Simulation Research of Order-Picking Processes in High-Bay Warehouses

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In the paper an effort to use a pre-defined simulation model of a high-bay warehouse was made. It was done in order to research dynamic changes of material-flow in such a logistics facility. The paper consists of brief information about research tools e.g. *Siemens Tecnomatix® Plant Simulation* software and the logistics facility designing method, pre-defined by author of the paper (the method considers supplementary option, which is the *sub*-optimisation of functional and spatial areas inside a warehouse being designed with using the method). In addition, phases of the simulation research procedure are briefly described in the paper. The simulation research procedure is defined by author of the paper and it especially consists of constructing and using any simulation model. Chosen results of the research are enriched by some conclusions. Besides, the paper contains suggestions about forthcoming considerations of the research matter.

Keywords: simulation, warehouse designing, order-picking process, short-time planning.

1. INTRODUCTION

A warehouse is a primary and one of the most important types of logistics facilities in a logistics supply chain. Over the last dozen of years, a new trend in warehouses constructing has been observed. This trend is high-bay warehouse designing and applying. There is no need to emphasize specially the fact that this is one of the expression of the universal globalization of local and regional markets. Possibilities connected to automation of logistics processes are one of the factors that opts for this kind of constructions. High-bay warehouses, with HBW acronym, are also known as high-rack warehouses or Hochregallager (HRL) in German. In colloquial speech they are called "pallet silos" because of buildings height and bulk of load units flowing inside a building. These load units often are pallet load units, consisting of load obviously and a pallet of *EUR1* type, Ferscht (2006). High-bay warehouses either have a permanent building structure (concrete construction; usually constructed of a steel structure) in which the storage units (racks) are free standing or the storage units are part of a supporting structure for walls (façade) and a roof of a building. High-bay warehouses are single-purpose facilities that cannot be used for other purposes. This definition is not doubtful in qualitative issue nevertheless quantitative issue is not obvious and questionable. In literature it is said that the minimum height is 12 meters according to Voestalpine (2012) or 14 meters according to Fijałkowski (1995) and currently the maximum height is about 50 meters, according to Voestalpine (2012). It is worth mentioning, however it is not the subject matter of this paper.

High-bay warehouses as storage facilities of the most complex design and sophisticated technology. They require special treatment in terms of research before they arise (pre-project studies), and then when they are designed (designing studies) and finally when they are operated (operating studies). This concerns not only aspects of the technologies applied in high-bay warehouses but also such a weighty issue as structural strength of materials, which are implemented in high-bay warehouse construction (author's further work will lead to the development of other issues).

Modern high-bay warehouses are several tens of thousands square meters surfaces (or even more cubic meters in cubature), on which multi-assortment load units can be stored. Inducting the solutions for functioning facilities of this type is not equivalent to the abandonment of fundamental research on issues of these facilities construction and technologies used inside of them. Therefore conducting simulation studies on the dynamics of logistics processes in these facilities is considered as appropriate. Order-picking processes are one of many logistics processes which occur in storage facilities. And this process is one of the most finance consuming. Order-picking processes costs are accounted in range of from half to three quarter of total warehouse operating processes costs according to Drury (1988). Meanwhile other sources define order-picking costs strictly as: 55% - Tompkins *et al.* (1996), 60% - Frazelle *et al.* (1994), Frazelle (2001), 65% - Coyle *et al.* (1996) of total warehouse operating costs. Of all warehouse operations, order picking is considered to be the most cost-consuming one. Although it must be emphasised that mentioned range and percent estimations concerns every kind of warehouse without distinction whether it is a high-bay warehouse or not.

In the paper an effort to use a pre-defined simulation model of a part of a high-bay warehouse was made. Simulation model was constructed by using a tool for making the implementation of realistic simulation models: *Siemens Tecnomatix® Plant Simulation* software. This paper presents and discusses the results of the work on the model and makes an attempt to reach research conclusions.

