ROUTE PLANNING MODEL IN ROBOTIC SYSTEM

[1]Robert GIEL, [2]Marcin PLEWA

Wrocław University of Science and Technology, Poland, EU,
[1]robert.giel@pwr.edu.pl, [2]marcin.plewa@pwr.edu.pl

Abstract

The aim of the article is to develop a simulation model that can be used to analyse route selection algorithms for autonomous mobile robots. The developed model can also be used to assess the impact of factors such as the number of robots and the topology of the warehouse on the performance of the entire system. The results of the simulation show the importance of the factors such as: route selection algorithm, number of robots and storage topology for the efficiency of the described transport system. The assessment model presented in this article is the basis for further research into the issue of the impact of individual factors related to the operation of autonomous transport systems on the performance of these systems.

Keywords: Path planning, storage, robots

1. INTRODUCTION

The subject of this article is related to the dynamic development of the Polish e-commerce market. The e-commerce market generates the need for professional handling and order processing in logistics system [1]. Particularly in the preparation of goods for shipment to the customer.

Currently, most of the warehouse processes in the e-commerce industry are implemented in accordance with the "person-to-goods" principle. According to this principle, the person responsible for collecting the goods moves between the storage racks. It has been proven that this way of handling the process is inefficient, mainly due to large time losses by employees (time needed to reach the rack, searching for the right goods, picking up the goods, returning to the packing station). The disadvantage of this approach is also the sub-optimal use of storage space (the need to ensure sufficient space between storage racks for a forklift truck). An alternative to the above-mentioned principle is the implementation of a system that uses the "goods-to-person" principle, according to which the employee only devotes time to properly pack the goods and prepare them for shipment [2]. Such activities can be implemented thanks to a significant degree of automation of warehouse processes and in particular with the use of intelligent transport systems [3].

The precursor of the commercial implementation of the above-mentioned principle was the Amazon online store, which started using mobile robots transporting shelves in 2012, manufactured by KIVA (Amazon Robotics since 2015). Currently, Amazon uses approx. 30 thousand robots, mainly in warehouses in the USA. Amazon uses the technology created by KIVA exclusively for your needs. After the takeover by Amazon, KIVA ceased any activity aimed at selling its robots. Amazon's takeover of almost the entire market of mobile robot suppliers has sparked the interest of other companies that are trying to deliver their own solutions.

One of the major problems associated with the design of this type of autonomous systems is the problem associated with the selection of appropriate algorithms to control the movement of robots. The solution to this problem is closely related to the method of determining the appropriate number of robots necessary to achieve the required system performance [4,5].

The aim of the article is to develop a simulation model that can be used to analyse route selection algorithms for autonomous mobile mobiles. The developed model can also be used to assess the impact of factors such as the number of robots and the topology of the warehouse on the performance of the entire system. The presented results provide an introduction to further research into the issue of the impact of individual factors related to the operation of autonomous transport systems on the performance of these systems.

2. MODEL DESCRIPTION

This part of the article describes a simplified schematic of the simulation model, which can be used to assess autonomous transport systems based on robots moving along routes determined by a square grid of connected points. The developed model consists of consecutive algorithms (**Figure 1**).

The first algorithm *(Defining a warehouse topology)* creates a square grid of points based on the length and width of the warehouse. The number of points depends on the fixed distance between the points. In the next step, the points are combined with each other. Connections are created between points that are next to each other from the top, bottom, left and right.

After creating the grid, storage racks are inserted at selected points, which will be carried by autonomous transport robots.

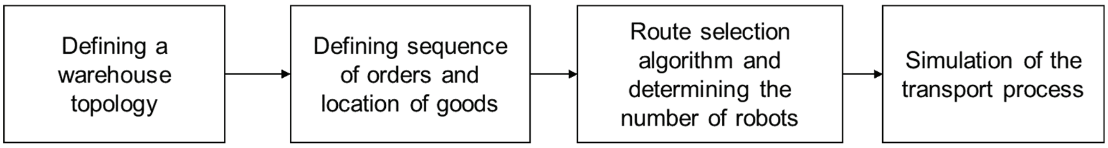

Figure 1 Autonomous transport system based on robots moving along routes determined by a square grid of connected points evaluation model

The next step (*Defining sequence of orders and location of goods*) concerns the method of entering and queuing orders, which are transferred to robots in the modelled system.

