Utilizing Computer Simulation to Optimize Furniture Production System

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Computer simulation methods are currently used to simulate production processes and optimize production systems. Computer simulation is one of the most effective tools for implementation of Industry 4.0 principles in industrial practice. This research focused on the optimization of production processes in furniture production using simulation, which is an innovative method of production optimization for furniture manufacturers. The aim of this research was to improve the production system of Slovak furniture manufacturing enterprise by creating a discrete event simulation model of production based on the analysis of its current state. Improvement indicators are specific parameters of the production system, which primarily include material flow, productivity, and workload utilization. First, with the use of Tecnomatix Plant Simulation software and the collected real production data, the original production system processes were simulated and analyzed. Second, the incorporation of more powerful devices was proposed to improve the production line. Third, the proposed improvements were simulated and analyzed. The result of this research was a statistical comparison of the parameters of the current production line and the proposed production improvements.

Keywords: Furniture production system; Industry 4.0; Simulation model; Optimization of manufacturing processes

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INTRODUCTION

The current rapid growth and development of information and communication technology (ICT) and modern computational methods enables the designing and modeling of production systems and their processes. Information technology aids the modernization of production. Worldwide and Pan-European innovative trends in complex information and digitization technology of production systems require the research, development, and implementation of new system solutions to introduce new intelligent methods for optimizing, managing, and diagnosing complex processes. Expansion of information technologies into industry is referred to as the Fourth Industrial Revolution. Industry 4.0 represents a revolution in industry that offers advanced solutions to improve the competitiveness of production enterprises through implementation of advanced automation and digital technology (Ratnasingam *et al.* 2018, 2019). Industry 4.0 is a new platform to connect the best scientists with industrial practice to increase the competitiveness of businesses or the country's economy. Digitization is the main driver of the massive changes that interfere with modern production systems. Digitization includes product digitization and digitization and optimization of all processes, including the digitization of services.

The main vision of Industry 4.0 in manufacturing is to combine cyber-physical systems with industrial automation systems. This integration of systems, which differs greatly from nature, aims to create context-aware factories, in which people and machines are in real-time alignment (Prause and Weigand 2016).

The Industry 4.0 philosophy and the associated method of digital factory require a wide range of tasks and skills to be managed for their successful application and efficient operating. One of the key competencies for their reliable operation is mastering computer simulation of various processes that take place within the enterprise (Neradilova and Fedorko 2017).

Optimization of the production processes is one of the most common optimization tasks in production. The complexity and demands of the market environment force businesses to pay attention to improving operating conditions (Alavi and Habek 2016). The enterprise must work so that the input-output transformation proceeds with the optimal consumption of production inputs, the optimal choice of production processes and resources, and the optimal utilization of production capacity (Simanova and Gejdos 2016). In addition, it must enable the enterprise to complete and achieve goals with increased efficiency. In planning and manufacturing, modern sophisticated methods are implemented, such as the just in time/just in sequence or Kanban methods to plan and build new production lines and manage production (Krauszova 2015). Deciding the basis of objective criteria will help management evaluate and compare alternative approaches. Optimization consists of choosing the best solution from many existing options.

Simulation is the reproduction of a real system that contains dynamic processes in simulation models. In a broader sense, simulation involves the preparation, implementation, and evaluation of specific experiments using a simulation model. The model is a simplified replica of a planned or real system characterized by processes in another system. Tecnomatix Plan Simulation (TPS) from Siemens is a simulation tool that helps to create digital models of systems, such as production, to generate system characteristics and optimize performance. Digital models allow experimentation with scenarios without disturbing existing production. Simulation can also be used in the planning process long before the changes are introduced into the production process (Bangsow 2010, 2012). The Tecnomatix solution optimizes business processes through simulations that determine the ability to deliver the product faster. TPS enables the matching of production capacities with the production goals from product development to delivery by reducing the lengthy introduction of processes, which improves their quality and ultimately increases enterprise flexibility, market share, and brand value. Creating a simulation model is currently a major challenge for enterprises aiming to modernize their processes through the latest Industry 4.0 trends in enterprise digitization.

