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ANALYSIS OF THE IMPACT OF STORAGE PARAMETERS AND THE SIZE OF ORDERS ON THE CHOICE OF THE METHOD FOR ROUTING ORDER PICKING

The paper presents an analysis of the impact of the number of picking aisles, slots in a rack, the size of pick lists, and the routing method on the performance of the order picking process. In the analysis, the forklift truck's maneuvers such as turns back and turns aside, omitted by some scientists, are considered. Although only random storage assignment is examined in this paper, the possible congestion effect is considered. Experiments were performed by the use of simulations.

Keywords: *logistics, order picking, warehouse management, simulations*

1. Introduction

Order picking can be described as the process of retrieving items from stocking locations in a warehouse to fulfil a set of orders [7, 13]. Orders are usually converted into pick lists with information for the person who collects items about the amount of stock keeping units (SKU) to be picked and the sequence in which the items need to be collected. In this paper, splitting orders into batches is not considered, so both terms: orders and pick lists, are used interchangeably. Order picking is a very laborious process. The order picking costs may reach the level of about 60% of total warehousing costs. A warehouse's efficiency can be improved in several ways and usually begins with determining a new order-pick route.

There are many types of warehouses. For the calculations in this paper, we consider a standard one block rectangular warehouse with the pick-up/drop-off (PD) point

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located in the south-west corner. Only a manual picker-to-part order picking system will be considered. The number of items of the same type and their shape and weight will not be considered in the simulations.

The paper is organized as follows. Section 2 presents a brief literature review. The order picking process is succinctly described in section 3. Next, in section 4 five well known routing heuristics and the optimal algorithm are presented. Section 5 describes the tool used for performing experiments: the Warehouse real-time simulator. The simulations, together with the description of their results, are shown in section 6. The paper is concluded in section 7.

2. Literature review

The problem of the effectiveness of well known heuristics in comparison to the optimal route has been analysed by researchers. Appropriate formulas for order picking times using different routing methods have also been derived. Using this, it is possible to establish when to apply a specific heuristic or derive the optimal solution.

There are known formulas for determining the mean order picking time for different warehouse layouts, routing methods, and storage policies. Kunder and Gudehus [12] have developed formulas for random storage and three routing methods: the S-shape heuristic and two versions of the return heuristic. Jarvis and McDowell [11] expanded the formulas to the case of assigning the most frequently picked items close to the PD point. In [7] equations are presented for the average order picking times when using one of three heuristics: S-shape, midpoint and largest gap. The author compared the results with the times obtained by using the optimal route. De Koster and Van Der Poort in [4] analysed warehouses with a decentralised depot. Using simulations, the authors showed that Hall's formulas can even give over a 25% mean time difference. De Koster's modifications reduced the average error to around 2% (with the maximum value of 7%). Le Duc and De Koster in [13] developed formulas for an ABC storage strategy and return routing heuristic, but they used a slightly different warehouse layout than the standard one block rectangular. A comparison of 6 routing methods for different PD point localisations, warehouse shapes, and numbers of items on pick lists was presented by Petersen [15].

Fijałkowski [5] presents simple formulas for determining order picking times, taking a forklift truck's parameters into consideration. His equations are used for calculations in many papers, e.g. Jacyna and Kłodawski in [9] used Fijałkowski's formulas to compare warehouses with centralized and decentralized PD.

The differences in average order picking times obtained by using formulas and from the simulations in [4] and [13] are disturbing. The results obtained by Petersen

differ from Hall's conclusion, too. As De Koster and Van Der Poort [4] noticed, the formulas are not as precise as simulations, but they give the result rapidly. Another problem is noted by Jarvis and McDowell ([11]). They mentioned that their model does not consider possible congestion effects. When many pickers work simultaneously, they can interact and block each other. This problem was thoroughly studied by Huber ([8]) but it can be easily simulated, too.

From the literature study, it seems that the best way to analyze the impact of warehouse shape and the pick list's size on the efficiency of a routing method is by simulation.

Researchers have also compared heuristic solutions with the optimal route. Hall [7] noticed that when the number of picking aisles is higher than the number of items on the order, then the midpoint and the largest gap heuristics give very good results. When the pick list size is large in comparison to the number of picking aisles, then the S-shape heuristic performs better (the number of items on the pick list has to be at least 3.7–3.9 times higher than the number of picking aisles). Hall did not consider various lengths of picking aisles, so his conclusions need to be verified.

The weak side of Petersen's analysis is a small number of replications used: only 30. De Koster and Van Der Poort ([4]) assumed that order picking times have a normal distribution and showed that the number of replications has to be about 10 000.

None of the authors mentioned above (except for Fijałkowski) took into account such manoeuvres as a forklift's turns back and turns aside in their calculations. Only De Koster and Van Der Poort [4] assumed in one of their experiments that it is time-consuming for a truck (conveyor) to change picking aisles. Consideration of these operations may affect the total order picking time determined using different routing methods by varying degrees.

