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THE PROBLEM OF LOCATION SELECTION DURING THE ORDER-PICKING PROCESS

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Abstract. The paper treats the problem of optimizing the order-picking process in multi locations of the same item. The issue concerns multi-criteria decision- making. The main goals that can be achieved in this situation are the minimization of average order-picking time and the maximization of the number of locations totally cleared. In the paper, the proposed simple heuristic that minimizes the number of picking-aisles visited by the picker is compared using the Dmytrów's TMAL method. The results are evaluated by the following criteria: the average distance covered by the picker, the average order-picking time, priority ratio and the number of locations totally cleared. The manual system and one-block rectangular warehouses with two popular routing heuristics, return and S-shape, are considered in the analysis. The research was carried out using simulations.

Keywords: decision tree, logistic regression, turnover intention.

JEL Classification: C15.

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1. Introduction

The main task performed by logistic chains is the delivery of items from manufacturers to the end users. A very important role in this process is played by warehouses, where the items are stored, picked and sent to the customers. Bartholdi and Hackman [2011] distinguish five warehouse processes: (1) receiving and (2) putting-away (inbound processes); (3) storage; (4) order-picking and (5) checking, packing, shipping (outbound processes). Order-picking, the process of retrieving items from storage locations in response to customer demand, is the critical one. In manual systems this process demands a lot of labour, as in automated systems it is considered a very capital intensive activity. Tompkins et al. [2002] estimate that the cost of the order-picking process can generate as much as 55% of the total warehouse operating costs. For

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this reason the warehouse managers tend to optimize the order-picking process. This task is usually accomplished through the reduction of the order-picking time, which for manual systems is usually the equivalent of decreasing the distance traveled by the picker. The factors that influence the average order-picking time are: demand pattern, warehouse layout, storage policy, routing method, zoning method, batching policy, and the orders sequencing method [Petersen 1999; Le-Duc, De Koster 2005; Yu, De Koster 2009]. In this paper a quite different situation, where the same items are stored in multiple locations is considered. Here the proposed solutions are evaluated not only by the time of the order-picking process, but other criteria are also considered. The main goal of the paper is a proposition of simple heuristic for location selection that minimizes the number of aisles visited by the picker. The heuristic will be multi-criteria evaluated and compared with the TMAL method.

The paper is organized as follows. In the next section the literature review connected with the optimization problems with multiple locations for the same item is presented. The third chapter contains a description of the warehouse and the routing heuristics considered in the research. The results of the experiments are shown in section four. The paper concludes with the fifth section.

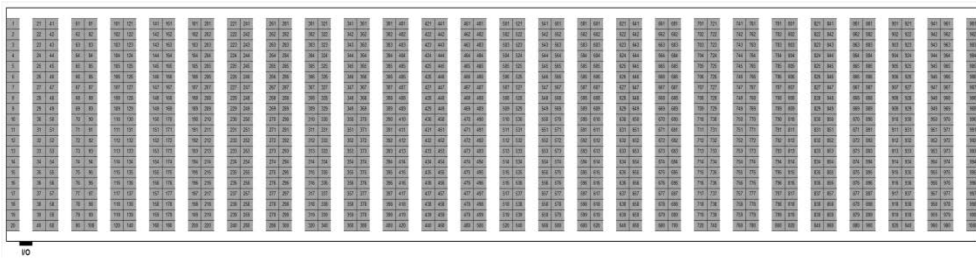
2. Literature review

The vast majority of research dedicated to order-picking optimization problems deals with warehouses where items are stored in single locations. The problem of multiple locations of the same item is considered by Daniels et al. [1998]. The authors present the model (and heuristic) for optimal picker's route in a one-block rectangular warehouse. As the issue of designating the optimal route in one-block rectangular warehouses is very easy to solve in cases of the single location of each item (using dynamic programming, Ratliff, Rosenthal [1983]), the multi-location variant in NP-hard.

