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SOLVING THE BOTTLENECK PROBLEM IN A WAREHOUSE USING SIMULATIONS

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***Abstract*:** The uneven workload distribution and working time utilisation create a bottleneck, leading to inefficient utilisation of capacity and increased costs. A bottleneck is a limiting and risk factor for any business entity. In the case of a distribution warehouse, the bottleneck limits its ability to meet the requirements for sending an order within the required time limit. Delays at any phase of a distribution process may result in non-compliance with customer requirements. In solving capacity problems and bottlenecks elimination, computer simulations and optimisation are often used. The article presents a basic simulation analysis of workload distribution and work times, useful for logistics companies, thus for the area of human and financial resources. In the article, the use of simulations in the ExtendSim9 program to eliminate the bottleneck is discussed. The bottleneck is solved by experiments on a simulation model when optimal workers assignment to individual workplaces of the warehouse is sought. The two final proposals for workers allocation, with the current and increased number of workers, are compared in workforce utilisation and system stability. The simulation method allows verification of the proposals' impacts in advance and practically with no financial costs.

1 Introduction

The efficiency of activities in a distribution warehouse depends on several factors. The organisation of storage space, the layout of shelves and management of workforce and workflow are among the most important. The process of ensuring the shipment, from receiving the order, determining its priority, packaging, and picking, must be managed within the required time limit. Delays at any stage may result in non-compliance with the delivery deadline. The issue of warehouse optimisation is solved in science papers from different points of view. Warehouse layout and the picking performance were solved in many of them. For instance, Amorim-Lopes et al. [1] presented a three-step methodology to analyse and experiment with layout and storage assignment policies to improve the picking performance.

Similarly, [2] studied the optimal layout design for block stacking. Minimising the travel distance of a picking tour is often considered an imperative factor in improving warehouse operation efficiency. The paper by [3] concentrated on the performance of the genetic algorithm method and its comparison to other routing strategies such as heuristics, the experienced warehouse picker and the brute-force algorithm under given assumptions. Possibilities of optimisation the stocks were pointed out in [4]. Mirčetić et al. [5] focused on the problem of forklifts engagement in warehouse loading operations. The methodology for carton set optimisation in e-commerce warehouses was proposed and evaluated by [6]. Their carton set optimisation approach can improve the shipping cost and carton utilisation, and so considerably improve the carbon footprint of the operations. An increased number of e-commerce companies implement the unmanned smart warehouses. In order to reduce the demand response time in this smart warehouse, a novel picking strategy was designed by [7] to firstly split the orders, and then assign the partial orders to different pickers. The paper by [8] discussed the optimisation of warehouse management in the assembly and distribution company, which was made using particular methods of multi-criteria evaluation of variants. Using the data envelopment analysis, the performance of a logistic company with twelve warehouses was evaluated in [9].

Order picking is one of the most challenging activities in terms of time, labour, and cost for most warehouses [10]. Mainly e-commerce warehouses face ever smaller orders that must be delivered ever faster, often within 24 hours. That puts pressure on the order picking process as the orders pickers' workload becomes higher and higher and leads to congestion in the warehouse [11]. Firms need to focus on many factors to achieve their goals such minimising costs, profit maximisation and increasing system efficiency. One of the significant factors impacting the productivity of warehouses is workforce. Besides the correct selection of employees, their motivation and qualifications, also correct assignment of employees to workplaces and a fair distribution of work among the employees is important. Personnel scheduling has a significant influence not only on the warehouse productivity but also on the development of employee competencies [12]. Ernst et al. [13] considered an employee scheduling problem arising in service industries with flexible employee availability and flexible demand. In the literature review [14], new trends and approaches were presented for the personnel scheduling problems. Similarly, authors of [15] reviewed rostering problems in specific application areas and the models and algorithms that had been reported in the literature for their solution.

It is important to state that many software tools are developed for staff scheduling, often based on mathematical models using efficient optimal or heuristic algorithms. Masoud [16] developed a simulation-based optimisation framework for labour management to optimise labour allocation. Andersson [17] presented a simulation-optimisation system for personnel scheduling in which the multi-objective evolutionary algorithm NSGA-II had been implemented. Among the software tools, ExtendSim is often used for simulation and optimisation [18]. In the literature, there are presented many researches and real-word studies about ExtendSim application. For example, using ExtendSim to optimise the delivery process is presented in [19], to streamline production logistics in [20], to optimise wastes flow in [21] and assess the meat processing and cutting production in [22]. Also, optimising the command and control process based on ExtendSim was researched by [23] and machinery allocation in the container terminal by [24]. In the nonindustrial area, as an example can be mention [25], which used CPLEX and ExtendSim to solve the stochastic optimisation model for Emergency Department.