2. RESEARCH PROCEEDING PROCEDURE

The advance procedure in order to dynamise research on material-flow in warehouse is given in fig. 1. After logistics task formulating, solving of the task was introduced. The method of logistics facilities designing was used for this purpose. This method description can be found in Kostrzewski (2012a, 2012b). Based on gained technological and organizational parameters, the theoretical model was prepared (financial parameters were not necessary in the model elaborating). The theoretical model was implemented in the *Siemens Tecnomatix® Plant Simulation* software, which is generally prepared for simulation models constructing, researching, evaluating *etc*. Therefore the theoretical model became the simulation model. According to Korzeń (1998) "*a simulation model is the multi-modules software creating with the compatible computer a kind of functional simulator, which allows to generate states of modelled system.*" The requirements for above definition are fulfilled. The above mentioned technological and organizational parameters were put into the simulation model. As a result of repeated simulation processes executing, some results of the simulation are obtained and discussed in the next parts of the paper. The prepared simulation model was based on literature: Anon. (2006, 2010), Bangsow (2010, 2012). What is more, the mathematical model of order-picking process was implemented in the simulation model. This mathematical model is similar to the real state of order-picking process because it considers random processes. It is described in Kostrzewski (2012c). The mathematical model is:

$$t^{n}_{ckom}(w,p) \in \boldsymbol{T} \rightarrow \Re^{+} \tag{1}$$

$$\forall p \in \boldsymbol{P} \;\; \forall w \in \boldsymbol{W} \;\; \forall n \in N^{+}: \;\; t^{n}_{ckom}(w,p) =$$
$$= (\mathrm{w}+1)\cdot \mathrm{A} + \mathrm{L}\cdot(\mathrm{F}_1 + \mathrm{F}_3) + (\mathrm{n}\cdot\mathrm{H} + \mathrm{h}_2)\cdot(\mathrm{U}+\mathrm{D})$$
$$+ 6\cdot\mathrm{N} + \mathrm{t}_{\mathrm{pro}} + \mathrm{w}\cdot(\mathrm{t}_{\mathrm{ro}} + \mathrm{p}\cdot\mathrm{t}_{\mathrm{pl}})$$
$$\boldsymbol{W} = \{\mathrm{w} : \mathrm{w} = \mathrm{X}(\mathrm{e_w})\}; \;\; \boldsymbol{P} = \{\mathrm{p} : \mathrm{p} = \mathrm{X}(\mathrm{e_w})\}; \;\; \mathrm{w},\ \mathrm{p},\ \mathrm{n} \in \mathrm{N}^{+}$$

$$\overline{t_{ckom}} = E\left[t^{n}_{ckom}(w,p)\right] = \frac{\sum_{n=1}^{N} t^{n}_{ckom}(w,p)}{N}$$

where $\boldsymbol{W}$ is a set of rows numbers in *n*-lists of orders in order-picking process (*w* - number of types of products to pick in an order-picking process on one of order-picking orders *n*-lists), $\boldsymbol{P}$ is a set of numbers of goods (products of one type) to take (per one row in an order-picking orders list), *n* is the next order-picking order list. Elements of these two sets are random numbers generated by a pseudorandom number generator (*PRNG*). All parameters of the mathematical model are discussed in Kostrzewski (2012c), as well as in the book: Fijałkowski (1995).

3. THE TOOLS USED IN THE RESEARCH

Siemens Tecnomatix® Plant Simulation is a tool for numerical simulation-models constructing and researching. Mainly, the software is used in the simulation of manufacturing processes. The software's name stems from it (called *a plant* – a factory). Generally, according to the entrepreneur who possess copyrights for *Tecnomatix® Plant Simulation*, it can be used in most industries. It can be especially used in the automotive industry, aerospace, plant manufacturing, mechanical engineering, process industry, electronics industry, consumer packaged goods industry, airports, logistics companies, which include transport logistics, production logistics and last but not least **storage logistics**. As promotional material of *Siemens Tecnomatix® Plant Simulation* says "*for Warehousing and Logistics software enables you to rapidly create realistic simulation models of dynamic warehousing and logistics operations*", Anon. (2011). By noting the potential of the software, it has begun to be used in order to create simulation models of logistics systems. What is more, in opinion of the author of the paper, the warehouse is a kind of plant that "produces" loading units (mainly while order-picking processes are realised). Using *Siemens Tecnomatix® Plant Simulation* solutions can include attempts to optimise the material-flow (load units flow), the usage of resources *etc*. *Siemens Tecnomatix® Plant Simulation* software allows also checking the characteristics of the systems and optimising their performance. Simulation models allow conducting experiments and testing "*what-if …?*" scenarios, both in the case of already existing systems, or – in the case of a planning process – long before.