3. Warehouse processes

The main goal of warehouse processes is the organization of work, which enables high quality customer service at minimum cost. These two criteria are often conflicting, but some organizations give priority to the quality of customer service. A high level of customer service can be attained by fast and correct order picking. The basic structure of the processes in warehouses is shown in Fig. 1. All these processes interact and influence the total order picking time. Other authors distinguish only four main phases of the warehousing process, that is: reception, storage, picking and delivery.

In this paper, the research is limited to the order picking process (more about work organization and optimization in warehouses can be found e.g. in [3]). The main stages of the order picking process are [9]:

- preparation of loading units for order picking,
- picking the appropriate order,
- quantitative control,
- packing and forming transport units,
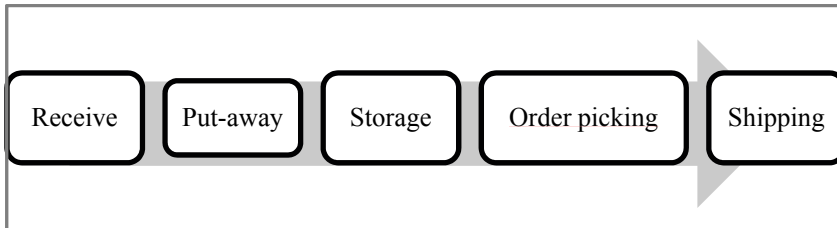- movement to the shipping zone.

Fig. 1. A simplified structure of the processes in the logistics chain. Source: [1], p. 24

Fijałkowski [5] presents the classification of only four basic functions of the order picking process: preparation for download, download, movement, and release. Preparation for download (how to put items from the racks into the preparation area) can be implemented in a static way (picker-to-part systems) or in a dynamic way (automated storage/retrieval systems, AS/RS). Order picking can be performed manually or mechanically (the order picker picks items by hand or using a mechanical device) or automatically (without any physical human participation). Movement, i.e. transitions between the PD point, appropriate storage locations, and back to the PD point, can be one-dimensional (one level of storage) or multidimensional (e.g. high bay warehouses). The release function may be achieved in a centralized or decentralized manner.

4. Methods for routing order picking

One of the simplest order picking heuristics is the S-shape (in some papers called traversal or transversal) method (Fig. 2). Using this routing method, the order picker enters only aisles with items to be picked. After collecting all the items from one picking aisle, the order picker leaves the aisle at a different point to which he entered it. The shape of the picker's route is thus similar to the letter S, hence the name of the method.

The midpoint routing heuristic (Fig. 3) is as simple to implement as the S-shape method. The warehouse is divided into two equal parts and the picker firstly collects items only from the part closest to the PD point. The picker can cross the border only after picking all the items from the first area. Of course, he or she enters only aisles with items to be picked.

Fig. 2. The S-shape routing method. Source: author's elaboration based on [14]

Fig. 3. The midpoint routing method. Source: author's elaboration based on [14]

The return method (Fig. 4) is also very easy for practical use. Using this heuristic, only one main aisle is in use. After entering a picking aisle, the picker collects all the requested items and leaves the aisle through the same entry as he entered it.

Fig. 4. The return routing method. Source: author's elaboration based on [14]

The largest gap heuristic (Fig. 5) is an improved version of the midpoint method. The division of the warehouse into an "upper" and "lower" part is determined separately for each pick list and each picking aisle. The partition is performed according to the largest gap in each aisle. These gaps are determined between two slots with items to be taken or between the slot with the SKU needed and one of the main aisles. The largest gap method usually gives a shorter route than the midpoint method, but its application in practice may cause some problems.
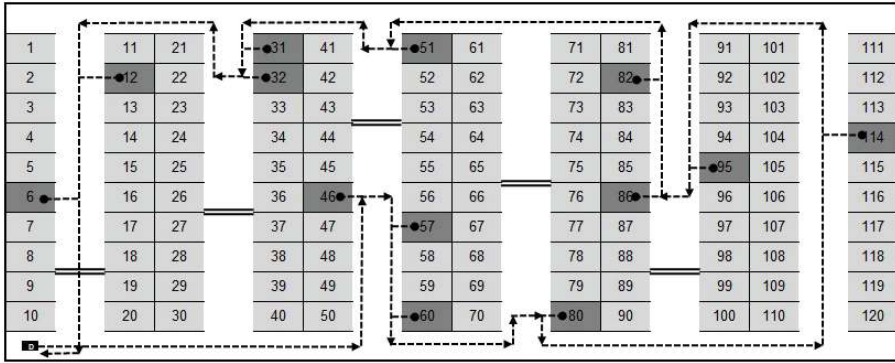
Fig. 5. The largest gap routing method. Source: author's elaboration based on [14]

