order Number Form

| Order Picker (OP) | Route                                                                 | Total Distance (cm) | Legend |
|-------------------|------------------------------------------------------------------------|---------------------|--------|
| OP 1              | Node A → Node 1 → Node E → Node F → Node G → Node H → Node 12          | 2782.27             |        |
| OP 2              | Node B → Node 5 → Node F → Node G → Node H → Node 12 → Node 11        | 2743.27             |        |
| OP 3              | Node A → Node 1 → Node 2 → Node E → Node F → Node G → Node 5 → Node 3 → Node 8 | 2208.65             |        |
| OP 4              | Node A → Node 1 → Node 2 → Node E → Node F → Node 5 → Node 3          | 2304.28             |        |
| OP 5              | Node B → Node 1 → Node 3 → Node F → Node G → Node 10 → Node 8        | 2208.65             |        |
| OP 6              | Node C → Node 3 → Node 5 → Node 6 → Node 10                           | 850.8               |        |
| OP 7              | Node C → Node 9 → Node 7                                             | 710.82              |        |

Based on the results, Part A.ii results in the minimum shortest path of 6320 cm. In this case, each OP has equal number of items to be picked and equal trip to pick all items. Part A.i results in average total distance of 1139.81 cm. Similar to Part A.ii, the number of items to be picked for each OP are equal. However, the drawback is, each OP must collect different item to complete their quota of 220 maximum items to be picked. This may be the reason of longer path involve in completing the task. Part B shows the longest distance taken for each OP, 13808.74 cm. Results between Part A and B are summarised and compared in Table 8.

Table 8. Comparison of total distance obtained between Part A. i and ii, and Part B

| Order Picker (OP) | Total Distance (cm) |
|-------------------|---------------------|
|                   | Part A.i. | Part A.ii | Part B  |
| OP 1              | 770.82    | 1211.35   | 2782.27 |
| OP 2              | 603.48    | 964.17    | 2743.27 |
| OP 3              | 1138.76   | 300.00    | 2208.65 |
| OP 4              | 1929.52   | 1275.30   | 2304.28 |
| OP 5              | 850.82    | 440.00    | 2208.65 |
| OP 6              | 1767.55   | 1211.45   | 850.8   |
| OP 7              | 917.73    | 917.73    | 710.82  |
| Total Distance (cm) | 7978.68  | 6320.00  | 13808.74 |
| Average Total Distance (cm) | 1139.81  | 902.86   | 1972.68  |
| Average Total Distance (in cm) | 1021.34 |
| Percentage Improvement | 48.22% |
4. Conclusions
The aim of a manufacturing companies mainly is to minimize costs and at the same time trying to make profit by improving their productivity within their warehouses and distribution centres. All this is to ensure the warehouse operation meets the customers’ demand. Main feature that may contribute to this achievement is the efficient and productive process in order picking. Since order picking is crucial in supply chain part, any underperformance that leads to customer dissatisfaction is unacceptable. Due to this, it is vital for the companies to always make sure the customers demand is fulfilled. The success in order picking process may be contributed from the layout of warehouse, item arrangement and its distance from one place to another, the placement and good management of OP and various routing methods.

Under this study, a modified DP method is discussed and applied in the real data from a selected car manufacturing company in Malaysia. The objectives are to obtain shortest path and distance for every OP and at the same time to ensure that all items stated in the Delivery Order is collected.

A sensitivity analysis on three scenarios are done: Part A.i., Part A.ii. and Part B and shows that as a result, Part A.ii returns the best result for the company. In this scenario, every OP is given equal number of items to be collected based on the item part. On the whole, the total distance achieved is 6320 cm. As a result, reducing the path for the OP, means they have more time to collect more order and at the same time, the waiting time for customer can also be reduced. This leads to satisfaction for customers. Not only that, this may motivate the workers as well since everybody has the equal chances of picking an order and equal portion of workload to be completed. As a conclusion, the result obtained gives the optimum value for each OP. The whole study demonstrates that by considering the situations, the efficiency of the order picking process can also be improved. The procedure of this study is hoped to help and can be applied to other areas with a similar situation.

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