Simulation Method in Research on Material-Flow in a Warehouse

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This paper presents an attempt to apply the simulation model in the study of the dynamic aspects of material-flow in a warehouse. At first the research approach was briefly subjected under explanation and literature review was given. Then simulation tools are noted and various stages of the simulation research procedure, developed by the author of the paper, are discussed. The general way of construction and the use of the simulation model are also described. The paper contains several conclusions based on results of simulation runs as well as suggestions of topics for further study.

Keywords: simulation model, warehouse designing, research approach.

1. INTRODUCTION

The vital role, which logistics plays in economic systems, is the main reason why the reduction of logistics costs has become an increasingly important task for supply chain managers and, what is more, for logistics systems designers. *Both practice and theory prove that final company successfulness depends on logistic costs influence. In 2007 a research was published, which informed logistics market that logistics costs represent almost 10% of sales in Western countries (*Logistics Cost and Service, 2007).

Many authors have their own definition of a supply chain. The one mentioned below is, in opinion of the paper author, the most congruent to the research described in the paper. Ganeshan and Harrison (1995) defined a supply chain as *"a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers."* From the point of view of this research the most important part is *"logistics facility". In the entire supply chain at its micro level it is a warehouse, which is one of the key logistics facilities and* a key element in supply chain efficiency. Material handling in a warehouse can make up to 20 – 50% of the total operating expenses (which are actually a part of mentioned logistics costs) as it is noticed by Tompkins *et al.* (2010). Therefore a proper incoming and outgoing material-flow needs to be realized. In order to be competitive in a dynamic environment, companies pursue searching for some new warehouse management concepts. Over the last years focus on logistics concept of warehouse management has been emphasized, which is based on the complex analysis of material and information-flow. The understanding of the way in which the entities or information are moved between the points of origin (pick-up points) and destination points (deposit points) in a warehouse, allows to plan and optimise individual stages of entities or information movement. In the modern logistic system every manipulation of materials is subjected to detailed verification at the stage of planning. Using a simulation tool is a very good opportunity for making this verification.

It should be emphasized first that simulation modelling is one of types of research approaches. According to Homburg (2007), four research methods are defined: empiricism, morphology, pure theory and modelling (fig. 1.). Extensive discussion on the issues can be also found in Kemme (2013, pp. 112-115). Empiricism, morphology and pure theory can be omitted here as research approaches not used in logistics research in general. In contrast to a group of three approaches mentioned above, modelling is highly recommended. It can be stated that two types of mathematical models are distinguished. They are analytical and simulation models – it is mentioned in Ashayeri and Gelders (1985, p. 285-294), Kostrzewski (2009, p. 96), Valkengoed (2004, p. 18). „*Analytical models are usually applied to obtain exact analytical solutions for planning problems rather simple systems. If a solution of such a mathematical model is available and is computationally efficient, it is usually recommended to study the model analytically rather than by a simulation model*", Kemme (2013, p. 113) after Law and Kelton (2000, p. 5). However, in case of complex systems such as logistics systems, it can be difficult to model their behaviour in analytic way because they are not trivial. They should be researched as simulation models.

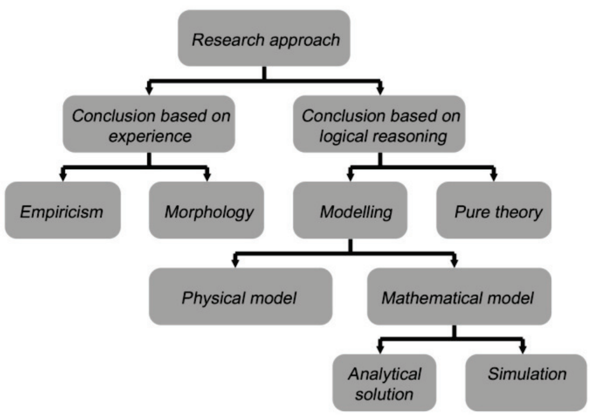

Fig. 1. Classification of research approaches
Source: author himself based on Law and Kelton (2000), Homburg (2007), Kemme (2013)

As it is mentioned in literature, a discrete-event simulation models the processes of a system as a discrete sequence of events in time. Each of these events occurs at a particular instant in time and marks a change of state in a system. This is why using discrete-events simulation tools have become considered as a crucial planning and control option when production lines or complete factories designing is realized. Why not traverse the idea of using simulation tools into researching material-flow in logistics facilities then? This paper presents an attempt to apply the simulation model to research of some aspects of material-flow in a logistics facility. The use of planning and simulation models can help to identify optimisation potential in terms of throughput, cycle times, transporters (and vehicles) utilization or warehousing equipment and infrastructure utilization *etc*. Simulation, even a discrete-event one, can help to map in detail the dynamic behaviour of a complex system.

While talking about simulation of processes in logistics or production, some key terms must be defined.

According to Ören T. (2011) numerous definitions of *simulation* are given in the literature.

Defining after Banks (1999) and Heilala (1999) "*simulation is the imitation of the operation of a real-world process or system over time*". They add that simulation "*involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented*."