The combined heuristic (Fig. 6) is a combination of the S-shape and return methods. Here, after collecting all the items from one picking aisle, the order picker always moves to the main aisle closest to him.
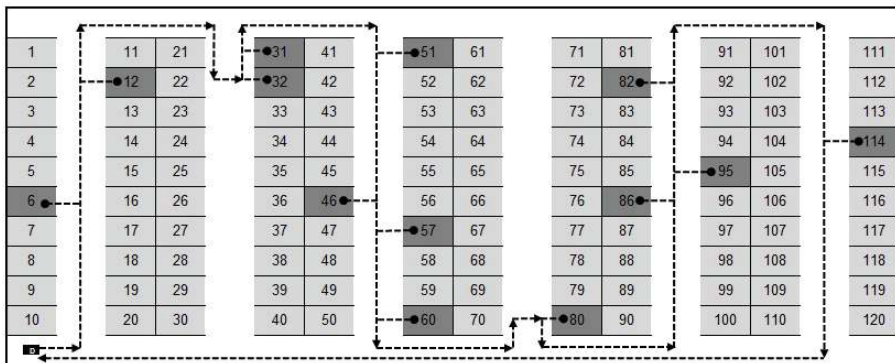
Fig. 6. The combined routing method. Source: author's elaboration based on [14]

The task of determining the shortest order picking route is a slightly modified traveling salesman problem. Ratliff and Rosenthal [16] developed a very fast algorithm for one block rectangular warehouses. The algorithm is based on the graph theo-

ry and was expanded to the case of a third main aisle by Roodbergen and De Koster [17], De Koster being the author of more modifications of this algorithm. The algorithm is very fast, and the computation time depends linearly on the number of picking aisles. An example of an optimal route is shown in Fig. 7.
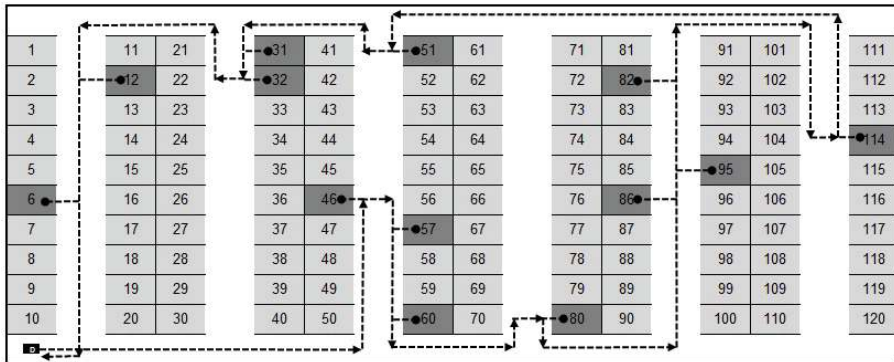

Fig. 7. The optimal routing method. Source: author's elaboration based on [16]

5. The Warehouse real-time simulator

The experiments presented in the next section were performed using the Warehouse real-time simulator. It is a tool based on Microsoft Excel macros. It simulates

Fig. 8. Screenshot from an animation of order picking. Source: author's own work

the order-picking process in one-block rectangular warehouses. The software allows the user to check how the order-picking time depends on both: the assignment of storage locations and one of seven routing methods. The Warehouse real-time simulator allows the user to set up: the number of racks, number of slots in a rack, number of storage levels, number of pickers working simultaneously, number of items on a pick list (pick lists can be randomly generated from a dataset, as well), forklift movement times, routing methods, warehouse working hours, the way in which orders appear, pick probabilities for getting items from each storage level, number of replications, and random seed (this allows the user to repeat the same experiment with other settings). Figure 8 shows a screenshot from an animation of order picking. The author hopes that the Warehouse real-time simulator will be soon published and available for free download.

6. Simulations

For the simulations presented below some assumptions were adopted based on a real Polish distribution center presented by Jakubiak and Tarczyński ([10]):

• Warehouse working hours (when orders are collected) are from 8 am to 4 pm. Forklift trucks will work until the last pick list is completed. The time between two consequent orders is generated from an exponential distribution. The exponential distribution is often used in queuing systems (see e.g. [2]). The average times between two consequent orders in seven time periods are presented in Table 1.

Table 1. Average times between the arrivals of orders (real data)

Time interval	Average time between the arrivals of orders
8:00–9:00	03:31
9:00–10:00	04:15
10:00–11:00	04:01
11:00–12:00	06:59
12:00–14:00	10:12
14:00–15:00	05:01
15:00–16:00	04:05
Whole workday (8:00–16:00)	06:02

Source: author's own work.

• Forklift movement times are taken from Fijałkowski [6] or were determined in the distribution center (Table 2).
• A rack's size and the width of aisles were measured in the distribution center.

• Only random storage assignment is analyzed.
• In a real distribution center there are many picking zones with different layouts. In the simulations only one level of storage is considered.

Table 2. Forklift truck's working time norms

Activity	Symbol	Unit	Time [min]
Acceleration after stop (empty)	AE	full period	0.0300
Acceleration after stop (loaded)	AL		0.0300
Speed (3 km/h) – loaded truck	FL	per 1 m	0.0200
Speed (3 km/h) – empty truck	FE		0.0200
Stop (empty truck)	SE	full period	0.0200
Stop (loaded truck)	SL		0.0360
Turn left (moving forward)	TFL		0.0550
Turn right (moving forward)	TFR		0.0550
Putting a pallet onto the forks	NP	full operation	0.1333
Scanning and putting the good onto a pallet	CP		0.1733
Putting loaded pallet onto s storing field	OP		0.2000
Laminating a pallet, sticking on and printing a label	OFP		0.3533
Moving back (0.8m)	RE	0.8 m	0.0750

Source: author's elaboration based on [6].

