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ANALYSIS OF PRODUCTION PROCESS PERFORMANCE USING COMPUTER

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Abstract:
Planning a production process in terms of correctly defining its efficiency, duration and the level of generated costs is a difficult task. Manufacturing processes are characterized by a high level of complexity and are exposed to a large number of external factors that are difficult to predict. In many cases, one of the tools supporting decisions in the analysis of manufacturing process parameters is the use of computer simulation both at the process planning stage and in real time during its implementation. In this article, a computer simulation tool (FlexSim simulation software) was used to analyze the parameters of a selected production process. The conducted analyses allowed for indicating the direction of actions in the use of computer simulation as a decision support tool at selected stages of production process planning in the area of evaluating solutions aimed at implementing improvements.

Key words: computer simulation, FlexSim simulation software, production planning, production process improvement

INTRODUCTION

One of the basic goals in manufacturing companies is the continuous improvement of manufacturing processes [1, 2]. Growing competition on the market and the implementation of Industry 4.0 solutions force manufacturers to use techniques and methods that allow for the maximum use of their production capabilities [3]. The fourth industrial revolution has opened up many opportunities for the implementation of modern digital technologies capable of changing the traditional way of planning production processes and the way they are managed [4, 5]. The Internet of Things (IoT), digital twins (DT), cloud computing or simulations of real processes are becoming standard solutions that form the basis of the operations of many manufacturing companies [5, 6].

One of the most commonly used decision-support tools is computer simulation. Manufacturing companies decide to purchase simulation software due to the prospect of improving the organization of the process and predicting the results in terms of assessing the decisions made. Proper use of simulation can lead to shortening the duration of the production process, increasing its efficiency while reducing costs [7, 8]. An indisputable advantage of using programs to simulate manufacturing processes is the ability to conduct many experiments in a short time. Due to the high costs and numerous organically impossible to conduct a large number of analyses, for example, of the effects of implementing selected improvements or assumptions at the stage of planning processes on real production systems [9]. Therefore, using computer simulation as a decision-support tool seems to be the right solution, allowing for the prediction of parameters generated by the production process as a result of the introduced changes.

The aim of the article was to verify the possibility of using computer simulation (FlexSim simulation software) as a tool supporting decision-making in the assessment of parameters generated by the production process (level of use of production stations, level of use of inter-operational buffers and financial analysis) in real time and to check the impact of planned improvements on the functioning of the analyzed process. The use of computer simulation to analyze the actual production process in the furniture industry (case study) can complement existing research conducted in the field of the possibility of using simulation at the stage of planning the production process and its assessment. The obtained results can confirm the validity of using the simulation tool to verify existing production solutions, as well as planned changes or indicate limitations that were identified during the conducted research.

REVIEW OF THE LITERATURE

There are many programs available on the market that allow for the simulation of discrete processes (DES), including simulation software: Enterprise Dynamics, FlexSim, Plant Simulation, ARENA and many others [9, 10, 11]. These programs allow, among others: identification of bottlenecks in the production and storage process [12, 13, 14, 15, 16], reduction of production and logistics costs [17], analysis of solutions in the scope of flows in production processes [18, 19], reduction and elimination of delays [20] and areas related to planning of production and logistics processes [21, 22, 23]. In each case, the authors of the articles used real data and specific examples to demonstrate the validity of using computer simulation to analyze all areas related to production processes.

