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APPLICATION OF COMPUTER SIMULATION IN INTERNAL TRANSPORT PLANNING – A CASE STUDY

Summary. In this article, a computer simulation of a selected production process was carried out. The simulation aimed to determine the number of internal transport means that allow the implementation of the manufacturing process, considering parameters such as the efficiency of the production process, the number of inter-operational stocks, and the level of use of means of transport. FlexSim simulation software was used to conduct the simulation. The simulation made it possible to obtain results, which were then analyzed and used to select the most advantageous solution. The conducted process, which was intended to determine the resources necessary to implement a specific production plan, confirmed the validity of using computer simulation at the stage of planning production and logistics processes, as well as their evaluation.

1. INTRODUCTION

Constant technological progress requires companies to quickly adapt to prevailing standards to maintain their position in a highly competitive market [1]. Current technological capabilities and the prospects for their development have resulted in the unprecedented industrial revolution that we are now facing [2]. More and more frequently implemented solutions within the framework of the "Industry 4.0" concept, also known as the "Fourth Industrial Revolution," aim to improve the efficiency of the production process. In many cases, technologies introduced on a large scale, such as the Internet of Things (IoT), Big Data, or digital twins, have become a necessity in enabling the continued existence of organizations [3]. In the coming years, a significant increase in competition is expected between entrepreneurs who implement techniques and tools that are consistent with the philosophy of Industry 4.0 [4]. The purpose of reaching increasingly higher levels of automation of manufacturing processes, supported by artificial intelligence, is to provide opportunities to create a knowledge network that will cooperate with humans [5].

One of the increasingly used solutions included in Industry 4.0 is computer simulation. This type of simulation allows users to predict the consequences of obtained solutions while assuming selected boundary conditions. Simulations of production processes may cover both the area of the analysis of the parameters of the production process within its technological aspect and logistic processes and

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the flow of materials between individual production stations. Currently, processes for modeling and simulating logistics are an important, if not key, part of all larger production plants [6]. The use of computer simulation to analyze logistics processes is related to the high sensitivity of supply chains to delays or the selection of not always the most favorable sequences of solutions for delivering products to individual production stations [7].

The correct selection of supply chain management solutions reduces costs while the outlined plan is implemented, which is a priority when planning logistics processes. The costs of the production process are among the most important factors determining competitiveness in the global market. Therefore, reducing or eliminating waste is a key task for manufacturing companies. One of the methods for identifying waste and, consequently, reducing the costs of the production process is the use of computer simulation to analyze the parameters of the production process both at the stage of process planning and during its execution. Production process simulation activities aimed at mapping the actual connections between elements included in the model being created make it possible to track the impact of implemented changes on the level of generated parameters. Obtaining data on the behavior of parameters generated by the production process can be the basis for making decisions on further actions to improve the production process.

This article aimed to select the number of internal transport means enabling the implementation of the production process, taking into account the efficiency of the production process, the number of inter-operational stocks, and the level of transport use. FlexSim simulation software was used to carry out the analysis.

2. COMPUTER SIMULATION OF LOGISTICS PROCESSES

Many research programs aim to study and verify data obtained from analyzing phenomena and processes. In the modern world, where we have wide access to tools such as ICT, computer simulation is becoming a critical and effective research method. Using a computer simulation tool makes it possible to reflect real objects created using mathematical models [8]. Simulation is a copy of a real process that allows one to conduct many experiments and generate results in the form of parameters obtained by the model as a result of implemented conceptual changes [9]. Computer simulation allows for the verification of changes occurring in production processes as a result of implemented corrections, including changes in the arrangement of production stations, the duration of individual technological operations, bottlenecks in the manufacturing process, and the number of production resources or the level of delays resulting from, for example, machine failures.

