Journal of Turkish

Operations Management

Order picker routing problem in a single block warehouse

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Article Info

Article History:
Received: 22.03.2022
Revised: 01.06.2022
Accepted: 06.06.2022

Keywords

Order picking,
Picker routing,
Routing heuristic

Abstract

Picker Routing Problem (PRP) is a sub-problem of the Order Picking Problem in which the goal is to choose orders in such a way that storage costs and distances are minimized. The Picker Routing Problem (PRP) is an NP-Hard problem that can't be solved in a reasonable amount of time. Many heuristic algorithms have been developed in the literature to overcome this challenge. This study investigates the return, S-Shape, mid-point, and largest gap heuristics for PRP in an online retailer's warehouse.The results show that, when used in single-block warehouses, the Midpoint Routing Heuristic performs better on average than other routing heuristics.

1. Introduction

Warehouse functions are a number of procedures related to receiving, storing, picking up, and shipping products as suitable under specified organizational and technological constraints (Kłodawski et al., 2017). As a result, the repository's primary functions are as follows (Smith, 1998):

1. Receiving products from the sources
2. Storing them until they are needed
3. Product preparation as required
4. Delivering products to the customer

The OPP is one of these warehouse operations that are both important and inconvenient because it is the most labour-intensive and complex. Therefore, the order picking process is the one where the most improvement can be made. As a result, OPP is widely used and improved in the literature and operational field. OPP involves the RPR is a problem in which the aim is to minimize the total distance and travel time between orders to be picked (Şahin, 2014; Boz and Aras, 2022).

Because some nodes may not be visited and certain nodes may need to be visited more than once, the order picker routing problem can be considered as the Steiner Traveling Salesman Problem, which is a particular case of the Traveling Salesman Problem (TSP) in the literature (Cornuéjols et al., 1985; Koster et al., 2007). If the minimal distances between each pair of storage locations have been computed in advance, the Steiner Traveling Salesman Problem (STSP) can be written as a standard TSP (Lu et al., 2016). The STSP can be solved in two ways (Theys et al., 2010): To begin, formulate STSP as a standard TSP by calculating the distance between each pair of nodes necessary and solving the problem with heuristics created for TSP, and then to solve the problem with algorithms developed for STSP.

Figure 1 shows a graph representation of a warehouse layout and order picking points. The filled black dots represent a specific sales order and picking locations. The remaining points are possible corridor transition points (Tuna Taşoğlu G., 2013).

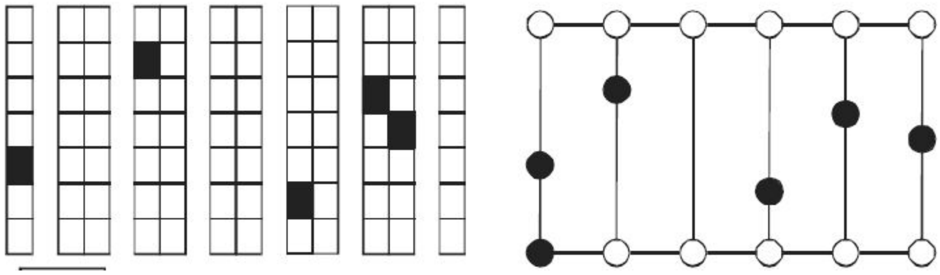

Figure 1. Order picking and graph representation (Koster et al., 2007)

The first step in solving the problem is to figure out how far apart the orders are. Euclidean distances cannot be used due to rack systems; hence Manhattan distances must be determined. The Manhattan distance is derived by multiplying the horizontal and vertical linear distances (Theys et al., 2010). The distances between two orders have been estimated in a variety of ways in several investigations (Ho et al., 2008; Vaughan, 1999). Because it belongs to the NP-hard class, STSP, like other Traveling Salesman Problems, is extremely difficult to solve. As a result, a number of heuristic methods have been created, as given in Figure 2.

The research question of this study is which order picker routing method provides the best results in terms of distance in the warehouse. We implement these methods to answer this question in the warehouse of the company that picks the orders with a manual order picking system. Therefore, this study's contribution is that it has been determined that the routing technique can be used more effectively in that warehouse.

This paper is organized as follows: In this Section explains the research problem. Section 2 expresses the related studies in the literature. Section 3 examines the problem description. Section 4 gives the empirical results. Section 5 demonstrates the result of this study.