Meantime Korzeń (1998) gives a more strict definition. According to him "*the simulation model is a multi-modules software creating with a compatible computer a kind of functional simulator that allows to generate states of modelled system*."

The American researchers from *Stanford Research Institute* (U.S.A.) are confident that the simulation is a key technology for the new millennium. According to the statement the use of simulation solutions will be increasing 20% *per annum*, which has been confirmed by the worldwide trends and statistics, according to UGS Corp. (2006). It is not a surprising course of things. Simulation allows to establish a system or a set through experiments executed directly on a tested model (of a system or a set). Furthermore, it can be applied to the analysis of large and complex decision problems that cannot be resolved by other methods (*e.g.* operations research). At the same time it allows quick decision-making by analysing the results of experiments executed for a number of consecutive periods of time. It also allows to provide answer to "*what-if …?*" questions.

Simulation methods are currently the most used in the United States of America, Japan and Western Europe. In Central Europe (including Poland), until relatively recently, these methods were used infrequently. According to Korzeń (1998), it began to change in the late 80s of the previous century with the expansion capabilities of object-oriented simulation feature (this is the major reason why in the paper "old" papers and publications are mentioned – it is highly important to know predefinitions of simulation research: Zeigler, 1976; Zeigler, 1984; Ashayeri and

Gelders, 1985). However, a still valid statement is that while searching scientific databases not many papers dealing with simulation of warehouses operating can be found (*e.g.*: Colla and Nastasi, 2010; Colla *et al*., 2008; Karkula, 2013). The opposite situation takes place in case of simulation in production and manufacturing. Many authors prepare research and publications on production and manufacturing, recalling here only a few well known national experts such as Susz and Burduk (Chlebus *et al*., 2000; Susz *et al*., 2004; Kowalski *et al*., 2005; Chlebus *et al*., 2010).

In the paper, chosen simulation tools and various stages of the simulation research procedure, developed by the author of the paper, are discussed. A way of construction and using the simulation model are described.

This paper is an elementary description of the results of research on simulation model, previously constructed by the author. The paper contains the results of a simulation of the second type, which allows the analysis of the results as a function of input parameters changes. Basic knowledge of theoretical issues concerning the idea of simulation methods and advantages/disadvantages of simulation methods are concluded in Kostrzewski (2009, 2013a). Based on the design of the warehouse, prepared beforehand, it was decided to arrange a simulation model that allows to observe the dynamics of logistic processes taking place in the logistics facility. The paper deals with the discrete-event simulation of pallet load entities (units) flows in every typical area in a warehouse: an entry area, a warehousing area, an order-picking area, an exit area etc. The interpretation of obtained simulation results is overviewed. The paper gives results and summary, based on chosen results, and it also contains suggestions and potentialities for further consideration of the issues.

2. RESEARCH PROCEDURE

The procedure for the research of dynamics of the material-flow in a warehouse is presented in fig. 2. Firstly, a warehouse logistics task was analysed – its contents, the parameters and their corresponding values can be found in Kostrzewski (2009). The next step after the logistics task formulating was obviously to solve the task. And then a warehouse was designed. For this purpose an original method of logistics facilities designing, described in Kostrzewski (2012), was used. From prepared designing variants, the best design was chosen. Then, basing on its concept and technological and organizational parameters, a theoretical model (formal one) was constructed. The theoretical model was a basis of constructing a simulation model. The simulation model is a complex one, including a pair: a formal model and functional numerical algorithms occurring in the simulation software. Technological and organizational parameters mentioned above were introduced to the simulation model. And finally, as a result of many simulations, the results discussed below were gained. These results generally should be compared with the existing conditions, although research is under theoretical circumstances and are not related with the effects of the existing facility logistics (warehouse). The same applies to the issue of updating the logistical tasks in relation to the existing conditions. These steps are omitted then.

3. TOOLS USED IN THE RESEARCH

Both the theoretical and the simulation models considered in the paper were developed in accordance with guidelines of atomic *Discrete Event System Specification* (*DEVS*) structure. *DEVS* structure is specified in Zeigler (1976), Zeigler (1984), Zeigler *et al.* (2000), Zeigler and Sarjoughian (2003). The formalism of its structure consists of septuplet, the ordered elements given as:

$$M^{DEVS} = \langle X, S, Y, \delta_{\text{int}}, \delta_{ext}, \lambda, t \rangle \quad (1)$$

where

X – the set of inputs,

S – the set of states,

Y – the set of outputs,

δ_{int} – the internal transition function, $\delta_{\text{int}} : S \to S$,

δ_{ext} – the external transition function, $\delta_{ext} : Q \times X \to S$ where Q is the total states set, $Q = \{(s,e) \mid s \in S, 0 \le e \le t(s)\}$ and e is the time elapsed since last transition,

λ –the output function, $\lambda : S \to Y$,

t – the time advanced function $t : S \to \boldsymbol{R}^{+}$.

Atomic *DEVS* model can be used to construct a coupled *DEVS* model.