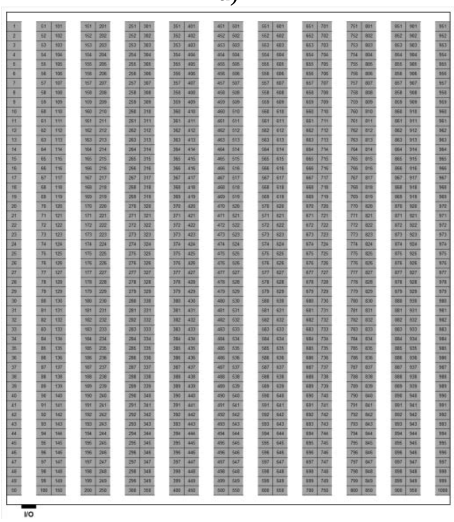
Dmytrów [2013] considers the problem with many locations of the same item and proposes the model for maximizing the number of locations totally cleared during the order-picking process. The author mentions different criteria for selecting the specified location with the item to be picked: (1) the distance from the location with the required amount of items to the I/O point, where the picker starts and finishes the order-picking process; (2) the expiry date of the item; (3) the minimum amount of the item in the location. Using the last criterion usually leads to longer distance and order-picking time, but allows to allocate new items in the totally cleared locations. A different way of selecting the location is by using the Taxonomical Measure of Location's Attractiveness (Taksonomiczna Miara Atrakcyjności Lokalizacji, TMAL) formulated by Dmytrów [2015]. The TMAL measure is the aggregate variable that can be helpful in the order-picking process. Dmytrów summarizes the standardized values of three criteria: (1) the distance from the location to the I/O point; (2) the degree of demand satisfaction; and (3) the number of different items picked from the specified neighborhood of the location. The role of the decision maker is the determination of the weights for each criterion. The author presents the idea of the TMAL measure and states that the selected criteria can differ. In the next paper, Dmytrów [2016] recommends choosing the third abovementioned criterion, which leads to the task of grouping locations. Dmytrów and Doszyń [2015] consider the ideal location, the so-called "pattern location" and use Hellwig's Development Pattern Method [Hellwig 1968] for determining the preferred location. The influence of the number of locations with the same item on the distance covered by the picker using simulation tools is analyzed by Tarczyński [2017c]. The author considers two popular routing heuristics: S-shape and return and different storage policies based on the ABC classification. The conclusion from the research is that increasing the number of locations with fast moving items does not always lead to better solutions.

3. Warehouse layout, picker's routing heuristics and other assumptions for the experiments

In the theoretical study of manual order-picking systems there are usually only two layouts of the warehouse considered: one-block rectangular and multi-block rectangular. In the one-block layout the picker can change the picking aisles only using two cross aisles: front cross aisle and back cross aisle. In the multi-block warehouse there is a specified number of middle aisles, too. A specified type of multi-block is the two-block with one middle aisle. The warehouse considered in this paper is one-block rectangular (for the examples of the use of two-block rectangular warehouses the reader can see e.g. [Caron et al. 1998], and for multi-block rectangular see [Roodbergen at al. 2008]). The research will cover warehouses with two layouts: the first one with a higher number of short picking aisles (25 picking aisles and 20 locations in a rack, 25x20, Figure 1a); and the second with fewer but longer aisles (10 picking aisles and 50 locations in a rack, 10x50, Figure 1b). The total number of locations in both cases is 1000. The pick-up/drop-off point (I/O) is located in the front cross aisle opposite the first picking aisle.



a)



b)

Fig. 1. One-block rectangular warehouse with:
a) 25 picking aisles and 20 locations in a rack; b) 10 picking aisles and 50 locations in a rack

Source: own elaboration.

In the experiments the number of positions on the pick lists (number of visited locations) is five. Six variants are considered:

- each item from the pick list is stored only in one location (this variant is used only for comparison),
- four items from the pick list are stored only in one location, one item is stored in three different locations,
- three items from the pick list are stored only in one location, two items are stored in three different locations,

- two items from the pick list are stored only in one location, three items are stored in three different locations,
- one item from the pick list is stored only in one location, four items are stored in three different locations,
- all the items are stored in three different locations.

