CASE STUDY OF REAL MANUFACTURING SYSTEM IMPROVING THROUGH SIMULATION MODELS

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The paper deals with a real manufacturing system improving through simulation models creation. The aim of the paper is to present the possibilities of simulations models as a tool for optimization and quantification of proposals to improve production lines in engineering production. The research is carried out as a case study of a production plant in a Slovak machine-building company dealing with the components for the automotive sector production. The paper presents the creation of simulation models of the original line as well as the simulation model of improved line where robotic arms were used for material handling. Output statistics comparing the performance of the original line and its improved variant are part of the paper. We expect that in the coming years there will be an increased demand for creation of simulation models of manufacturing systems by modern enterprises that will try to implement the Industry 4.0 strategy and thus increase its competitiveness.

KEYWORDS

simulation model, production line, output statistics, improving, Industry 4.0

1 INTRODUCTION

In the last few years, Industry 4.0 has been considered as one of the most prevalent topics in production engineering [Almada-Lobo 2016]. With evolving industrial and technological progress, faster and more precise production is necessary to be accomplished by companies to gain competitive advantage. Therefore, manufacturing industry is challenged with advancements in digital technologies that allow companies to easily connect physical and virtual world of production to enhance future project planning and optimization of current production lines [Dado 2018]. This vision can be achieved with creation of simulation models that represent an essential tool for planning, operating and evaluating manufacturing systems [Bialy 2018]. Simulation model complexity provides several advantages in the planning phase of a future projects [Popovics 2016].

Simulation is the reproduction of a real system containing 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) is a simulation tool that helps to create digital models for systems such as production to generate system characteristics and optimize performance. Digital models allow experimentation with scenarios without disturbing existing production. They can also be used in the planning process long before the changes are introduced into the production process [Neradilova 2017]. The Tecnomatix solution through simulations optimizes business processes that determine the ability to deliver the product faster. Tecnomatix makes it possible to match the production capacities with the proposed intent from product development to delivery to reduce the lengthy introduction of processes, thereby improving their quality, and ultimately to increase company flexibility, market share and brand value. Creating a simulation model is currently a major challenge for businesses with ambition to engage in the modernization of their processes through the latest trend in enterprise digitization, Industry 4.0 [Saniuk 2018].

2 CHARAKTERISTICS OF COMPUTER SIMULATION AS A TOOL OF INDUSTRY 4.0 APPLICATION

The simulation model can be characterized as a system that mimics the actual idea of the simulated system and its movement. Simulation define the created artificial material objects. An important feature is that the imitation system must maintain the same configuration changes over time. Thus, the sequence of events cannot be changed, otherwise the simulation model denounces the fact [Gregor 1992].

Simulation of the production line in the TPS environment is an effective method for solving our research objectives aimed at analysing the line processes efficiency. The outputs of the preformed simulation are resource statistics, from which we can determine the cost of individual workstations and thus determine the effectiveness of the solution.

Tecnomatix Plant Simulation (TPS) is a simulation tool that enables you to create digital system models to help you define the system characteristics and optimize performance. Digital models allow us to experiment with scenarios without disturbing the existing production being able to use them in the planning process long before the changes are introduced into the production process. Extensive analytical tools, such as narrow space analyses, statistics and graphs allow you to evaluate different production scenarios. Simulation of results provides the information needed for quick and reliable decisions in the initial stages of production planning. Using TPS, we can model and simulate manufacturing systems and their processes. In addition, TPS allows you to optimize the material flow, resource utilization, and logistics for levels of production plant planning, through local plans to specific lines [Bangsow 2010].

TPS simulations are used with high efficiency to optimize production and minimize the process work. Simulation models make it possible to consider the internal and external supply chains, production resources and business processes, allowing you to analyse the impacts of different production variants. It is possible to evaluate different production lines, control strategy and verify the synchronization of lines. The system allows to define different material flows and determine their effect on the line and its performance. Control rules are selected from libraries and can be further modelled as highly sophisticated controls. Optimization can also be done automatically using algorithms in TPS. This is useful, if there are a number of system parameters and limitations and it is difficult to find the optimal solution. Algorithms optimize the system parameters for a number of limitations, such as throughput, inventory, resource usage, and delivery times. These solutions are further evaluated using simulations and are interactively searching for the optimal solution using the balance line and the different dose sizes. TPS analytical tools make it easy to interpret the simulation results using statistical analysis graphs for the use of balancing items, machines and staff. It is possible to create extensive statistics and charts to support the dynamic performance analysis including the line load, failures, inactivity and repair time [Siemens 2019]. Therefore, Tecnomatix Plant Simulation can be considered an excellent remedy in the planning stage of production and verification plans in different kinds of production [Trebuňa 2014].