The automotive sector is mainly focused on the simulation of manufacturing processes and the implementation of Industry 4.0 principles into production (Bambura *et al.* 2019; Cortés *et al.* 2019; Villagomez *et al.* 2019; Sujova *et al.* 2020). However, simulation is also a viable optimization method for the furniture manufacturing and woodworking industries (Kosturiak and Gregor 1999; Klein and Thomas 2006; Carlson and Yao 2008; Kofjac and Kljajic 2008a, 2008b; Ali and Zulkifli 2017; Rahman *et al.* 2018). Computer simulation is an excellent method to support decision making in furniture manufacturing with fast analysis of various scenarios in production systems in a relatively short time to choose the best production solutions (Plinta and Grznar 2019; Jurczyk-Bunkowska 2020). Kršulja *et al.* (2011) showed that TPS software can be used in woodworking industry to investigate material flow and number of products manufactured per unit of time was increased by Perzyna (2019) with the use of TPS. Malega and Kováč (2015) showed possibilities of TPS in wood processing to help businesses to increase productivity and optimize costs associated to the production, especially to save money and time. TPS possibilities for analysis of the benefits resulting from investment in modern manufacturing equipment, cost savings, reduced production times, decreased work capacity, balancing equipment capacity, and improvement of product quality was done by Freiberg and Scholz (2015).

Another important part of Industry 4.0 vison is ethical recognition, which leads to fundamental changes in production and human society. Ethical importance and potential ethical risks need to be evaluated to allow rapid technology growth. Therefore, the civilization changes under Industry 4.0 and the adaption to the parameters of new industrial revolution highlight the ethical caution and moral sensibility of reducing or eliminating the potential negative impacts on humans and their existential conditions.

Industry 4.0 is deeply linked with Digital Factory concepts. Digital Factory (DF) shows manufacturing processes of real production in a virtual environment. DF tools allow for planning, simulating, and optimizing manufacturing of a selected product. Verification and optimization of production systems can be completed in the beginning of the planning stage, which ensures that the subsequent stages, *e.g.*, production and usage stage of the product, are secured in terms of quality, time, and costs. Mainly, automotive companies and large manufacturers with high series production implement DF tools into production. However, DF tools are also successfully implemented into production lines with smaller seriality and higher necessity to change or rebuild production lines. DF tools are frequently used in the unit production and are gradually set in other production types, *e.g.*, mass or batch production with aim to increase productivity, reduce costs, and increase efficiency (Maslarić *et al.* 2013; Andrejszki *et al.* 2015; Nikolina *et al.* 2015; CeitGroup 2020).

This paper deals with optimization of furniture production systems using the computer simulation method. The simulation of one product from the company's portfolio were analyzed, and human interaction was not considered in proposed research. Expansion of simulation with addition of other manufactured products and human interaction will be a part of the future study. The result of this paper is the design of an optimized production system to increase production efficiency. Simulation results are also expressed quantitatively using statistical data that indicates the effectiveness of the solution.

EXPERIMENTAL

Basic Mathematical Model of Production Planning in Simulation Models

N product groups are considered ($i = 1, 2, ..., N$). The time horizon is divided into time intervals T ($t = 1,2, ..., T$). The demand D_{it}, is predicted for each product group ($i = 1, 2, ..., N$) at individual time intervals ($t = 1, 2, ..., T$). There are M types of sources ($m = 1, 2, ..., M$) with limited capacity R_{mt}, which varies in time intervals ($t = 1, 2, ..., T$) due to repairs and maintenance of equipment and dismissal and hiring of human resources. To produce a group of production unit, r_{im}, *m-type* resource units are required. Indicator x_{it} represents the quantity of product group i in time interval t, and indicator I_{it} represents the product stock i at the end of time interval t. The initial stock for item i is indicated by I_{i0}. Due to the uncertainty of demand, the stock level cannot fall below the security level I_{it}^{+}, for each product group i and the time interval t. Indicator c_i represents unit storage costs per unit of product group i in one time interval t. The aim was to plan the amount of production and inventory of each product group at intervals to meet demand forecasts at minimum storage costs.