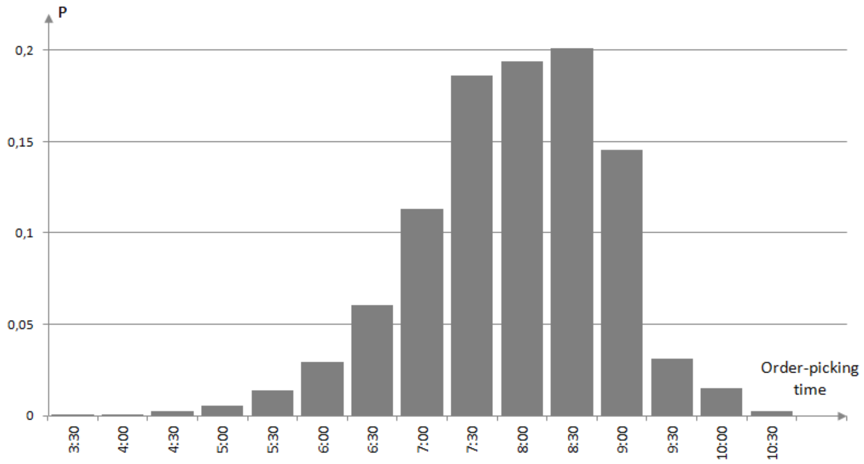
If the item is stored in three locations, then the amount of items from one of the locations satisfies 100% of demand, from the second – 80% of demand, and from the third – 60% of demand.

One of the criteria used for evaluating the results is the location's priority. It was assumed that when the item is available only in one location then the priority equals 1. For three locations of the same item, we prefer the locations with the smallest supply. So, the priority for the location that satisfies 100% of demand is 1, for the location with 80% needed items it is 2, and for the last one (meets 60% of requirements) the value of the priority ratio is 3.

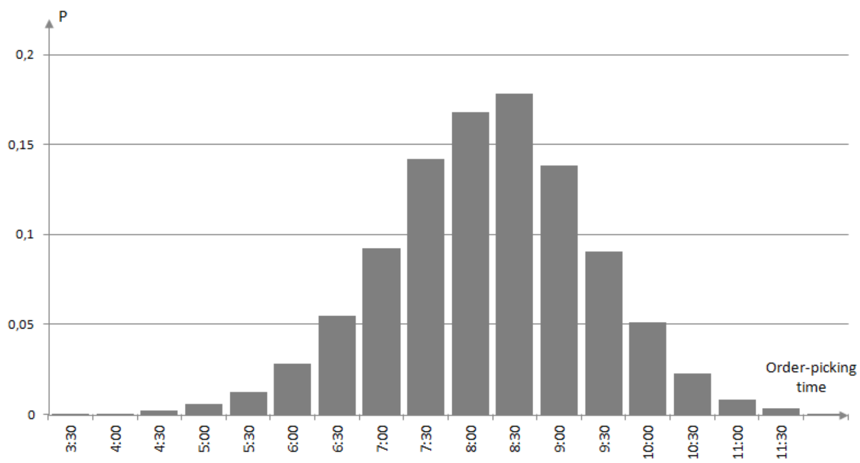
For the calculation of the average values of the distance traveled by the picker and the order-picking time, it is assumed that the initialization time for each order is 5 seconds, the time of searching and picking the items from one localization is 10 seconds, and the movement speed of the picker is 5 kilometers per hour.

The simulations were performed using the simulation tool Warehouse Real-Time Simulator [Tarczyński 2013]. Each experiment was replicated 10,000 times and the values were averaged. Assuming the normal distribution of order-picking time for confidence level equals 0.95 and the maximum measurement error equals 2 seconds, the expected number of replications for each experiment does not exceed 10,000. The examples of empirical probability distributions from the performed experiments are presented in Figure 2. More about the problem of determining the number of replications in order-picking simulations can be found in Tarczyński [2017a].