The experiments were performed for all combinations of:
• number of picking aisles (10, 11, 12, 13, 14),
• number of slots in a rack (10, 12, 14, 16),
• the size of a pick list (5, 7, 9, 11, 13, 15),
• routing method (optimal, S-shape, midpoint, return, largest gap, combined).

The number of simulations is equal to the number of combinations ($5 \times 4 \times 6 \times 6$ = 720). For each combination, 500 working days with a total number of over 45 000 pick lists were simulated.

Figure 9 shows how the average order picking time is dependent on the number of picking aisles for various methods for routing order picking. The results indicate that the quality of heuristics in comparison to the optimal route does not depend on the number of picking aisles in the warehouse. As the size of the warehouse increases, the order picking time becomes longer. This applies to a similar extent to both: the optimal solution, and the heuristic solutions. Among the heuristic solutions, the best results were obtained for the largest gap method (only from 2.83% to 12.33% worse than the optimal time). The midpoint method, being much simpler to implement, performs only slightly worse (3.30–12.33% slower than optimal).
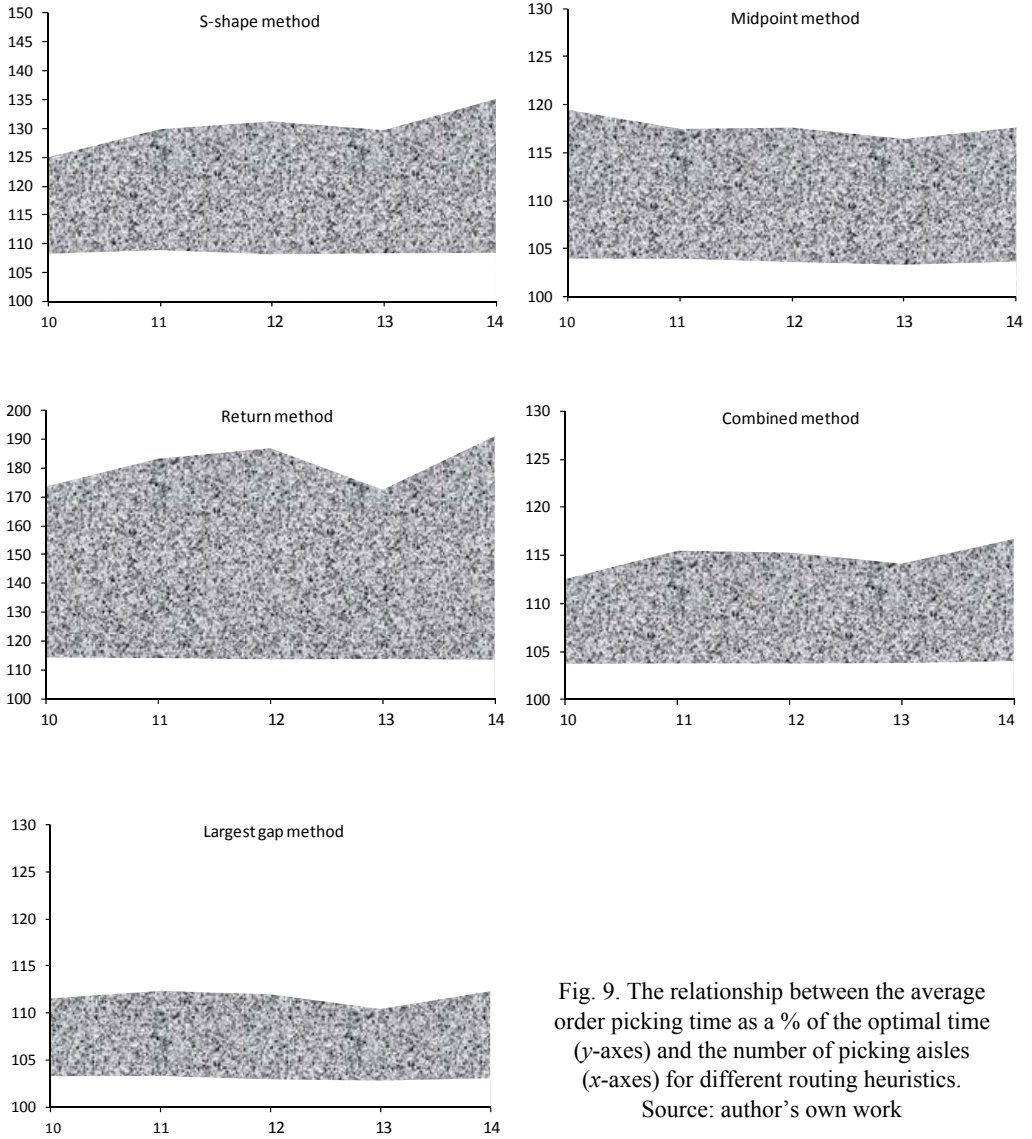
Fig. 9. The relationship between the average
order picking time as a % of the optimal time
(*y*-axes) and the number of picking aisles
(*x*-axes) for different routing heuristics.
Source: author's own work

The worst heuristic is the return method. The average order picking time obtained by using this method was 13.36–90.97% slower than optimal.