Currently, production process simulation tools have built-in modules supporting activities in the scope of decision-making using the production function of obtained results, taking into account selected boundary conditions or even proposing the most advantageous solutions in specific conditions [24]. Obtaining correct results (consistent with reality) as a result of the conducted simulations requires building a simulation model with an appropriate level of detail. In the literature [25], it is pointed out that designing complex models of production and logistics systems requires the integration of strategies in the field of production process organization, manufacturing system architecture, process management tools, evaluation of parameters generated by the production process, analysis of proposed solutions and risk analysis. Regardless of the simulation software used, the process of designing a computer simulation should begin with defining the simulation goal and determining the boundary conditions of the activities carried out [26]. Clearly defined boundary conditions allow for limiting the conducted analyses to a precisely defined area, thus allowing for the implementation of the assumed simulation goal. Limiting the scope of the simulation allows for reducing the risks associated with the negative impact of independent factors on the model, which can cause numerous disruptions in the simulation process. Another element that must be taken into account during the construction of the simulation model is the implementation of high-quality data. The use of data that does not reflect reality in the area of, among others, the duration of individual production operations, distances between production stations, or the level of machine failure and changeover time is one of the most common threats leading to the falsification of results generated by the simulation program. As a result, the results obtained from a successfully conducted simulation are burdened with an error. Such a situation can lead to taking inappropriate actions that do not have a positive impact on the process subjected to analysis. Therefore, the process of creating a computer simulation should be assessed on an ongoing basis.

METHODOLOGY AND RESEARCH AREA

The aim of the article was to verify the possibility of using computer simulation as a tool supporting decision-making in the scope of evaluation of parameters generated by the production process in real time and to verify the impact of planned improvements on the way the process subjected to analysis operates. In order to implement the set assumptions, a 5-step methodology was developed, covering:

STAGE 1: Building a simulation model – creating a simulation model in simulation software in a way that reflects production reality.
STAGE 2: Selecting statistical indicators – allowing for the assessment of the current state of the production process and after the implemented improvements.
STAGE 3: Conducting a computer simulation – conducting a simulation and generating results within the level of statistical indicators defined in the second stage.
STAGE 4: Analyzing the obtained results and proposing improvement solutions – performing a preliminary analysis of the results together with identifying areas that could be improved. Proposing and implementing changes to the model, in accordance with the specified assumptions.
STAGE 5: Comparative analysis and evaluation of the obtained results – summary of the obtained results, evaluation and decision on verification of further improvements or termination of the study.

The manufacturing company on the basis of which the analysis (case study) was carried out has been operating for many years in the furniture industry and has extensive experience in the serial production of finished products. The process subject to verification concerned the production of a bedside cabinet for self-assembly made to a special customer order. The annual production volume assumed the production of 10,000 pieces of the finished product, for the purposes of the study, simulations were carried out of one batch of the product, which amounted to 100 pieces. The production process included the production of a total of 6 elements (Item_1 – 2 pieces, Item_2 – 2 pieces, Item_3 – 1 piece, Item_4 – 1 piece), which were part of the finished product. The production process analyzed also included packaging operations. The production process was carried out on conventional machines adapted to perform operations in the scope of furniture production. The flow of components between individual production stations was carried out in a parallel system, Figure 1.

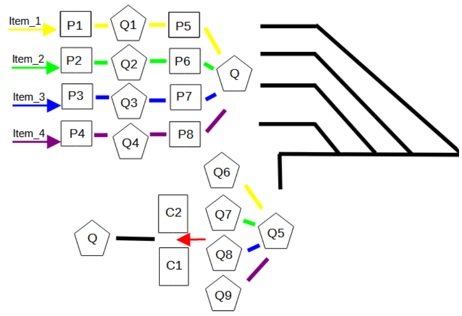


Fig. 1 Scheme of the production process, where: P1÷P8 – production stations, Q1÷Q9 – inter-operational warehouses, C1 and C2 – packaging stations

The flow of components between individual production stations was realized in a parallel system. The duration of the operation and the cost of the stations were provided by the production company, Table 1.

The execution time of item number three (Item_3) is the longest and, without taking into account the packaging time, amounts to a total of 140 seconds. Item number 4 (Elememt_4) is characterized by the shortest execution time of 45 seconds. Due to the type of production stations, their hourly labor cost was \$80/h and \$55/h. In the case of stations performing packaging operations, the costs were \$30/h.

The basic production parameters that were analyzed using computer simulation were the level of utilization of production stations, the level of utilization of inter-operational buffers and the amount of costs generated by the process.