There are many software tools, which use the mentioned *DEVS* model in their simulation process making structure. Some of them are (products names are given only as examples, without comparison of theirs unique possibilities): *Arena*

(Kelton *et al.*, 2010; *Arena* software can be used to model a variety of systems including business and manufacturing processes), *Automod* (Chen and Jiang, 2011; *Automod* software can be used to model manufacturing and production mainly), *Dosimis-3* (Kubiński *et al.*, 2012, *Dosimis-3* software can be used to model material-flow processes), *Promodel* (Harrell and Price, 2002; *Promodel* software can be used for manufacturing, logistics and warehousing applications), *Witness* (Briano *et al.*, 2010), *Plant Simulation*, *FlexSim* (Gelenbe and Guennouni, 1991). Various simulation and programming tools are commercially (unfortunately it means: necessary to purchase expensive software and pay yearly subscriptions) available to aid in developing a warehousing model. Some of these tools are made specifically for simulating aspects of warehouses, whereas others can be adapted to achieve the necessary result. These are examples of discrete simulation software for material flow, production and processes. It must be remember that GUI-based warehouse simulators, such as mentioned above can be far too expensive, especially when only one plant (warehouse) is going to be researched. "*(...) the targets of these systems are more likely to be warehouse designers and builders or very large companies*" – it hard not to admit to Colla and Nastasi (2010, p. 473). Simulation models can be also realized in *Matlab*® or even *MSExcel* (*Visual Basic Application* in *MSExcel*), which can be better (much cheaper) in such a situation (one warehouse solution).

Mainly two tools were used in the research. One of them was the method of logistics facilities designing implemented in the *OL09* software and the second one was *Plant Simulation* software, which were used for designing and testing the warehouse simulation model. The logistics facilities designing method and the *OL09* software are discussed in Kostrzewski (2012).

Plant Simulation is a tool for digital simulation-models constructing. Generally, the software is used in the simulation of manufacturing processes. The software's name stems from it (called *a plant* – a factory). By noting the potential of the software, it has begun to be used in order to create simulation models of logistic systems. According to the author, the warehouse is a kind of plant that "*produces*" loading units (mainly in case of order-picking processes). The components of *Plant Simulation* are given in in such a way that it can be treated as warehouse equipment, not only as factory equipment. Using *Plant Simulation* solutions can include making attempts to optimise the material-flow, the usage of resources *etc*. The tool also allows 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 implementation and commissioning.

The choice of these tools from a range of other simulation tools was dictated by the nature of object-oriented software, accessible language programming, ability to implement multi-faceted issues of process and prosaic reality of author's direct experience working with the tool and working together with its developers.

Last but not the least, it must be emphasised that, comparing analytic versus simulation modelling, „a*nalytic models are usually applied to obtain exact analytic solutions for planning problems rather simple systems. If a solution of such a mathematical model is available and is computationally efficient, it is usually recommended to study the model analytically rather than by a simulation model*", Kemme (2013, p. 113) after Law and Kelton (2000, p. 5). This is why the formal model of the warehouse is not given here – the complexity of the real warehouse may significantly hinder the construction of a formal model (mathematical). Therefore, the author uses simulation modelling.

4. SIMULATION MODEL

As it was mentioned before *"a multi-modules software creating with a compatible computer a kind of functional simulator that allows to generate states of modelled system"*. *Plant Simulation* is the object-oriented kind of software. Additionally to its object-oriented nature, it allows programming by implementing procedures in *SimTalk* programming language. This is undoubtedly the advantage: makes it versatile and allows constructing repetitive elements without necessity of constructing every singular element, as well as it allows performing multiple simulation processes.

Building the warehouse simulation model was based on combining together *Frame window* platform with some objects on it, which are identical to: processes taking place in the building, vehicles, infrastructure facilities (*e.g.* roads, storage shelves), other equipment and employees. These elements are selected from a wide range of multi-parameter objects, which are characterised by complex characteristics (*Tool box*). Fig. 3. is an example, which the author would like to use to explain bases of constructing a simulation model. The object that generates the *Entities* (⌗) is the *Source*. *Entity* means loading units (pallet loading units – in case of the warehouse simulation model used in the research; where it should be mentioned that the theme of the unit ⌗ may become any product *etc*.). The purpose of the *Source* object is to generate the next unit loads, which participate in successive processes (*SingleProc*, *SingleProc1*, ...). And at last, unit loads get to *Drain*, the material-flow estuary. Objects reflecting processes (*SingleProc*) may (after giving them appropriate parameters and characteristics) reflect pallet places

The *Source* here (in the paper) is the equivalent of the moment when pallet load units are unloaded from a truck on the ramp at the entrance to the warehouse (and more precisely: the moment, which a unit load pallet is put on the ramp's floor). The *Drain* in turn is equivalent to the moment of loading a pallet load unit on a truck, which awaits near the ramp at the exit of the warehouse. Moving between points of origin (pick up points) and destination points (deposit points) can even better reflect real conditions by introducing to a simulation model objects that are identical to the roads (*Track*). On these roads means of transport (*Transporter*), such as forklifts, are moving.