Figure 10 shows how the average order picking time depends on the number of slots in a rack for different methods of routing order picking. For most of the heuristics, an increase in the number of racks causes a larger increase in order picking times in comparison to the optimal route. However, this relationship is not as visible for the

two best heuristics: midpoint and largest gap. Their quality does not depend directly on the number of slots in a rack.
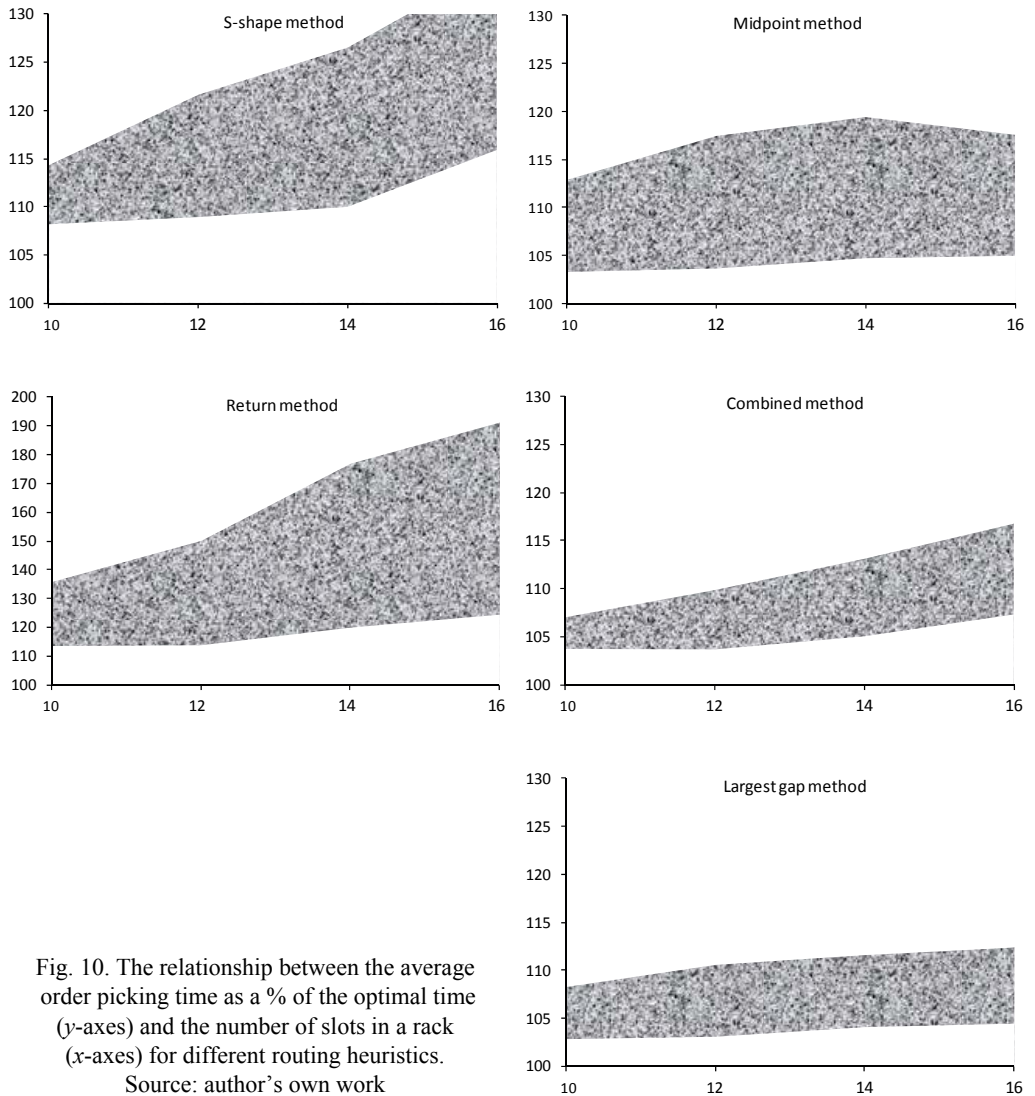
Fig. 10. The relationship between the average order picking time as a % of the optimal time (*y*-axes) and the number of slots in a rack (*x*-axes) for different routing heuristics. Source: author's own work

How the average order picking time depends on the size of pick list for different order picking methods is shown in Fig. 11. For all of the heuristics, an increase in the number of items on the order implies a worsening of the average order picking time in comparison to the time obtained using the optimal route.