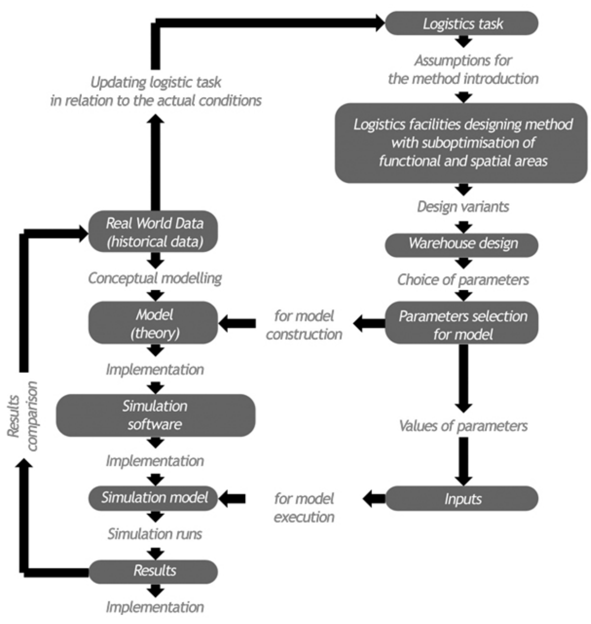

Fig. 1. Scheme of research procedure
Source: author himself (Kostrzewski, 2013) with elements of Bangsow (2012, p. 440)

4. CHOSEN RESEARCH RESULTS

In figures 2. – 8. some results of the research and effects of using the simulation model can be found. The research was limited to the fragment of high-bay warehouse, consisting of four down-aisles. In each of the following figures some individual marks are exposed, whose meaning is as follow: 1 - number of pallet load units on exit of the first down-aisle, 2 - number of pallet load units on exit of the second down-aisle, 3 - number of pallet load units on exit of the third down-aisle, 4 - number of pallet load units on exit of the fourth down-aisle.

In fig. 2 the number of pallet load units after order-picking process is presented as a function of high-bay warehouse daily working-time. This result of simulation does not include random events. In this simulation, as the result of order-picking process realized in four down-aisles, 583 pallet load units were "created". Subsequent simulations, the results of which are presented in figures 3. – 8., include random events. As the quality of service in a warehouse is largely dependent on the proper functioning of the means of transport and other transport equipment, random failures of the suprastructure elements have been selected. Levels of damage are in ranges as follow: $p_1 \leq 25\%$ and $p_2 \leq 50\%$ in relation to the duration of simulation. And at the same time *MTTR – Mean Time To Repair* were differentiated. *Mean Time To Repair* values occur between one minute and half an hour, depending on the simulation run. For the initiation of random processes in the simulation model, pseudorandom number generator was used. Pseudorandom number generator is implemented in the software.

Fig. 2. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, which does not include random events

In the simulation, which results are included in fig. 3., after order-picking process realized in four down-aisles, 576 pallet load units were "created". However, other simulations results given in numbers of pallet load units are: fig. 4. – 560 pallet load units, fig. 5. – 545 pallet load units, fig. 6. – 147 pallet load units, fig. 7. – 415 pallet load units and at last fig. 8. – 280 pallet load units.

Discussing *e.g.* fig. 5, it is concluded that the failure of means of transport rarely occurred in the down-aisle No. 3 (according to the marks in mentioned figure). That conclusion follows from the fact that in case of this down-aisle the largest number of pallet load units "got away" from down-aisle. In turn, taking into consideration fig. 6. and 8. (analysing warehouse operation with the assumed conditions), the failures of means of transport most frequently occurred of all the simulations presented in the paper. These failures had the longest average durations time.