The basic model of production planning can be formulated as a task of linear programming:

$$\sum_{t=1}^{T} \sum_{i=1}^{N} c_i I_{it} \rightarrow min \quad (1)$$

The purpose-based mathematical function expresses the objective of minimizing total storage costs over the entire time horizon with restrictions:

$$x_{it} + I_{i,t-1} - I_{it} = D_{it} \qquad i = 1, 2, \ldots, N \qquad t = 1, 2, \ldots, T \quad (2)$$

The restriction expresses the balance between demand and production with the change in stocks of the previous and current period:

$$\sum_{i=1}^{N} r_{im} x_{it} \leq R_{mt} \qquad t = 1, 2, \ldots, T \qquad m = 1, 2, \ldots, M \quad (3)$$

The restriction compares the need for resources with their limited capacity:

$$x_{it} \geq 0 \qquad I_{it} \geq I_{it}^{*} \qquad i = 1, 2, \ldots, N \qquad t = 1, 2, \ldots, T \quad (4)$$

Under this limitation, lower limits are set for non-negative quantities of production to ensure stocks are not falling below the safety level.

The basic model may not have a solution due to insufficient resource capacity, but the original formulation does not identify where resources are overloaded. Therefore, the resource restrictions can be modified by introducing a variable $z_{mt} \geq 0$, which expresses the overload of the resource *m* over time *t*:

$$\sum_{i=1}^{N} r_{im} x_{it} \leq R_{mt} + Z_{mt} \qquad t = 1, 2, \ldots, T \qquad m = 1, 2, \ldots, M \quad (5)$$

Therefore, the purpose-based mathematical function can be modified to:

$$\sum_{i=1}^{T} \left(\sum_{i=1}^{N} c_i y_{it} + p \sum_{m=1}^{M} z_{mt} \right) \rightarrow min \quad (6)$$

where *p* is a penalty from the source overload.

The modification of the production planning model considers the variable level of labor and the possibility of deferred demand. The level of workforce W_t is complemented by the possibility of using overtime O_t and the possibility of hiring H_t and dismissing F_t the workforce. The stock level is divided into two parts to express an unlimited variable using two non-negative variables:

$$I_{it} = I_{it}^{+} - I_{it}^{-} \quad (7)$$

Deferred demand is modeled as a negative stock level. Cost coefficients c_{it}^{+}, c_{it}^{-} express storage costs and penalties, respectively, for deferred satisfaction of demand.

The whole model can be formulated as a task of linear programming,

$$\sum_i \sum_t (c_{it}^{+} I_{it}^{+} + c_{it}^{-} I_{it}^{-}) + \sum_t \left(w_{t_t} W_t + o_t O_t + h_t H_t + f_t F_t \right) \rightarrow min \quad (8)$$

with limitations:

$$x_{it} + I_{i,t-1}^{+} - I_{i,t-1}^{-} - I_{it}^{+} + I_{it}^{-} = D_{it} \qquad i = 1, 2, \ldots, N \quad t = 1, 2, \ldots, T \quad (9)$$

$$\sum_i r_i x_{it} \leq W_r + O_t \qquad t = 1, 2, \ldots, T \quad (10)$$

$$W_t = W_{t-1} + H_t - F_t \qquad t = 1, 2, \ldots, T \quad (11)$$

$$x_{it}, I_{it}^{+}, I_{it}^{-} \geq 0 \qquad i = 1, 2, \ldots, N \quad t = 1, 2, \ldots, T \quad (12)$$

$$W_t, O_t, H_t, F_t \geq 0 \qquad t = 1, 2, \ldots, T \qquad (13)$$

This mathematical model represents the mathematical expression of production processes and their limitations, which can be defined in the simulation model (Trebuna 2018).