The congestion effect is not significant. For all the routing methods, the average blocking time was lower than 0.5% of total forklift working time. This problem may exist to a greater extent when a specific storage policy is implemented.
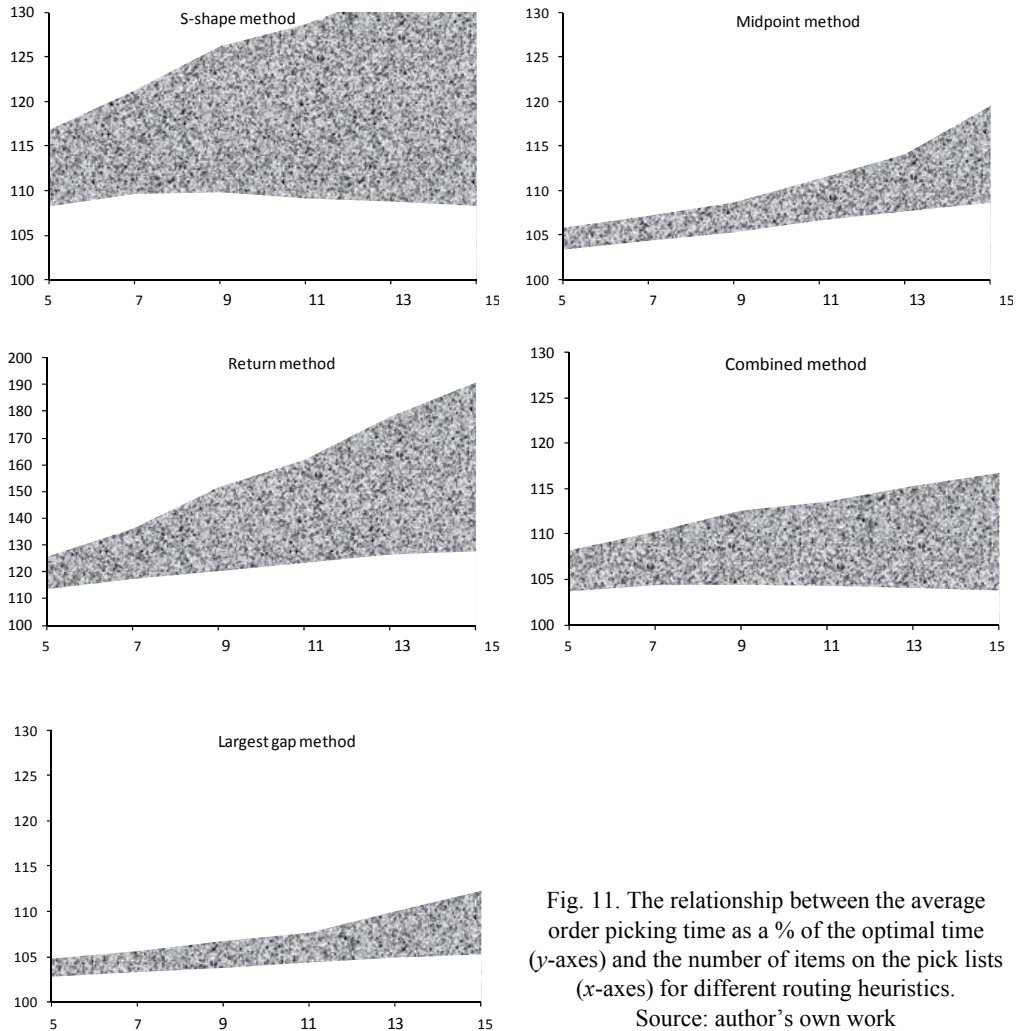

Fig. 11. The relationship between the average order picking time as a % of the optimal time (*y*-axes) and the number of items on the pick lists (*x*-axes) for different routing heuristics.
Source: author's own work

One of the aims of this paper is to compare the average order picking times for two of the most popular, and easiest for practical application, heuristics: midpoint and S-shape. In most cases, the best results are achieved using the midpoint method. The S-shape method becomes attractive only when there is a large number of items on the order list. This is consistent with Hall's conclusion ([7]). Figure 12 shows the average

order picking times obtained for the S-shape heuristic and the midpoint heuristic for pick lists containing 15 items. The midpoint method gains an advantage over the S-shape method as the number of picking aisles increases and the number of items on the pick list decreases. This problem requires a more detailed examination. With this aim in mind, a further 504 simulations were performed.
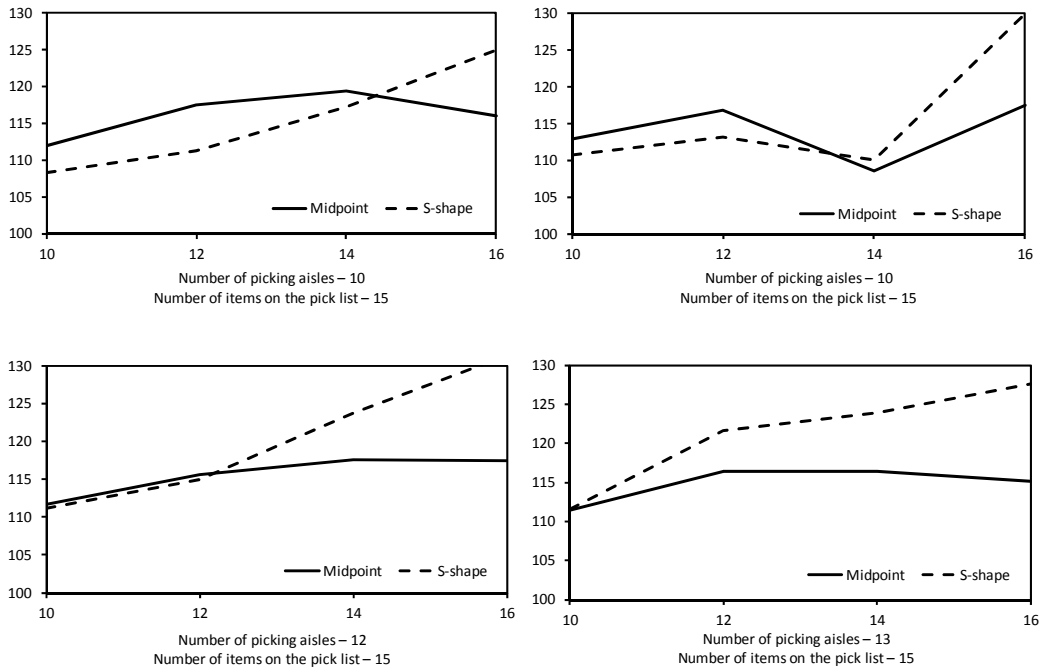