2. Literature Survey

The PRP is an NP-Hard problem. NP-Hard problems are not solved with exact solutions in a reasonable time. Because of this, heuristic algorithms are developed in the literature. PRP is solved with metaheuristic, heuristic, and exact solution methods in the literature. Metaheuristic algorithms are used 9.2%, heuristic algorithms are used 77%, and exact solution algorithms are used 13.8% (Masae et al., 2020).

The Order Batching Problem in a warehouse has been studied extensively with PRP. Because these two problems are combined into a single issue known as the Order Picking Problem. While the Order Batching Problem minimizes total costs by batching orders, the PRP seeks to minimize total distance by picking orders. However, studies in which the PRP was investigated alone are included in this section.

PRP is studied lots of times in single or two-block warehouses in the literature. The first of these studies was introduced by Ratliff and Rosenthal (1983). The authors examine the OPP in the rectangular and single block warehouse to minimize the total distance by developing an optimal algorithm for dynamic programming (Ratliff and Rosenthal, 1983). Hall, 1993 developed three heuristic algorithms for the PRP in a single block warehouse, referred to as S-Shape, midpoint, and largest gap heuristic algorithms (Hall, 1993). Vaughan and Petersen (1999) suggest the aisle-by-aisle algorithm, and the authors used a dynamic programming model to solve this algorithm (Vaughan and Petersen, 1999). Roodbergen and Koster propose an algorithm for the shortest tour by picking the order in the parallel aisle warehouse and focusing on the warehouse layout (Roodbergen and Koster, 2001). Shouman et al. (2007) propose two heuristic methods whose names are block-aisle one and block-aisle 2 in warehouses with multiple cross aisles. The authors expressed these algorithms are better than the other routing algorithms (Shouman et al., 2007). In the study of Scholz et al., 2016 a new mathematical programming model is developed for the Single PRP as a TSP in a single block warehouse. Weidinger, 2018 offers a heuristic algorithm for the PRP in a rectangular scattering storage warehouse. This heuristic algorithm tries to minimize the total distance by picking the customer orders. Cano et al., 2019 suggest a genetic algorithm that is a metaheuristic search algorithm to solve the PRP. The authors compare the results with the S-Shape heuristic algorithm, and they state the results provide average distance savings of 13.9% (Cano et al., 2019).

3. Material and Method

In this study, we examine the order picker routing heuristics which are produced to solve the PRP. The problem can be stated as TSP. Because of this, the problem is modelled as TSP (Scholz et al., 2016).

The formulation as follows: V= {0,1,…,n}, $A = \{(p,q)|p,q \epsilon V, p \neq q\}$, p and q are the vertex and h_p is position of the vertex p. x_{pq} is 1 if arc (p,q) includes in the tour, 0 otherwise. c_{pq} is a distance parameter.

$$min \sum_{(p,q)\in A} c_{pq}x_{pq} \quad (1)$$

$$\sum_{p\in V} x_{pq} = 1 \qquad \forall q \in V \quad (2)$$

$$\sum_{q\in V} x_{pq} = 1 \qquad \forall p \in V \quad (3)$$

$$h_p - h_q + (n+1)x_{pq} \leq n \qquad \forall (p,q) \in A{:}\, p,q \neq 0 \quad (4)$$

$$x_{pq} \in \{0,1\} \qquad \forall (p,q) \in A \quad (5)$$

$$h_p \geq 0 \qquad \forall p \in V/\{0\} \quad (6)$$

Equation 1 states the objective function of the PRP. The objective function minimizes the total cost of every picking tour. Constraints (2) and (3) provide that every node has been visited by the picker in any tour exactly once. Constraint (4) eliminates the sub tours. Constraints (5) and (6) are sign constraints.

The heuristic techniques were created in the literature since the PRP is an NP-Hard issue. We clarify these methods as follows:

3.1 S-Shape Routing Strategy

Of the order routing heuristics, the S shape heuristic is the simplest to use (Koster et al., 2007). When the total number of lanes containing all selections is even in this heuristic, the picker aisles all of the aisles they've chosen and eventually moves to the front cross aisles location to return to the P/D point. The whole length of corridors containing at least one selection is only visited once in such situations. If the total number of aisles including all options is odd, the collector does not travel all the way through the last aisle's products, but only to the farthest product in that aisle. As it needs to return to the P/D point, the collector uses a turn strategy to return to the front cross-aisle position (Rao and Gajendra, 2013).

