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Analysis of the Effects of Automation of Warehouse Processes – Building the Concept of Simulation Tests

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Abstract:

Purpose: *The purpose of this article is to develop a research concept for business process simulation models that take into account all possible automation scenarios activated depending on the tested configuration of their implementation.*
Design/Methodology/Approach: *As part of the research, warehouse processes were identified in one of the key Polish e-commerce companies. These processes were modeled in the next step using BPMN notation and simulated taking into account all model parameters. Thanks to the calibration of the models, it was possible to confirm their correctness. In the next step, the models were modified in order to implement automatic solutions, correct parameters.*
Findings: *The developed scenario models allow for a comparative analysis of automation scenarios by activating or deactivating individual variants of the model. The simulation results obtained for various scenario models which enabled to distinguish the potential of using the simulation, i.e. a set of process parameters that should be subject to comparative analysis in subsequent stages of the research so that it was possible to verify the results of the implemented automatic solutions.*
Practical Implications: *The changes taking place in modern logistics and warehouse processes are mainly caused by the increase in the requirements of final recipients in terms of the quality of services provided and the time of their implementation. The growing importance of online sales and the very intensively developing COVID-19 pandemic have made this distribution channel one of the key forms of obtaining and delivering products to end recipients. One of the essential elements of development is shortening process cycles, elimination of human errors or effective use of the resources involved through automation.*
Originality/Value: *As a result of the analyzes, a research concept that allows the use of multi-scenario simulation models taking into account automatic solutions in warehouse processes, implemented in the e-commerce industry, was developed. This model will be used in further research on the results of automation implementation.*

Keywords: *Warehouse processes, automation, simulation models, e-commerce.*

JEL codes: *R15, R40, R49.*
Paper type: *Research article.*

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1. Introduction

The development of the e-commerce industry observed in recent years and the increasing requirements for logistics services provided to end users contribute to the emergence of the need to adapt warehouse processes to specific levels of efficiency faster and faster (Ecommerce Europe, 2021). Online trade, in particular in the era of the coronavirus pandemic, has become one of the key channels for delivering goods to customers. With the inability to make stationary purchases, a very large increase in customer interest in online sales was observed (Bozzi, Neves, and Mont'Alvão, 2022), which translated into a noticeable increase in requirements for the efficiency of warehouse and logistics processes.

One of the ways to increase the efficiency of warehouse processes implemented in the e-commerce industry is process automation characterized by the use of the latest technologies. These technologies include robotization, not only to shorten the time of warehouse activities, but also to increase the capacity of warehouse systems, eliminate human errors, improve processes or development of e-commerce enterprises allowing for full autonomy of warehouses in the future.

The effectiveness of logistics processes largely depends on the effectiveness of warehouse processes, which is why this paper focuses on building a research concept that allows to comprehensively assess the results of implementing automation for these activities.

An additional aspect in favor of the need to develop the e-commerce industry, and thus also to increase the efficiency of warehouse processes, may be the results of research carried out in recent years, which, apart from the coronavirus pandemic and multiple lockdowns introduced in all countries of the world, show an increase in the interest in online trading among various groups customers (Qidi, 2021).

A review of the literature relating to the topics covered in the paper indicated that there are articles available in the Scopus and Web of Science databases describing simulation models of warehouse processes. The authors of the publication refer only to the simulation model used in the process of automatic product placement in the warehouse (Haibin *et al.,* 2022). Additionally, in the next publication, the authors refer to the created model simulating the warehouse process. This tool allows you to predict the effects of implementing automation in the process (Peixoto *et al.,* 2016).

The analysis of the literature showed that there are papers on the simulation of warehouse processes available, however, none of the initiatives described relates to

the creation of a tool enabling the comparison of an infinite number of simulation scenarios at one time.

The aim of this article is to develop a research concept for business process simulation models that take into account various automation scenarios simultaneously. These comprehensive models will allow for a comparative analysis of the results of simulation of warehouse processes implemented in the e-commerce industry, taking into account and not including automatic solutions, without the need to build separate models for each of the automation scenarios.

This paper consists of sections, the first of which is a reflection on the definition of the concepts of modeling and process simulation. The third section is devoted to research methodology while the fourth section covers research results. The last section of this article is conclusions and future research.

2. Process Modeling and Simulation

Business process modeling (BPM) is one of the methods of graphical representation of business processes carried out in the enterprise, the effect of which is a business process model built in accordance with the notation (Recker *et al.,* 2009; Gawrońska and Nowak, 2017). Modeling allows you to map the main flow of processes, thus taking into account auxiliary processes (Baykasoglu and Kaplanoglu, 2006).

