APPLICATION OF SIMULATION METHOD IN ANALYSIS OF ORDER-PICKING PROCESSES IN A HIGH-RACK WAREHOUSE

Mariusz Kostrzewski*

* Transport Faculty, Warsaw University of Technology, Warsaw, 00-662, Poland,
Email: markos@wt.pw.edu.pl

Abstract. The aim of this paper is to discuss and explain the use of simulation methods in basic research on the most complicated type of processes in internal logistics, namely order-picking process, in case of high-rack warehouse(s). The research was conducted for randomised orders in picking lists. The analysis in the paper leads to determination whether the gained samples of data could be assigned as any theoretical probability distribution. By the name "samples of data", time durations of entire order-picking processes are understood. In order to study these processes, a simulation model was developed. The model was validated in order to compare its performance with classic method of order-picking time calculation in engineering practice. The simulation model considered in the paper was developed in accordance with guidelines of Discrete Event System Specification (DEVS) structure. The simulation tool used to build and analyse the simulation model was Plant Simulation 10.1.

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1. INTRODUCTION

Defining after Banks (1998, 1999) and Banks, Carson, Nelson & Nicol (2000), a simulation is an imitation of systems and processes occurring in reality. Pfohl (1998, p. 330) defines simulation as imitation of dynamic process taking place in a system by using a suitable experimenting model to obtain information that are possible to transfer in the reality. These and many other definitions of a simulation indicate that it is an imitation of reality. It is important to adopt appropriate assumptions that „imitation" was adequate to „reality", which will be discussed later in the paper.

Many aims of simulations implementing in logistics may be specified. Kuhn (1987, p. 35) and Pfohl (1998, p. 333) distinguished the following four possible groups of uses: planning, process control, training and at least research and development. The planning group includes: systems that are executed with a small effort for entry data compilation (e.g. diagnoses of quantity of vehicles or other means of transport, which are needed to operate the system), systems that are executed with a big effort for entry data compilation (e.g. simulations or warehouses operating), universal simulation models (e.g. overall simulation models including combination of logistics areas) or special simulation models (e.g. route planning). In terms of process control there may be issues as: process control oriented to a user and in this case mentioned authors propose division on simulations accompanying a process (e.g. bottlenecks analysing in a workplace) and process control associated with a product (in the last one authors include: transfer strategies control simulation e.g. control strategies vehicles, and systems trials and tests e.g. control of connected systems). Simulation can be used as a pedagogical device to reinforce analytic solution methodologies, therefore another group is training, which is divided into: simulations of the process (e.g. a planning tool) and interactions with failures (e.g. warehouse planning, dispatcher position function teaching). The last group is the research and development, within an empirical studies (e.g. studies of possibilities of a project), technical simulation (e.g. identification of indicators) and requirements for robots (e.g. an analyses of sensors) can be specified.

Simulation methods and so does simulation models need data, sometimes lots of data. If no data are available, not even estimated, simulation must not be treated as advising tool. The ability to verify and validate a simulation model are the important rules of simulation methods. If there is not enough time or if personnel, which can help to prepare adequate simulation model, is not available, a simulation method is not appropriate. If managers of a company that need an answer about prediction based on simulation methods have unreasonable expectations, simulation might not be appropriate.

The simulation model, deliberated in the paper, has been prepared for the order-picking process within the storage area of high-bay warehouse. To be more precisely, the model simulates chosen operation of the picking process i.e. picking products from decomposed pallet load units and the completion picked products into new pallet unit load according to order-picking orders' lists. The research was conducted for randomised orders in order-picking lists, which makes the process closer or direct to real-world warehouse operating, which – as an assumption – will be subject to detailed discussion later in this work. According to Alicke, Arnold, Knöss & Töpfer (2011) and Ulbrich, Galka & Günthner (2007), the process of order-picking is considered as one of the most important issues of internal logistics due to the fact that it involves the most resources among all processes. Other authors estimate the costs of order-picking process referenced to the total cost of a warehouse i.e.: 55% according to Tompkins, White, Bozer, Frazelle, Tanchoco & Trevino (2003) or 65% according to Coyle, Bardi & Langley (1996, 2007).