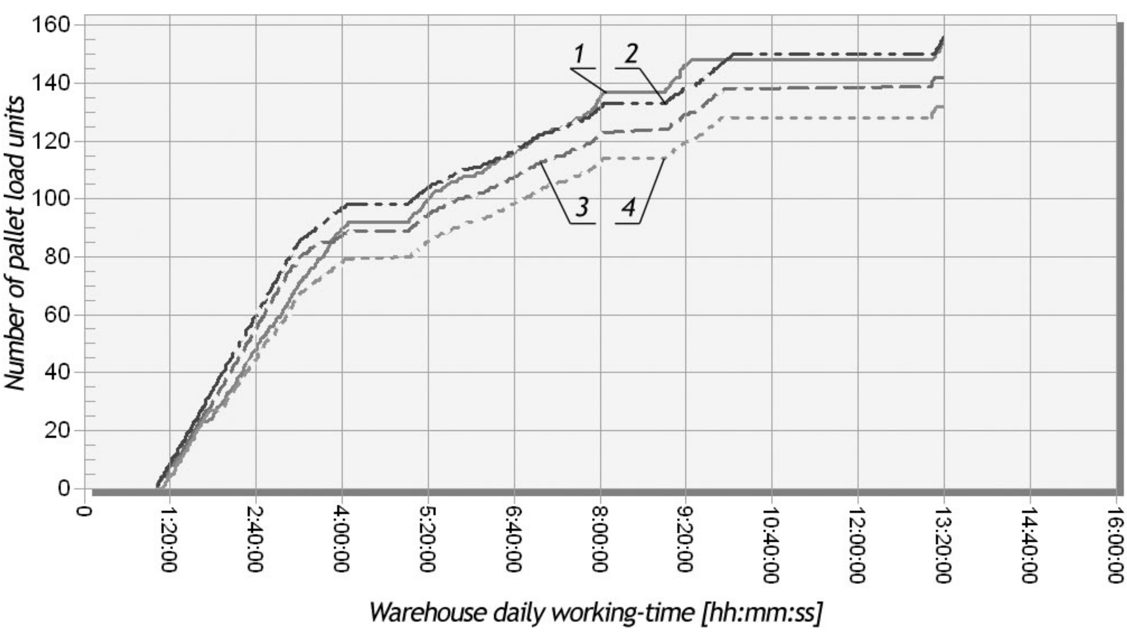

Fig. 3. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 25\%$, MTTR = 60 [s]

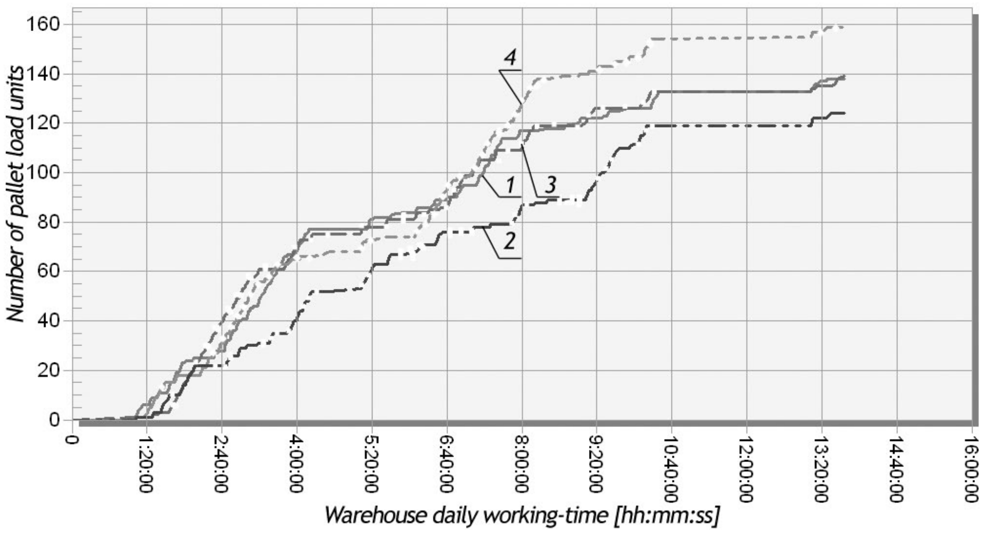

Fig. 4. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 25\%$, MTTR = 60 ÷ 900 [s]

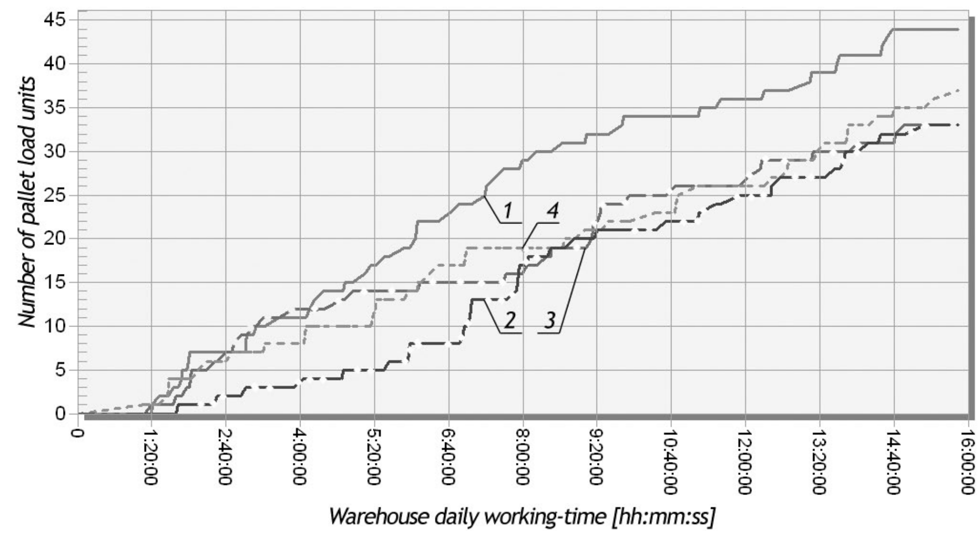

Fig. 5. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 25\%$, MTTR = 60 ÷ 1 800 [s]