The aim of the paper is optimisation of the workforce allocation in the warehouse. Simulation and optimisation are performed by software tool ExtendSim9. The simulations will verify alternatives for assigning workers to the picking and packing workplace to eliminate the existing bottleneck and uneven workload.

2 Materials and Methods

2.1 Case study description

The distribution warehouse of the internet storage with nutritional supplements is operated as an e-shop without stone shops. Customers order goods through the company's website. The store delivers the goods within 24 hours, if the order was placed within the specified time limit. If later, then the shipment is delivered within 2 days. Approximately 80% of orders go to export. The average number of orders received is 2 600 to 2 800 per day. Table 1 shows the time and number of received orders from 15.01.2020, when 2 673 orders were received. Picking starts at 6:00 and lasts until 18:00. From the overview in Table1, it is evident that most orders come for picking at 6:00, but this does not mean that customers sent their order at this time. All orders that arrive after the 24-hour delivery time limit are carried over to the next day and packed in the morning at the beginning of the shift.

Table 1 Time and number of orders received for individual transport companies

	Transport company /Number of orders						
Time	Cargus	GLS Hr	Zásielkovňa	PPL	GLS HU	Post	DHL
6:00	236	42	83	73	116	95	76
7:00	7	6	10	8	11	7	6
8:00	37	10	18	14	18	14	13
9:00	58	17	26	21	34	19	19
10:00	67	22	31	37	38	30	27
11:00	73	27	43	43	44	39	34
12:00	87	32	46	46	57	37	41
13:00	17	6	54	55	63	51	56
14:00					69	54	51
15:00					26	39	62
16:00					12	21	20
17:00						6	16

Picking up goods in the warehouse is done manually using human force. Orders are packed according to priority. The highest priority is given to orders that belong to the transport company that leaves the warehouse first. The company uses services of seven transport companies for delivery. Transport companies and departure times for individual transport companies are listed in Table 2.

Table 2 Departure times for individual transport companies

Transport company	Deadline for packing all packages
Cargus	13:50
GLS HR	13:50
Zásielkovňa	14:20
PPL	14:50
GLS HU	17:20
Post	17:50
DHL	18:00

2.2 Problem definition and method of solution

Observations have shown that picking and packing workers are unevenly distributed, causing significant downtime. The high number of pickers and the low number of packaging workers will cause them not to catch up to pack orders, and the conveyor will become clogged. Therefore, the pickers will not send another order and will have to wait until the space on the conveyor becomes free. On the contrary, the high number of people at the packaging lines and the low number of picker will cause few crates to come on the conveyor and thus workers will have to wait for the order, which causes considerable downtime, which threatens delivery to the customer within 24 hours of ordering.

The solution of this problem is sought by using a simulation model in the ExtenSim9 program, which simulates the arrival of an order for picking, its picking and the arrival to packing lines. Alternatives to the allocation of workers to the picking and packing workplace to eliminate the existing bottleneck and uneven workload will be experimentally verified by simulations.

2.3 Creating a simulation model in ExtendSim9

The simulation model is created based on data from the analysis of the order picking process. The basis for the simulation model is a scheme of the simulation model showing chronologically the sequence of activities. The intervals and the number of incoming orders per day were determined by observation and measurement. Subsequently, the time of picking up of one order and the time required for its packaging were measured. The scheme of the simulation model is shown in Figure 1., other input data related to the process of picking orders are in Table3.

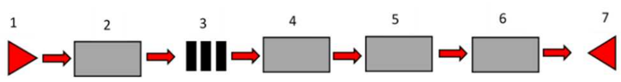

Figure 1 Scheme of simulation model
1. received orders, 2. priority assignment to orders, 3. row, 4. product pickup, 5. product transfer, 6. packing, 7. dispatch

Table 3 Input data for the simulation model

Workplace	Time of process (min.)			Conveyor capacity (crates)	Emploee
	Min.	Max.	Likelist		
Picking	2.5	5.5	4.0		28
Transport	0.6			40	
Packing	2.5	4.0	3.3		

Based on the scheme, a simulation model is created in the environment of the simulation program ExtendSim9 (Figure 2). Parameters for the simulation are entered based on measured values. The simulation time is 720 minutes and represents a 12-hour work shift. The model is shown in Figure 2, and the individual blocks of the model are marked with a number in the figure, while the description of their function is as follows:

1. "Create" blocks, each of which represents the transport company to which the orders belong. The blocks generate orders that arrive to the system at time intervals specified in Table 1.
2. The "Set" blocks assign priority to each order. Prioritisation is done in descending order.
3. The "Select Item In" block is used to combine input request streams into one stream.
4. The "Queue" block represents the stacker at Picking, where orders waiting to be processed are accumulated. The "Queue" block setting is by priority system.
5. The first block "Activity" in the model represents Picking, where the products are picked up from the warehouse according to the order. The time to pick up one order here is at least 2.5 minutes, at most 5.5 minutes and most often 4 minutes.
6. The block "transport" represents the movement of the order in the crate on the conveyor, where the movement time is 0.6 minutes, the capacity of the conveyor is 40 crates.
7. The second block "Activity" represents the packaging, where the products picked up from the "Picking" on the conveyor come. The time settings are as follows: at least 2.5 minutes, at most 4 minutes and most often 3.3 minutes.
8. The "Select Item Out" block is used to divide one input request stream into any number of output streams.
9. Requests leave the system via the "Exit" blocks. The simulation model contains seven such blocks representing transport companies.
10. The last block "Plotter Discrete Event" plots graphs of the simulation process from the input values.

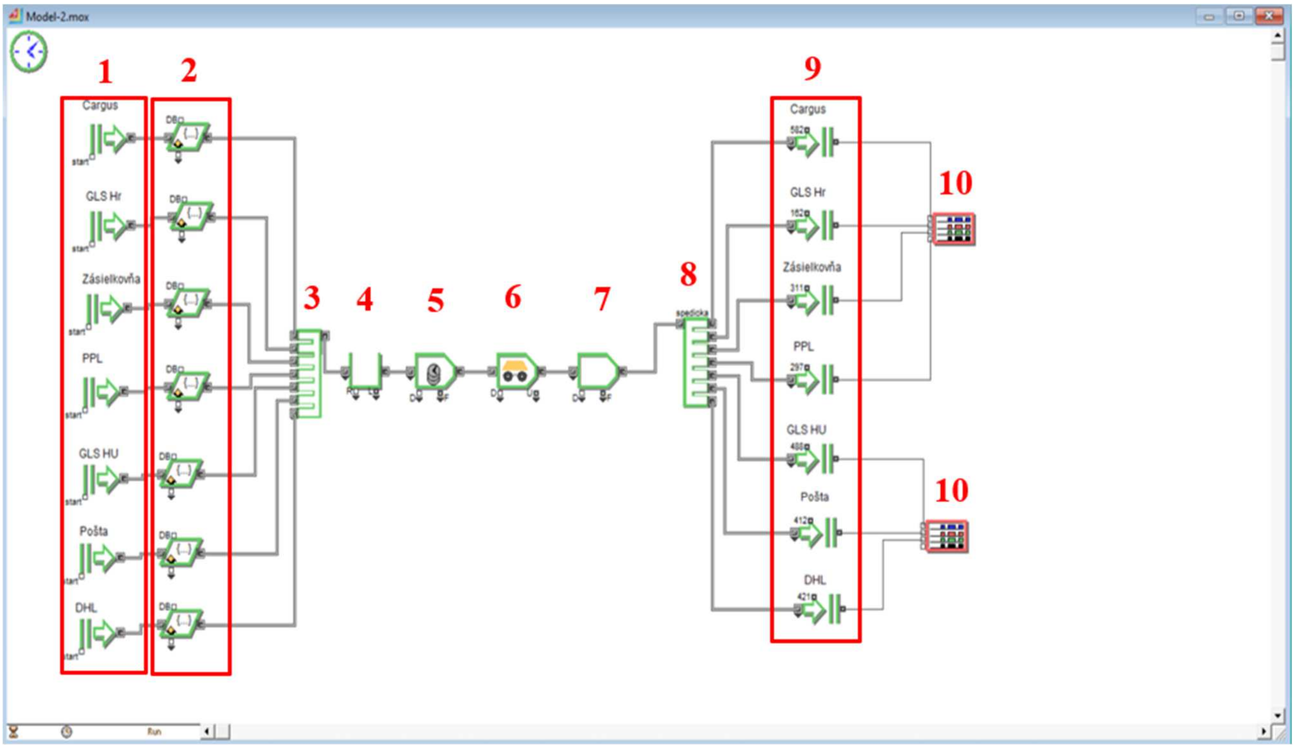

Figure 2 Simulation model in ExtendSim9 program

3 Results and discussion

The simulation model is applied to experimentally verify the operation of the warehouse and optimise the schedule of activities for the workforce. Two proposals for the organisation of work are verified experimentally. Proposal number 1 considers the current number of employees and experimentally redistributes the employees at both workplaces in order to find the optimal distribution of the workforce. Proposal number 2 envisages an increased number of workers to reduce the system's high workload and tension. Also, in proposal number 2, the schedules of the increased number of employees are experimentally verified in order to achieve an optimal workload utilisation of approximately 80%. This would reduce the risk of bottlenecks and failure of processes.

