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Proposal of the Assembly Line Structure Modification

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ABSTRACT

This paper describes the application of computer simulation for the purpose of analysis of an assembly line and the subsequent proposal of changes to increase productivity. Tecnomatix Plant Simulation software was used for modelling, simulations, and analyses. Based on simulations and analyses of the original state, the bottlenecks of the line were identified, and improvement measures were proposed. The simulation model was adjusted, and the new state of the line was simulated. Based on the new simulation, it was proven that the proposed improvement would help in increasing the productivity of the assembly line. Computer simulation, in addition to verifying the production process itself, enables the optimal setting of the assembly line without interfering with the production itself.

Keywords: assembly line, simulation, tecnomatix plant simulation, production line bottleneck, automotive production.

INTRODUCTION

The use of simulation tools enables the verification of intended changes and testing them in a given simulation environment. This prevents costly errors that could arise during solution implementation [14]. The efficiency of the whole process is greatly affected by the utilization of human resources or machines [13]. The automotive industry is built on a supply chain. It is necessary for component suppliers to deliver their products on time [6]. The requirements, as well as the degree of satisfaction of the final customers of car manufacturers, are increasingly demanding. Therefore, it would not be possible to fulfil them without innovations in products and production technologies [10]. By innovating production technologies, costs are reduced, production time is shortened, quality is increased, and the efficiency of use of production machines and equipment is increased [5, 8].

Strong emphasis is placed on the delivery system and the required quality of the products. The task of logistics is to deliver the right product, at the right time, in the right quantity and the required quality, to the right place in the right packaging and at an agreed price [7, 9]. Most companies use Just in Time logistics. This system is not only used for the supply of components and materials but is also applied to the supply of production or assembly lines [1, 3]. When supplying production lines, this method relates to another method, which is Kanban labels. This simplifies the orders of material and their subsequent delivery from the warehouse. Kanban labels provide each material in the warehouse with a certain serial number, which determines the material and the specific location where it is stored. The advantage of these two systems is that there is no unnecessary overstock in the warehouse [2, 4].

It is now the standard practice to apply simulations to solve various types of problems, including those related to production processes. A very common task is the analysis of problems and bottlenecks in production processes, including the analysis of What-If scenarios. Various software solutions are widely used. One of these software solutions is, for example, Tecnomatix Plant Simulation, which we selected for our research. Its widespread application in companies as well as in research tasks and various project types can be demonstrated by its mention in the literature as well as in scientific articles [20, 21, 22, 23].

This paper deals with the detection and analysis of a bottleneck, the so-called bottleneck of the assembly line. This is followed by a proposition of a possible solution to achieve optimisation by increased production capacity.

It is usually not necessary to have detailed level of simulation. Details are always available in companies without any difficulty such as breakdown patterns, rework rates, operator performance variations, etc. The Industry 4.0 concept assumes that smart manufacturing factories should be resistant to those failures which result when creating self-organising manufacturing systems with redundant resources [18].

Problem was solved directly for the needs of concrete company located in East of the Slovak republic and within the cooperation with the company it is possible to use it for the practical scientific goals also the university staff.

SELECTION OF PRODUCTION LINE

An assembly line for electrical components was selected as the subject of analysis. This line is located in the premises of a company with high quality output. This line produces different types of fuse boxes. A fuse box is a component found in every car. Its task is to control various functions in cars, such as wipers, turning lights, headlights, and others. Unfortunately not all of the problems can be eliminated. Therefore, a company, knowing the scale of the problems, can make a manufacturing system resistant to the troubles to protect client [17]. The effectiveness of an actual assembly system partly depends on the utilization stage [19]. The inputs of the assembly line include all the components necessary for assembling (Figure 1). These include logic and power boards, connectors, bottom, and top covers and fuses.

The assembly of the fuse box takes place on the production line, which consists of 7 assembly stations and one control station, the supervisor (Table 1). The supervisor is in control of every single unit that is located at the assembly stations.

MATERIAL AND METHODS

The subject of the analysis is the assembly line for the production of electrical components and the assessment of the structure change impact of the assembly line on the overall efficiency, which is expressed by the number of produced pieces per time unit.

The solution method is the application of discrete event simulation based on input data, which are the duration times of individual assembly operations and the duration times for transporting components between workstations. The times