Fig. 12. Average order picking times as a % of optimal time (*y*-axes)
for the midpoint heuristic and the S-shape heuristic (*x*-axes). Source: author's own work

The S-shape heuristic and the midpoint heuristic were compared for different sizes of warehouse and for a variable number of items on the pick lists. It was tested whether the choice between these methods should depend on: the average number of items required from one picking aisle (when completing one pick list) or a factor which expresses how densely items from one order are placed in a warehouse. A graphical illustration of the results of simulation are presented in Figs. 13 and 14.

Based on the results from the simulations, it can be concluded that if the average number of items required from one picking aisle is lower than 1.25, then the midpoint heuristic gives better results. If this value is greater than 1.67, a faster order picking route can be obtained by using the S-shape heuristic.
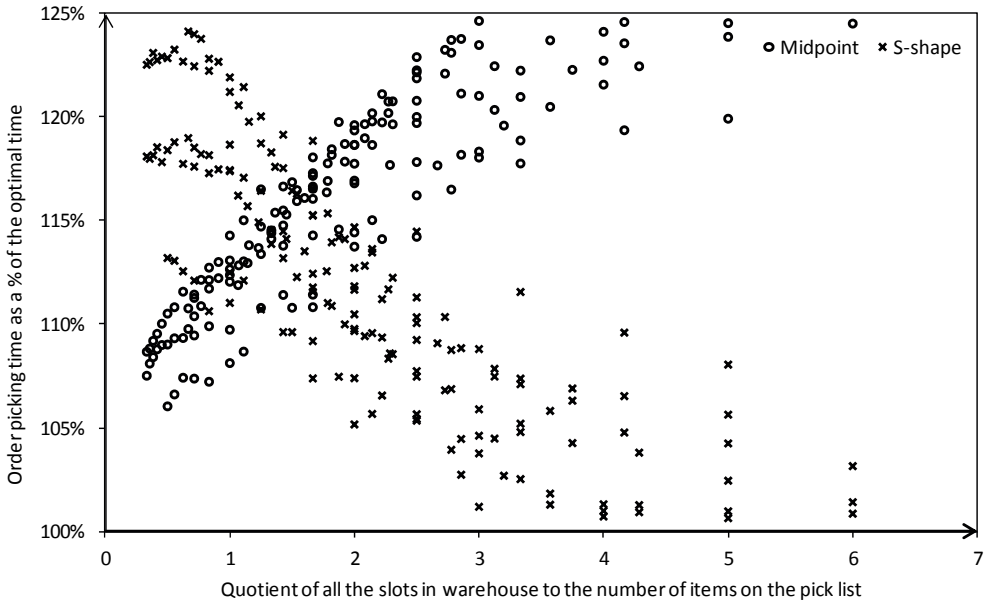
Fig. 13. The relationship between the order picking time and the average number of items to be picked in one picking aisle for the midpoint heuristic and the S-shape heuristic. Source: author's own work
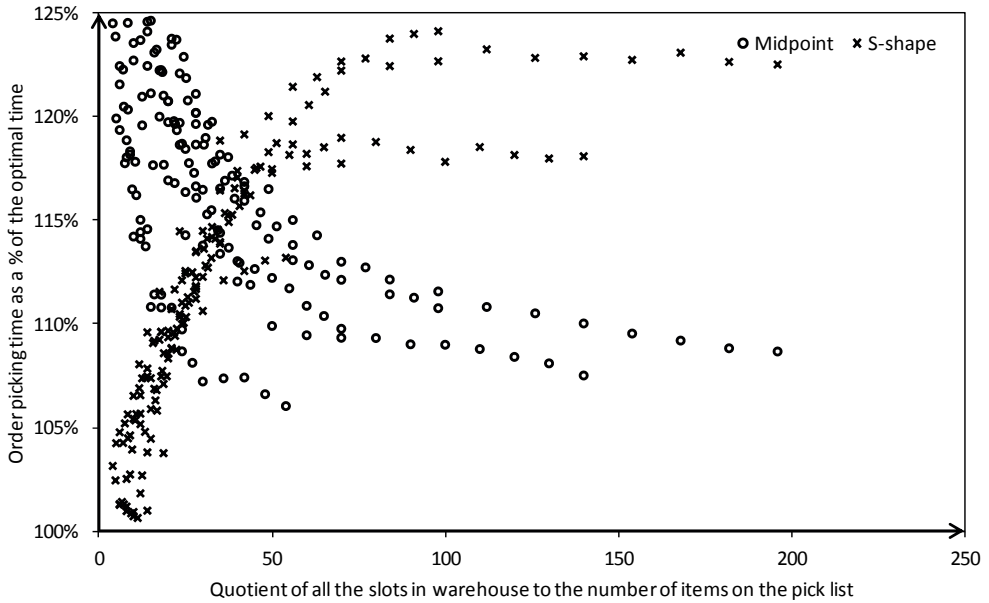