3.1 Proposal No. 1 with the available number of employees

The first proposal simulates a system with an available number of employees, representing 28 employees per one shift. The model is first necessary to enter the measured values for the individual "Activity" blocks. In the first "Activity" block, which represents Picking, we set the shortest time to 2.5 minutes, the longest time to 5.5 minutes and the most likely time to 4 minutes. The second "Activity" block represents the packaging lines, where the time settings are as follows: shortest: 2.5 minutes, longest: 4 minutes and the most likely time to 3.3 minutes. In the "Transport" block, a value of 0.6 minutes for the move time is entered, representing the time required to move the crate from Picking to the packing line. Finally, it is necessary to enter the number of employees in the individual "Activity" blocks. The utilisation of "Activity" blocks is shown in Figure 3.

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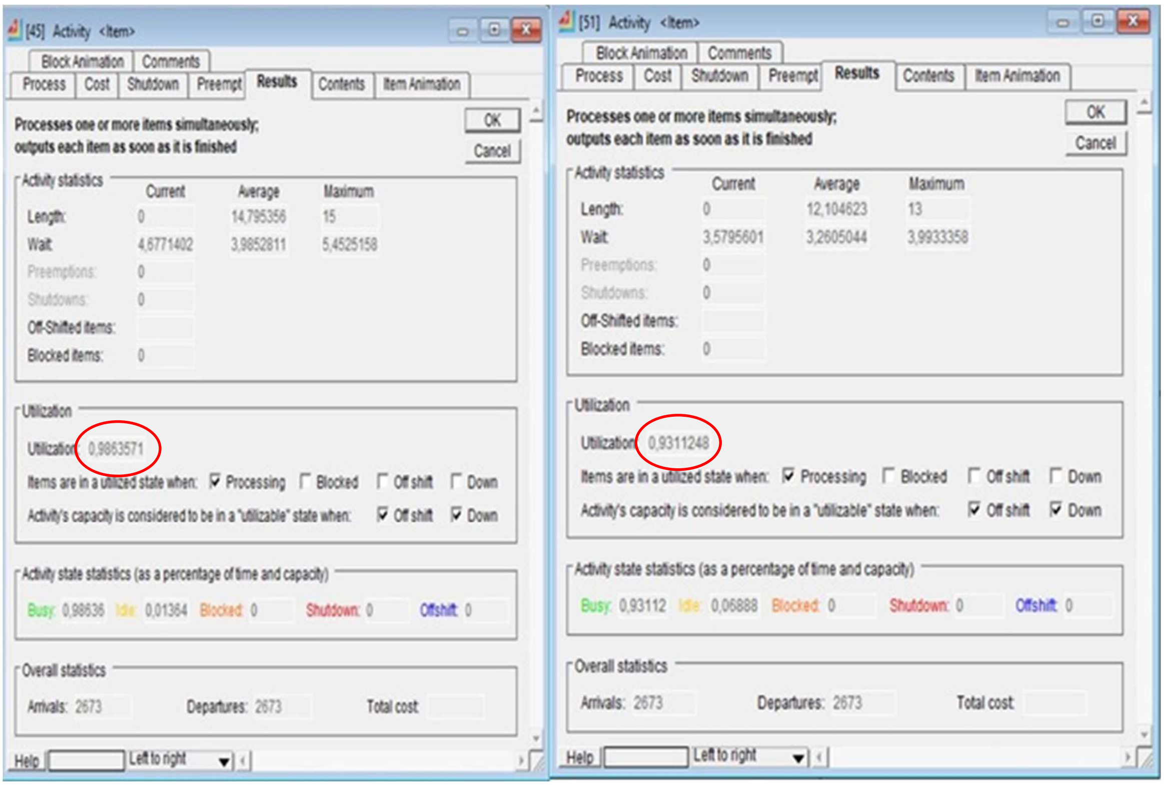

Figure 3 Use of activity-Picking and packing blocks

Figure 4 and Figure 5 display the course of the simulation in proposal 1. In the figures, order packing times for individual transport companies are expressed by colour curves. The vertical axis expresses the number of processed orders. The graphs show that all orders received were packaged but just before the time limit.