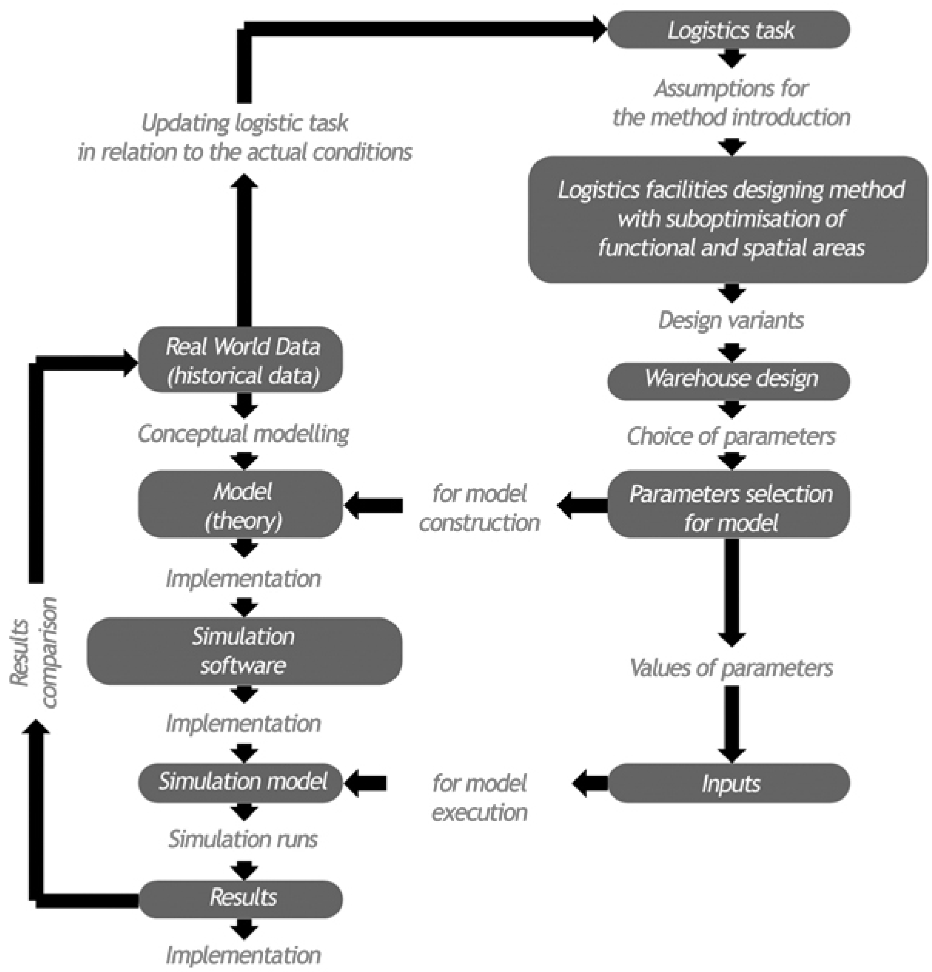

Fig. 2. Scheme of research procedure
Source: author himself (Kostrzewski, 2013b, p. 273) with elements of Bangsow (2012, p. 440)

(and therefore the appropriate combining of objects of this type may be used in simulation model as a warehouse rack), points of origin (pick up points), destination points (deposit points), identify and control points or other items, predefined by a simulation model constructor.

A part of the warehouse simulation model is presented in fig. 4. This is a part of *Frame*, in which a warehouse storage area was modelled. On the left side in the figure some object are: a work schedule (*ShiftCalendar*), a social object (*WorkerPool*), which provides employees with an object acting as a shift manager (*Broker*). Objects *TransferStations* are a specific type of points of origin (pick up points) and/or destination points (deposit points). Here are realised processes of loading or unloading a forklift (*Transporter*) moving on the road (*Track*) between these points. Elements on the right in fig. 4. reflect the part of the warehouse rack and at the same time processes taking place within the rack. In fig. 4. it can be noted that the forklift *Transporter2* currently transports the pallet loading unit type *Entity1* on the route between point of origin (pick up point) at the beginning of the buffer at the entrance to the warehouse (not shown in the figure) and one of the destination points (deposit points) at the beginning of the storage area. *Workplace* object, empty at the moment of print screening of fig. 4., indicates that an employee of the warehouse operates the forklift.

The duration time of each activity or process, or other characteristics of these are attributed to each of objects properties or transmitted *via* the appropriate procedure written in the *SimTalk* programming language.

Moving parts such as means of transport (forklifts), trucks and pallet load units are controlled by procedures (*Formulas*) written in the *SimTalk* programming language, for example by running the *Init* - initialisation procedure in the simulation model - which is quoted below:

```
is
do
  .MUs.Transporter1.create(.Models.Frame.Frame.Track);
end;
```

The quoted part of *Init* procedure means that the forklift *Transporter1* starts movement within a dedicated road (*Track*).