The paper deals with optimization of processes running on a real production line using the computer simulation method. The result of this thesis is the process of creating a simulation model of a production line consisting of two CNC machining centers. Simulation results are also expressed quantitatively, using statistical data that characterize the effectiveness of the solution. The research is a part of the KEGA 011TU Z-4/2017, which deals with integration of progressive information technologies into education.

3 MATERIALS AND METHODS

3.1 Simulation of original line

In order to create a simulation model of a production line consisting of 2 CNC machining centers, it was necessary to obtain relevant production data that characterize the ongoing production processes in the first step. Additionally, we created simulation models of two per partes CNC machining centres that were merged together to the complete model of the LN1 production line. Subsequently, in the case study, statistical characteristics outputs of the real model for the machining (production) line were generated. The simulation model illustrates the manufacturing processes for three types of components with real processing times and processing sequences within one working day [Urban 2018].

Workstation	Operation	Suc_1P/1L
	Input and Output	17.7
S1 Machining 1	Drilling absorber holes	14.0
	Roughing the piston hole	13.0
	Other	4.8
S1 Machining 2	Milling of flange	24.0
	Recessing, drilling holes	5.6
	Other	5.2
S1 Machining 3	Machining brake pad wall	12.3
	Roughening of duster	5.5
	Milling guide surfaces for brake pad	5.0
	Other	5.3
S1 Machining 4	Seal ring groove machining	4.2
	Duster machining	7.2
	Sealing groove machining	12.6
	Other	6.2
S1 Machining 5	Chamfering and drilling of connection holes	8.7
	Thread cutting of connection holes	8.1
	Reaming of piston hole and bearing bush inserting	14.1
	Other	2.9
Total		176.4

Table 1. Working times for S1 machining used in simulation

The simulation model of the machining line for brake components consisting of two CNC machining centres is shown in Fig 1. and Fig 2. Note: the simulation model was split into two parts due to formatting of the paper. Table 1 represents input data and machining times for simulation model which were set according to real data from real production line.

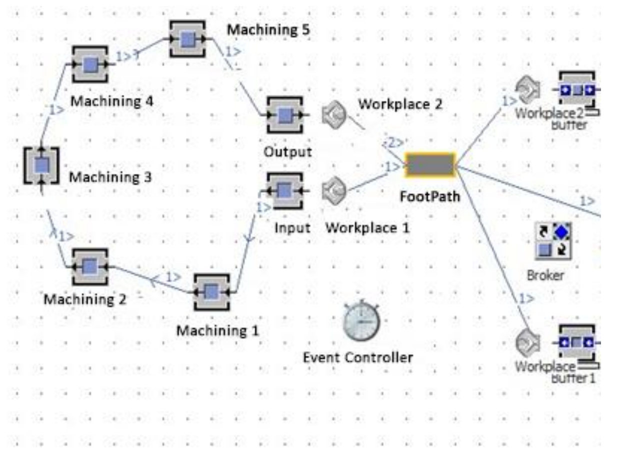

Figure 1. Complete simulation model of production line with 2 CNC machining centres (TPS) part 1/2

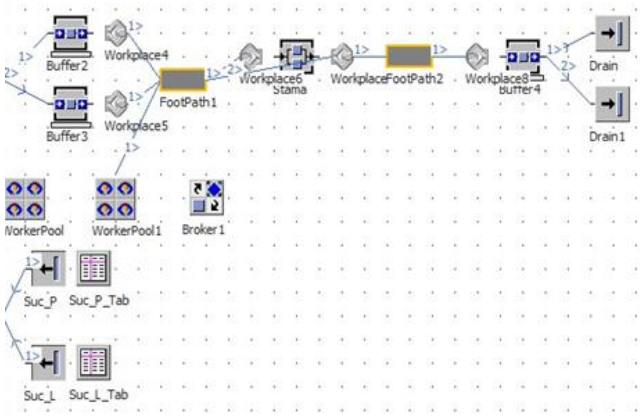

Figure 2. Complete simulation model of production line with 2 CNC machining centres (TPS) part 2/2