Table 1
Production process parameters

Production station	Description of the performed operation	Semi-finished product number	Operation execution time [s]	Production station costs [$/h]
P1	Cutting material according to technical drawing	Item_1	40	80
P2		Item_2	40	
P3		Item_3	95	
P4		Item_4	20	
P5	Making mounting holes and cuts according to the technical drawing	Item_1	70	55
P6		Item_2	42	
P7		Item_3	45	
P8		Item_4	25	
Combiner 1	Packaging of products	Item_1 Item_2 Item_3 Item_4	30	30
Combiner 2				

The obtained results allowed for the assessment of the current production process in terms of, among others, the occurrence of bottlenecks and enabled the assessment of the introduced improvements.

Thanks to the information obtained regarding the production process, as well as that related to the form of production organization and the layout of production stations, the discussed process was an appropriate model for conducting an analysis within the scope of the defined work objective. Verification of the possibility of using computer simulation and evaluation of its effectiveness in a real process (case study) allows for confirmation of its effectiveness in the analysis and evaluation of production processes, which may constitute further evidence confirming the validity of its use.

To perform the computer simulation, the FlexSim 22.2.1 simulation software was used, which has extensive possibilities in the field of simulation of production processes and analysis of their parameters. The choice of the FlexSim simulation software was dictated by its availability, as well as the possibilities it offers, i.e. the possibility of building logical models, analyzing parameters by generating numerous diagrams and reports, as well as an extensive library of models. The validity of using FlexSim simulation software to evaluate the parameters generated by the production process has been confirmed in numerous publications [9, 12, 13, 18, 27, 28, 29].

RESULTS AND DISCUSSION

In accordance with the procedure methodology, a simulation model was created in the first stage. The simulation model consisted of a total of 29 objects including: 8 production stations (P1-P8), 2 packaging stations (Combiner1 and Combiner2), 11 interoperational buffers (Queue), sources generating input material (Source) and interoperational transport means (conveyors), Figure 2.

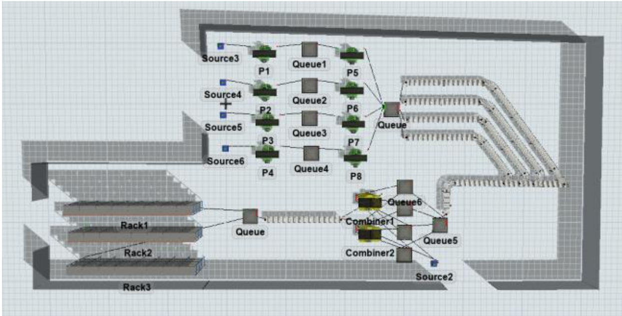


Fig. 2 Process model in FlexSim simulation software

In the second stage, statistical analyses were selected to define the parameters generated by the production process, which were used to verify the current state and constituted a reference point for the assessment of the proposed improvements, Table 2.

Table 2
Indicators used in the analysis of parameters in the FlexSim simulation software

Indicator	Description
The level of utilization of production stations	It shows the level of utilization of production stations during the production process. A high result may indicate that the workstation is overloaded
The level of utilization of inter-operational warehouses	Information about a high level of interoperational stocks in the buffer in the case of parallel flow may indicate a bottleneck in the process.
Financial analysis of the process	The financial analysis indicates the amount of costs related to the production resources used the production process.

As a result of determining statistical analyses and their implementation in the FlexSim simulation software, it was possible to conduct simulations.

As a result of performing a computer simulation of the current state of the production process, results were obtained in terms of the level of use of production stations (Figure 3), the level of use of inter-operational buffers (Figure 4) and the amount of costs generated by the production process (Figure 5).