Application Possibilities of Simulation in Production Scheduling in TPS Software Environment

The aim of the discrete-event simulation (DES) is to simulate the production system, including its dynamically changing processes. The DES provides creation of various variants of experiments in which results and outputs are transferred to the actual production system in the form of knowledge. DES allows for the change of the system's parameters in successive steps. The main advantage of the DES, in contrast to classical static mathematical calculations, is the ability to perform system monitoring and analyze behavior of resources in a specified period. The results of the DES are a set of information, which can be used to implement optimization changes into production systems to increase production (Jain and Lechvalier 2016). Solving complex problems with analytical methods can be time consuming. Therefore, this procedure is effectively replaced by planning using simulation. The aim of planning is to design a suitable combination of successive production operations so that the final product is processed in the shortest time (Pinedo 2016). DES planning consists from creation of a simulation model that includes all resources that are used and transformed within production. Heuristic decision rules define the quality of the resulting production schedule. The simulation model represents the actual production system and captures all its parameters and properties, including operating and setting times of equipment, material flows, failure rate, product processing priority, *etc.* (Bangsow 2015; Hodon *et al*. 2018)

TPS allows the creation of well structured, hierarchical simulation models through object-oriented modelling, which allows the creation and maintenance of complex systems. DES can use algorithms to evaluate various material flows and strategies with analysis of their performance and then optimize system parameters such as throughput, use of resources, delivery times, *etc*. TPS analytical and statistical tools facilitate the interpretation of simulation results (Siemens 2020). The outputs of the simulation are resource usage statistics, from which one can determine the cost of individual workstations, and thus determine the effectiveness of the solution.

Materials

The focus of this research was to optimize the production systems of the furniture manufacturing enterprise through simulation. The aim was to make appropriate changes to increase production capacity, increase production efficiency, reduce costs, *etc*.

First, data collection and the analysis of production data was performed. One type of product was chosen for the analysis of the production system, which was a commode drawer/cabinet with drawers with external dimensions 1800 mm × 910 mm × 420 mm shown in Fig. 1. The product consisted of eight different parts made from wood composite chipboard with wood veneer in matt paint (Palik 2017).

To create a simulation model, it was necessary to analyze the current state of the technical equipment of production. The identified production line machines and equipment are listed in Table 1.

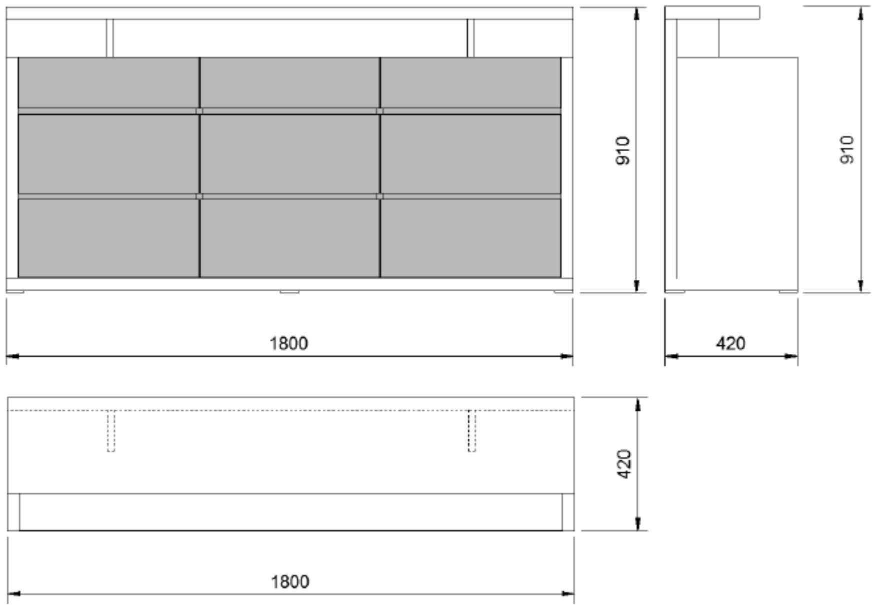

Fig. 1. The analyzed product dimensions (mm)