3.2 Return Routing Strategy

The return heuristic is similar to the S shape heuristic in terms of clarity. The order picker enters the aisle and exits the same aisle after completing the order picking. When determining between the S-shaped and return heuristics, the picking point from one or both sides should be considered. When the aisles are wide, it's easier to use the return heuristic since one side is chosen first, followed by the other. If the corridors are narrow and order selecting must be done from both sides, the S shape heuristic is preferable (Goetschalckx and Ratliff, 1988).

3.3 Mid-Point Routing Strategy

Except for the first and last aisles, the midpoint heuristic allows the picker to enter the center of the aisle to take the products and return from the same aisle (Cergibozan and Tasan, 2019). In other words, according to the return heuristic, the products in the higher and lower parts of the warehouse shelves are picked separately, as if there is a line in the middle of the warehouse shelves.

3.4 Largest Gap Routing Strategy

The picker, like the midpoint strategy, exits each aisle from the same side (with the exception of the first and last aisle) from which it arrived. The picker, on the other hand, does not stop at the midpoint of a corridor; instead, he enters the greatest gap. A gap is a distance between any two sequential elections, such as the first election and the front aisle or the last election and the back aisle. The section of the aisle where the picker does not move has the largest gap (Hall, 1993).

3.5 Composite Routing Strategy

The S-shape heuristic and the return heuristic are combined in this heuristic (Roodbergen and De Koster, 2001). After selecting all of the items in an aisle, the picker must choose whether to continue on to the next aisle via the back aisle or return. It is mentioned in the literature as a more useful method in specific circumstances.

3.6 Combine Routing Strategy

The combined method is considered a dynamic programming component. Because the picker decides that which routing strategy to choose according to the aisle ahead. For example, if the distance result of the ahead aisle is better for the return method, but the distance result of the next aisle is better for the S-shape method, the picker chooses the S-shape method because this choise has overall better resultes (Roodbergen and De Koster, 2001).

3.7 Optimal Routing Strategy

In the optimal method, the order picker evaluates separately for every aisle every method and decides the most efficient method. According to this, it can apply to every aisle in different methods. Therefore, the least distance is found with this strategy.

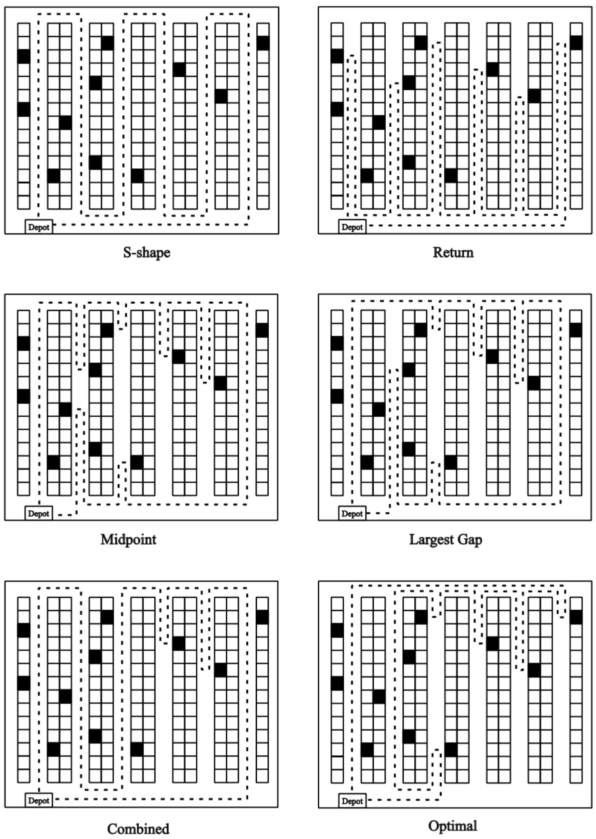

Figure 2: Picker routing strategies (Roodbergen, 2001)

4. Experimental Results

The order picker routing methods are implemented in the warehouse in this section. The methods are compared to see which one is the best. The warehouse's parameters are listed in Table 1. Table 2 also shows the vertical distance between aisles in the warehouse where parts are located. Simultaneously, the parameter of orders is shown in Table 3. In terms of these data, the methods are run for the 28 batches. Every batch has its own order, and each order has its own set of pieces. As a result, the distance results for these batches differ.