The implementation of the simulation process consists of a number of stages for defining the operating methodology that allows for the creation of an efficiently functioning simulation—that is, one that allows information reflecting the state of the real system to be obtained. When designing the simulation process, it is necessary to specify its purpose and define various research methods that allow the appropriate selection of the model and data necessary for the simulation process [10]. The selection of input data is a preliminary stage that allows for a better understanding of the issues of a given process and the development of a simulation model with an appropriate level of detail. The type of data present determines the method of collecting information and influences the tools used to obtain it [11]. Data analysis is conducted after the necessary information, which is characterized by an appropriate level of detail, has been collected. The purpose of this is to select information with a precisely defined meaning, which directly influences the course of the simulation and the appearance of the simulation model. Input data implemented into the simulation software may include information on the duration of the manufacturing process, the type of flow of semi-finished products between production stations, and the number of production resources, among other things. The amount and type of data used to create the simulation model determines the level of detail in the results obtained. The data selection stage requires the data that are essential and impact the final results generated by the simulation program to be identified. The incorrect selection of input data or the selection of data of insufficient quality can cause significant problems in obtaining objective data from simulation software. Obtaining data that are inconsistent with production reality can cause their incorrect interpretation, which leads to incorrect decisions in the field of production process management.

When creating simulation models, the principles of operation of individual elements, objects, and their relationships are precisely determined. The processes that take place during an experiment are similar to analogous processes that take place in a real facility. The simulation model includes the logic of operation, the possibility of animation showing the course of the process, and statistical analysis. Statistical analysis may concern any model parameters, but it allows information about the operation of the tested production process and many factors closely related to it to be obtained. The accuracy of the data depends on the degree of similarity of the model made and its detail.

Computer simulations have been widely used to model logistics processes carried out in production plants. Computer simulation is a standard approach to assessing the performance of logistics systems [12]. The benefits of using computer simulation to analyze logistics processes result from their high complexity and number of connections. Computer simulation used at the stage of planning production processes or the verification of other solutions allows the user to identify bottlenecks in the production process, determine the effectiveness of logistics systems, analyze the interaction of various system elements with the logistics system, and evaluate alternative solutions and define the resources necessary to conduct an effective transport process, among other benefits [13].

It should be noted that the use of computer simulation should be justified. Simulation is not recommended when the problem can be solved using analytical tools. At the same time, attention should be paid to the high costs associated with using simulation. In many cases, this may constitute a barrier for small manufacturing companies, as pointed out in the publication [14]. At this point, it should be noted that more and more simulation programs are appearing on the market that allow for the simulation of production and logistics processes. Due to strong competition from many software manufacturers, the availability of such programs has increased significantly. Currently, simulation software enables the representation of production processes in terms of organization, technology, and visuals (construction of 3D models). An additional option of simulation software in virtual reality (VR) is becoming increasingly popular. VR makes it possible to conduct real activities in the virtual world, which can make it easier for employees to adapt to future working conditions. VR has been applied in areas related to occupational safety and ergonomics. The presentation of virtual reality in simulation programming can allow for better adaptation of production stations to the needs of employees.

Currently, there are many simulation software packages available on the market. Programs such as Enterprise Dynamics software, Plant Simulation software, and ARENA software allow for the analysis of production process parameters and logistics systems. The great versatility of simulation programs is a noteworthy advantage due to which many manufacturing companies are increasingly using them.

3. CHARACTERISTICS OF THE RESEARCH PROBLEM AND METHODOLOGY

Based on an analysis to select the appropriate means of transport to increase the efficiency of the production process, the production plant specializes in producing large-sized metal elements. The analyzed production process consisted of six operations that were carried out at independent production stations: operation number 10 – cutting the input material, operation number 20 – milling, operation number 30 – bending the material, operation number 40 – assembly of the structure, operation number 50 – painting, and operation number 60 – quality control. The production of individual elements begins with receiving a production order, which includes information regarding, among others, the production volume and a list of semi-finished products necessary for its implementation. Then, individual stations transmit the demand to the warehouse along with information about the number of semi-finished products, enabling the execution of the production plan. As a result of these activities, the internal transport process is carried out in accordance with the reported demand generated based on production orders. Semi-finished products are delivered to input material buffers located next to production stations. Work at the production plant is carried out in two shifts. The arrangement of production stations and the warehouse of input materials is shown in Fig. 1. The internal transport process, which is the subject of the article, is carried out by cabin forklifts. Forklifts move according to designated transport paths. The course of transport paths and the layout of production stations were not the subject of the analysis.