In the theoretical study there are five routing heuristics for a one-block rectangular layout: S-shape, return, midpoint, largest-gap, and combined. The designation of the shortest route is very easy and fast thanks to the Ratliff and Rosenthal [1983] algorithm. Unfortunately the majority of heuristics and the optimal route has only slight practical significance. In this paper the two most often used heuristics, S-shape and return, are considered. The description of the others the reader can find in e.g. [Tarczyński 2012].



a)



b)

Fig. 2. Examples of empirical probability distributions for the layout 25x20, each of five items stored in three locations and:
a) S-shape routing heuristic; b) return routing heuristic

Source: own elaboration.

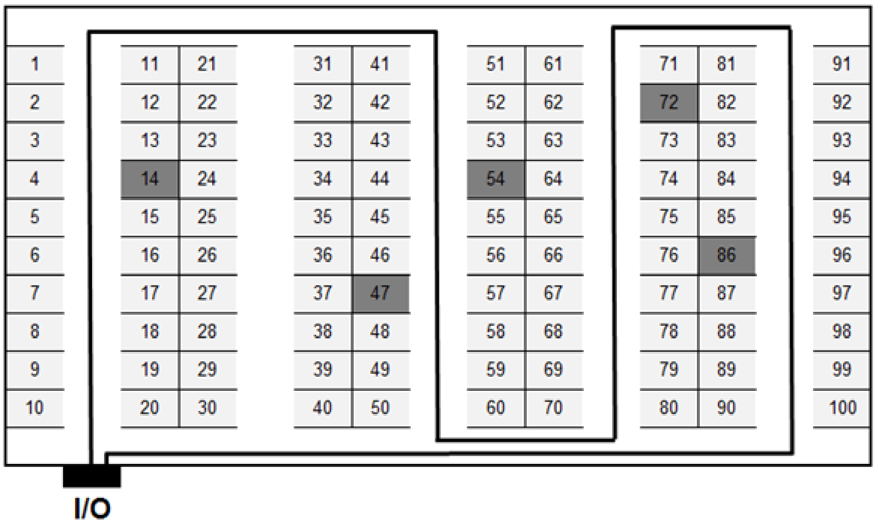


Fig. 3. Example of S-shape routing heuristic

Source: own elaboration.

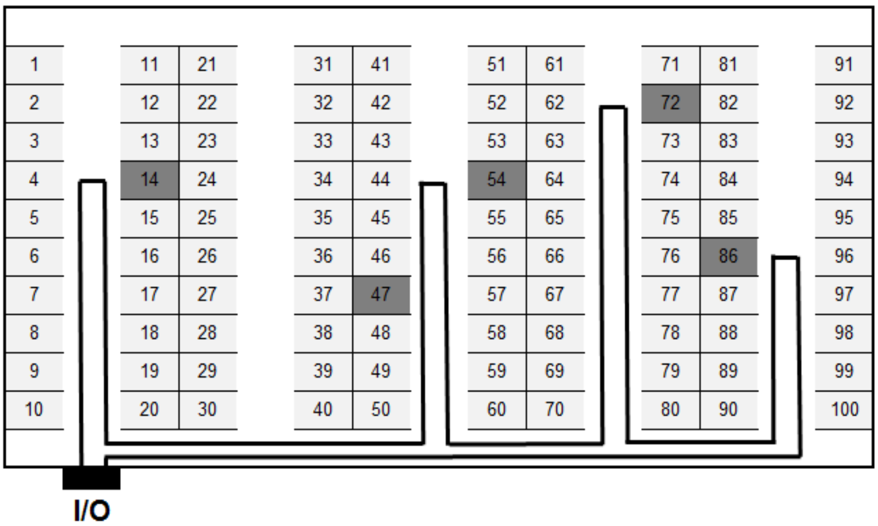


Fig. 4. Example of return routing heuristic

Source: own elaboration.