The whole simulation model is so complicated to build, that it is impossible to discuss all its aspects. The author hopes that these explanations will allow the reader to understand the principles of model constructing.

A simulation model was designed to simulate one day of warehouse operations (more precisely 16 hours of work in two-shift work schedule: first shift from 8:00 to 14:00, the second shift from 14:00 to 22:00).

The prepared simulation model should be subjected to verification and validation. Verification is a simulation stage, designed to confirm the theoretical assumptions of the simulation model. Validation is the next step. The aim of validation is therefore seen as a statement whether modelled simulation model reflects a real system. In both cases, it is difficult to obtain an unambiguous opinion, as the discussed simulation model has been developed on the basis of purely theoretical considerations.

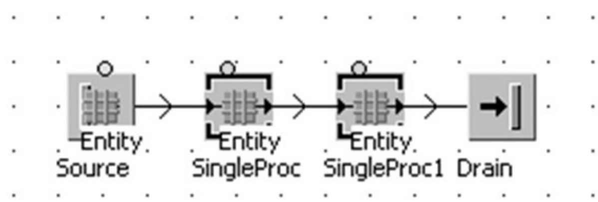

Fig. 3. Example of objects composition in Plant Simulation tool
Source: Bangsow (2010)

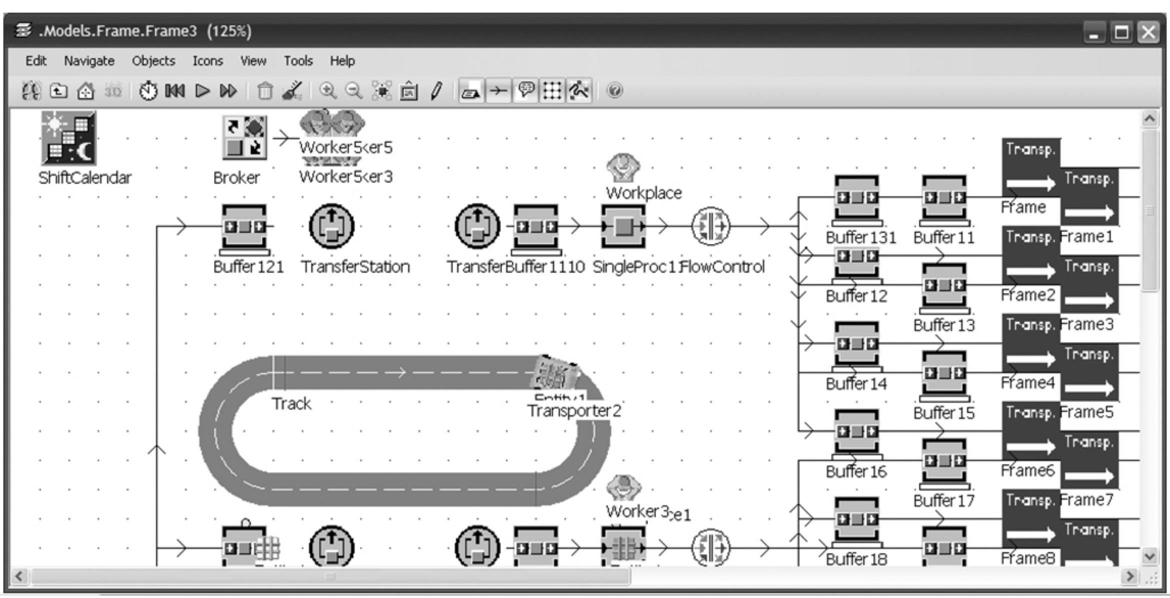

Fig. 4. Part of storage area in a warehouse simulation model

5. CHOSEN RESEARCH RESULTS

The research on the dynamics of the material-flow in a warehouse required for charts programming to be automatically updated during the simulation running. The *on-line* changes on charts are obviously impossible to be shown in the paper, therefore the final moment of the graphs creation is presented (fig. 5.).

Fig. 5. presents the flow of materials (movements of pallet load units) between the points of origin (pick-up points) and destination points (deposit points) as a function of shifting time. This material-flow is subjected to day-work schedule prepared at the time when the warehouse was designed with using logistics facilities designing methods.

In fig. 5. (and in table 1.), to mark lines, the following letter symbols were used:

- *d* – a quantity of pallet load units moving between the warehouse ramp and the buffer on entry to the warehouse,
- *e* – a quantity of pallet load units moving between the buffer on entry to the warehouse and the storage area,
- *f* – a quantity of pallet load units on estuary of the storage area,
- *g* – a quantity of pallet load units on estuary of the storage area and dedicated to order-picking process,
- *c* – a quantity of pallet load units on estuary of the order-picking area,
- *a* – a quantity of pallet load units moving between the storage and the order-picking areas and the buffer on exit from the warehouse,
- *b* – a quantity of pallet load units moving between the buffer on exit from the warehouse and the warehouse ramp.

In fig. 5. some lines are horizontal. Reasons for that fact are: either the work schedule or the lack of availability of means of transport or lack of orders for the pallet load units transportation.