In the third step (*Route selection algorithm and determining the number of robots*), the number of robots used to operate the system and route selection algorithm are determined. Robots only move in straight lines and can rotate around their own axis. In the model, delivery orders are made according to the following diagram (**Figure 2**). As can be seen in the drawing below, the order consists of three stages performed by the robot: access to the rack, transport of the rack to the packing point and return with the rack to the designated place.

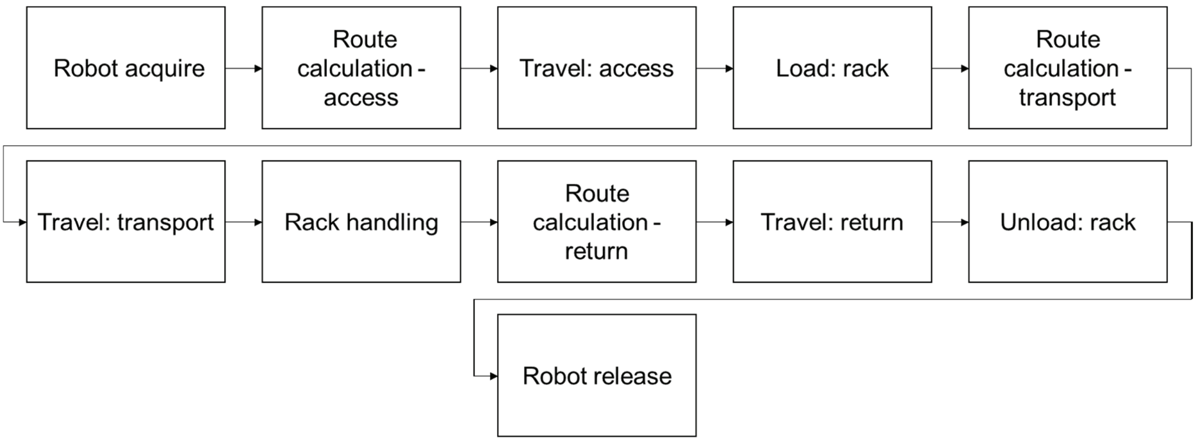

Figure 2 Single order algorithm

One of the ways to increase the efficiency of this type of systems, understood as the number of serviced racks in a given time, is to increase the number of robots that implement the process. The consequence of such action may be an increase in the number of interactions between robots. Interaction is understood here as a meeting of two robots during the transport process. The result of such a meeting is stopping the robot (or several robots) and waiting for the road to be released.

The last step (*Simulation of the transport process*) is a simulation that checks the system performance in a given scenario. Operational indicators are also analysed. It allows to properly interpret the obtained results, such as: the ratio of the distance travelled without a rack to the total distance travelled. This is the stage in which the impact of previous assumptions on system performance is examined. This applies to topology, the number of robots, the method of queuing and transferring orders to robots and route selection algorithms.