In the S-shape (Figure 3) heuristic, the picker enters only picking aisles with items specified on the pick list. He or she enters the picking aisle from one cross aisle, picks the needed items and leaves the picking aisle using the opposite cross aisle. Only after picking the last needed item the picker can turn back and return to the same cross aisle. Using the return (Figure 4) heuristic only the front cross aisle is in use. The picker after picking the last needed item from the picking aisle always has to turn back and return to the front cross aisle.

4. Results of experiments

Dmytrów [2015] uses only three criteria for the TMAL method, but he recommends the creation of an aggregate variable containing more criteria. For the experiments the TMAL measure was composed of four criteria: the distance from the location to the I/O point; the minimum distance from the location to another potentially visited location; the degree of demand satisfaction; the priority ratio. The weights for all criteria are the same.

The criteria that can be used for the optimization of the multi-location problem and for the evaluation of the results are:

- the average order-picking time,
- the average distance covered by the picker (in the case of multiple location of the same item the order-picking time is not always proportional to the picker’s distance),
- the number of locations totally cleared,
- the number of visited locations,
- the number of visited picking aisles,
- the maximum distance from the visited picking aisle to the I/O point,
- the average priority ratio of picked items (e.g. based on the expiry date).

In the experiments the TMAL method was compared with two simple heuristics: (1) the former maximizes the priority ratios of picked items; (2) the latter minimizes the number of visited aisles. In addition, as a reference point, the simulations were performed for the cases with only one location of each item.

The results of the experiments for the layout with 25 aisles and 20 locations in the rack are presented in Tables 1-5. The average distance and order-picking time for the TMAL method are for all the experiments worse than in the case with only one location of each item. The difference varies from about 3% for the case with only one item stored in three locations to 11%-18% for the case with five items stored in three locations. The cause of the deterioration of the value of those two criteria evaluation functions is that the picker has to visit more locations to satisfy more criteria functions. Optimizing the priority criterion leads to a significant prolongation of the distance and order-picking time: the results were worse from 9% to 50% in comparison to the case with only one location of each item. The method that minimizes the number of visited aisles can even slightly cut the average order-picking time, but only when a small number of items are stored in multi locations. Comparing routing heuristics, for the layout 25x20 the S-shape gave in all cases better values of order-picking time, but the difference is not vital.

Table 1. Results of experiments for the layout 25x20 and one item stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	218,87	221,55	7:00	7:04	5,00	4,62	1,00	0,00
TMAL	225,17	227,15	7:17	7:20	5,66	5,03	1,25	0,32
Max priority	239,80	243,42	7:45	7:51	6,00	5,44	1,50	1,00
Min no. aisles	216,64	220,70	6:58	7:05	5,24	4,39	1,03	0,13

Source: own elaboration.

Table 2. Results of experiments for the layout 25x20 and two items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	218,87	221,55	7:00	7:04	5,00	4,62	1,00	0,00
TMAL	231,10	233,17	7:33	7:37	6,33	5,38	1,45	0,65
Max priority	258,80	263,89	8:26	8:35	7,00	6,21	1,86	2,00
Min no. aisles	217,16	222,69	7:03	7:12	5,58	4,11	1,06	0,24

Source: own elaboration.

Table 3. Results of experiments for the layout 25x20
and three items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	218,87	221,55	7:00	7:04	5,00	4,62	1,00	0,00
TMAL	236,00	238,45	7:48	7:52	6,99	5,68	1,61	0,98
Max priority	276,97	283,07	9:07	9:17	8,00	6,96	2,13	3,00
Min no. aisles	219,75	226,97	7:11	7:23	6,00	3,81	1,10	0,35

Source: own elaboration.