Looking at the example on lines *d* and *e* in fig. 5., it can be seen that pallet load units are unloaded from trucks just after substituting a vehicle to the ramp and put aside in the buffer at entry to the warehouse. Transporting them to the storage area starts one hour later, which is introduced in accordance with the schedule. It can be considered as wrongly prepared schedule. Tracing the graph in fig. 5. can determine where in the schedule errors occur. Moreover it may be helpful to exclude them.

As a result of further observations of the simulation model some more problems were found. Material-flow of pallet load units outgoing of the storage area and dedicated to order-picking process is not fully realised. Consequently a lack of complete realisation of the plan provided for one-day (actually two shifts) warehouse operation turned out. According to calculations in the logistics facilities designing method the quantity of these units should be 230 pallet load units, while the analysis of simulation shows 215 pallet load units. Therefore the question is what the situation would be if the material-flow in the warehouse would not be limited by the plan. In case of checking whether the problem of incomplete realisation of movement of pallet load units outgoing of the storage area and dedicated to order-picking process would occur, the following was done. Simulations were executed without the implementation of the daily realisation plan, and limited only by working time of logistics facility. It was decided not to include the graph, and the results are presented as the table. The results at 22:00 (Table 1.) allow to blame the schedule of warehouse processes for the lack of implementation of the plan. Of course, this is one of several reasons, but a very weighty one.

As a result of the research can also be noted that too many vehicles were designed (calculated). Arguments are provided in fig. 6 and table 2. (both in figure and in table some symbols are given; these are explained as: *T1* – pallet movers numbered in consecutive, *T2* – counterbalanced forklift trucks numbered in consecutive, *T3* – reach trucks numbered in consecutive; after each dot in mentioned symbol a successive number occurs). The utilization rate of transport is defined in accordance with the contents of the procedure set out below:

```
g:=(time_to_num(.MUs.Transporter1:1.statAvgLifeSpan)-
    7200);
    d:=time_to_num(.Models.Frame.Frame.SingleProc101.
    statFailTime);
    h:=time_to_num(.Models.Frame.Frame.SingleProc101.
    statPausingTime);
    i:=time_to_num(.Models.Frame.Frame.SingleProc101.
    statEmptyTime);
    Trucks Utilisation Percentage[1,1]:=((g-d-h)/g)*100;
```

Table 1. Material-flow values at the end of the workday at warehouse

Symbol consistent with the description of mean title 5.	The material-flow rate per day, resulting from the application of logistics facilities designing method; given in pallet load units	The material-flow rate per day, resulting from the simulation with material-flow realisation plan; given in pallet load units	The material-flow rate per day, resulting from the simulation without material-flow realisation plan; given in pallet load units
1	*2*	*3*	*4*
d	562	562	597
e	562	562	597
f	468	462	469
g	230	215	215
c	867	677	1214
b	1097	1076	1678
a	1097	1076	1455

T2.7. These are the counterbalanced forklift trucks transporting pallet load units between the storage area and the order-picking area. It was found that the majority of time these vehicles run empty or wait for an order, which raises concerns about designed quantity of means of transport (discussed in Kostrzewski (2009)).

A new tool, which is a bottlenecks analyser, is useful in the research. Using it, it was noted that the output buffer in the warehouse is full and locked. This fact can be observed already in the analysis of the diagram at fig. 5 and values listed in the table. 1. (line *g*). The results of the bottlenecks analyser are the confirmation. Using the bottlenecks analyser has shown that 14.40% of the time the output buffer is locked.

In addition, in the case of the warehouse workers, being "*unable*" to perform the tasks (objects are *fail*) was noted. It is related to the existence of physiological needs of people *etc*. It makes simulation models more realistic.

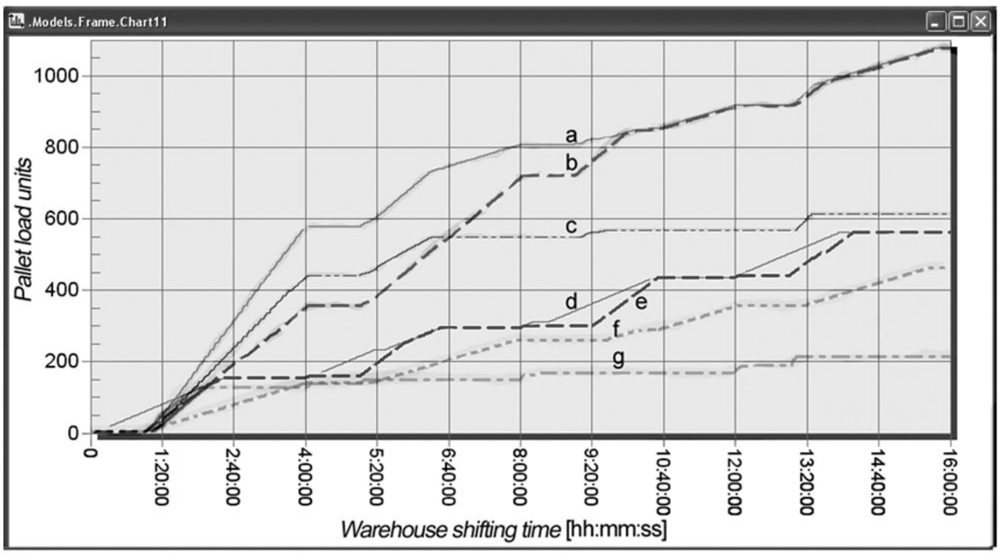

Fig. 5. Material-flow in warehouse in function of shifting time

Most likely to oversize, while using logistics facilities designing method, are vehicles with the lowest values of the utilisation indicator, *e.g. T2.6*,