Table 1. Summary of Production Line Processes and Workstations

Process Indicator	Process Definition	Workstation	Machine Type
OP1_BR	Sawing of wood panel based on cutting plan	Automatic panel saw; Sliding table saw	Sector 430 F45
OP2_BR	Chipboard edge banding	Edge banding machine	Akron 440
OP3_BR	Sanding	Wide belt sander; Belt sander	Buldog 5 R/C Husky 22 PBB
OP4_BR	Surface treatment	Painting line	
OP5_BR	Drilling, boring, and assembly	Dowel drilling and boring machine; Drilling machine	M-29 Pro-Center 2000
OP6_BR	Packaging and shipping		

The sawing section (OP1_BR) cuts the chipboard panels according to the documentation. The panel saw Sector 430 (Biesse S.P.A, Pesaro, Italy) workplace cut all commonly machined parts. However, on a sliding table saw F45 (Altendorf GmbH, Minden, Germany), the employee must finish workpieces with a 45° cut edge. OP2_BR section consisted from an edge banding machine Akron 440 (Biesse S.P.A, Pesaro, Italy). The surface treatment section (OP3_BR and OP4_BR) is a section with a complex production process. In this section, the parts enter in the raw state and, after spraying with the respective finishes, parts are returned for sanding the lacquers on wide belt sander Buldog 5 R/C (Houfek, Golčuv Jeníkov, Czech Republic) or belt sander Husky 22 PBB (Houfek, Golčuv Jeníkov, Czech Republic) so that they can be processes on final surface treatment. The assembly section (OP5_BR) is the most demanding in terms of work and time. Throughout the production line, this is the longest lasting process. The employee in this section assembles the individual workpieces into one final product. After a complete surface treatment of all workpieces belonging to the selected product, the employee drills all necessary holes for ironmongery hardware according to the documentation on dowel drilling and boring machine M29 (Detel, Logatec, Slovenia) or drilling machine Pro-Center 2000 (Blum, Swarzędz-Jasin, Poland). After drilling, the employee mounts the product into one dismountable unit. After completing all assembly work, the final functionality check of all parts is performed with the subsequent packaging and shipping (OP6_BR) of the product.

Data collection for the creation of the simulation model also included a summarization of the production process times for individual parts of the analyzed product. The process times for the individual processes sorted by product parts are shown in Table 2.

Table 2. Process Times for Individual Produced Parts of the Analyzed Product

Process	Process Times for Individual Parts (min)								Total (min)
	Side Panel	Bottom Panel	Support Panel	Back Panel	Middle Panel	Drawer	Cover Panel	Strip	
OP1_BR	32	32	10.5	20.5	17	48	22	13	195
OP2_BR	30	30	20	20	17.5	52.5	20	5	195
OP3_BR	7	17	3.5	7.5	10	18	7	10	80
OP4_BR	88	58	24	25	46	194.5	86	43.5	565
OP5_BR	150	60	10	30	60	485	60	45	900
OP6_BR	2	2	0.5	1	1	6	2	0.5	15
Total	309	199	68.5	104	151.5	804	197	117	1950

RESULTS AND DISCUSSION

The aim of this research was to analyse production line efficiency *via* the simulation method (Fig. 2).