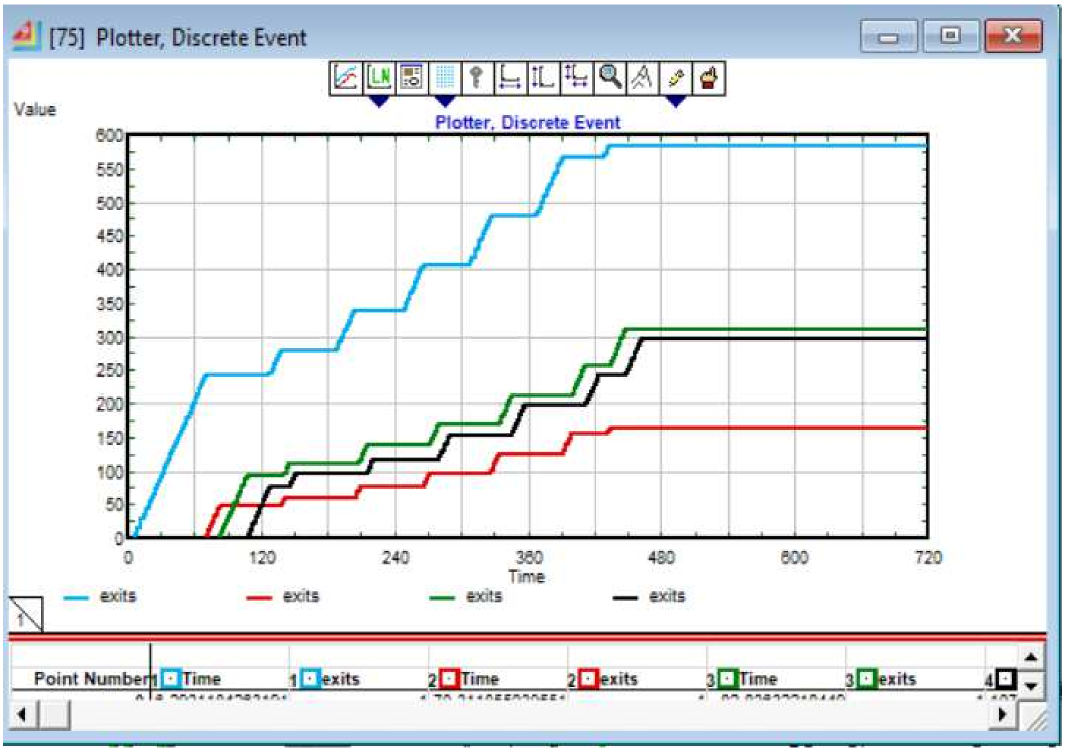

Figure 4 Result of proposal No. 1 for transport companies (Cargus, GLS HR, Zásielkovňa , PPL)
Cargus, GLS HR, Zásielkovňa, PPL

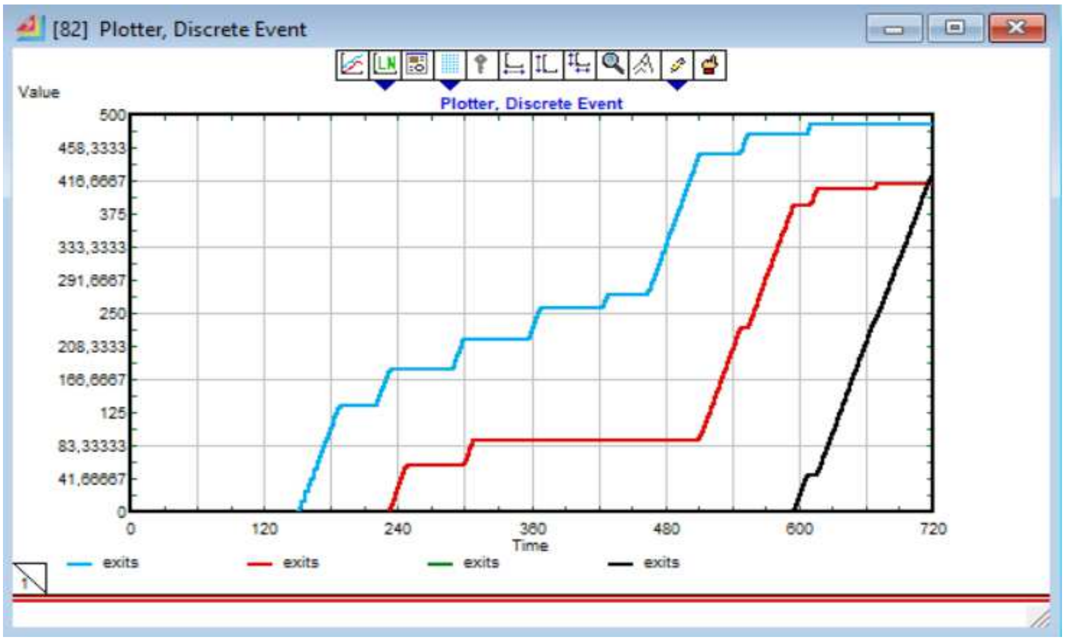

Figure 5 Result of proposal No. 1 for transport companies (GLS HU, Post, DHL)
GLS HU, Post, DHL