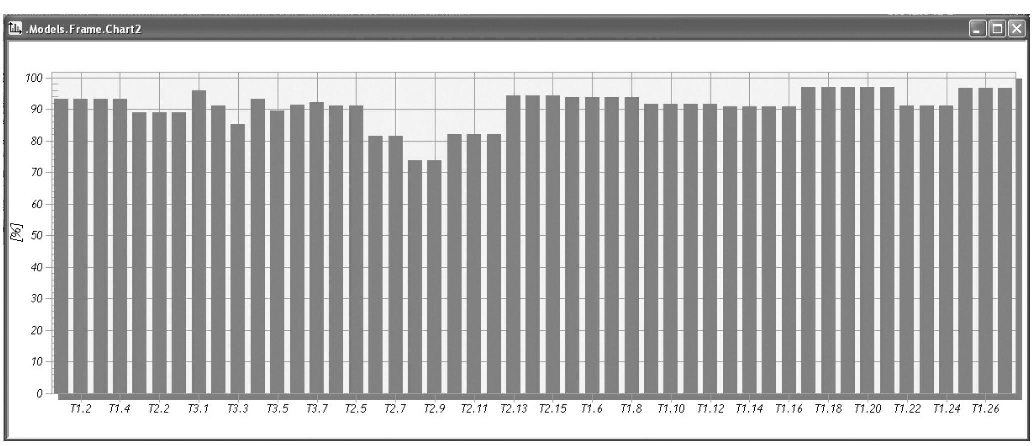

Fig. 6. Vehicles' utilization indicator values, [%]

Table 2. Tabular vehicles' utilization indicator values, [%]

Vehicle symbol	Vehicle indicator value, [%]	Vehicle symbol	Vehicle indicator value, [%]	Vehicle symbol	Vehicle indicator value, [%]	Vehicle symbol	Vehicle indicator value, [%]
1	*2*	*1*	*2*	*1*	*2*	*1*	*2*
T1.1	93,40	*T3.6*	91,51	*T2.14*	94,35	*T1.15*	90,95
T1.2	93,40	*T3.7*	92,26	*T2.15*	94,35	*T1.16*	90,95
T1.3	93,40	*T2.4*	91,29	*T1.5*	93,83	*T1.17*	97,15
T1.4	93,40	*T2.5*	91,29	*T1.6*	93,83	*T1.18*	97,15
T2.1	89,13	*T2.6*	81,54	*T1.7*	93,83	*T1.19*	97,15
T2.2	89,13	*T2.7*	81,54	*T1.8*	93,83	*T1.20*	97,15
T2.3	89,13	*T2.8*	73,76	*T1.9*	91,73	*T1.21*	97,15
T3.1	96,03	*T2.9*	73,76	*T1.10*	91,73	*T1.22*	91,12
T3.2	91,24	*T2.10*	82,02	*T1.11*	91,73	*T1.23*	91,12
T3.3	85,35	*T2.11*	82,02	*T1.12*	91,73	*T1.24*	91,12
T3.4	93,37	*T2.12*	82,02	*T1.13*	90,95	*T1.25*	96,72
T3.5	89,72	*T2.13*	94,35	*T1.14*	90,95	*T1.26*	96,72

T1 – pallet movers, *T2* – counterbalanced forklift trucks, *T3* – reach trucks

Apart from results mentioned above some other aspects of dynamics can be defined. In the paper simulation modelling is considered, however analytical one can be defined either.

In the paper the research of dynamics of the material-flow process in a warehouse is discussed. It can lead to analytical way of considering: how to define whether it is a dynamic process or not. The following basics of considerations way forward in the research are proposed – the full mathematical model for analytic way of research on dynamics in a logistics process is presented in Kostrzewski (2014a) and Kostrzewski (2014b).

A slope angle in case of a whole logistics process (which can give information about dynamics of a logistics process) can be counted as in formula (2).

$$\varphi(t) = \arctan\left(\frac{|u_J - u_0|}{t_J - t_0} \cdot \tau\right) \qquad (2)$$

where:

u_0 – a quantity of load units taking part in a logistics process at the beginning of a logistics process duration, [load unit],

u_J – a quantity of load units taking part in a logistics process at the end of a logistics process duration, [load unit],

t_0 – a beginning of a logistics process duration, [time unit],

t_J – duration of a logistics process, [time unit],

$\varphi(t)$ – a slope angle of a logistics process, [rad],

τ – units reducer,

$\tau \overset{const}{=} 1[\text{time unit/load unit}]$.