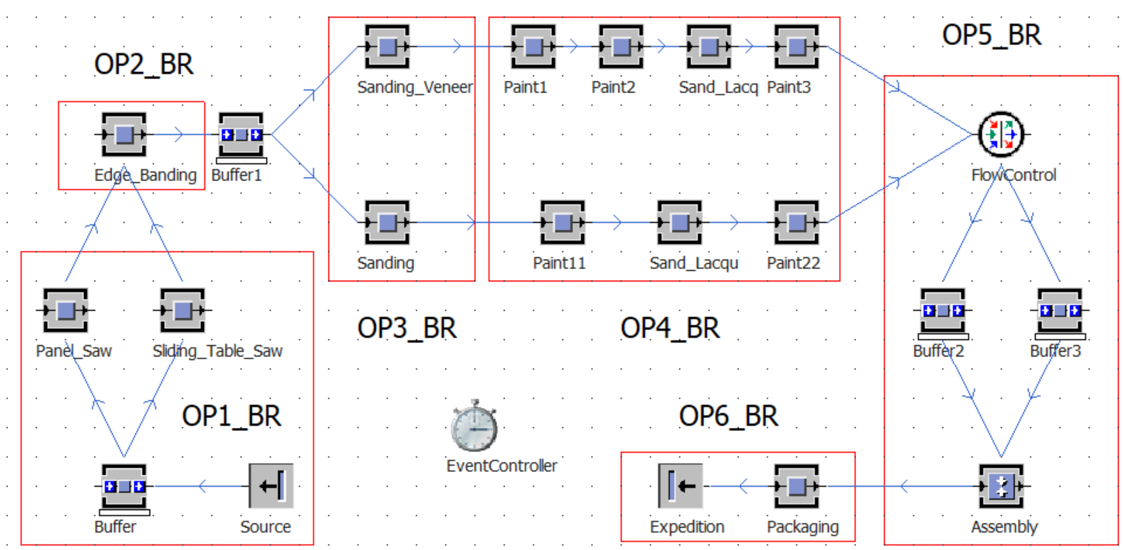

Fig. 2. The original line simulation model in TPS software

Using the real production data for commode drawer/cabinet with drawers manufacturing, a simulation model of the production system was created using the simulation method in the TPS software (Siemens, Plano, TX, USA) to simulate production of the analyzed product.

Based on the initial simulation, the resource usage statistics of the original production line are shown in Fig. 3. The results showed that the production line was not working efficiently. The simulation of only one product from the company's portfolio resulted in relatively inefficient production.

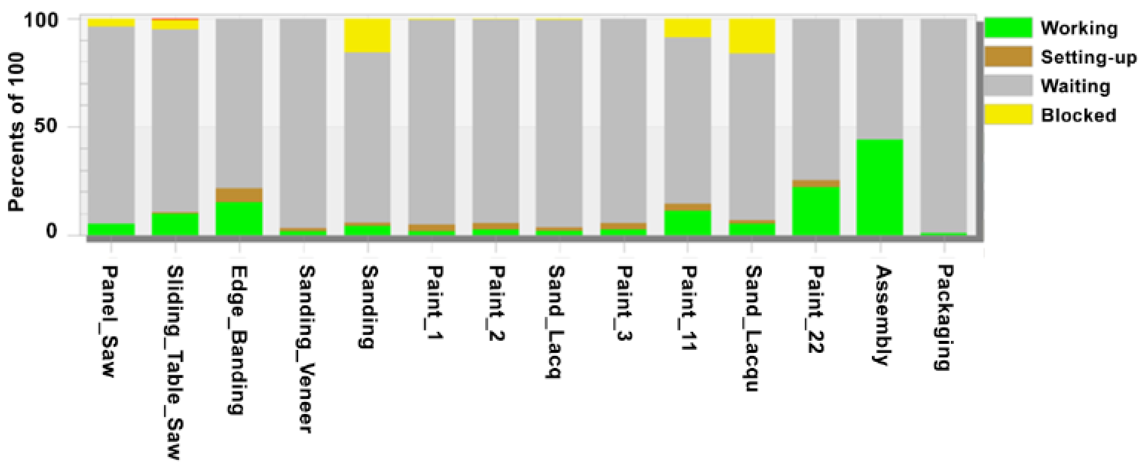

Fig. 3. The original production line resource usage statistics

However, the production line worked efficiently up to the assembly section. The high percentage of "waiting time" in each section was filled with other orders in the real production line. The assembly section was the most occupied section. This was also due to the fact that all workpieces necessary for the assembly of the selected product were surface treated before they were drilled and assembled into one unit. Therefore, the employee in this section must be extremely careful, which requires additional working time.

The proposed improvement of the production line consists of optimization of the sanding section. Currently, two sanders operate in the sanding section, and they are directly intended for solid material. In some cases, the sanding of wood veneer can be overdone, which is undesirable. When this occurs, the damaged part must go through the whole process again. Surfaces are often treated manually by an employee, which further extends the production time. Therefore, purchasing a new, more powerful sander SWT 335 RQH (Homag, Denkendorf, Germany) would result in more efficient production. Specifically, the lacquer sanding section should be completely replaced or merged with the sanding section before surface treatment.