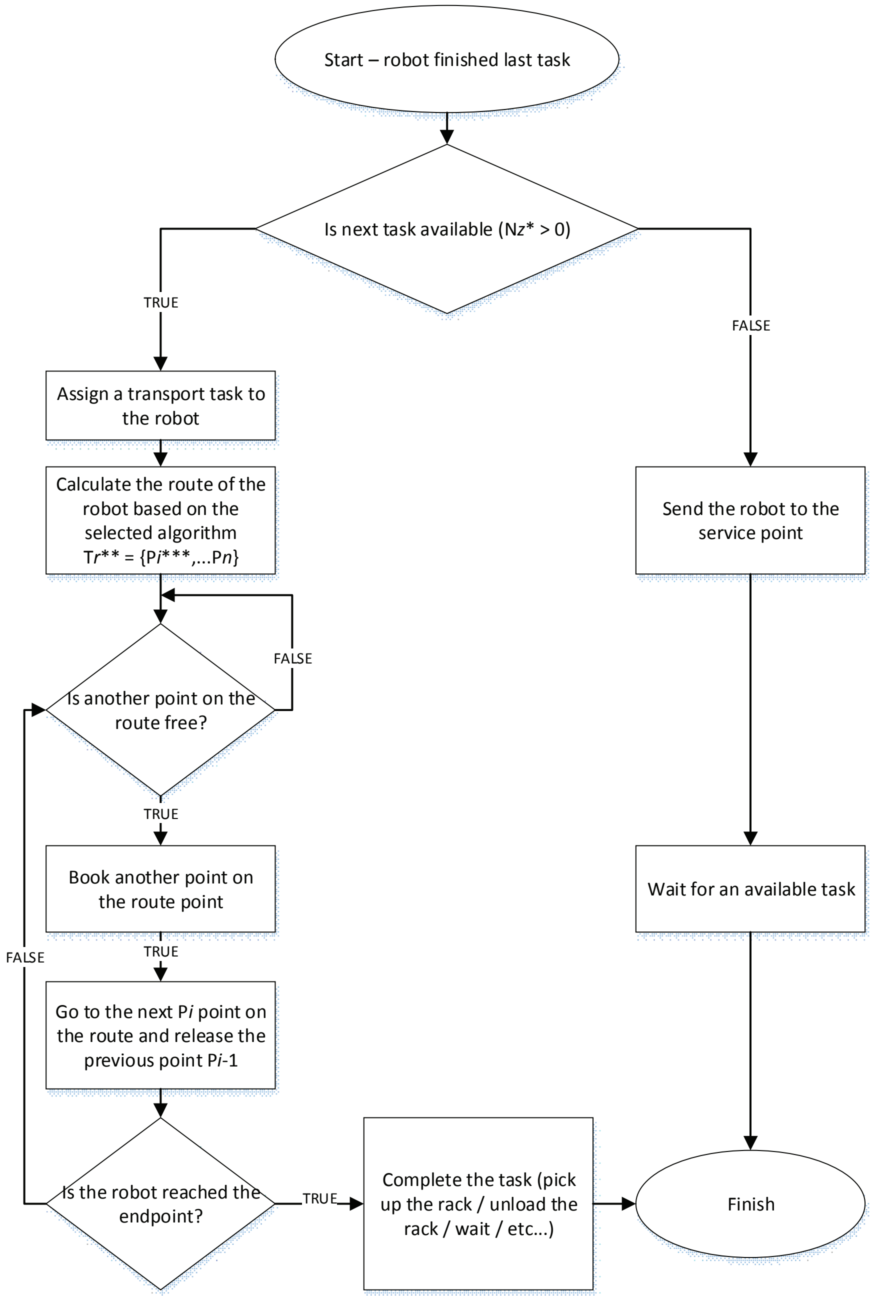

Figure 3 Simulation model algorithm

* Nz - task list;
** T*r* - the route between two graph edges;
*** P*i* - *i*-th point on the robot route.

The simulation model was created in the FlexSim program. This software is widely used to model material flows in logistic systems [7,8,9,10]. The developed model contains ten algorithms in total. Four of them are used to compute routes between points and to perform tasks related to loading and unloading of the racks. The other algorithms are responsible for managing other activities performed by robots (sending robots to the charging stations when there are no new transport tasks, etc.). The last algorithm is responsible for creating new transport tasks (using lists or time intervals in a random order). The general description of the model is shown on the **Figure 3**. The model has an undirected graph character. The structure of the net on which robots move can be freely change by the decision maker.

The assumptions and results of the obtained experiments are presented in the third chapter.

3. EXPERIMENTS RESULTS

The assumptions to the model adopted during the experiments are described below.