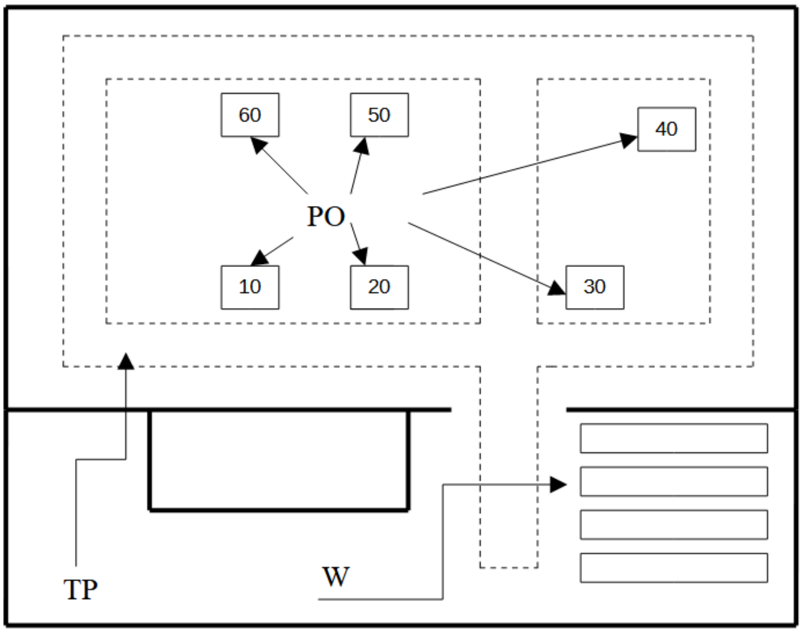

Fig. 1. Layout of the production hall. PO – production operations, TP – transport path, W – warehouse

The following activities were carried out to conduct a simulation aimed at obtaining parameters generated by the production process, depending on the number of internal transport means used during the implementation of production works:

1. Constructing a simulation model reflecting the analyzed production process.
2. Selecting statistical analyses generated by simulation software.
3. Conducting an experiment to obtain information on the change of process parameters depending on the number of means of transport.
4. Conducting a comparative analysis of the obtained results.

In the first stage, data were compiled and implemented into the simulation software. Data regarding the manufacturing process and internal transport activities came from the production plant (Tab. 1).

Then, in accordance with the methodology used in the simulation software, a model was created to reflect the location of the elements included in the simulation.

Table 1

Selected data implemented into the FlexSim simulation software

Parameter	Data [unit]
Loading time of the input material	For operations 10, 20, and 50: 45 [s] For operations 30 and 60: 60 [s] For operations 40: 90 [s]
Unloading time of output material	For operations 10, 20, and 50: 45 [s] For operations 30 and 60: 60 [s] For operations 40: 90 [s]
The speed of movement of the means of transport	2 [m/s]
Distance between selected production stations and the warehouse	In accordance with the layout of the production hall
Simulation duration	1 shift: 7 [h] 15 [min]
Input material transport strategy	According to the demand required by the production station

A tool called FlexSim software was used to carry out the computer simulation. This tool allows the simulation of production and logistics processes while also presenting a wide range of statistical analyses, enabling the assessment of the selected solution. The use of FlexSim simulation software to analyze production and logistics processes has been presented in many works [15-17], confirming its validity. The choice of this simulation software was motivated by its availability and an extensive library of models that were used to create the simulation model that is the subject of the article. In addition, the FlexSim simulation software has numerous statistical functions that allow for the analysis of the process.