One of the aim of this paper is to discuss and explain the use of simulation methods in basic research on the most complicated type of processes in internal logistics, namely order-picking process, in case of high-rack warehouse(s). The research was conducted for randomised orders in picking lists. The analysis in the paper leads to determination whether the gained samples of data could be assigned as any theoretical probability distribution. In the paper, as an effect of a process of order-picking modelling, correlation of physical objects (connected to infrastructure of a high-bay warehouse, equipment and means of transport) occurring in the storage system are presented. It is done due to ultimately ensure the achievement of the objectives and aims of planned system. In addition, sensitivity parameters of the system in case of describing the impact of systems' changes on the objectives of the system were subjected into consideration (where rack stackers, fork-lift trucks or conveyors failures, problems related to the human factor etc. are understood by a possible change).

While groups of simulation uses are discussed, the paper concerns "planning group". And taking into consideration the structure that is described above a "special simulation model" is described here.

2. RESEARCH METHOD AND SOFTWARE IMPLEMENTATION

Simulation models are generally used when it is impossible or very difficult to obtain analytical solution of given problems. These applies, for example, analyses of dynamic behaviour of logistics systems and logistics processes. As mentioned above, simulation methods were used in this research. The procedure used to implement a problem connected to material flows in warehouses into simulation methods is given in Kostrzewski (2013, p. 273), therefore its description is omitted in the paper. The basic contents of simulation theory are also omitted here – these are referred in Korzeń (1998), which identified the main types of simulation, the advantages and disadvantages of using simulation methods and simulation models.

There are various software tools for the construction and analysis of simulation models. From the point of view of logistics or production, simulation packages of the largest usefulness are characterised by the fact that its operating structure uses the concept of modular graphic implementation (Kostrzewski, 2009, p. 87), and modelling occurs as a series of discrete events (Carson, 1993). Among this type of software, the following can be distinguished: Dosimis-3 – often used in studies of logistics: Bukowski & Karkula (2003), Grabara & Kot (2001), Grabara, Dima, Kot & Kwiatkowska (2011), Karkula (2014), Karkula & Bukowski (2012), Karkula, Jurczyk & Bukowski (2012), and production: Kubiński, Kubińska-Jabcoń & Niekurzak (2012), Arena - this software may be used to model different systems and processes, including business and manufacturing processes, for example as the one given in: Kelton, Sadowski & Sturrock (2007), Automode – software can be used for modeling mainly to the production and manufacture: Chen & Jiang (2011), Promodel – software may be used for modelling manufacturing, logistics and storage, e.g. in: Harrell & Price (2002), Quest, Witness, Mosys, Taylor, Enterprise Dynamics FlexSim – e.g. in: Gelenbe & Guennouni (1991), and finally Tecnomatix Plant Simulation, used in studies of logistics: Karkula (2013), Kostrzewski (2013), Ulbrich, Galka & Günthner (2010) and production: Danilczuk, Cechowicz & Gola (2014), Kłos & Kuc (2015). Tecnomatix Plant Simulation in recent years is becoming widely used in scientific research and industrial applications, mainly in logistics and production. The last software is used in the research described below.

3. RESEARCH PROCEDURE AND SIMULATION MODEL

Diagram of procedure for the use of simulation methods in research on material-flows in warehouses is given and precisely described in Kostrzewski (2013, p. 273), and is based on Bangsow (2012). The analysis of warehouse design methods described in Kostrzewski (2014) were used for the procedure development.

Simulation model, depending on the characteristics or attributes of model describing state of a system in a moment or period of time, can be divided into four types: dynamic, static, stochastic, deterministic; based on Zeigler (1976) and Zeigler (1984, pp. 46–48). Simulation model considered in the paper has been developed in accordance with the guidelines and specifications of the discrete event system structure (DEVS) detailed in Zeigler (1976) and Zeigler (1984).

