# APPLICATION OF SIMULATION TECHNIQUES IN LOGISTICS SYSTEMS DESIGN USING A CASE STUDY OF WAREHOUSE FACILITIES

JACYNA Marianna[1], WASIAK Mariusz[2]

*Warsaw University of Technology, Faculty of Transport, Warsaw, Poland, EU*
[1]maja@wt.pw.edu.pl, [2]mwa@wt.pw.edu.pl

**Abstract**

The effectiveness of simulation techniques in the design of logistics systems is becoming increasingly emphasized nowadays. With this in mind, a system design procedure, including simulation research, is proposed in this article. An important element of the developed procedure is the generation of the initial solution using classical design and optimization methods. This allowed us to obtain a solution from the decision maker which meets accepted functional and efficiency criteria for a tested logistics system. The application of this developed procedure is illustrated in the research project SIMMAG3D. A description of the created model was provided following the literature review of methods used to support logistics systems design and selected tools for simulation research of logistics processes. Analysis of the literature review shows that the current approaches turn out to be insufficient, especially when implemented separately.

**Keywords:** Modeling, simulation research, SIMMAG3D

## 1. INTRODUCTION

Currently, simulation research is a crucial element in system design and implementing changes within these systems. IT tools for simulation and visualization of logistics processes are considered essential in procedures by many researchers for the analysis and evaluation of a suggested logistics design option (see [3], [15], [17]). Application of the appropriate IT systems significantly improves logistician, analyst and designer work. This allows for the result analysis of decisions made in complex systems with variable parameters. While decisions are not made by the simulation, they do provide essential knowledge about system behavior during various disruptions.

Due to the high cost and length of time associated with creating and reorganizing logistics systems, extensive knowledge about the effects of implemented changes in such dynamic and rapidly changing surroundings is required. Therefore, simulation studies which allow us to predict the outcomes of decision making in hypothetical situations are particularly important. Unreliability of information and emergency situations are also taken into account in this type of research. In addition, by taking into consideration many different project design options for a specific logistical system, it is possible to choose the best option and improve upon it.

A procedure for logistics system design along with simulation research is presented in this article. This procedure may be applied to the design of logistical systems, including, for example, micro, mezzo and macro scale systems. The application of this procedure and simulation is demonstrated using the SIMMAG3D research project.

## 2. PURPOSE AND SCOPE OF CREATING SIMULATION MODELS

In theory, the definition of a system is very broad and may refer to many various fragments of our reality, including the flow of material goods and logistics systems [18]. Elements and relationships defined in a system must ensure a possibility of carrying out specific functions resulting in the completion of its objective. The main goal of a logistical system is completing the conversion of cargo steams and their associated information streams on their path from the production site to the place of consumption [14].

It is crucial to create extremely precise models while analyzing existing or designing new logistical system structures on account of the fact that process completion is complex and determined by many technical, technological, organizational, economic and ecological factors.

Utilizing computer technology, it is possible to study the behavior of a created logistical system model under various conditions. The simulation allows us to observe how the analyzed system will respond in a given situation and accurately predict the result of decisions under certain conditions. The simulation method should be applied if it is not possible to use analytical methods. Therefore, simulation methods are particularly useful for studying complex systems, including logistical systems [18].

Furthermore, when considering uncertain information, it is appropriate to perform simulation studies for proposed and existing logistics systems because it is unfeasible to develop analytical relationships concerning the theory of mass service for complex systems (see [12], [14]).

The simulation model enables us to track the process in a certain system and obtain information that can be transferred over to reality [9]. Hence, this model is especially useful in determining the results of various decisions during logistics system development, analysis of current solutions and management [12].

Simulation methods are divided into two categories, fixed step and random, based on the way the simulation is performed [7], [12]. In the fixed step method, the simulations are completed periodically, whereas in the random method, they are only performed in moments of defined occurrences. Thanks to this, the effectiveness of the chance method calculation is usually significantly higher [12].

Furthermore, we can determine answers to research questions by: a complete review, undirected random search, directed random search, systematic search along consecutive coordinates, directed systematic search or heuristic search.

We can include the following as common goals of creating logistics system simulation models [12]:

- To determine a qualitative / quantitative influence of selected factors on system operation
- To establish values of specific functional characteristics of the system
- To compare alternative systems or factors under certain conditions or choose the best system option from a set of options.