Table 1. Warehouse parameter

Parameter	Value
Number of aisles	19
Aisle width	0.32
Number of storage locations	100
Length of the storage unit	100

Table 2. The vertical distance of the parts and their aisle number

Part number	**Aisle number**	**Vertical distance**	**Part number**	**Aisle number**	**Vertical distance**	**Part number**	**Aisle number**	**Vertical distance**
1	1	0.10	11	4	0.28	21	1	0.20
2	8	0.14	12	10	0.03	22	5	0.34
3	9	0.28	13	13	0.23	23	3	0.30
4	2	0.09	14	14	0.08	24	12	0.39
5	3	0.31	15	5	0.45	25	15	0.04
6	15	0.19	16	6	0.10	26	9	0.09
7	12	0.21	17	10	0.45	27	17	0.07
8	7	0.30	18	11	0.50	28	16	0.28
9	17	0.35	19	16	0.11	29	8	0.06
10	19	0.20	20	19	0.09	30	19	0.08

The implementation of this study is done in the single block warehouse of an online retailer is given in Figure 3. There are picking aisles, and the depot is in front of the warehouse.

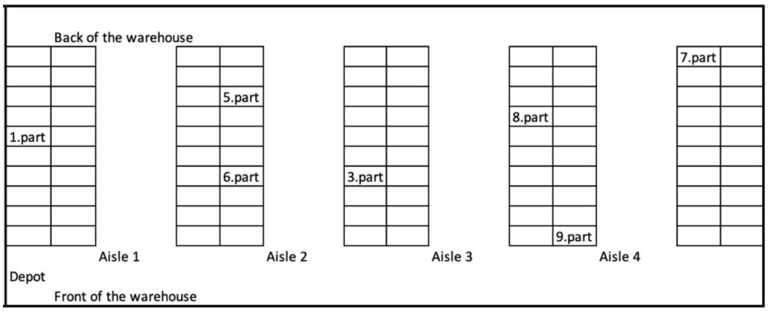

Figure 3. Warehouse layout

Table 3. Order parameter

Parameter	**Value**
The number of batches	28
The number of orders	70
The number of parts	30

The method was implemented in PYTHON and tested on a computer with an Intel Core i5, 2GHz, and 16 GB RAM. Table 4 shows the results of the methods. The best method, according to the order parameter and in the given warehouse layout, is the Mid-point routing method, followed by the Return method. Although the total distances of both methods are not close, the distances per batch are. Among these methods, the S-Shape routing method is the worst method. The reason for this might be that the S-Shape method travels down the aisle even if there is no order at the end. At the same time, the results are given in Figure 4. According to the findings shown in Figure 4, the mid-point and return heuristic algorithms are relatively near in terms of average.

Table 4. Experimental results

Batch number	**Return**	**S-Shape**	**Mid-point**	**Largest gap**
1	1.3248	6.4512	1.3024	3.2256
2	1.1248	2.4192	3.2312	2.2656
3	2.8552	2.8224	2.8456	5.2416
4	1.6888	1.2096	2.1480	1.2816
5	1.4328	5.2416	3.3488	3.2256
6	2.8895	6.8544	2.9248	1.3856
7	3.2424	4.0320	1.4352	4.4352
8	2.1184	6.0480	2.4976	2.4152
9	3.0352	6.8544	3.7112	7.2576
10	5.1751	4.0320	1.4176	3.9176
11	2.4160	3.2256	3.6952	5.6448
12	0.9176	4.4352	2.4520	2.2048
13	2.3368	5.2416	1.3848	4.4352
14	3.9032	6.0480	1.3576	2.8952
15	1.7256	6.8544	3.7112	6.4512
16	1.2320	3.2256	1.0160	2.7712
17	3.1976	3.6288	2.3288	6.4512
18	2.1760	5.6448	2.6880	2.5512
19	1.2360	6.4512	1.6680	7.2576
20	2.4888	5.6448	1.2144	2.0776
21	1.2000	4.8384	1.2000	1.2096
22	2.4056	4.0320	2.0928	1.3696
23	3.6224	4.0320	2.0192	7.2576
24	1.7496	5.2416	2.3552	3.0776
25	1.0896	6.0480	0.9848	4.8384
26	1.0312	5.6448	1.8648	1.8984
27	2.4424	1.2090	3.2112	5.2416
28	3.7360	6.8544	2.1880	1.0016
TOTAL	63.7934	134.265	40.6922	103.2856
AVERAGE	2.2783	4.7951	2.2248	3.6887