The model consisted of facilities such as a warehouse for input materials, six production stations, six buffers for input materials, transport paths, and means of internal transport. The objects were connected using the appropriate functions, namely, *Connect Objects* and *Connect Center Ports.* The last stage of building the model was the implementation of process parameters and the selection of an appropriate strategy for supplying input materials to production stations (Fig. 2).

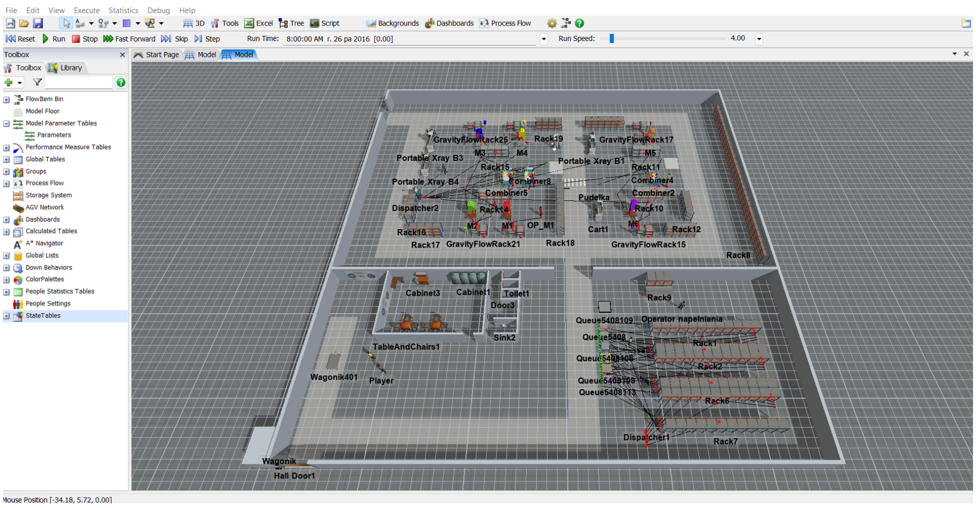

Fig. 2. Model of the production process in FlexSim simulation software

Three statistical analyses generated by the FlexSim simulation software were selected in order to determine the appropriate number of means of transport necessary to be used, which will increase the efficiency of the production process and enable the analysis of model parameters (level of efficiency of the production process, level of use of inter-operation buffers, and degree of use of means of transport).

Then, a number of activities were carried out to implement system settings that allowed the simulation of the production process, taking into account a variable number of means of transport. The *Experimenter* function was used to obtain process data based on the analysis of many variants (scenarios) of solutions. Correctly carrying out activities to obtain results required us to define the number of scenarios to be verified regarding the number of means of implementing internal transport, among other things. Five scenarios were defined, which means that the process simulation was performed assuming the use of several means of transport in the range of 1–5 (where Scenario 1 means there was one means of transport and Scenario 5 means there were five means of transport). In the performer simulation, the replication number for each scenario was 25. The *Experimenter* function allowed us to obtain information about the parameters generated by the production process depending on the number of means of transport used. This solution is very beneficial because it allows the analysis of many potential solutions of the production process subjected to analysis based on one model. The *Experimenter* function also allows for significant time savings while enabling the simulation software to generate high-quality parameters.

The last stage of the research was the analysis of the results obtained and the selection of a solution that would increase the efficiency of the production process while taking into account the parameter of the volume of inter-operation inventories and the level of use of transport means. Based on the results, a comparative analysis was carried out to indicate the best of the analyzed solutions as they relate to the selection of the number of means of transport necessary for the production process subjected to analysis.

4. RESULTS AND DISCUSSION

As a result of activities aimed at creating simulations of the logistics process, a simulation model was obtained that reflected reality in the production plant. The data prediction performed using the *Experimenter* function confirmed the correct method of data implementation and the appropriate selection of connections between objects.