## 3. PROCEDURE OF WAREHOUSE DESIGN TAKING INTO ACCOUNT SIMULATION RESEARCH

Designing logistics systems may pertain to new or existing systems. In the latter case, new solutions ensuring system adaptation to changing circumstances are sought out. When the design process concerns an existing warehouse, detailed information about its operation is available and can be obtained with the help of WMS software. However, in the case of new facilities, references should be made to their position in the logistics network, the resulting connections and intended flow of materials. A simplified procedure of new and existing logistics system design is presented in **Figure 1**.

According to this figure, simulation research must be performed after identifying the tasks which must be completed by the logistics system and creating a variant solution design.

In order to accomplish this, a simulation model must be created. They can be developed by using one of the tools available on the market (see point no. 5) or by applying an original program for warehouse process simulation, as was done in the SIMMAG3D project. Following a positive assessment of results from the simulation experiments, it is possible to implement the design solutions into economic practice. Additionally, the best solution obtained with the help of analytical methods may be improved during simulation research according to the developed procedure.

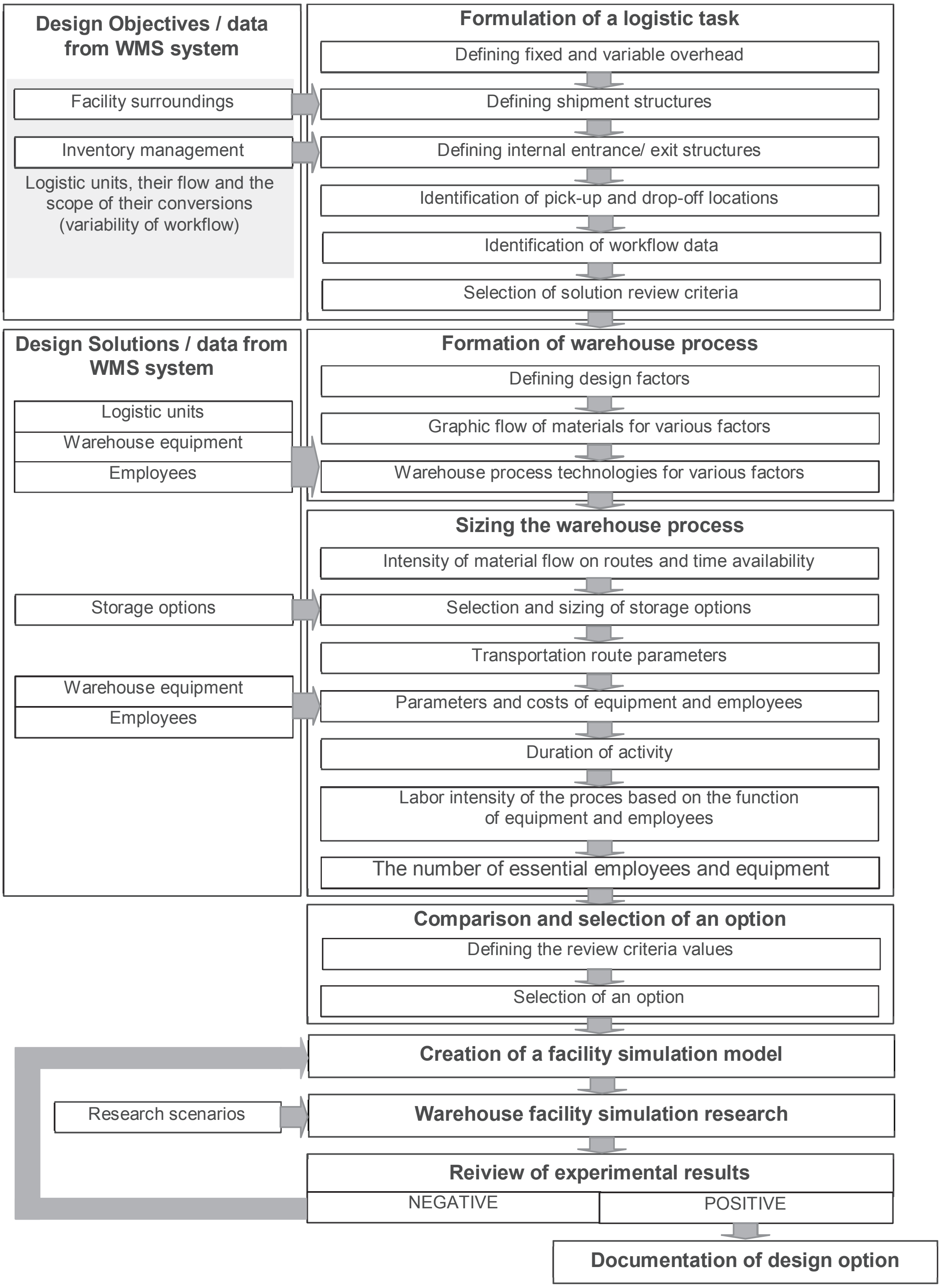


**Figure 1** Procedure for Warehouse Facility Design (own elaboration)

## 4. GENERAL ASSUMPTIONS OF WAREHOUSE FACILITIES SIMULATION MODEL

It is accepted that the created simulation model will allow the movement of individual loading units in a logistical facility to be reflected. In order to achieve this, it is necessary to consider the model's technical resources, the technical, operational and economical characteristics and the occupations of employees. The visualization of the state of the warehouse facility will be ensured by reflecting the occupation status of individual locations through unit loads. Unit loads serviced by a given facility may vary by size, mass, color and other cargo characteristics, which may depend on capability and requirements on many levels of detail, from material groups to SKU. The types of loading units are defined in the set $\boldsymbol{R} = \{r : r = 1,...,\overline{R}\}$, and individual unit loads in sets are defined as $\boldsymbol{N}(r) = \{n(r) : n(r) = 1,...,\overline{N(r)}\}, r \in \boldsymbol{R}$. In the warehouse facility, unit loads undergo various conversions which can be classified based on location, time and state. The number of individual conversions are defined in the set as $\boldsymbol{P} = \{p : p = 1,...,\overline{P}\}$. The aforementioned conversions result from internal orders which are initiated by recipient orders or stock replacement processes. As part of the internal