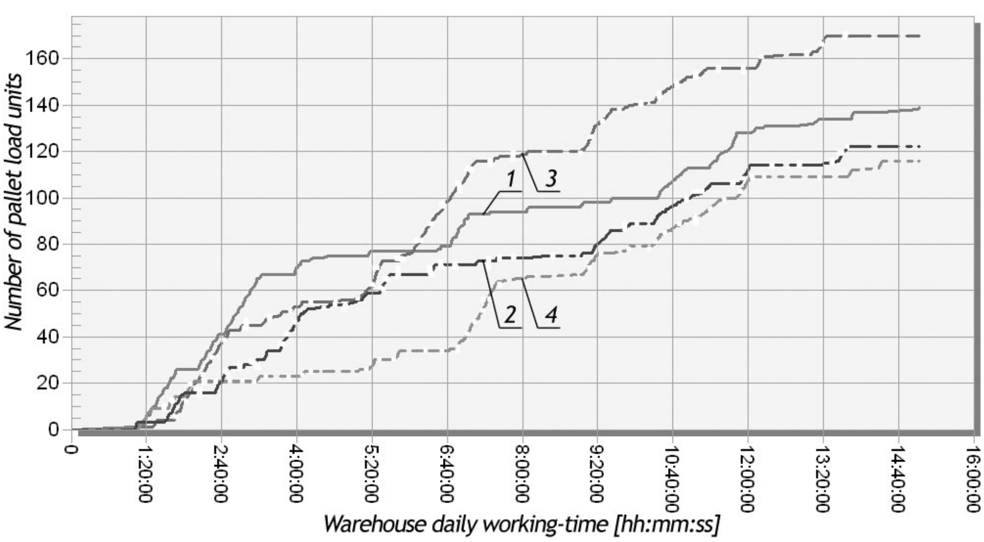

Fig. 6. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 25\%$, MTTR = 60 ÷ 3 600 [s]

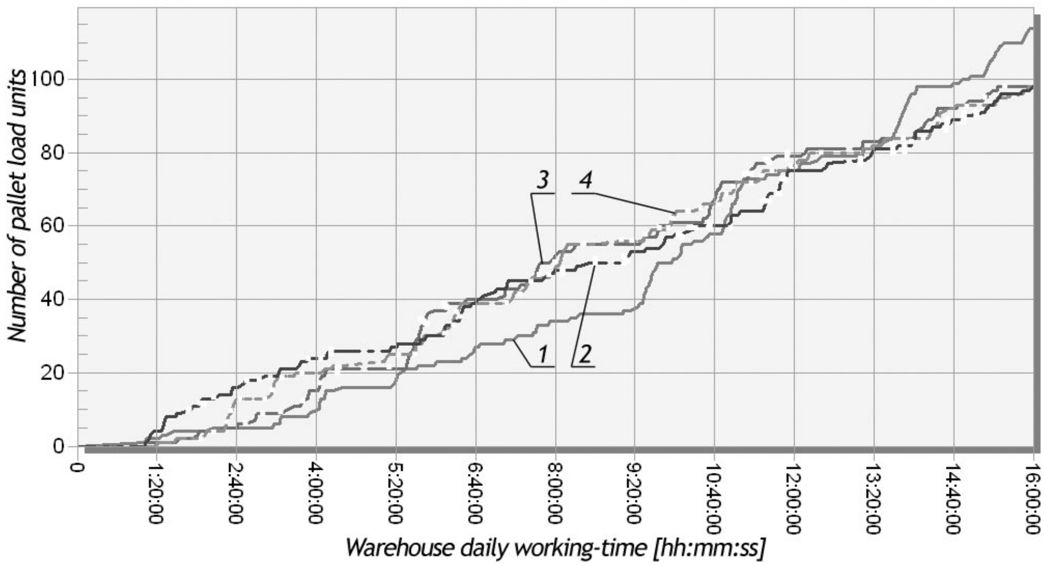

Fig. 7. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 50\%$, MTTR = 60 ÷ 1 800 [s]

The observation of such a situation occurring in a warehouse is directly connected to short-term planning. Short-term planning in turn can be based on an examination of potential problematic events on a simulation model. A person responsible for planning would be able to determine an occurrence and extent of potential risk of non-implementation of a short-term plan, and also to predict the consequences of possible failures. And, therefore, he or she would take appropriate measures to ensure the stability of work in a warehouse.