The results obtained from the simulation of the production process carried out in the FlexSim simulation software show the average efficiency level generated by production stations depending on the number of means of transport (Fig. 3).

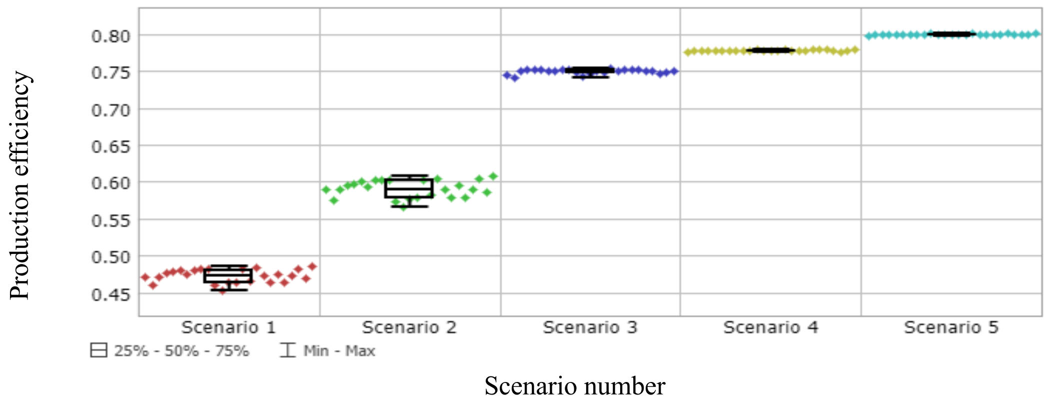

Fig. 3. The result of the experiment conducted in the FlexSim simulation software in terms of production efficiency

In Scenarios 1 and 2, the efficiency level of production stations was 47% and 58%, respectively. Scenario 3 allowed for 16 percentage points more efficiency than Scenario 2. The difference in efficiency levels between Scenarios 3 and 5 decreased to four percentage points. The solutions proposed in Scenarios 3, 4, and 5 increased the efficiency of the production process to above 75%. A production efficiency rate above 70% allows for the implementation of production works in accordance with the schedule; therefore, it is accepted by the company's management. A significant increase in efficiency when using three or more forklifts seems to be a reasonable solution due to the level achieved in the efficiency of the production process.

The parameter considering the use of inter-operational buffers depending on the scenario used was subjected to a similar analysis (Fig. 4).

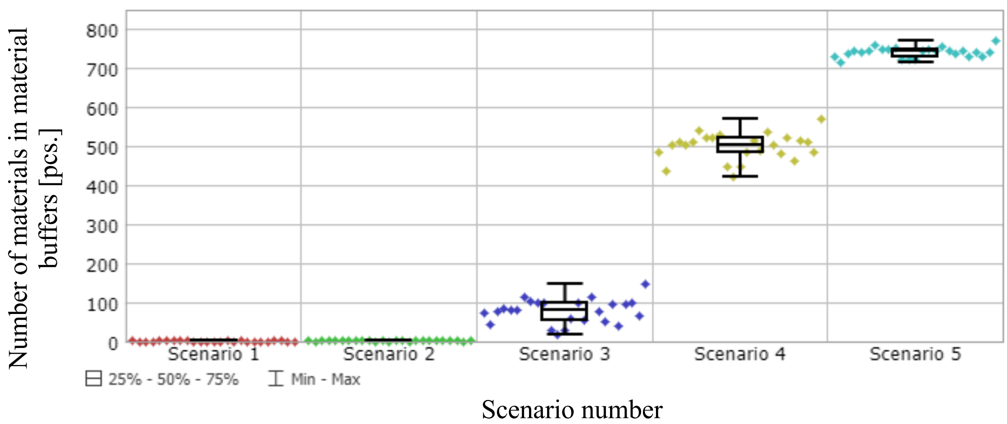

Fig. 4. Results of an experiment conducted in the FlexSim simulation program in terms of the level of buffer utilization