orders $\boldsymbol{Z} = \{z : z = 1,...,\overline{Z}\}$ defined loading units $\boldsymbol{N}(r,z) = \{n(r) \in \boldsymbol{N}(r) : \lambda 1(n(r)) = 1\}, r \in \boldsymbol{R}(z), z \in \boldsymbol{Z}$ of individual types $\boldsymbol{R}(z) = \{r \in \boldsymbol{R} : \lambda(r) = 1\}, z \in \boldsymbol{Z}$ undergo certain conversions $\boldsymbol{P}(z) = \{p \in \boldsymbol{P} : \lambda 2(p) = 1\}, z \in \boldsymbol{Z}$. Internal orders defined in this way reflect the logistical objective of a given warehouse facility. Completion of logistic objectives requires, with specified performance criteria, commitment of certain work crews (material and human resources) in established areas of the warehouse facility. These types of crews are defined in the set $\boldsymbol{ZP} = \{zp : zp = 1,...,\overline{ZP}\}$ and the number of individual crews are denoted as $\boldsymbol{M}(zp) = \{m(zp) : m(zp) = 1,...,\overline{M(zp)}\}, zp \in \boldsymbol{ZP}$.

Moreover, there are functional areas in a warehouse facility, such as zones, locations and connections between them. Both logistics facility resources and its structural elements have defined characteristics, for example, fixed cost and variable cost indicators of labor, technical readiness indicator, unit costs of servicing logistical units in individual elements of a logistics facility and capacity. Additionally, logistic tasks are completed by taking into account defined principles, including the choice of storage location, choice of labor resources, etc.

It should be noted that both requests to service unit loads in a warehouse facility and the conversion processes of the units themselves are dependent on time. The number of analyzed time of work at a warehouse facility is denoted in the set $\boldsymbol{T} = \{t : t = 1,...,\overline{T}\}$. The state of the warehouse facility is related back to individual moments in time, and the state of the warehouse facility is determined by the state of its individual elements. As it was already established, these elements are logistic units and work crews. The state of the $n(r)$th logistic unit of the $r$th kind at time $t$ is denoted by the symbol $x(r,n(r),t)$ and the state of the $m(zp)$ th work crew of the $zp$th kind at time $t$ is denoted as $y(zp,m(zp),t)$. Therefore, the sate of a warehouse facility at time $t$ is defined as follows:

$$\mathbf{X}(r,t) = \left[x(r,1,t) \quad (...) \quad x(r,n(r),t) \quad (...) \quad x(r,\overline{N(r)},t)\right] \tag{1}$$

$$\mathbf{Y}(zp,t) = \left[Y(zp,1,t) \quad (...) \quad Y(zp,m(zp),t) \quad (...) \quad Y(zp,\overline{M(zp)},t)\right] \tag{2}$$

$$\mathbf{X}(t) = \begin{bmatrix} \mathbf{X}(1,t) \\ (...) \\ \mathbf{X}(r,t) \\ (...) \\ \mathbf{X}(\overline{R},t) \end{bmatrix} \tag{3}$$

$$\mathbf{Y}(t) = \begin{bmatrix} \mathbf{Y}(1,t) \\ (...) \\ \mathbf{Y}(zp,t) \\ (...) \\ \mathbf{Y}(\overline{ZP},t) \end{bmatrix} \tag{4}$$