Fig. 14. The relationship between the order picking time and the ratio of the number of slots in the warehouse to the number of items on the pick list for the midpoint heuristic and the S-shape heuristic. Source: author's own work

When the ratio of the number of slots in the warehouse to the number of items on one pick list is less than 24, the S-shape heuristic performs better. If this value is greater than 42, the midpoint heuristic gives the shorter order picking time.

Some problems may be caused by the fairly large ranges in which both routing methods give similar results. This question requires in-depth analysis and will be studied by the author in the future.

7. Conclusions

The difference between average order picking times obtained using heuristics and the optimal solution are usually insignificant. Only the performance of the return method was much worse than the optimal route, and this occurred in all the experiments. The effectiveness of heuristics, in comparison to the optimal solution, decreases very slowly as the following increase: the number of slots in the racks or the number of items on the pick lists. The S-shape heuristic and the midpoint heuristic are very simple to implement in practice. Both of them guarantee quite fast performance in comparison to the optimal route. The S-shape heuristic gives better results than the midpoint heuristic when the number of items on the pick lists is large. The midpoint heuristic performs better when the items to be picked are "not densely" placed in the warehouse.

These conclusions are similar to Hall's [7]. Hall assumed that the order picking time is proportional to the length of the route. The realization of the midpoint heuristic requires an increased number of forklift maneuvers, such as turns back. When maneuvers are more time-consuming, the midpoint heuristic becomes less attractive.

In this paper, only random storage assignment was considered. The congestion effect was not significant in any of the experiments performed. The problem of forklift trucks blocking each other could be more evident when using a specified method of storage assignment.

References

[1] BARTHOLDI III J.J., HACKMAN S.T., *Warehouse and Distribution Science*, Georgia Institute of Technology, Atlanta 2011.
[2] BOCHAROV P.P., D'APICE C., PECHINKIN A.V., SALERNO S., *Queuing Theory*, VSP, Utrecht 2004.
[3] DE KOSTER R., LE DUC T., ROODBERGEN K.J., *Design and control of warehouse order picking. A literature review*, European Journal of Operational Research, 2007, 182 (2), 481–501.
[4] DE KOSTER R., VAN DER POORT E.S., *Routing order pickers in a warehouse. A comparison between optimal and heuristic solutions*, IIE Transactions, 1998, 30, 469–480.

[5] Fijałkowski J., *Storage technology. Selected topics*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 1987 (in Polish).

[6] Fijałkowski J., *Internal transport in logistic systems*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2003 (in Polish).

[7] Hall R.W., *Distance approximations for routing manual pickers in a warehouse*, IIE Transactions, 1993, 25 (4), 76–87.

[8] Huber C., *Throughput Analysis of Manual Order Picking Systems with Congestion Consideration*, KIT Scientific Publishing, Karlsruhe 2011.

[9] Jacyna M., Kłodawski M., *Laboriousness of the order picking process for various methods of item assignment in the picking area*, Prace Naukowe Politechniki Warszawskiej, z. 70, Warszawa 2009 (in Polish).

[10] Jakubiak M., Tarczyński G., *Selection of manual order picking concept in a warehouse by means of simulation tools*, Mathematical Economics, 2012, 8 (15), 47–64.

[11] Jarvis J.M., Mcdowell E.D., *Optimal product layout in an order picking warehouse*, IIE Transactions, 1991, 23 (1), 93–102.

[12] Kunder R., Gudehus T., *Average travel times for one-dimensional order picking*, Zeitschrift für Operations Research, 1975, 19, B53–B72 (in German).

[13] Le Duc T., De Koster R., *Travel distance estimation in a single-block ABC storage strategy warehouse*, [in:] B. Fleischmann, B. Klose (Eds.), *Distribution Logistics. Advanced Solutions to Practical Problems*, Springer, Berlin 2005, 185–202.

[14] Le Duc T., *Design and Control of Efficient Order Picking Processes*, PhD Thesis, Erasmus University, Rotterdam 2005.

[15] Petersen C.G., *An evaluation of order picking routing policies*, International Journal of Operations and Production Management, 1997, 17 (11), 1098–1111.

[16] Ratliff H.D., Rosenthal A.S., *Order-picking in a rectangular warehouse. A solvable case of the traveling salesman problem*, Operations Research, 1983, 31 (3), 515–533.

[17] Roodbergen K.J., De Koster R., *Routing order pickers in a warehouse with a middle aisle*, European Journal of Operational Research, 2001, 133 (1), 32–43.