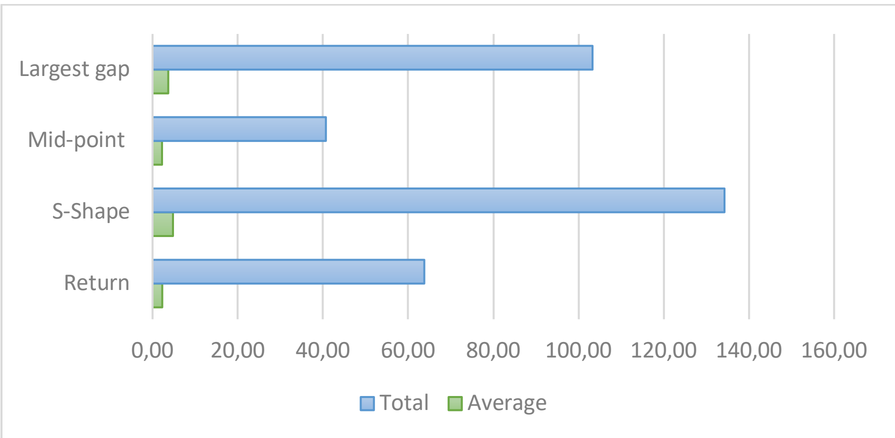

Figure 4. The results of the heuristic algorithms

5. Result and Discussion

Nowadays because of the pandemic through the huge masses it has reached and the conveniences it has supplied, e-commerce has found the possibility to be applied and progressed to all parts of the economy. Because of this, the companies have to compete with each other in the logistics field. As a result, they place a greater emphasis on the in-warehouse process. One of these processes is the PRP, which is a subproblem of the Order Picking Problem. In this study, the order picker routing problem is investigated, which entails routing order components to reduce warehouse distance. In the warehouse, heuristic strategy methods such as Return, S-Shape, Mid-point, and Largest Gap are used. According to the order parameters in Tables 2 and 3 and the given warehouse layout in Table 1, the Mid-point routing method was determined to be the best, while the S-Shape routing method was found to be the worst.

This research can be expanded by including the other warehousing problem (zone picking problem etc.). Furthermore, the data may be used to compile the findings using different picker routing algorithms. This problem may also be handled in a different warehouse layout and the results compared to the original. As a result, in terms of methods, the best warehouse layout may be identified.

Acknowledgment

This research is supported by the Eskisehir Technical University Scientific Research Project Grant No 20DRP060. This paper includes a part of the PhD thesis is written by Esra BOZ

Conflict of Interest

No conflict of interest was declared by the authors.

Contribution of Authors

Esra Boz: Collect the data, Perform the analysis, Write the paper
Nil Aras: Write the paper, Check the paper

References

Boz E. , Aras N. The order batching problem: A state-of-the-art review. Sigma Journal of Engineering and Natural Sciences. 2022; 40(2): 402-420. https://doi.org/10.14744/sigma.2022.00018

Burkard, R. E., Deineko, V. G., Van Dal, R., van der Veen, J. A., & Woeginger, G. J. (1998). Well-solvable special cases of the traveling salesman problem: a survey. SIAM review, 40(3), 496-546. https://doi.org/10.1137/S0036144596297514

Cano, J. A., Correa-Espinal, A. A., Gómez-Montoya, R. A., & Cortés, P. (2019, June). Genetic algorithms for the picker routing problem in multi-block warehouses. In International Conference on Business Information Systems (pp. 313-322). Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-030-20485-3_24

Cergibozan, Çağla, and A. Serdar Tasan. (2019). "Order Batching Operations: An Overview of Classification, Solution Techniques, and Future Research." Journal of Intelligent Manufacturing 30(1):335–49. https://doi.org/10.1007/s10845-016-1248-4

Cornuéjols, Gerard, Jean Fonlupt, and Denis Naddef. (1985). "The Traveling Salesman Problem on a Graph and Some Related Integer Polyhedra." Mathematical Programming 33:1--27. https://link.springer.com/article/10.1007/BF01582008

Goetschalckx, Marc, and H. Donald Ratliff. (1988). "Order Picking in an Aisle." IIE Transactions 20:53--62. https://doi.org/10.1080/07408178808966150