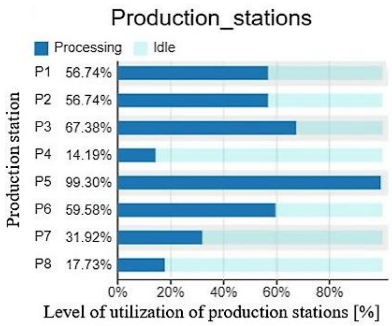


Fig. 3 Level of utilization of production stations before the improvements were introduced

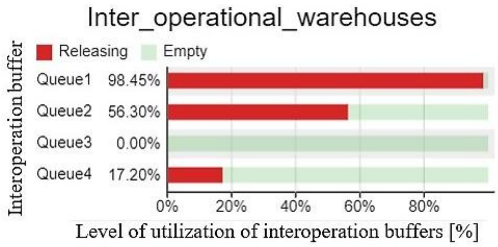
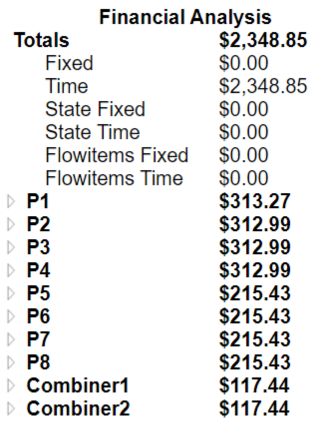


Fig. 4 Interoperation buffer utilization level before the improvements were introduced



Financial Analysis

Totals	**$2,348.85**
Fixed	$0.00
Time	$2,348.85
State Fixed	$0.00
State Time	$0.00
Flowitems Fixed	$0.00
Flowitems Time	$0.00
P1	**$313.27**
P2	**$312.99**
P3	**$312.99**
P4	**$312.99**
P5	**$215.43**
P6	**$215.43**
P7	**$215.43**
P8	**$215.43**
Combiner1	**$117.44**
Combiner2	**$117.44**

Fig. 5 Costs generated by the production process before the improvements were introduced

The highest percentage level of utilization was recorded at station number 5 (P5), which amounted to over 99% of the production process duration. The lowest percentage of utilization was generated by stations number 4 and 8 (P4 and P8), 14.19% and 17.73%, respectively.

During the analysis of the buffer utilization level, it was found that the highest level of inter-operational stocks occurred on buffer number 1 (Queue1), its utilization level was over 98%. Also taking into account the fact that station number 5 (P5) performing the production operation of mounting holes on element 1 (Item_1) has the highest utilization level (Figure 3), it is concluded that this operation is a bottleneck in the production process. The duration of the analyzed production process was 3.92 hours, while the total cost level was equal to $2,348.85

Based on the obtained results, solutions were proposed to reduce the bottleneck phenomenon by reducing the percentage level of use of station number 5 (P5) while increasing the level of use of stations number 4, 7 and 8 (P4, P7 and P8). In connection with the above, a decision was made to remove station number 4 (P4) performing material cutting operations for item number 4 (Item_4) and to divide the work in the scope of the mentioned operation into stations number 1 and 2 (P1 and P2). Due to the high level of use of station number 5 (P5) performing operations of making mounting holes for item number 1 (Item_1), part of the production was shifted to stations number 7 and 8 (P7 and P8), Figure 6, Table 3.

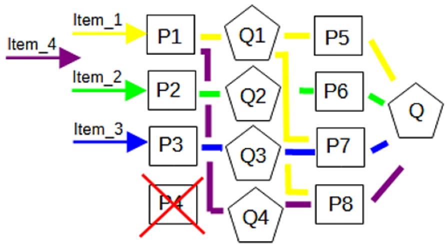


Fig. 6 Changes in the production process diagram

Table 3

Production process parameters after the changes introduced

Production station	Description of the operation performed	Semi-finished product number	Operation execution time [s]
P1	Cutting material according to technical drawing	Item_1	40
		Item_4	**20**
P2		Item_2	40
		Item_4	**20**
P3		Item_3	95
~~**P4**~~		~~Item_4~~	~~20~~
P5	Making mounting holes and cuts according to the technical drawing	Item_1	70
P6		Item_2	42
P7		Item_3	45
		Item_1	**90**
P8		Item_4	25
		Item_1	**90**

In accordance with the procedure methodology, another computer simulation was carried out to generate results that would allow for a comparison of the proposed solution with the original process. The obtained results showed that the percentage share of production stations 1 and 2 (P1 and P2) increased to 88.24% and 88.41%, respectively, due to the removal of station 4 (P4). By redirecting part of the production to stations 7 and 8 (P7 and P8), a reduction in the percentage use of the station was found by 18 percentage points, with a simultaneous increase in the involvement of the underutilized stations 7 and 8 (P7 and P8) by 56 and 69 percentage points, respectively, Figure 7.