The assembly section was also inefficient. The assembly section includes complete drilling of all ironmongery hardware parts and final assembly. Manual drilling is demanding in terms of preparation and accuracy. The purchased single-purpose computer numerical control machining center (CNC) C-Express 920 (Felder-Group, Hall in Tirol, Austria) relieves the assembly section, which allows the machine to perform all recurring drilling and simple milling operations. This means that all parts would be completely drilled. Therefore, any undesirable damage to the parts during drilling would be eliminated.

The implementation of proposed changes to the production line and simulation model of the improved section in TPS software is shown in Fig. 4.

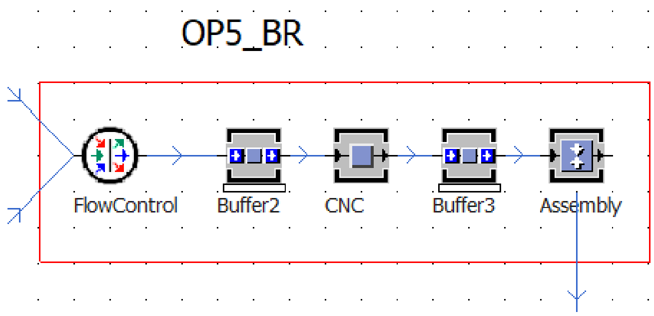

Fig. 4. The improved assembly section in TPS software

The resource statistics for the improved production line with a more powerful sanding machine and an additional CNC machine in the assembly section are shown in Fig. 5.

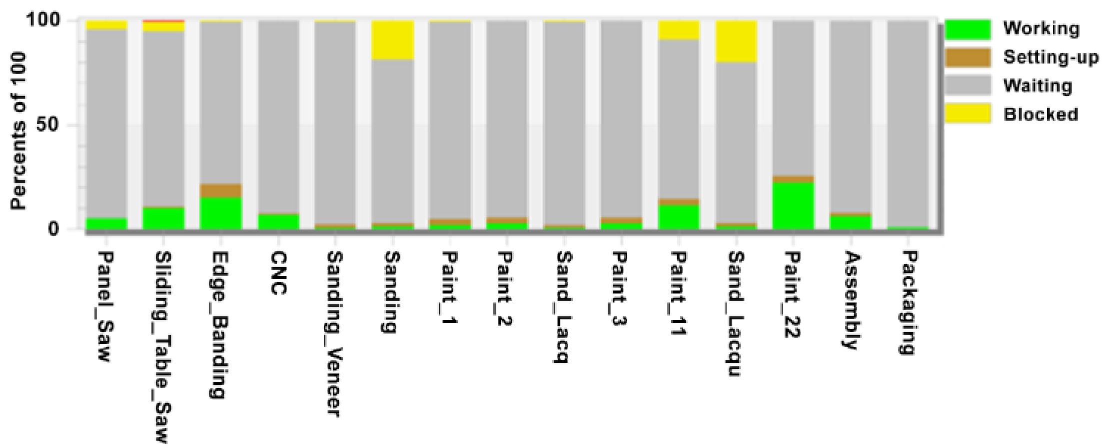

Fig. 5. The resource usage statistics for the improved production line

Comparison of original and improved production line is expressed through an indicator of overall equipment effectiveness (OEE), which identifies the percentage of manufacturing time that is truly productive. The comparison is shown in Table 3.

Based on the resource statistics of the improved production line, workloads in the workplaces were equalized, and the inclusion of a single-purpose CNC machining center reduced the workload of the manufacturing system bottleneck (assembly) from 4.8% to 5.84%. Overall equipment effectiveness reduction is beneficial because only one product was simulated. Due to the reduction in OEE, the processing of other products could be completed more quickly. Therefore, the overall productivity of the furniture production was increased.