$$\mathbf{SO}(t) = \left[\mathbf{X}(t), \mathbf{Y}(t)\right] \tag{5}$$

The state of the system at time $t$ results from its previous state, previously generated internal orders $\boldsymbol{Z}(t-1)=\{z \in \boldsymbol{Z}: \tau(z)=1\}, t \in \boldsymbol{T}$, as well as disturbances occurring at time $t$ $\boldsymbol{A}(t)=\{a(t): a(t)=1, \ldots, \overline{A(t)}\}, t \in \boldsymbol{T}$. Given this, and looking beyond the general definition of the process as a series of consecutive changes to the state of a system, the warehouse process is denoted in the following way:

$$\mathbf{SO}(t)=f(\mathbf{SO}(t-1), \boldsymbol{Z}(t-1), \boldsymbol{A}(t)), t \in \boldsymbol{T} \quad (6)$$

## 5. SELECTED COMPUTER TECHNIQUES FOR LOGISTICS SYSTEM RESEARCH

Many suggestions for designing logistics systems using simulation research applications can be found in literature on this subject ([1], [2], [7], [12], [17], [18], [19]). It is possible to observe and track changes in system productivity, resources within the system and labor organization with the help of this type of research. This, in turn, allows us to appropriately select elements for equipping the facility.

Some specialized applications for simulation research mentioned in the literature are ([9], [16]): **DYNAMO** (DYNAmic MOdels) developed in 1959-1986 [4]; **EXTENDSIM** (formerly Extend) [10], [www.extendsim.com]; **GPSS** (General Purpose Simulation System) [www.minutemansoftware.com]; **SIMPLE** (Simulation of Industrial Management Problems with Lots of Equations) the first programming language used to convert model solutions into machine code [6]; **SIMSCRIPT** [www.simscript.com/about/]; **SIMULA** (SIMUlation LAnguage) developed until 1967 the first object- oriented programming language (Simula I, Simula 67) [11]; **SIMULINK** serves to perform computer simulations as a MATLAB numerical suite [www.mathworks.com/products/simulink/]; **SLAM** (Simulation Language for Alternative Modeling) [13]; **STELLA** (Systems Thinking, Experimental Learning Laboratory with Animation, also known as iThink) [4], [www.iseesystems.com/store/products/stella-architect.aspx]; **VENSIM** [https://vensim.com/].

Another well-known tool for simulation research used in logistic system analysis is the program DOSIMIS ([8] or Flexim [20]). Moreover, there are many other tools for logistics process simulation with advanced graphics interface available. One of the new tools in this class is the program, eM-Plant. Among the new simulations tools which can be applied to logistics system research, the Enterprise Dynamics suite (formerly Taylor II) deserves attention [9]. It is a simulation program with advanced process flow visualization in 3D. This program can be applied to production, logistics and other system research [5].

The described simulation research tools often offer an ability to create cause and effect charts and structural diagrams, more or less customized to the nature of processes taking place in warehouse facilities. There is a lack of commercial tools, which fully reflect the nature of the processes which take place in real warehouse facilities, and most importantly, allows optimization of these facilities based on the productivity of processes. At most, it is possible to start with an initial solution, acquired by analytical methods in this field, and take a trial and error approach in order to obtain a solution meeting all required efficiency criteria. Therefore, a need to develop a tool dedicated to process simulation in warehouse facilities and visualization of the warehouse state has been identified, where the initial solution will be obtained with the help of implemented optimization tools or by importing real data from a WMS system.

## 6. CONCLUSION

An approach to logistic process simulation in warehouse facilities for the need of 3D visualization was presented in this article. The complexity and costliness of decision-making processes needed to appropriately design and equip warehouse facilities particularly justify the need to perform simulation research on initially obtained solutions. Thanks to this, it will be possible to discover potential errors and obtain insight on how the designed logistic facility will respond when its function is somehow disrupted. Additionally, due to the potential application of many organizational solutions to specific areas of the warehouse facility, it is warranted that a system for simulation research contains a selection optimization of these solutions.

A developed simulation model allows a detailed analysis to be performed concerning the completion of converting individual loading units along with identifying their exact location in the logistics facility. Thanks to this, implementation of, for example, procedures pertaining to selection of assembly paths and obtaining near real-time completion of individual orders, will be possible. At the same time, the model will enable the acquisition of tools which will accurately reflect processes in warehouse facilities. Moreover, this tool will be compatible with WMS systems. To the authors' knowledge, this kind of solution is not currently available.