Table 4. Results of experiments for the layout 25x20
and four items stored in three locations

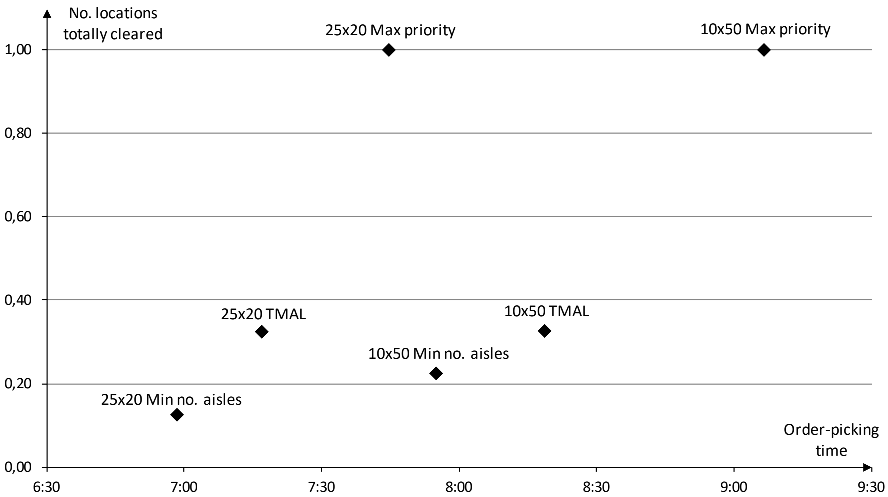
Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	218,87	221,55	7:00	7:04	5,00	4,62	1,00	0,00
TMAL	240,20	243,36	8:02	8:07	7,66	5,95	1,75	1,32
Max priority	293,59	301,23	9:44	9:57	9,00	7,68	2,33	4,00
Min no. aisles	224,83	233,67	7:24	7:39	6,45	3,52	1,13	0,43

Source: own elaboration.

Table 5. Results of experiments for the layout 25x20
and five items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	218,87	221,55	7:00	7:04	5,00	4,62	1,00	0,00
TMAL	243,68	248,12	8:14	8:22	8,32	6,18	1,87	1,66
Max priority	309,52	318,63	10:21	10:36	10,00	8,37	2,50	5,00
Min no. aisles	230,96	241,57	7:39	7:57	6,95	3,21	1,16	0,51

Source: own elaboration.



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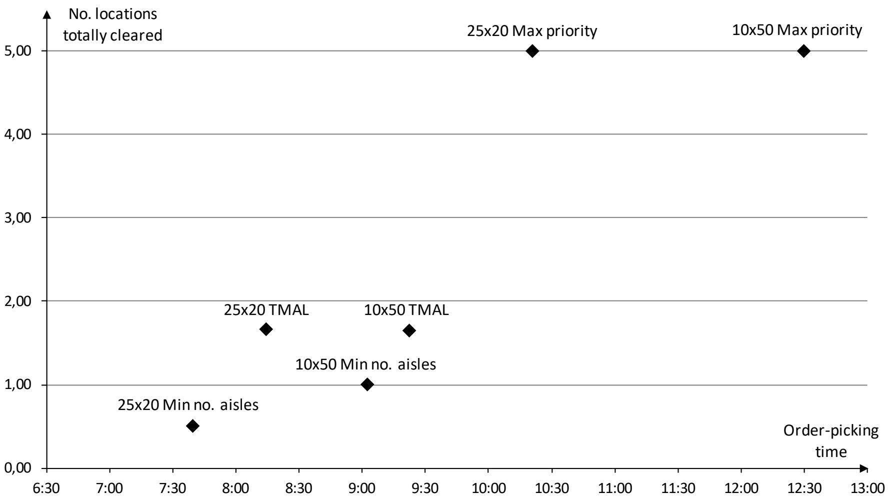

b)

Fig. 5. Comparison of two evaluation criteria for the layout 25x20 and:
a) one item stored in three locations; b) five items stored in three locations

Source: own elaboration.

The results of experiments for the layout with 10 aisles and 50 locations in the rack are presented in Tables 6-10. The general conclusions for this layout are similar to the 25x20 layout. Comparing the methods of location selection, for both layouts the dominated variants cannot be determined. Only the return routing heuristic is dominated by the S-shape heuristic. However, it is worth nothing that the return method performs quite well with the ABC storage location assignment (across-aisle policy, for more details see e.g. [Tarczyński 2017b]). The comparison of variants for two evaluation criteria is presented on Figure 5. For each method of location selection the variants with the layout 25x20 seem to be better than variants with the layout 10x50 because they generate shorter order-picking times while the number of locations totally cleared is similar.