In the developed model, it was assumed that the racks are arranged in rows. There are transport routes between the rows. Racks cannot be inserted at the extreme points of the grid. These points are intended for transport routes

Two storage systems were tested. The presented article defines a reference magazine for 200 storage racks. The comparison of the magazine in the vertical (**Figure 4**) and horizontal (**Figure 5**) is shown in the table below (**Table 1**).

Table 1 Comparison of warehouse size

	Length [m]	Wide [m]	Warehouse area [m^2]	The number of racks [units]
Horizontal	16	22	352	200
Vertical	31	12	372	200

The obtained results indicate that to use the same number of storage racks in the case of a horizontal warehouse system, it is necessary to allocate an additional 20 square meters of space in comparison with the horizontal system.

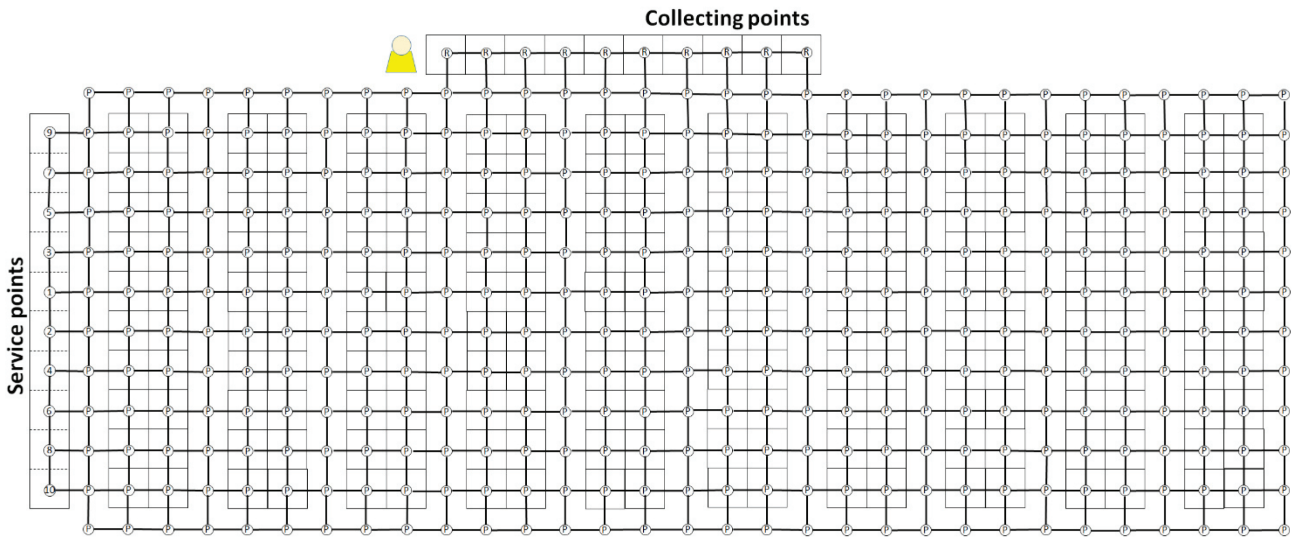

Figure 4 Warehouse visualization in a horizontal layout

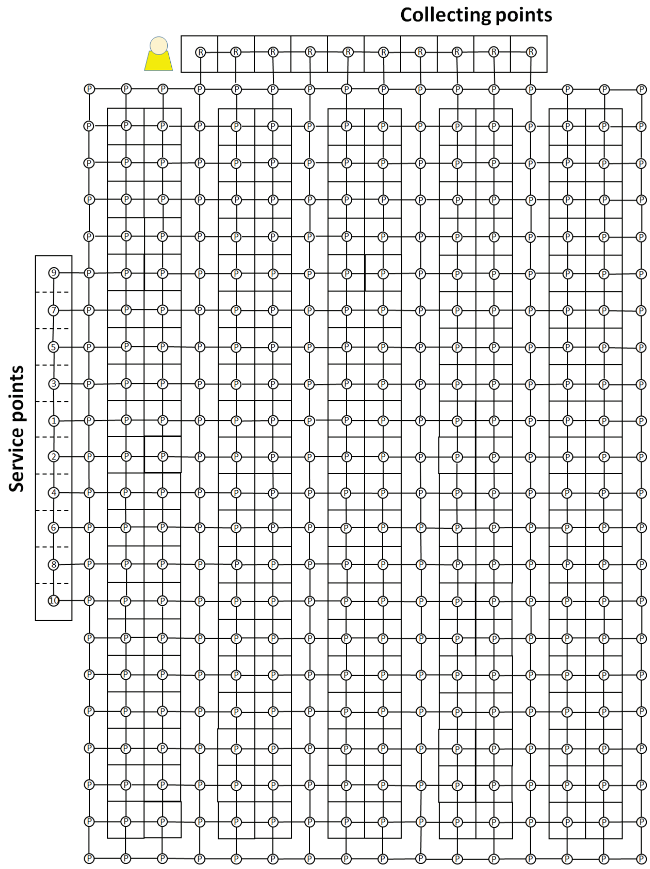

Figure 5 Warehouse visualization in a vertical layout

In the next step, the method of queuing and transferring orders to robots was established. The developed model assumes that orders are queued in accordance with the FIFO principle and subsequent orders are transferred to the first free robots. In the performed study, orders were generated (column and row corresponding to the position of the storage rack) in accordance with the even distribution. Then the orders were placed in the table from which they were collected by the first free transporting robots. The conducted experiments are an analysis of the transport of storage racks to the packaging point, with a fixed schedule of orders, within 20 minutes.