3.2 Simulation of improved line

Since simulation of production systems in TPS can be also used for prediction of modified or improved production line, therefore in the next part of the case study, we focused on modeling the proposed improvement of the production line. The main innovation was the replacement of employees with a robotic arm that will be used for loading and unloading components into S1 and S2 machines. The components will be imported to the robot with conveyors. As a result of these changes, only one employee will be required on the analyzed line to load and unload parts onto the conveyor.

The great benefit of simulation model is that it allows to pre-model the assumed changed state. In our case study, we modified the original simulation with the following changes to compare the results from both simulations at the end of the research:

1. Employees change in simulation, where instead of two employees that load and unload parts into machines, only one worker is working on loading and unloading parts onto a conveyor.

2. Employee Transfer Trails (FootPath) have been replaced by conveyors that will be used to transport machined parts from employee to S1 and S2 machines.
3. Adding a robotic arm for loading and unloading components into S1 and S2 machines.

The simulation time was set to 22.5 hours, which represents 3 working shifts. A simulation model of the improved production line with the described improvements for component handling is shown in Fig 3. and Fig 4. Note: the simulation model was split into two parts due to formatting of the paper.

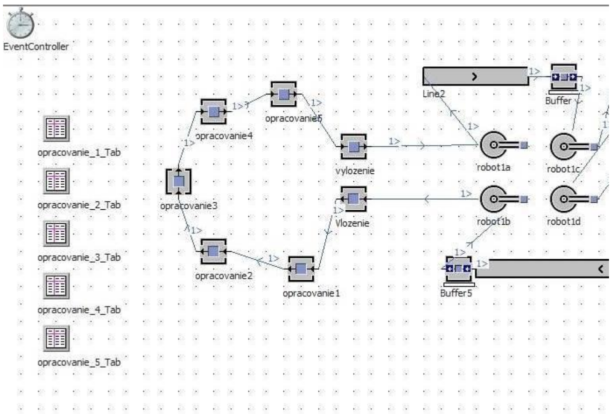

Figure 3. Simulation model of improved production line with 2 CNC machining centers (TPS) Part 1/2

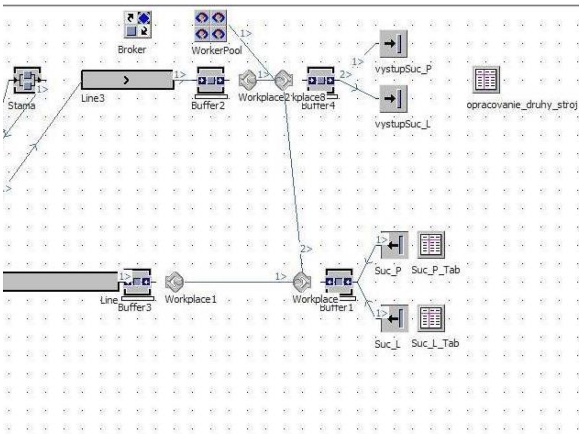

Figure 4. Simulation model of improved production line with 2 CNC machining centers (TPS) Part 2/2

4 RESULTS AND DISCUSSION

The aim of our research is to highlight the possibilities of applying the Industry 4.0 principles to current production systems. Digitalization procedures of a company within Industry 4.0 principles are implemented, in addition to other methods by simulation of manufacturing systems, which is indicated in the case study. The simulation output is a simulation model of the production system, which is a digital counterpart of real production processes of a CNC machining line. Simulation analysis from TPS software provides a lot of information about behaviour and efficiency of production processes, which are presented as tables of graphical statistical outputs. Statistical simulation outputs serve to compare the current status of the production line with the proposed optimized production line, where we plan to implement improvements.

Simulation time is set to 8 hours = 1 working day, after completion of simulation TPS software generates a table with basic statistical evaluations of the process efficiency for individual workstations shown in Table 2, which shows the working time, waiting time, blocked time and fault time.