Table 6. Results of experiments for the layout 10x50
and one item stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	257,56	269,40	8:04	8:24	5,00	4,09	1,00	0,00
TMAL	262,24	271,61	8:19	8:34	5,66	4,20	1,25	0,33
Max priority	288,92	306,48	9:07	9:36	6,00	4,67	1,50	1,00
Min no. aisles	249,77	268,37	7:55	8:26	5,37	3,72	1,07	0,22

Source: own elaboration.

Table 7. Results of experiments for the layout 10x50
and two items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	257,56	269,40	8:04	8:24	5,00	4,09	1,00	0,00
TMAL	266,32	274,95	8:32	8:46	6,32	4,29	1,45	0,66
Max priority	317,46	341,40	10:04	10:44	7,00	5,20	1,86	2,00
Min no. aisles	250,55	274,29	8:00	8:40	5,78	3,37	1,12	0,42

Source: own elaboration.

Table 8. Results of experiments for the layout 10x50
and three items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	257,56	269,40	8:04	8:24	5,00	4,09	1,00	0,00
TMAL	270,98	279,81	8:46	9:01	6,98	4,39	1,61	0,99
Max priority	343,10	374,21	10:57	11:49	8,00	5,69	2,13	3,00
Min no. aisles	256,25	285,29	8:14	9:03	6,24	3,03	1,16	0,61

Source: own elaboration.

Table 9. Results of experiments for the layout 10x50
and four items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	257,56	269,40	8:04	8:24	5,00	4,09	1,00	0,00
TMAL	276,56	285,56	9:02	9:17	7,63	4,52	1,75	1,32
Max priority	366,26	404,65	11:45	12:49	9,00	6,11	2,33	4,00
Min no. aisles	266,94	299,68	8:37	9:32	6,72	2,71	1,20	0,80

Source: own elaboration.

Table 10. Results of experiments for the layout 10x50
and five items stored in three locations

Method of location selection	Average distance [m]		Average order-picking time		Average number of visited locations	Average number of visited picking aisles	Average priority ratio	Average number of locations totally cleared
	S-shape	Return	S-shape	Return				
-	257,56	269,40	8:04	8:24	5,00	4,09	1,00	0,00
TMAL	284,64	291,40	9:22	9:34	8,29	4,69	1,87	1,65
Max priority	386,89	433,36	12:30	13:47	10,00	6,51	2,50	5,00
Min no. aisles	278,86	316,36	9:02	10:05	7,27	2,40	1,24	1,00

Source: own elaboration.

5. Conclusions

In many warehouses the same items can be stored in a few locations. One of the problems to be optimized in that case is the selection of the locations to be visited by the picker. The problem is not easy to solve because many criteria should be optimized simultaneously. The method that can be used in that case has been developed by Dmytrów, the TMAL measure, but optimizing only the number of visited aisles leads to good results, too. The shortest order-picking times were obtained for TMAL, and the minimum number of visited aisles heuristic. For the S-shape routing method the minimum number of visited aisles always performs faster than TMAL, but the latter method can be adjusted by the criteria weights. When the number of items stored in multi-locations was small, the possibility of picking the item from more than one location may lead to the reduction of order-picking time – even when the picker has to visit more locations.

The distance covered by the picker for the layout with a bigger number of shorter aisles was smaller than for the layout with longer aisles. For all the experiments the random storage of items was assumed. For this reason the return routing heuristic was dominated by the S-shape heuristic. Only the proper assignment of fast moving items increases the effectiveness of the return method.

A certain problem with the TMAL measure is the calculation of the distance from the location to the other visited location, as on this step of the method we are not sure which location will be in fact chosen.

The heuristic that minimizes the number of visited aisles is very simple and easy to implement. As it generates quite good values of evaluation functions, it can be recommended as an alternative to the TMAL method.

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