In the third step, algorithms for route selection for robots were determined. The model assumes that the rack transport will be carried out using the left-hand rule. This action was supposed to reduce the number of interactions between robots. For travel to the point containing the storage rack, it is possible to choose one of two algorithms: BFS and the rule of the left hand [6]. Both algorithms have been widely described in the literature. The importance of choosing the right route planning algorithm for a robot moving without a storage rack will be the subject of further considerations in this article. The assumed average speed of the robots is v = 0.5 m/s.

In case the robots meet face-to-face, they expect 20 seconds, their trajectory is changing. If it is possible, the robot rotates to the right, goes one space forward and performs a counter clockwise rotation, drives the next field forward and then rotates once again to the left, passes the next field forward and rotates to the right. Robots do the same at the same time (**Figure 6**). In the developed model, robots moving in accordance with the BFS algorithm can move under storage racks.

In the case of using the left-hand rule to determine the way of robots, interactions between robots do not occur, however, robots cannot use the possibility of travelling under storage racks. In the case of the BFS algorithm, the frequency of interaction depends on the number of robots and the structure of the warehouse. In this work, we tested the impact of the route planning algorithm, the number of robots and the structure of the warehouse on the achieved system performance. If BFS is used, the average length of the route to the rack will be much shorter, while the number of interactions will increase.