## ACKNOWLEDGEMENTS

***The scientific work carried out in the frame of PBS 3 project "System for modeling and 3D visualization of storage facilities"* (SIMMAG3D) *is financed by the National Center for Research and Development.***

## REFERENCES

[1] AMBROZIAK T., JACYNA M. Queueing theory approach to transport process dynamics, Part 1. Dynamics of transport network connections. Archives of Transport, Vol. 14, Iss. 4, 2002, pp. 5-20.

[2] AMBROZIAK T., JACYNA M. Queueing theory approach to transport process dynamics, Part 2. Parameters of the transport process dynamics. Archives of Transport, Vol. 15, Iss. 1, 2003, pp. 5-21.

[3] ASHAYERI J., GELDERS L.F. Warehouse design optimization. European Journal of Operational Research, Vol. 21, Iss. 3, 1985, pp. 285-294.

[4] CLARK T.D. Jr., KURONO H. A Conversion Table of DYNAMO into STELLA II. In System Dynamics '95 - International Conference, Vol. II, Tokyo: 1995, pp. 424-433.

[5] DOBRZAŃSKA-DANIKIEWICZ A., KRENCZYK D. Production flow synchronization versus buffer capacities in assembly systems. Journal of Achievements in Materials and Manufacturing Engineering, Vol. 29 Iss. 1 (July), 2008, pp. 91-98.

[6] FORRESTER J.W. The Beginning of System Dynamics. Banquet Talk at the international meeting of the System Dynamics Society. Stuttgart: 1989, p. 16.

[7] JACYNA M., WASIAK M. Badania symulacyjne przepływu strumieni ładunków w obiektach logistycznych In NADER M., TYLIKOWSKI A. (ed.). Symulacja w Badaniach i Rozwoju, XII Warsztaty Naukowe Polskiego Towarzystwa Symulacji Komputerowej, Warszawa, 2006, pp. 110-116.

[8] KARKULA M. Application of decision tables in discrete event simulation models. In Wybrane zagadnienia logistyki stosowanej, Nr 5, Oficyna Wydawnicza TEXT: Kraków, 2008, pp. 252-260.

[9] KORZEŃ Z. Logistyczne systemy transportu bliskiego i magazynowania, Tom II - Projektowanie, Modelowanie, Zarządzanie. Instytut Logistyki i Magazynowania: Poznań, 1999.

[10] KRAHL D. Extendsim: A history of innovation. In LAROQUE C., HIMMELSPACH J., PASUPATHY R., ROSE O., UHRMACHER A.M. (eds). Proceedings of the 2012 Winter Simulation Conference, Berlin: 2012, p. 8.

[11] KROGDAHL S. The birth of Simula. In: IFIP Conference on History of Nordic Computing. Springer: US, 2003. pp. 261-275.

[12] LESZCZYŃSKI J. Modelowanie symulacyjne w transporcie kolejowym. Wydawnictwa Komunikacji i Łączności: Warszawa, 1973.

[13] O'REILLY J.J. Introduction to SLAM II® and Slamsystem®. In ALEXOPOULOS C., KANG K., LILEGDON W.R., GOLDSMAN D. (eds), Proceedyngs of the 1995 Winter Simulation Conference. IEEE: 1995, pp. 467-471.

[14] OBRETENOV A., DIMITROV B. Teoria masowej obsługi. Poradnik. Państwowe Wydawnictwo Naukowe: Warszawa, 1989.

[15] RUSHTON A., CROUCHER P., BAKER P. The handbook of logistics and distribution management 3rd edition. Kogan Page Limited: London and Philadelphia, 2006.

[16] TURBAN E., MEREDITH J.R. Fundamentals of management science. Fifth ed. Irwin: Homewood, Boston, 1991.

[17] WASIAK M. A queuing theory approach to logistics systems modelling. Archives of Transport, Vol. 19, Iss. 1-2, 2007, pp. 103-120.

[18] WASIAK M. Modelowanie przepływu ładunków w zastosowaniu do wyznaczania potencjału systemów logistycznych. Prace Naukowe Politechniki Warszawskiej. Transport, z. 79. Oficyna Wydawnicza Politechniki Warszawskiej: Warszawa, 2011.

[19] WASIAK M. Static optimization of potential of logistic systems. Archives of Transport, Vol. 20/3, 2008, pp. 75-83.

ZHU X., ZHANG R., CHU F., HE Z. and LI J. A Flexsim-based Optimization for the Operation Process of Cold-Chain Logistics Distribution Centre. Journal of Applied Research and Technology, Vol. 12, April 2014, pp. 270-278.