Experimenting with the deployment of employees, we came to the conclusion that the optimal solution is 15 people on Picking and 13 people on Packing. The advantage of this proposal is that the company does not have to spend any funds to hire more employees. The disadvantage is the high workload, which represents 98% at the Picking and 93% at the Packing (Figure 3). Another disadvantage is the small time reserve, which means that the system operates in a highly tense mode. From the graphs in Figure 4 and Figure 5, we can see that all orders were packed but just before the time limit. An unexpected increase in orders would mean that the warehouse would not be able to ship all orders, which would lead to non-delivery of the order and cause customer dissatisfaction.

3.2 Proposal No. 2 with an increased number of employees

The second proposal simulates a system with an increased number of employees. The setting of times in individual "Activity" blocks is the same as in proposal 1. In this proposal, we have increased the number of employees at Picking by 3 and at the Packing by 2. A total of 33 workers are employed in this proposal. The result is a reduction in Picking utilisation from 98% to 82% and Packing from 93% to 80%. The utilisation of "Activity" blocks in proposal 2 is shown in Figure 6.

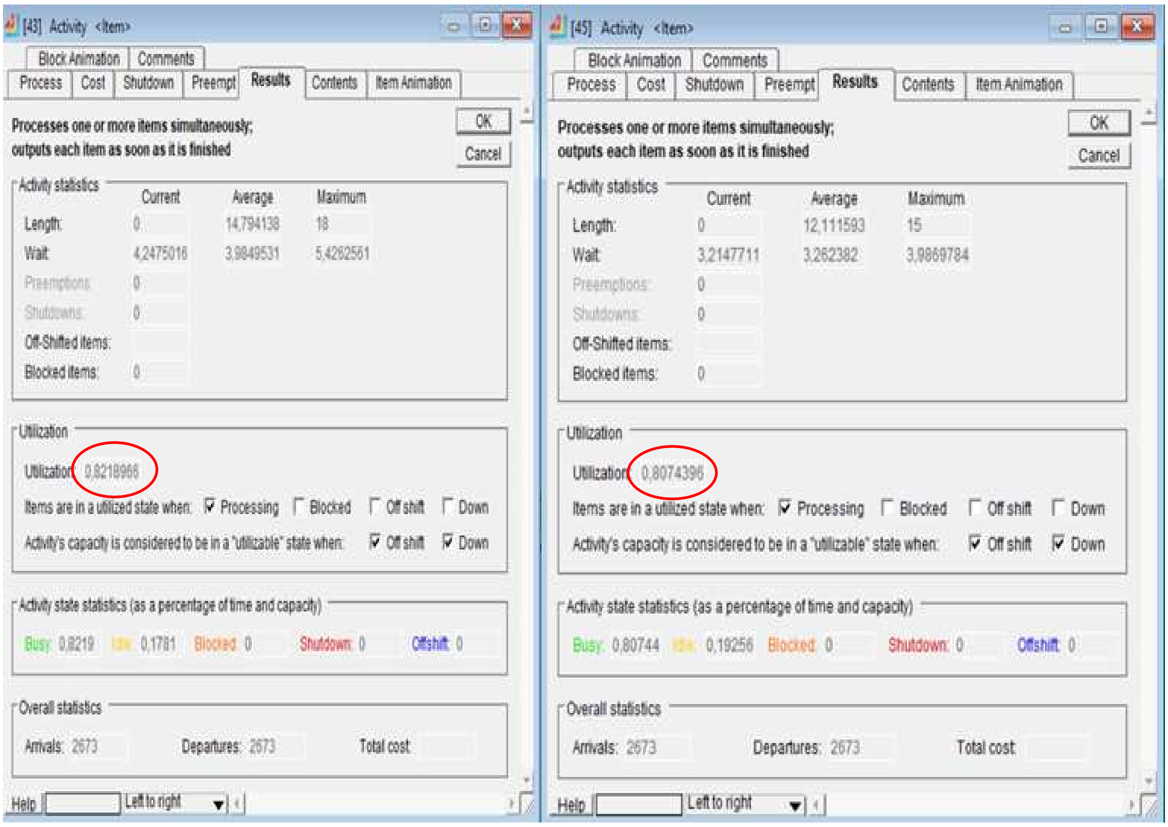

Figure 6 Use of activity-Picking and packaging blocks in proposal No.2

Figure 7 and Figure 8 show the course of the simulation in proposal 2, where the colour curves represent the packing times of orders for individual transport companies and the vertical axis shows the number of orders. The graphs show that the time reserves are much larger than in proposal 1.