Tracking changes in simulation mode allows also to define acceptable level of damage, which is still "safe" for the operation in case of technological aspects in a warehouse, *i.e.* at which acceptable level of damage operating in a warehouse would be still possible despite any potential disruptions (downtime, interlocking *etc.*).

The use of simulation models is also desirable for warehouse designing in technological and organizational aspects. It allows to exclude a number of possible designing malfunctions, defects or mistakes at the conceptual stage, before implementation of designing concept (before its realization). This has a direct impact on the reduction of expenditure on warehouse investment and investment risk reduction. Ashayeri *et al.* (1985) constitute that using of an analytical approach to warehouse designing only is insufficient. Their conclusions lead to the claim that the designing method should be based both on the analytical approach and application of simulation solutions. This approach is used by the author of the paper.

5. SUMMARY

Simulation tool allows each warehouse equipment and every employee to be moved into the virtual world of a simulation model. This allows a warehouse manager or other decision-making person to be able to identify immediately any bottlenecks that can occur in any period of time. And, what is more he or she can take measures to avoid bottlenecks. In addition, it is possible to track short-term changes in productivity of employees, warehouse equipment and infrastructure components. The increase in orders is often noticeable for several or several consecutive days. Inevitably, this has an impact on the work quality in a warehouse.

As it can be seen both in theory and practice, the most problematic processes in warehouses are order-picking processes. This is due to factors such as unpredictable variations of order-picking orders lists, allocation of loading units in stock, and therefore duration of individual cycles of transport processes or/and order-picking processes and finally failures of means of transport and other types of equipment. Therefore a simulation model can be a great tool for improving quality of work in the warehouse.

The simulation model discussed in the paper should be expanded by information-flow. This has not been done yet. The task is time-consuming – as indeed the construction of each of the simulation model such as to correspond to the actual conditions. Research are expected to be continued then.

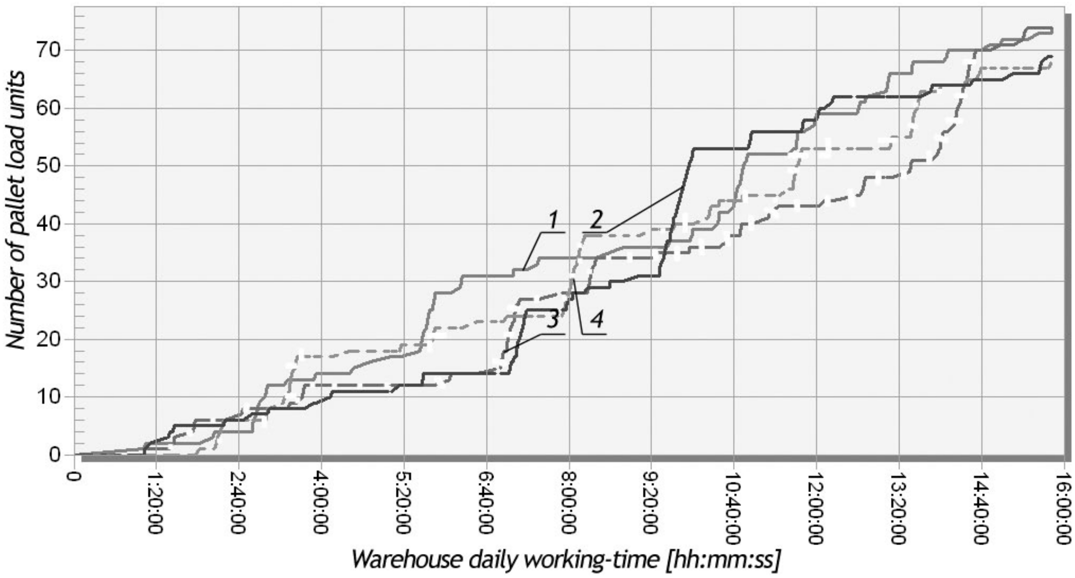

Fig. 8. Number of pallet load units being operated in order-picking process, in function of high-bay warehouse daily working-time; version of simulation, random events are included: $p_1 \leq 50\%$, MTTR = 60 ÷ 3 600 [s]

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