This model allows to generate any number of orders which aim is order-picking process (for the purpose of this research was initiated 100 orders per each simulation model execution). The number of rows in each of orders is $w = 6$ (it is the number of products) each, and the number of items per one line of order is between $p = 1 \div 12$ (it is a number of items in case of any kind of products). It differs on validation fulfilling; in the validation case: $w = 4$ and $p = 1 \div 10$. Orders are generated as a result of the initiation of the *Generate orders* procedure. The procedure inputs stochastic orders into the *Orders* table. Its position assign values for each of the 6 products in each of a hundred orders. While to generate a number of product items per single order line a discrete uniform distribution was used. It was decided to use this distribution because it is used when all the values from minimum to maximum are equal. It is a discrete uniform distribution in case of which the equal probability is assigned to *n* different real numbers $k_1, \ldots, k_n$, and it was assumed that $k_1, \ldots, k_n$ are all integers in the range from 1 to 12 (or from 1 to 10 in case of simulation model validation). That was conducted for randomised orders in picking lists and following this, it served to make simulation model more adequate to real-world warehouse operating.

In the real process there might occurs unpredicted events such as running down-time, failures, physiological needs, etc. Therefore, availability of means of transport in the model and availability of other devices are at the level 90%.

Other specific parameters and limitations were introduced:

- cycle times taken after the *Method Time Measurement* standards,
- the length of the aisle: $L = 130$ [m],
- the mean value of means of transport velocity: $F_1 = 0{,}0079$ [min/m],
- the number of rows in order-picking orders list (the number of products in assortment): $w = 6$,
- the numbers of products' items to be picked – diverse from 1 to 12, $p \in \{1, 12\}$, $p \in$ N,
- the problem is dealt with within a single aisle.

4. SIMULATION MODEL VALIDATION

Before proceeding to experimentation on a simulation model, its validation was made. A validation means decision whether a simulation model prepared in computing environment has a sufficient level of accuracy in its field of application, Karkula (2012, p. 718).

In the case of the simulation model used in this research, a validation was used to inspect and verify whether the results obtained from the model are consistent with calculations executed by engineering methods that are precisely described in Fijałkowski (1995) and Fijałkowski (2002).

The validation was performed by testing of simulation model with fixed values of the parameter p and compared their mean values (separately for p = 1, p = 2, …) with the values executed by engineering methods. It can be assumed that the results are comparable at the level of 96.26% (taken into account the percentage difference of the highest value – Table 1, column 4, line 1). A validation type applied here is event validity: events generated in the simulation model are compared with events taking place in the analytical model, according to Karkula (2012, p. 719).

Table 1. Comparison of calculations and its results in the context of the model validation

p	t_{ckom} **[min] (order-picking process time executed by engineering methods)**	t_{ckom} **[min] (mean value of order-picking process time sample executed by simulation model)**	**Difference between the columns 2 and 3 [%]**	***p***	t_{ckom} **[min] (order-picking process time executed by engineering methods)**	t_{ckom} **[min] (mean value of order-picking process time sample executed by simulation model)**	**Difference between the columns 2 and 3 [%]**
1	7.6031	7.898439337	3.74	**6**	27.6031	26.658312960	-3.54
2	11.6031	11.729403000	1.08	**7**	31.6031	31.839987520	0.74
3	15.6031	15.915816900	1.96	**8**	35.6031	35.189118640	-1.18
4	19.6031	19.738881680	0.69	**9**	39.6031	39.746780570	0.36
5	23.6031	23.719924330	0.49	**10**	43.6031	43.719924330	0.27

Table 2. Basic statistical parameters determined by the *DataFit* tool in *Plant Simulation* software