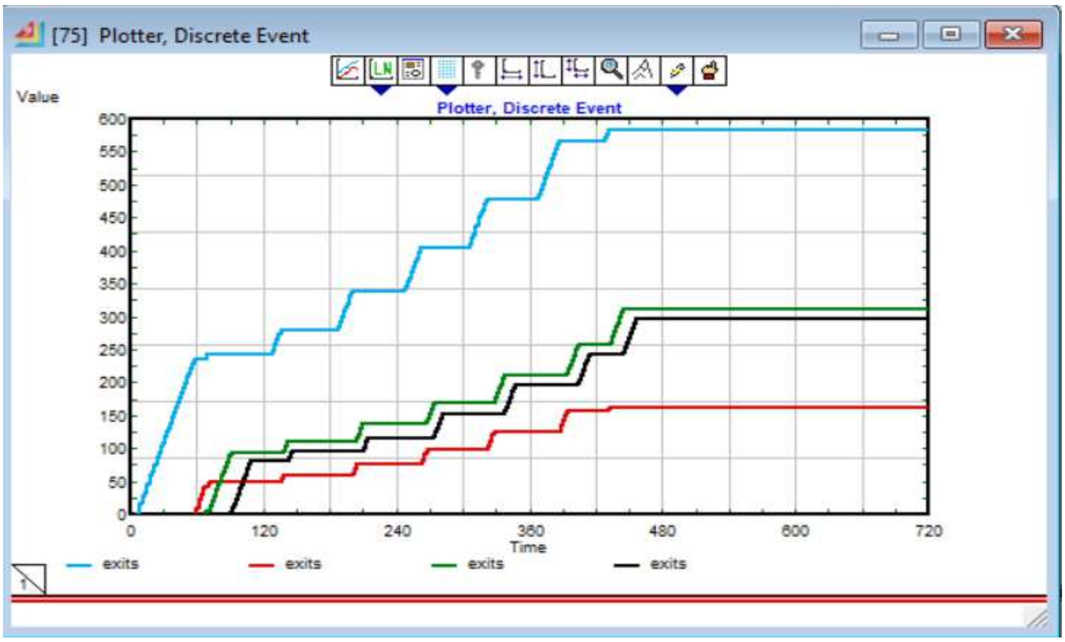

Figure 7 Result of proposal No. 2 for transport companies (Cargus, GLS HR, Picking, PPL)
Cargus, GLS HR, Zásielkovňa, PPL

The advantage of proposal 2 lies in the reduction of the workload of employees and in the creation of larger time reserves. The graphs and Table 3 show that the time reserves have increased significantly compared to the first proposal. Such system can withstand an unexpected increase of orders by about 300. The disadvantage of this proposal is that the company would have to hire another 5 employees, which would result in an increase in labour costs.

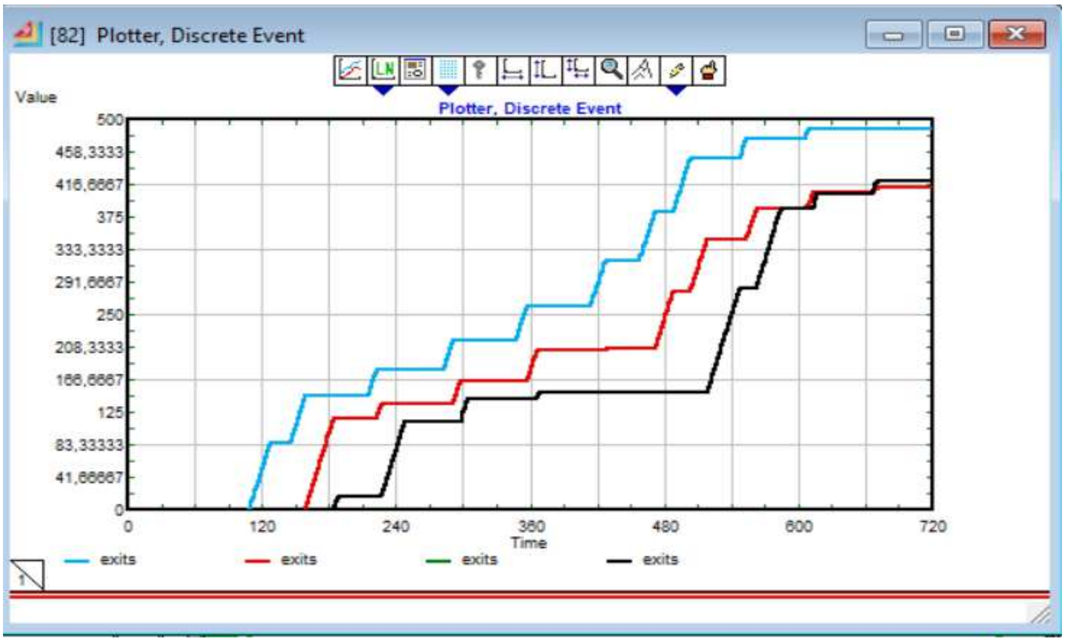

Figure 8 Result of proposal No.2 for transport companies (GLS HU, Post, DHL)
GLS HU, Post, DHL