The results can be recognised as (the range of values are results of arctangent function graph): exceptionally rapid change in the dynamic of a logistics process in the case of: $\frac{\pi}{2} > \varphi_j(t) > \frac{7\pi}{16}$, very rapid change in the dynamic of a logistics process in the case of: $\frac{7\pi}{16} \geq \varphi_j(t) > \frac{3\pi}{8}$, rapid change in the dynamic of a logistics process in the case of: $\frac{3\pi}{8} \geq \varphi_j(t) > \frac{5\pi}{16}$, rather rapid change in the dynamic of a logistics process in the case of: $\frac{5\pi}{16} \geq \varphi_j(t) > \frac{\pi}{4}$, no change in the dynamic of a logistics process in the case of: $\varphi_j(t) = \frac{\pi}{4}$ (the border value of dynamics in a logistics process), rather slow change in the dynamic of a logistics process in the case of: $\frac{\pi}{4} > \varphi_j(t) \geq \frac{3\pi}{16}$, slow change in the dynamic of a logistics process in the case of: $\frac{3\pi}{16} > \varphi_j(t) \geq \frac{\pi}{8}$, very slow change in the dynamic of a logistics process in the case of: $\frac{\pi}{8} > \varphi_j(t) \geq \frac{\pi}{16}$, exceptionally slow change in the dynamic of a logistics process $\frac{\pi}{16} > \varphi_j(t) > 0$ and at last no dynamics in a logistics process in the case of: $\varphi_j(t) = 0$.

The example calculation and statement of dynamics is as follow. In order to state rate of change for line *a* in fig. 5., it can be calculated as:

$$\varphi^a(t) = \arctan\left(\frac{1097[\text{plu}] - 0[\text{plu}]}{960[\text{min}] - 0[\text{min}]} \cdot 1\left[\frac{\text{min}}{\text{plu}}\right]\right) = 0.85190179 .$$

Since $\varphi^a(t) \in \left(\frac{\pi}{4}; \frac{5\pi}{16}\right\rangle$, it can be said that it is rather rapid change in the dynamic of *a*-logistics process. However the value is as close to border value $45° = \frac{\pi}{4}$ that it needs further research and definitions.

6. CONCLUSIONS

The simulation study of using of material-flow in a warehouse revealed inaccuracies and omissions made in the stage of logistics facilities designing methods. It was found that the output buffer of the warehouse is loaded. Moreover it was noted that inadvertently in the warehouse design too many means of transport were calculated. And finally in the designed warehouse about 2% of a material-flow plan of pallet load units cannot be subject of execution by a group of warehouse processes (which has been inferred from the last line of table 1.). These inaccuracies are related to the oversight that occurred in the warehouse design creation. Beside that, performance of any entity in the facility depends on the performers of others. Contrary to appearances, a message is not that the warehouse designer should be seen in a negative light. Neither application of logistics facilities designing methods should be denied. The usage of simulation tools does not preclude traditional designing way, which has been emphasized in particular in fig. 2. Ashayeri and Gelders (1985) drew the conclusion that analytic designing of logistics facilities is not enough. At the same time a logistics facility – after making an analytic design of it – should be implemented as a simulation model. It was also the subject of debate with exactly the similar findings in Kostrzewski (2009). The importance of evaluating a designed warehouse through the use of simulation studies next to an analytical evaluation was repeatedly suggested. The usage of planning and simulation models can help to identify optimisation potential in terms of throughput, cycle times, transporters and vehicles utilization or warehousing equipment and infrastructure utilization *et cetera*. Simulation, even a discrete-event one, can help to map in details the dynamic behaviour of a complex system. Scenarios can be built, either by simulation or other modelling, to consider a series of different situations in which the flexibility of the design can be tested. These scenarios may include for example alternative growth forecasts, changes in order profiles, and abnormal peak requirements. It should also be noted that the researched warehouse design has been optimised through the use of the simulation model, which was discussed in Kostrzewski (2009). Nevertheless, the simulation model used in case of this research "*comes*" from pre-optimisation phase (it was done on purpose). The simulation model designed for the warehouse design is not only momentaneous *i.e.* using the opportunity to verify the design of the warehouse. It can also be used in case of short-period planning. The increase in orders is often noticeable for several consecutive days. Inevitably, this has an impact on the work of the warehouse.

Simulation tool allows moving each employee into the virtual world of the warehouse, which is a simulation model. This allows the store manager or other decision-maker to be able to immediately identify bottlenecks that can occur in a given period and to take measures to avoid them. In addition, it is possible to make short-term changes in productivity of workers, vehicles and infrastructure components.

In the simulation model an information-flow should be also developed. This has not been done. The task is time-consuming – and indeed so is the construction of each of simulation models so that they correspond with the actual conditions.

Moreover a simulation tool is good enough to educate students or workers. It enables a student or worker to transfer manufacturing and material handling concepts into working computer simulations that test validity of their concepts and verify effectiveness of classroom or factory instruction.

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