The results show that there is no reserve for inter-operation buffers when one or two forklifts are used. In Scenario 3 (i.e., the use of three forklifts), the level of interoperational inventories in all buffers was 91 items. In Scenarios 4 and 5, this value increased to 511 and 743 pieces, respectively. Based on the literature [18], it can be concluded that the lack of inter-operating inventories is beneficial in terms of cost reduction. However, in the case analyzed, the lack of inter-operation stocks as a result of the application of Scenarios 1 and 2 did not result from the inability to deliver components due to insufficient transport resources. Scenario 3 appears to provide the most favorable outcome in terms of interoperability inventory levels. The use of three forklifts allows for continuous operation of production stations while minimizing current inventories.

The last parameter obtained as a result of the simulation was the analysis of the level of use of means of transport (Fig. 5). The verification of this parameter seems very important, as it allows for analysis of possibilities in the scope of inter-operational transport of the assumed number of input materials and semi-finished products. If the level of utilization is too high, it may indicate the involvement of too few forklifts, which may lead to financial losses related to the waiting of stations for the material necessary to perform the selected production operation. Meanwhile, if the level of utilization is too low, this may indicate the use of too many forklifts, which may lead to financial losses.

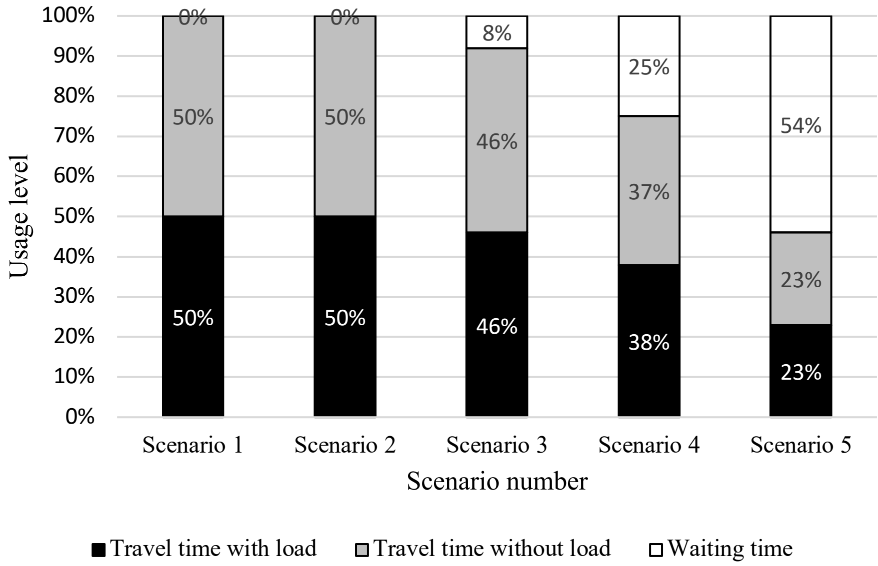

Fig. 5. The level of use of means of transport by scenario

The data obtained in Scenarios 1 and 2 confirm that too few means of internal transport resulted in their maximum use. In these scenarios, the level of utilization of production stations is 100%, which directly affects the low level of efficiency of the production process, as shown in Fig. 3. These results confirm that it is impossible to complete all transport orders within the prescribed time. In Scenarios 3, 4, and 5, unlike Scenarios 1 and 2, there was no waiting time for the means of transport, meaning that all transport orders were completed and their availability for further actions. Scenarios 4 and 5 seem less beneficial than Scenario 3. In Scenario 3, the waiting time for the means of transport to complete the transport process is only 8% of its total working time. In Scenario 4, however, it is 25%, and in Scenario 5, it is 54%. Based on the results obtained by the simulation of the production process, the use of three means of transport to carry out internal transport activities seems to be the best solution. If the input parameters or other external factors affecting the input data change, it would be necessary to conduct further simulations and analyze the obtained results in order to determine potential changes and simultaneously select the most advantageous solution.