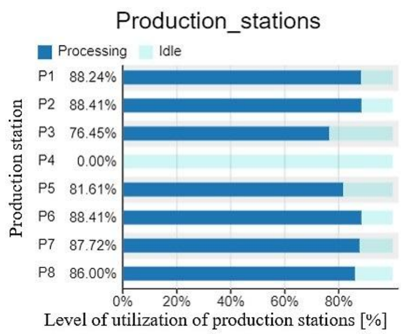


Fig. 7 Level of utilization of production stations after the implementation of improvements

As a result of the simulation, the percentage utilization of the interoperation buffer number 1 (Queue 1) was found to be reduced from about 99% to about 25% after the improvements were introduced. None of the four interoperation buffers had a percentage utilization above 30%, Figure 8.

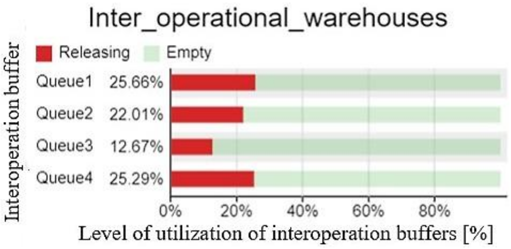


Fig. 8 Level of utilization of production stations after the implementation of improvements

The duration of the production process after the introduced improvements was 2.94 hours. The total costs generated by the production process subjected to analysis were reduced to the level of $1,597.34. The reduction of the production process duration, manufacturing process costs, the level of inter-operational inventories with the simultaneous elimination of one production station (P4) prove the validity of the proposed solutions in the case study subjected to analysis. The use of computer simulation allowed for the identification of areas that could be improved, e.g. by indicating a bottleneck in the production process, which has already been described in publications [12, 13, 14]. At the same time, the verification of the proposed solutions indicated that computer simulation can be a tool supporting decision-making in the scope of implemented changes in manufacturing processes [21, 23].

In further research, based on the analyzed example, it is planned to evaluate the actual results against those generated by the simulation software. Comparison of the obtained parameters as a function of time may allow for verification of the detail of the data implemented at the stage of creating the simulation and taking into account factors that were not taken into account before. Such action may make it possible to indicate key areas that determine the convergence of data obtained through the use of computer simulation at the stage of planning the production process and data generated by the actual production process after its launch.

CONCLUSIONS

The article presented an analysis of the production process using computer simulation as a tool supporting decision-making in the area of assessing the justification for introducing changes in production processes.

The study conducted using computer simulation (FlexSim simulation software) included an assessment of the parameters generated by the production process and, on their basis, proposing improvements. As a result of the activities carried out, it was found that:

- In the production process, based on the analysis of the level of use of inter-operational buffers and production stations, a bottleneck was identified, which was station number 5 (P5).
- The level of use of stations 4, 7 and 8 (P4, P7 and P8) was low, which reduced the efficiency of the production process.
- The improvements introduced in the area of redirecting part of the production of element 1 and 4 allowed for an increase in the use of station numbers 1, 2, 7 and 8 (P1, P2, P7 and P8) while eliminating station number 4 (P4) and reducing the level of inter-operational stocks.
- The duration of the production process was reduced from 3.92 to 2.94.
- The costs generated by the production process, resulting from the reduction of the duration of the production process and one production station (P4), were reduced by $751.51.

Based on the results obtained, it was found that the use of computer simulation allowed for an effective assessment of the current state of the production process subjected to analysis. The simulations carried out and the results generated in terms of the parameters generated by the process after the implemented improvements indicate the validity of using computer simulation as a decision support tool.

It should be noted, however, that the data on the basis of which computer simulations and the evaluation of the introduced improvements were performed come from a single production plant (case study), which does not allow for the definition of a clear rule describing the impact, effectiveness and validity of using computer simulation in other manufacturing processes.

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