Modeling of business processes assumes creating a graphic representation of the activities that are performed in it, taking into account all relations that occur between these operations. This model is most often called the current state map. The next step of modeling assumes the identification of errors and all activities that do not bring benefits, as well as their removal, which results in the creation of a map of the future state (Khabbazi *et al.,* 2013). For modeling, most often standardized notations are used, among which one can distinguish: Business Process Modeling Notation (BMPN), Unified Modeling Language (UML) or Icam DEFinition for Function Modeling (IDEF0) (Grzybowska and Kovács, 2014).

Process simulation can be defined as a reflection of a process carried out in reality through the use of an artificially created environment for these purposes, most often a computer one. As part of the simulation, the system state is saved in the form of process attributes. Process attributes, i.e. parameters, characterize a given process and can be used to identify it and introduce possible changes. Process attributes can also be used when formulating measures of a given process (Worobel *et al.,* 2018; Kluska, 2021).

The tools that are most often used to simulate processes that also include process automation innovations can be included: iGrafx Process, AnyLogic, FlexSim, Arena Simulation and SIMUL8 (Adamczak and Toboła, 2021).

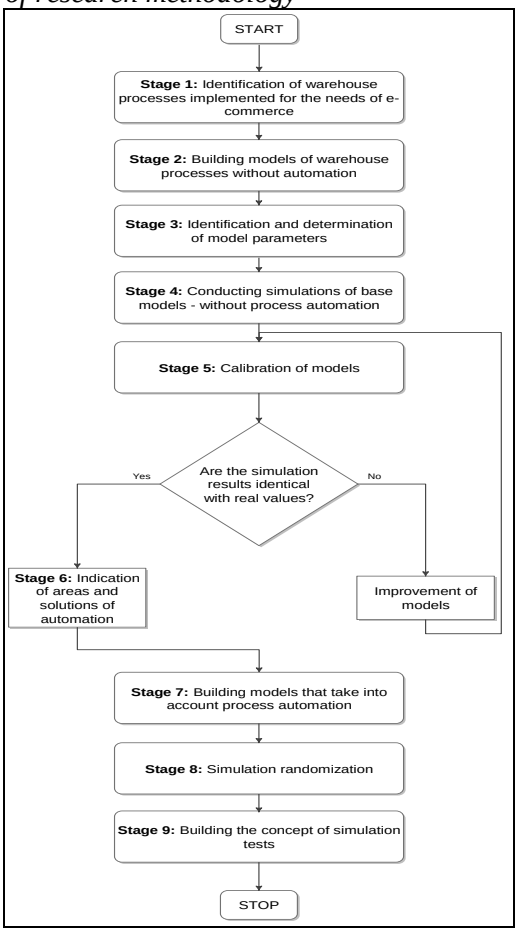
As indicated in their publication by Bai *et al.* (2009) both modeling and simulation of business processes are extremely important elements of process automation (Bai, Huang, and Koolmanojwong, 2009).

It is also worth pointing out that warehouse processes, due to their repeatability and ease of adaptation, enable the use of a number of modern technologies, such as the use of AGV robots, Pick by Voice, Pick by Light or Augmented Reality (Reif and Günthner, 2009).

3. Research Methodology

As part of this article, the identification and then analysis of business processes performed in a warehouse serving customers as part of the e-commerce channel was performed. The algorithm of proceeding within the research methodology is presented in Figure 1.

Figure 1. *Algorithm of research methodology*



Source: *Own study.*

The first stage of the research was to isolate warehouse processes carried out for the needs of e-commerce. Among the most frequently implemented processes were:

- receipt of goods,
- storage of goods,
- completion of goods,
- packing of goods,
- shipment of goods.

Other warehouse processes, carried out incidentally, were not taken into account in the analysis.

The next stage of the research was to build business process models using the BPMN notation, which allowed for graphical mapping of warehouse processes with an indication of the responsibility of individual departments of the company and the relationship between them. iGrafx for Six Sigma simulation software was used to build simulation models of processes, which enables modeling of processes based on multi-path cooperation.

The third stage included the determination of model parameters, i.e. the number of generated transactions, the number of resources, the probability of exits from decision gates, the time of activities, etc. The next phase of research involved simulating the base models - without automating the processes. In addition, the correctness of the models built was verified, which was carried out by comparing the historical data of the processes actually carried out in the enterprise with the results obtained in the simulation. Thanks to this, it was possible to calibrate the models, preventing researchers from making mistakes in the main analysis phase of the simulations.