The results and the conclusions drawn from them indicate the effectiveness of using computer simulation to verify logistics processes, as confirmed in many other publications [19-22]. It should be noted, however, that scientific studies indicate the wide application of computer simulation in solving problems related to logistics and others concerning, among other things, the analysis of production process efficiency and the identification and reduction of bottlenecks in the process [23, 24]. For this purpose, various simulation software is used, including Enterprise Dynamics software [25], Plant Simulation software [26], and ARENA software [27]. Many publications on the simulation of production processes and presentations of practical possibilities of their application have confirmed the validity of using simulation software to forecast parameters of production or logistics processes. The use of simulation at the stage of planning production processes allows for the assessment of the validity of introduced changes in the scope of, among others, correction of the layout of production stations, material flow or the number of production resources necessary to produce the finished product.

Based on the case study analyzed in this article, it is possible to conduct further analyses using computer simulation in the future in order to increase the efficiency of the production process. One potential beneficial solution is to verify the correctness of the layout of production stations in the hall and to verify transport paths. It may be that the improvements introduced in the mentioned areas will improve the operation of the production process and will impact the change in the number of means of transport, which will result in reductions in the costs necessary to be borne by the production company.

5. CONCLUSIONS

Using computer simulation to analyze the parameters of the production process allows a large amount of data to be obtained, enabling the assessment of potential solutions. The results of the present work may help make decisions regarding process design, as well as possible corrections to improve the current state. The use of computer simulation to analyze production and logistics solutions is a relatively low-cost activity for obtaining results. As such, this kind of simulation makes it possible to decide whether to implement a solution subjected to analysis. Owing to the large number of simulation programs and their increasing availability, the use of computer simulation is no longer a problem in many manufacturing companies, and simulation software is used in everyday activities in production process planning.

This study used FlexSim simulation software to analyze the production process of a company specializing in producing large-sized metal products to verify the impact of the number of means of transport on the efficiency of the production process. Specifically, the *Experimenter* function was utilized, which analyzes many solutions of a selected area of the production process without the need to perform many simulations. Five variants were adopted, differing in the number of means of transport used.

For the first scenario (one means of transport), a low level of efficiency in the production process was found (47%) in accordance with the adopted assumptions. This scenario was characterized by a lack of stocks in material buffers. However, the level of forklift utilization was 100% (Fig. 5). The second scenario (two means of transport) generated similar production parameters as the first scenario but with a higher estimated efficiency (58%). The third scenario (three means of transport) was characterized by an efficiency of 75%, inventories of 91 items, and 92% use of means of transport. The fourth scenario (four means of transport) achieved an efficiency of 78%, material inventories of 511 items, and the use of means of transport at the level of 75%. Finally, the fifth scenario (five means of transport) was characterized by an efficiency of 80%, inventories of 743 items, and 46% use of means of transport.

The analysis revealed that Scenarios 3, 4, and 5 achieved an acceptable level of production efficiency (i.e., above 70%), ensuring the implementation of production works. In the area of analysis of the level of material buffers used, Scenarios 1, 2, and 3 minimized the inventory level, which is beneficial in terms of cost reductions and the optimal use of production space. The use of three forklifts, in particular, allows for the continuous operation of production stations while minimizing current inventories. Regarding the percentage of means of transport used, Scenarios 1 and 2 were associated with a 100% use of forklifts, which, in combination with the low efficiency of the production process, indicates that the number of means of transport used is too small. Therefore, it was concluded that Scenario 3 is the best of the solutions considered in this study. However, it should be noted that changes in the input parameters of the production process subjected to analysis (i.e., changes in data regarding the times of production operations, the length of transport paths, or the arrangement of production stations in the hall) may change the parameters generated by the production process, which, in turn, affects the number of production resources that will provide the most favorable parameters for the entire production process.

Overall, we conclude that computer simulation can be used at the design stage to verify important processes from the point of view of the functioning of enterprises, including the selection of solutions allowing the achievement of goals.

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