The line simulation model also allows the expression of the total production time. The results show that the total production time of the production line was reduced from 34.25 h to 12.02 h. The results obtained from the simulation models showed that the inclusion of the CNC workplace eliminated the bottleneck in the original production line, and an approximately 38% reduction assembly time was achieved using this solution. Therefore, the production time of the product was also shortened. The simulation results showed that the proposed line was highly effective and worked with a balanced recovery rate.

Table 3. OEE of the Original and Improved Workstations

Workstation	Original OEE (%)	Improved OEE (%)
Automatic panel saw	4.87	4.87
Sliding table saw	9.98	9.98
Edge banding machine	15.09	15.09
CNC	-	6.52
Sanding veneer	1.58	0.51
Sanding_2	4.01	1.09
Painting _1	12.65	12.65
Painting_2	2.43	2.43
Sanding_Lacquer	7.11	1.46
Painting_3	24.33	24.33
Assembly	43.8	5.84
Packaging	0.73	0.73

The results of the simulation could support future investment, such as the purchase of new equipment. In this case, a new CNC machine was proposed. The advantages of creating simulation models of production plants are: 1) the emergence of new business models for the management of production systems using simulation models, in which flexibility in response to production changes can occur; 2) evaluation of projected innovations of production systems in the form of predictive simulation models; 3) customization of products based on the individual requirements of the customer; 4) elimination of waste in all areas of production and increased process efficiency by identifying bottlenecks in production systems.

In the broader literature (Bangsow 2012; Andrejszki *et al.* 2015; Neradilova and Fedorko 2017; CeitGroup 2020), the creation of simulation models is the first step towards comprehensive automation and computerization of the Industry 4.0 concepts. Automotive companies are predominantly focused on the implementation of the Fourth Industrial Revolution, which has been mentioned in the literature (Bambura *et al.* 2019; Cortes *et al.* 2019; Villagomez *et al.* 2019; Sujova *et al.* 2020). The implementation of Industry 4.0 is also essential for the development of furniture manufacturers and for the woodworking industry in general. Several scientific papers have also been published in this field (Nyemba and Mbohwa 2017; Koruca *et al*. 2018; Plinta and Grznar 2019; Jurczyk-Bunkowska 2020). This paper aimed to contribute to the promotion of computer simulations for furniture lines and show the first step for future implementation. Application of Industry 4.0 principles in furniture production is also described by Wang *et* *al.* (2017). The implementation of the Industry 4.0 concepts will give to businesses a great competitive advantage and product flexibility. However, the ethical risks associated with this process should be considered. Based on the above arguments, developments in the furniture industry will likely follow current trends in complex automation and computerization.

CONCLUSIONS

1. Implementation of various Industry 4.0 technologies and principles, *e.g.* simulation tools, into the production system can help enterprises to gain a competitive advantage.
2. The simulation method provided a fast, easy, and precise method to evaluate and analyze production processes and exploit bottlenecks of the production systems.
3. The optimization of manufacturing processes through simulation allows engineers to experiment with various scenarios of production before certain changes are implemented into real production, which is economically advantageous.
4. Industry 4.0 also represents a social turning point that results in ethical change.
5. The ethical risks and potential negative consequences of new technologies and use of digital data in relation to customers and partners should be explored.
6. Based on simulation results we were able to reduce total production time from 34.25 h to 12.02 h. Addition of the CNC workplace eliminated unwanted bottlenecks and reduced assembly time by 38%.
7. Virtual production line will be expanded in future by including more products into production and workers will be included in simulation to achieve 100% compliance between physical and virtual world.

ACKNOWLEDGMENTS

The authors would thank the APVV Agency for their support *via* project APVV-17-0400, which is titled “Enhancing the Ethical Environment in Slovakia (Institutional Procedures, Actors, Risks, Strategies).” This paper was created as part of the aforementioned project.

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Article submitted: April 22, 2020; Peer review completed: June 21, 2020; Revised version received July 6, 2020; Accepted: July 7, 2020; Published: July 14, 2020.
DOI: 10.15376/biores.15.3.6752-6765