The sixth stage assumed the indication of areas of automation that could be implemented in individual warehouse processes. Examples of automatic solutions included the use of belt conveyors, an automatic quantitative and qualitative control gate or the elimination of paper document flow in favor of electronic data exchange. The implementation of automatic solutions assumed the development of models with activities that take into account automatic solutions, which was the eighth step of the research process. As part of the process automation, parameters such as time of activities or human resource involvement were also adjusted. The simulations were randomized, thanks to which the influence of uncontrolled events on the results of the simulation experiment was eliminated.

In the last phase, the concept of the simulation test was developed. Authors of this publication verified how the results of the simulated experiment will be affected by individual changes resulting from the inclusion and exclusion of individual scenarios. The developed tool allows you to combine an unlimited number of simulation scenarios and verify the results of their implementation in virtually any configuration. Among the research limitations, the authors point to the threat

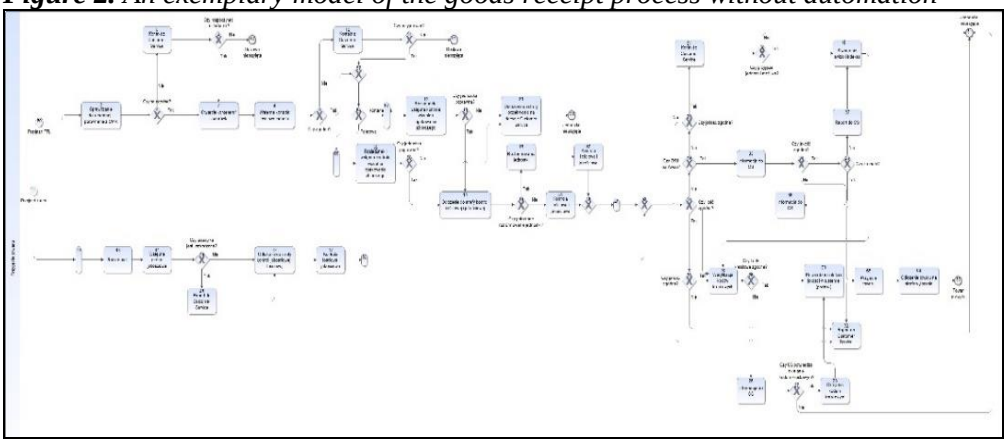
resulting from the inability to predict the effects of implementing automatic solutions (e.g. reducing the duration of activities, resource use, etc.).

4. Research Results

As part of the research, the results of which are presented in this publication, a set of five models of warehouse processes most often implemented in the e-commerce industry was developed. Each model was built on the basis of empirical data based on the observation of processes carried out by the leader of the e-commerce industry in Poland. The calibration carried out in the research process made it possible to verify the correct operation of building the models.

An exemplary model of a warehouse process that does not take into account automation, built in BPMN notation, is shown in Figure 2.

Figure 2. *An exemplary model of the goods receipt process without automation*

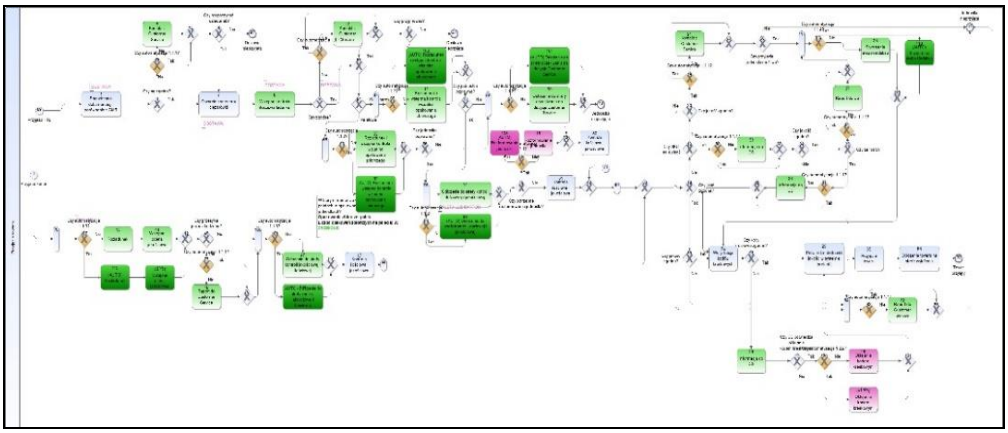


Source: *Own study.*

The analysis of the possibilities of process development and their enrichment with automatic solutions contributed to the development of models taking into account all possible automation scenarios dedicated to a given process. Automation scenarios in the case of built models are a probable variant of the development of a specific process area. An exemplary process model taking into account automation scenarios is presented in Figure 3.

In Figure 3, the automation scenarios that can be implemented in the near future are marked in green, while the automation scenarios with a much longer implementation horizon are marked in pink. For all the built process models, sets of scenario attributes were developed. Scenario attributes are global values that are assigned to all model elements at the same time. If any action changes the value of a scenario attribute then this value changes for all other model elements in a given scenario.