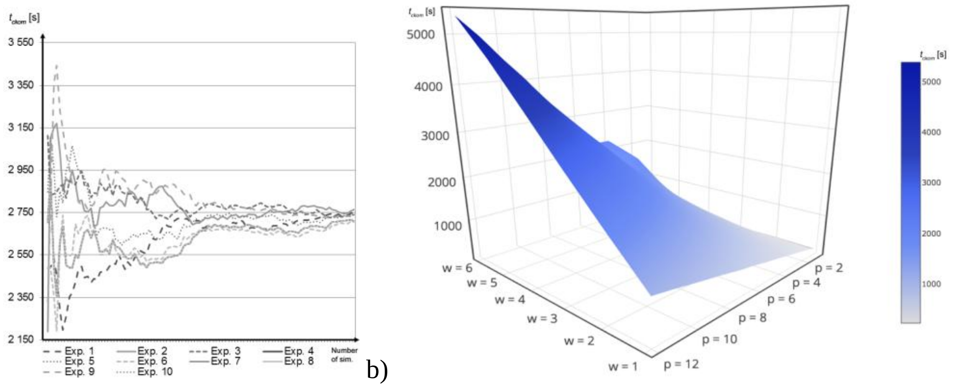
Parameter [min]	**The values - experiment No.**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Min-value	2195.93	2189.23	2719.67	2358.04	2594.75	2191.07	2358.04	2358.04	2327.09	2358.04
Max-value	2746.78	3170.67	3113.40	2914.81	3101.46	2737.52	2914.81	2914.81	3443.82	2914.81
Mean value	2621.42	2781.28	2792.96	2627.24	2728.48	2622.71	2627.24	2627.24	2822.32	2627.24
Mode	2694.70	2754.51	2784.43	2685.88	2714.30	2669.13	2685.88	2685.88	2762.13	2685.88
Standard dev.	124.40	102.98	61.73	80.23	95.63	77.67	80.23	80.23	129.33	80.23
Va-riance	15477.0	10605.6	3811.26	6436.66	9145.53	6032.95	6436.66	6436.66	16725.3	6436.66
Lower quartile	2516.25	2739.63	2747.82	2556.09	2670.90	2578.90	2556.09	2556.09	2756.64	2556.09
Median	2681.46	2764.03	2777.15	2663.18	2718.16	2650.85	2663.19	2663.19	2788.51	2663.19
Upper quartile	2711.26	2802.91	2831.88	2683.83	2736.58	2669.04	2683.83	2683.83	2872.71	2683.83
Skewn.	-1.20	-0.40	1.82	-0.32	1.85	-2.21	-0.32	-0.32	1.75	-0.32
Kurtos.	0.71	13.07	5.64	0.98	3.64	8.57	0.98	0.98	8.97	0.98
Coef. of variat.	0.05	0.04	0.02	0.03	0.06	0.03	0.03	0.03	0.05	0.03

5. RESULTS AND CONCLUSION

As it was previously mentioned, the analysis in the paper leads to determination whether the gained samples of data could be assigned as any theoretical probability distribution, such as continuous distributions: uniform, triangular, negative exponential, Erlang, gamma, Weibull, normal, lognormal, beta or discrete distributions: uniform, binomial, geometric and Poisson. For checking the eventuality, three test were used in the analysis: Chi-kwadrat test, Kolmogorov-Smirnov test and Anderson-Darling test. 10 simulation experiments were done. Every of them consisted of 100 orders for order-picking. Statistical parameters for every experiments are exposed in Table 2. The results were obtained at a significance level of 0.05.

Table 3. Comparison of calculations and its results in the context of the model validation