Workstation	Working time %	Waiting time %	Blocked time %	Fault time %	Overall process time %
S1 Machining 1	35.30	21.00	41.97	1.72	100.00
S1 Machining 2	37.90	21.40	39.97	0.73	100.00
S1 Machining 3	30.98	23.66	45.36	0.00	100.00
S1 Machining 4	34.76	21.78	43.46	2.10	100.00
S1 Machining 5	34.18	21.74	42.75	1.33	100.00
S2 Stama	73.67	3.62	21.51	1.20	100.00

Table 2. Basic statistical evaluations of process efficiency for original production line workstations

Another option offered by the TPS simulation software is to generate statistical results in various graphical outputs. Statistical methods are incorporated in TPS software and statistical evaluations are performed automatically through this software. The column chart in Fig. 5 created in TPS is based on selected processes. We present them in the original format. The charts are based on the data from Table 2. The column chart illustrates the efficiency of the selected processes and the inefficient times for individual workstations.

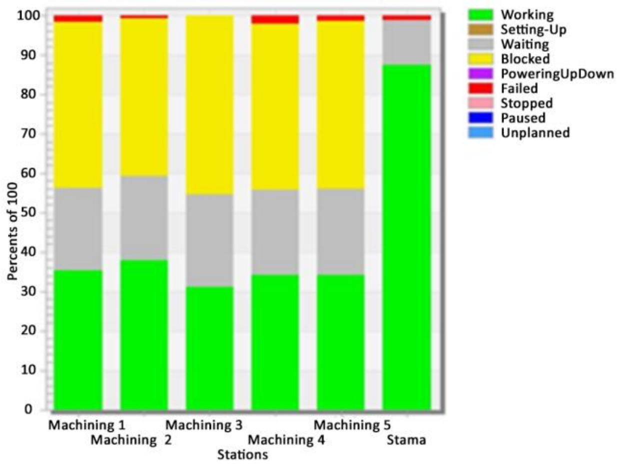

Figure 5. Process efficiency column chart for production model (TPS)

The working time, waiting time, blocked time, fault time and overall process time for the workstations are shown as percentages in Table 2 and as a graph in Fig. 5. The results show that the workstations operate from 30.98% to 37.90%. The majority of the time was not efficient, as we can evaluate from the results, and was spent for waiting for the material, which was from 21% up to 23.66%, or machining was blocked 39.97% to 45.36% of the overall process time. Only 2.1% of the process time was fault time. The Stama station working time efficiency was at 73.67%, but some minor changes can help increase the working time and decrease the blocked time to a lower rate compared to the current 21.51%. Therefore, this information and data will be used to create a more complex and detailed model for future improvement of the working time.

After completion of the set simulation time, the TPS software will generate tables with a basic statistical evaluation of process efficiency of individual workstations of the original (Table 2) and improved line (Table 3), which shows the time proportion of workstations work time and ineffective waiting, blocking and failures.

Workstation	Working time %	Waiting time %	Blocked time %	Fault time %	Overall process time %
S1 Machining 1	41.49	19.81	36.98	1.72	100.00
S1 Machining 2	45.91	19.81	34.92	0.73	100.00
S1 Machining 3	36.46	9.19	54.34	0.00	100.00
S1 Machining 4	39.91	6.70	51.29	2.10	100.00
S1 Machining 5	40.12	2.25	56.29	1.33	100.00
S2 Stama	87.53	11.27	0.00	1.20	100.00

Table 3. Basic statistical evaluation of workstation efficiency for innovated production line

Comparison of Table 2 with Table 3 shows positive increase in working time in the improved model due to improved handling processes for workpieces. Working time of individual workstations for S1 machining in the improved model ranged from 36.46% to 45.91%. It can be stated that the increased working time in the upgraded model ranges from 15% to 18%. We also anticipate an increase in the number of machined parts and greater process efficiency, as waiting and blocking was decreased. The fault settings in simulations remained the same, so the results remained unchanged.

Column charts illustrate the efficiency of selected processes and inefficient times for individual workstations of the production line. Fig. 5 shows statistical results for the simulation of original production line; and Fig. 6 graphically presents simulation results for improved production line.