Figure 3. *An exemplary model of the goods receipt process taking into account automation scenarios*



Source: *Own study.*

For example, if the simulation was to take into account the elimination of manual transfer of products between the picking and shipping zones in favor of the use of automatic belt conveyors, the value of the scenario attribute for this solution variant was 1. Then the model uses only the path that takes into account the example automation indicated above. If a given automation was not to be taken into account, then the scenario attribute would be set to 0. This solution made it possible to activate successive automation scenarios one by one, to compare them in any configuration (e.g., in pairs or threes) or to verify the effects of implementing all automation scenarios active at the same time.

Based on the randomized results of the simulation, an initial analysis of the results was performed in order to identify the key parameters for the evaluation of the processes.

Examples of the results of simulation tests carried out for various automation scenarios for goods receipt process are presented in Table 1.

Table 1. *An exemplary results of simulations tests*

Automation scenario	**Average Process Cycle [h]**	**Average Transaction Waiting Time [h]**	**Usage of resources [%]**
No automation	32,695	19,213	51,16
Automation implemented in **one** area of the process	30,689	16,665	58,97
Automation implemented in **two** areas of the process	30,39	17,209	59,3
Automation implemented in **three**	25,861	2,374	9,04

areas of the process			
Automation implemented in **four** areas of the process	25,821	1,681	7,96
Automation implemented in **five** areas of the process	25,821	1,681	7,96
Automation implemented in **six** areas of the process	25,821	1,681	7,96

Source: *Own study.*

As can be seen in Table 1, the constructed simulation models enable the comparison of results divided into individual automation scenarios, and thus allowed to build a research concept. The individual scenarios in Table 1 relate to the implementation of automatic technological solutions in the goods receipt process. The authors of this publication assumed that each subsequent scenario assumes the inclusion of an automatic technological solution in the simulated model. The expected results assume an improvement in the parameters relating to the average process cycle, average waiting time and resource utilization.

The expected results assume an improvement in the parameters relating to the average process cycle, average waiting time and resource utilization. In the case of the scenario with two and three improved areas, the parameters deteriorated despite the implemented automatic solutions, which may be the area of further studies by the authors. Due to the fact that the purpose of this paper is to present a research concept that allows for the inclusion and only of automation scenarios, there is no need to indicate automatic solutions implemented under each scenario.

Due to the specificity of business process modeling in BPMN, the following factors were identified:

- duration of activities,
- average duration of activities,
- number of transactions handled per unit of time,
- the degree of involvement of resources in the performance of activities,
- average working time of resources,
- average idle time of resources,
- process costs,
- costs of using resources,
- overtime costs,
- the average number of transactions waiting for resource availability.

The set of the above activities will allow to assess the impact of the implementation of individual automation scenarios on warehouse processes in further stages of the analysis.

5. Conclusions and Future Research

Simulation models of warehouse processes built as part of the research presented in this publication allowed for the development of a research concept, i.e., a method of assessing simulation models taking into account various configurations of automation scenarios implemented in e-commerce warehouses. As part of this concept, a number of parameters have been identified, the values of which obtained in subsequent simulation tests should be subjected to detailed analysis.

This analysis will be carried out in the subsequent stages of the research and will allow to identify the results of the implementation of automatic solutions depending on the activation of individual scenarios. The possibilities of the analyzes are virtually unlimited, i.e., the comparative analysis can include an unlimited number of scenarios in any number of configurations, thanks to which the complexity of the results obtained will contribute to even greater accuracy and reliability of the results of simulation tests. Thanks to the randomization of the simulation, it was possible to eliminate any random errors that could adversely affect the reliability of the results obtained. Based on the results of the simulation covering various variants of automation, a number of factors were distinguished, the analysis of which should constitute further research steps.

The identified parameters will allow for a comprehensive assessment of the results of the implementation of individual automatic solutions, which will translate into the selection of only those development variants that will bring the greatest benefits to the analyzed enterprise and, consequently, will translate into the development of the e-commerce industry, which plays an increasingly important role in modern logistics.

The research approach presented in this paper using a multi-scenario tool to verify various implementation scenarios can be used in the decision-making process related to the automation of processes. The use of a tool that allows for the simulation of processes, taking into account various variants of automation and the appropriate configuration, will contribute to reducing implementation costs by verifying the actual effectiveness of the improvement even before its deployment.

In further research, the authors of this paper should focus on the development of the model and its improvement in relation to the measured parameters of the processes.
On the basis of the above considerations, it should be indicated that the goal of this paper, assuming the construction of multi-scenario simulation models for warehouse processes, has been achieved.

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