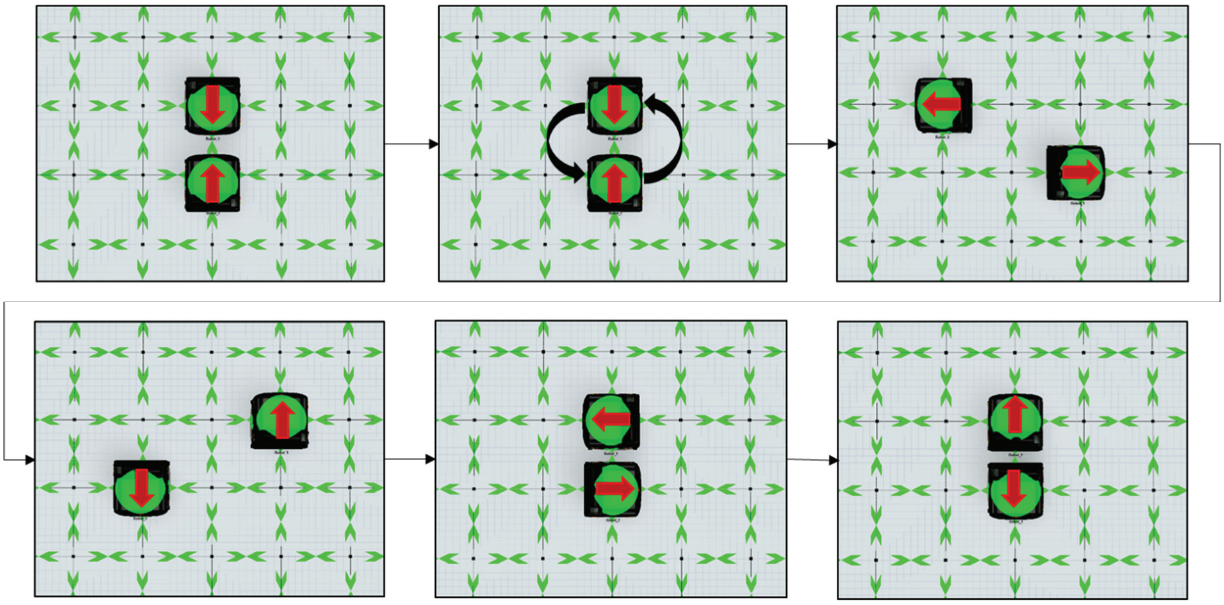

Figure 6 Collision removal algorithm

In subsequent scenarios, the number of robots changed (increment by n = 1).

The simulation results are presented in the graph below (**Figure 7**). Objectively better results were obtained by the BFS algorithm. This means that the choice of the variant with a shorter route was better than the variant without collision. Another interesting observation concerns on average higher results obtained for the horizontal system in the case of a lower number of robots, up to 5-6 pieces (in the case of both algorithms). The observed dependence changes as a function of the number of robots.