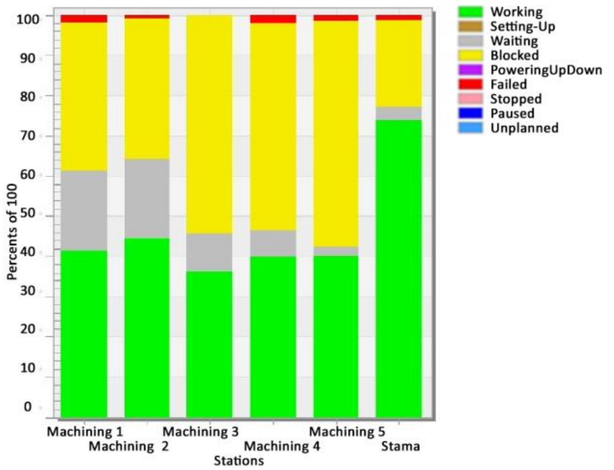

Figure 6. Process efficiency column chart for improved production model (TPS)

Changes in process times are due to a change in the handling of workpieces, which in the improved model has been changed from manual manipulation by employees to manipulation with a robotic arm and conveyor.

TPS provides high flexibility in changing the workstation capacity, number of products, materials, transport and machining speed. Therefore, these data can be implemented into created models, which allow to create more detailed models with automatic statistic recalculation. Such information and data can be used for various areas of business processes by technologists, production planners or economists. The aim of the research was to initially analyse the efficiency of the proposed production line.

Focus of Industry 4.0 principles is to increase the operational efficiency, resulting from the principle of digitization and fluidity of the data flow, as well as from the new concept of connecting preparatory phases of production with actual production [Trebuňa et al. 2015].

The results obtained by our research as an output from the simulation model created in TPS help the analysed organization evaluate the efficiency of the manufacturing processes. After changing the parameters in the model (e.g., change of production times), we are able to show the results of the change in the virtual model in terms of utilization of individual workplaces and the efficiency of individual processes.

5 CONCLUSIONS

Our research in the presented case study shows that the implementation of simulation models in the management of current production systems is very useful, it brings a lot of data and statistics that accurately reflect the real state of production. Simulations enable innovations in the model and predict their impact on production process efficiency. Created simulation model is relatively easy to change with various input parameters of the production, which allows to quickly respond to customer requirements and sufficiently flexible generate the anticipated results of the pending production presented in the already prepared simulation models.

The trend and the current challenge for businesses is the Industry 4.0 concept, the fourth industrial revolution aimed at digitizing all business processes. Optimization of production systems by means of digitization is currently focused on reducing the production time, costs, increasing the quality of production, addressing the ergonomics of workplaces with a regard to eliminate the workers' health and safety risks. The result is significant increase of operational efficiency of production. The aim of our research is to prove this paradigm. The basic method for digitizing dynamic production processes in enterprises is simulation. We expect that in the coming years there will be an increased demand for creation of simulation models of manufacturing systems by modern enterprises that will try to implement the Industry 4.0 strategy and thus increase its competitiveness.

Industry 4.0 constitutes a fundamental turning point that deserves ethical appreciation and solutions. The peculiarities of this paradigm should also be explored within ethics and enter, in a constructive manner, the discourse in the area of science and research, both within professional socialization and within the area of institutionalization of ethical instruments in order to minimize, to a maximum possible extent, the ethical risks and potential negative consequences of new technologies and use of digital data in relation to customers and partners. New ethical responsibility will have to be defined in relation to employees, stakeholders, and the environment. In order to implement these plans, it will be necessary to develop and form new dispositions and new approaches. The participatory role of the applied ethics, ethical consulting, and ethical expertise should be compatible with such unusual requirements and new mission.

Our research shows that implementation of simulation models for the management of the current production systems is very useful; it provides a quantity of data and statistics that accurately reflect the actual situation in the production, which allow the application of innovations in the model, and pre-assess their impact on the efficiency of production processes. In created simulation models, we can fairly easy change the input parameters of the production, which allows us to respond quickly to customer requirements and to flexibly generate enough data to produce the expected results of the unrealized production presented in already prepared simulation models.

This research will be further developed towards the development of additional simulation models. In the final phase, the research will lead to the creation of the so-called digital factory, which means that all production processes in real factory will be simulated in the created models. Simulation models enter Industry 4.0 solutions and provide up-to-date digitization of real operations as well as predictive production models.

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