Trend line	**Exp. 1**	**Exp. 2**	***Exp. 3***	**Exp. 4**	**Exp. 5**
linear	y=3.6237x+2438.4 R^2 = 0.7141	y=-1.1327x+2838.5 R^2 = 0.1018	y=-1.5519x+2871.3 R^2 = 0.5319	y=1.6127x+2545.8 R^2 = 0.3401	y=-0.9411x+2776.0 R^2 = 0.0815
logari thmic	y=113.15lnx+2209.9 R^2 = 0.7124	y=-35.01lnx+2908.6 R^2 = 0.0995	y=-53.63lnx+2988 R^2 = 0.65	y=32.77lnx+2508.1 R^2 = 0.1437	y=-54.02lnx+2925.0 R^2 = 0.2748
polyn omial	y=-0.0567x^2+ +9.3529x +2341.0 R^2 = 0.8307	y=0.0311x^2- +4.2746x+2891.9 R^2 = 0.0153	y=0.0251x^2- +4.0859x+2914.4 R^2 = 0.6245	y=0.0175x^2- +0.1577x+2575.9 R^2 = 0.3668	y=0.0679x^2- +7.8018x+2892.6 R^2 = 0.3645
power series	y=2228.4$x^{0.0443}$ R^2 = 0.7052	y=2888.7$x^{-0.0106}$ R^2 = 0.0681	y=2990.5$x^{-0.0189}$ R^2 = 0.6505	y=2505.7$x^{-0.0129}$ R^2 = 0.1516	y=2920.3$x^{-0.0188}$ R^2 = 0.2645
expot ential	y=2438.1$e^{0.0014x}$ R^2 = 0.6996	y=2832.3$e^{-0.0004x}$ R^2 = 0.8528	y=2870.8$e^{-0.0004x}$ R^2 = 0.5395	y=2544.7$e^{-0.0006x}$ R^2 = 0.3461	y=2771.3$e^{-0.0003x}$ R^2 = 0.0744
Trend line	**Exp. 6**	**Exp. 7**	**Exp. 8**	**Exp. 9**	**Exp. 10**
linear	y=1.5167x+2546.1 R^2 = 0.3209	y=1.5617x+2545.8 R^2 = 0.3401	y=1.6127x+2545.8 R^2 = 0.3401	y=-2.5167x+2949.4 R^2 = 0.3187	y=1.6127x+2545.8 R^2 = 0.3401
logari thmic	y=48.87lnx+2444.9 R^2 = 0.3410	y=32.77nx+2508.1 R^2 = 0.1437	y=32.77lnx+2508.1 R^2 = 0.1437	y=-68.28lnx+3070.7 R^2 = 0.2401	y=32.77nx+2508.1 R^2 = 0.1437
polyn omial	y=-0.0058x^2+ +2.1064x+2536.1 R^2 = 0.3241	y=-0.0175x^2- +0.1577x+2575.9 R^2 = 0.3668	y=0.0175x^2- +0.1577x+2575.9 R^2 = 0.3668	y=0.0144x^2- +3.9687x+2974.1 R^2 = 0.3257	y=-0.0175x^2- +0.1577x+2575.9 R^2 = 0.3668
power series	y=2443.5x^0.0193 R^2 = 0.3409	y=2505.7x^0.0129 R^2 = 0.1516	y=2505.7x^0.0129 R^2 = 0.1516	y=3055.2x^-0.0221 R^2 = 0.2126	y=2505.7x^0.0129 R^2 = 0.1516
expot ential	y=2544.2e^0.0006x R^2 = 0.3135	y=2544.7e^0.0006x R^2 = 0.3461	y=2544.7e^0.0006x R^2 = 0.3461	y=2943.6e^0.0009x R^2 = 0.3105	y=2544.7e^0.0006x R^2 = 0.3461



a) b)

Fig. 1. a) Plot lines of sets of data in case of each experiment; b) The impact of *w* and *p* parameters values on the duration time of order-picking process

None of compatibility testing has not demonstrated compliance with the theoretical probability distributions.

Plot of data are presented in Fig. 1a. and trends line for every set of data (by set of data one experiment is understood) are given in Table 3.

At last part of the research, the set of simulations were done for every combination of *w* and *p* parameters. The surface chart for the purpose of presenting data is given in Fig. 1b. This was done to present the effect of order-picking process time increasing with growth of the number of products being operate in the warehouse and the number of products items being picked in the process.

What is interesting, the plot reminds "saddle" with two extremes falling ($w = 1$, $p = 12$, and $p = 1$, $w = 6$) and with two extremes ascending ($w = 6$, $p = 12$, and $p = 1$, $w = 1$). It is worth of further research. This research gives effects obtained in one aisle only. In future simulation model for complete warehouse will be generated. Furthermore, identification of critical nodes in logistics facility, so called "bottlenecks", will be researched and described.

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BIOGRAPHICAL NOTES

Mariusz Kostrzewski is an Assistant Professor in the Transport Faculty, Warsaw University of Technology. He teaches strenght of materials, basics of mechanical engineering, descriptive geometry, technical drawing, intellectual property protection and techniques of presentation. Scientific activities of him are connected to logistics systems designing, monitoring and analysing of technical state of rail-vehicles and track settlement. He worked in 4 projects and 5 grants. He prepared so

far more than 40 papers in numerous journals and his publication can be found in Web of Science. He was awarded in 2006, 2013, 2015 for scientific research. Currently, he implements innovative forms of education in the WUT within he realises animations and performs prototypes with students. He is more interested in seeking new questions than finding final answers.