Hall, Randolph W. (1993). "Distance Approximations for Routing Manual Pickers in a Warehouse." IIE Transactions (Institute of Industrial Engineers) 25(4):76–87. https://doi.org/10.1080/07408179308964306

Ho, Y. C., Teng Sheng Su, and Zhi Bin Shi. (2008). "Order-Batching Methods for an Order-Picking Warehouse with Two Cross Aisles." Computers and Industrial Engineering 55(2):321–47. https://doi.org/10.1016/j.cie.2007.12.018

Kłodawski, Michał, Marianna Jacyna, Konrad Lewczuk, and Mariusz Wasiak. (2017) "The Issues of Selection Warehouse Process Strategies." Pp. 451–57 in Procedia Engineering. Vol. 187. Elsevier Ltd. https://doi.org/10.1016/j.proeng.2017.04.399

Koster, R., T. Le-Duc, and K. J. Roodbergen. (2007). "Design and Control of Warehouse Order Picking: A Literature Review." European Journal of Operational Research 182(2):481–501. https://doi.org/10.1016/j.ejor.2006.07.009

Lu, Wenrong, Duncan McFarlane, Vaggelis Giannikas, and Qan Zhang. (2016). "An Algorithm for Dynamic Order-Picking in Warehouse Operations." European Journal of Operational Research 248:107--122. https://doi.org/10.1016/j.ejor.2015.06.074

Masae, M., Glock, C. H., & Grosse, E. H. (2020). Order picker routing in warehouses: A systematic literature review. International Journal of Production Economics, 224, 107564. https://doi.org/10.1016/j.ijpe.2019.107564

Smith, J. D. (1998). The Warehouse Management Handbook. Tompkins p.

Rao, Subir S., and Gajendra K. Adil. (2013). "Class-Based Storage with Exact S-Shaped Traversal Routeing in Low-Level Picker-to-Part Systems." International Journal of Production Research 51:4979--4996. https://doi.org/10.1080/00207543.2013.784419

Ratliff, H. D., & Rosenthal, A. S. (1983). Order-picking in a rectangular warehouse: a solvable case of the traveling salesman problem. Operations research, 31(3), 507-521. https://doi.org/10.1287/opre.31.3.507

Roodbergen, K J, and De Koster. (2001). "Routing Order Pickers in a Warehouse with a Middle Aisle." European Journal of Operational Research 133(1):32–43. https://doi.org/10.1016/S0377-2217(00)00177-6

Roodbergen, K. J. (2001). Layout and routing methods for warehouses (No. EPS-2001-004-LIS). http://hdl.handle.net/1765/861

Scholz, A., Henn, S., Stuhlmann, M., & Wäscher, G. (2016). A new mathematical programming formulation for the single-picker routing problem. European Journal of Operational Research, 253(1), 68-84. https://doi.org/10.1016/j.ejor.2016.02.018

Shouman, M. A., Khater, M., & Boushaala, A. (2007). Comparisons of order picking routing methods for warehouses with multiple cross aisles. AEJ-Alexandria Engineering Journal, 46(3), 261-272.

Theys, Christophe, Olli Bräysy, Wout Dullaert, and Birger Raa. (2010). "Using a TSP Heuristic for Routing Order Pickers in Warehouses." European Journal of Operational Research 200(3):755–63. https://doi.org/10.1016/j.ejor.2009.01.036

Tuna Taşoğlu, Gökçeçiçek. (2013). "Evaluation Of Order Picking Systems Using Simulation." Dokuz Eylül University Graduate School of Natural and Applied Sciences. https://acikerisim.deu.edu.tr/xmlui/handle/20.500.12397/7606

Vaughan, TS. (1999). "The Effect of Warehouse Cross Aisles on Order Picking Efficiency." International Journal of Production Research 37:881--897. https://doi.org/10.1080/002075499191580

Weidinger, F. (2018). Picker routing in rectangular mixed shelves warehouses. Computers & Operations Research, 95, 139-150. https://doi.org/10.1016/j.cor.2018.03.012

Şahin, Yusuf. (2014). "Depo Operasyonları Ve Sipariş Dağıtım Faaliyetlerinin Sezgisel Yöntemler Kullanarak Eş Zamanlı Optimizasyonu." Süleyman Demirel University. https://acikbilim.yok.gov.tr/handle/20.500.12812/266652