Table 3 Packaging times of the last package for individual transport companies in proposal No.2

Transport company	Packing time of last order
Cargus	13:06
GLS HR	13:18
Zásielkovňa	13:40
PPL	13:50
GLS HU	16:10
Post	17:12
DHL	17:20

The analysis of activities in the warehouse showed that the company has a problem in the organisation of work in the warehouse, specifically a bottleneck in the picking section. The problem in the organisation of work was caused by the uneven distribution of employees in the picking and packaging departments. To overcome this problem, two proposals were verified by ExtendSim9 simulation program to find the optimal allocation of workforce into workplaces.

Proposal 1 considered the currently available number of workers, while the simulations examined the possibilities of dividing the workers into the picking and packaging department. The simulation results provided information on the optimal distribution of staff, which eliminated the bottleneck. The total number of employees 28 was in the optimal solution divided into 15 people for picking and 13 people for packaging. In this mode, the system managed to meet the requirements, all orders managed to be packed on time. However, the workload of picking workers was 98% and packaging 93%. The advantage of this proposal is that the company does not have to spend any funds to hire more employees. The disadvantage is the high work commitment and small time reserves, which would, in the event of an unexpected increase in orders, cause the warehouse not to be able to ship all orders.

Proposal 2 considered an increased number of employees. The aim of this proposal was to remove the bottleneck and at the same time reduce the workload of workers to about 80%. In case of unexpected delays and sudden increases in orders, this burden creates enough reserve time. Repeated experiments on the simulation model have provided a solution for the optimal distribution of workers in increased numbers. The results of the simulation showed that if we increase the number of workers in picking by three and in the packaging by two, the utilisation rate in picking will decrease to 82% and in packaging to 80%. In such a work schedule setting, the system would be able to withstand an unexpected increase in orders of approximately 300.

By comparing both proposals only based on direct costs, proposal 1 is a more appropriate solution to the bottleneck problem. It does not require any additional costs, and by a simple organisational change, the bottleneck can be eliminated. In terms of the overall risk of the assessed system, indirect costs, and concerning sustainability, the solution according to proposal 1 is unacceptable, or acceptable only in the short term. The analysed company is therefore forced to seek a solution to the bottleneck by increasing capacity. This is either by increasing the number of own employees, by relocating workers from other workplaces, if possible, or by hiring labour force for exposed periods. Another possibility of eliminating the bottleneck is investing in the modernisation of the used technologies.

4 Conclusions

Capacity constraints determine system performance. Simulation programs are often used in solving capacity problems and bottlenecks elimination. The article dealt with the issue of bottleneck elimination in the distribution warehouse using computer simulation. The initial analysis of the processes identified the bottleneck at one of the warehouse workplaces (packing), which led to the risk of non-compliance with the requirements for sending orders within the time limit. The reason for the creation of the bottleneck was preliminarily determined by the unbalanced distribution of warehouse workers to workplaces. Based on the determination of time and capacity parameters of the process, a simulation model was created in the ExtendSim9 program and the warehouse process was simulated. Experiments with a different redistribution of employees were used to find the optimal solution so that the process is managed, and workload allocation is optimal.

The simulations resulted in two proposals for staffing the Picking and Packing sites. In the first proposal, the current number of workers was considered 28, the optimal solution was to put 15 on picking and 13 on packing. However, based on simulations, this solution would mean mastering the process (all orders are sent on time), but the workload of employees would be 98% (picking) and 93% (packing) and even with a small increase in orders, the process would be unmanageable. In the second solution, an increased number of employees was considered and in order to achieve not only the mastery of the process but also the optimal load of workplaces (approximately 80%). This solution requires increasing the number of workers for picking by 3 and for packing by 2.

The advantage of the used method is solving the problem on the virtual simulation model and verification of the impacts of the proposed solutions in advance and practically with no financial costs. But several limitations also need to be pointed out. The simulation model is still a simplification of reality and does not take into account many, even significant factors. Work productivity and workplace performance depend not only on the number of employees and the production volume but also on the motivation, skills, and qualifications of the workforce. Also, the work environment and workplace equipment affect the performance provided. These factors have not been included in the presented simulation model.

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Review process

Single-blind peer review process.