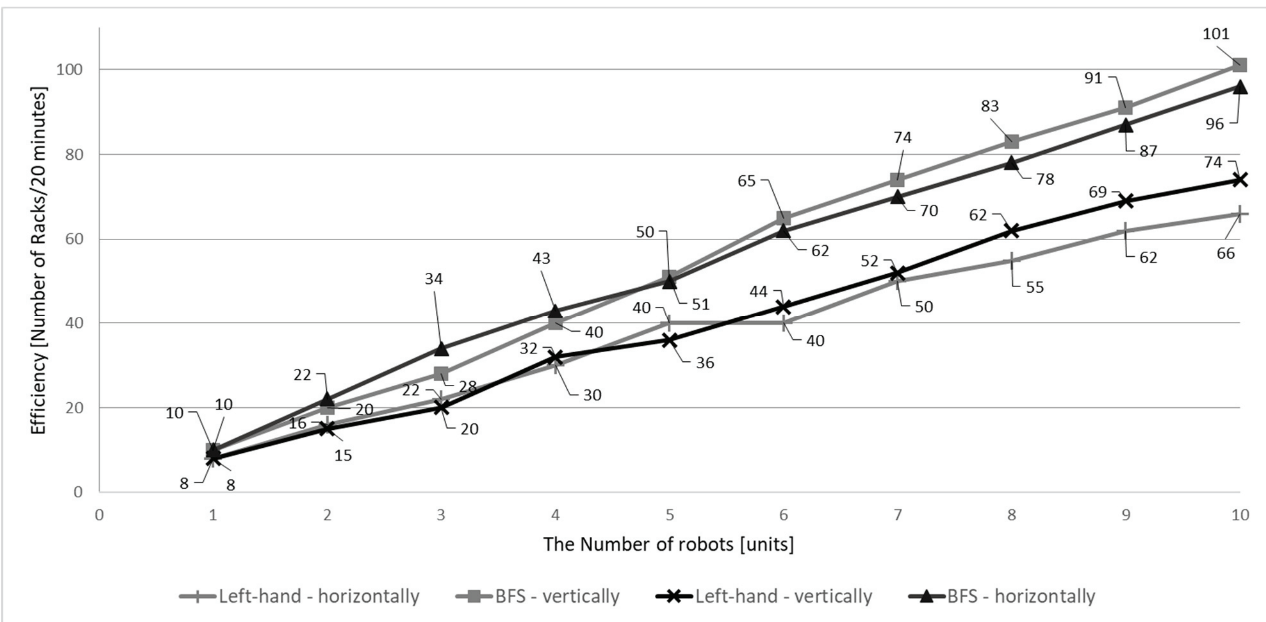

Figure 7 Efficiency in the function of the number of robots and the algorithm used to select the route

Further analysis concerned the average number of meters driven by robots depending on the chosen algorithm (**Table 2**) for ten robots.

Table 2 Comparison of the average distance travelled in the chosen variant

	Average [m]	Standard deviation
BFS - horizontal	984	33,38
Left-hand - horizontal	985	32,93
BFS - vertical	966	27,13
Left-hand - vertical	1031	25,82

Based on the obtained results, it can be observed that the vertical system is characterized by a more even workload of robots. While the average number of meters travelled by each robot is similar in every topology and algorithm, the ratio of the number of meters travelled with the rack to the total number of meters travelled is significantly changed (**Figure 8**). Vehicles using the left hand rule algorithm moved on average about 26 % more time without a rack. This directly affects the performance of the tested system.

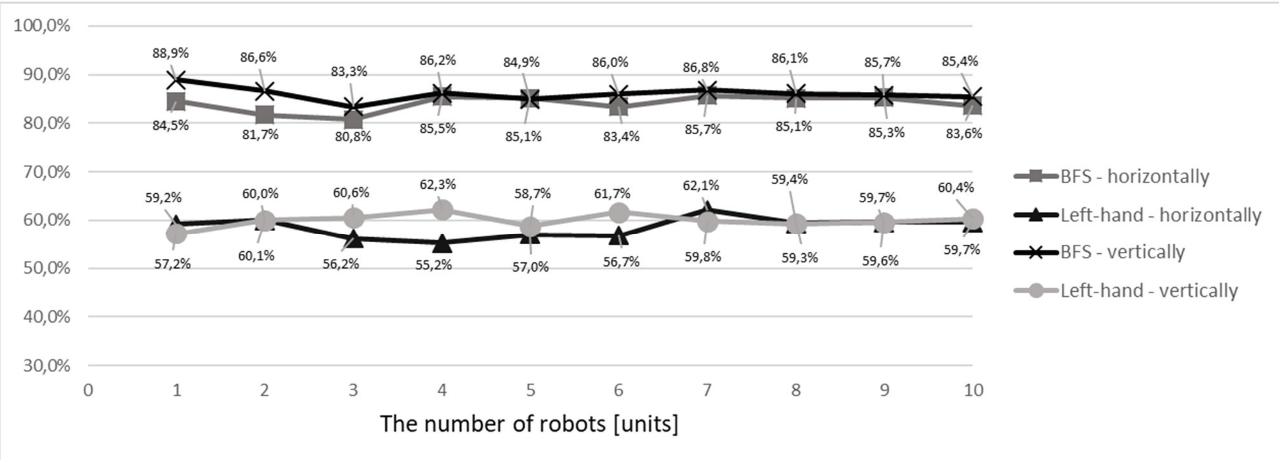

Figure 8 The ratio of the number of meters travelled with the rack to the total number of meters travelled in the function of the number of robots and the algorithm used to select the route

4. CONCLUSION

The results of the simulation show the importance of the factors such as: route selection algorithm, number of robots and storage topology for the efficiency of the described transport system. The assessment model presented in this article is the basis for further research on the factors relevant to the evaluation of such systems.

It is planned to conduct research on the impact of order scheduling on productivity growth. The next stage will be the development of the reliability model of individual system components and multi-criteria analysis of the results.

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