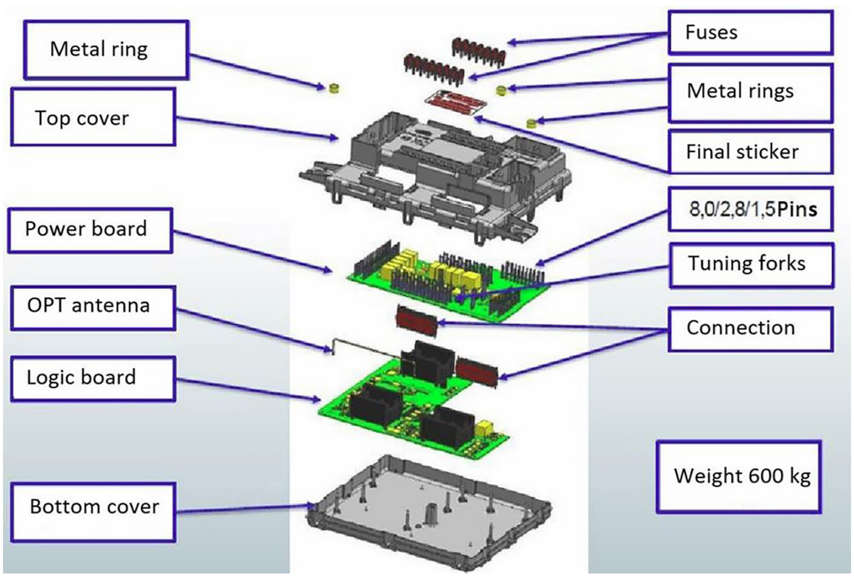
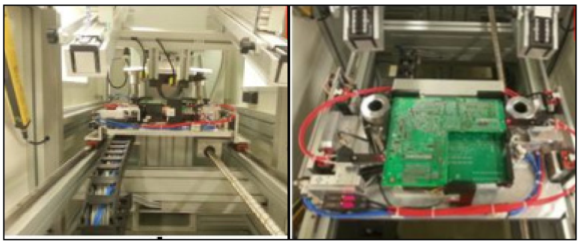
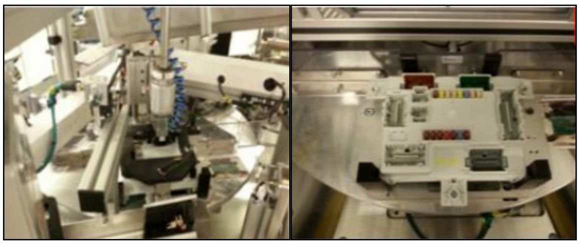
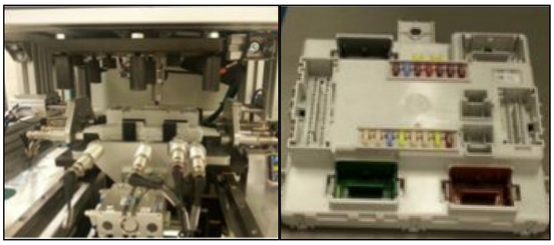
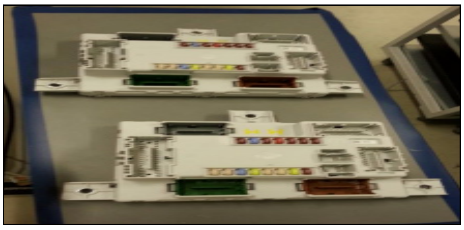
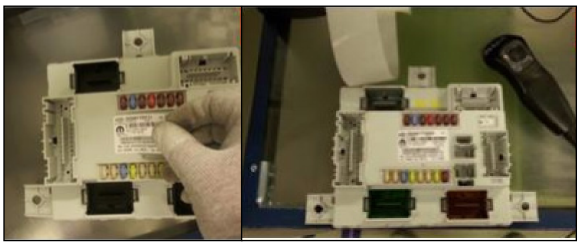


Figure 1. Fuse box components

Table 1. Workplaces of analysed assembly line

Workplace – segment of the assembly line	Description	Illustration
ST 10	Moulding of PCB power/logic	
ST 20	Repositioning of PCB and cover/charging of fuses/ manual gluing of label	
ST 30	Moulding of the top cover, bottom cover and PCB board	
ST 40	Run in	
ST 50	Final testing	
ST 60	Sticking a label	
ST 70	Packaging	

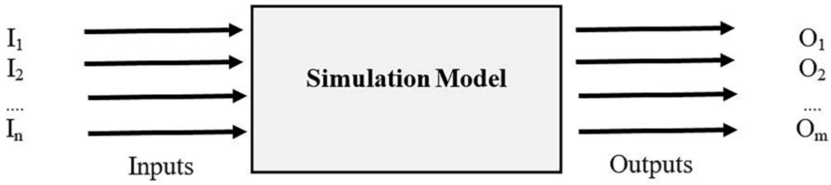


Figure 2. Formal simulation model

used in the simulation were found by measurement and they are the average times of the individual operations duration.

On Figure 2 is shown the simulation model, where (I_1, I_2, … I_n) are the input variables and (O_1, O_2, … O_m) are the output variables depending on the inputs.

Number of pieces produced per time unit:

$$n = \frac{T_{ws}}{T_k} \tag{1}$$

where: n – number of produced products;
T_{ws} – time of working shift;
T_k – production time per piece.

Production time of individual piece:

$$T_k = \sum_{i=1}^{m} t_i + t_t + t_m \tag{2}$$

where: t_i – processing time on the workstation;
t_t – transport time between workstations, respectively from and to the store;
t_m – manipulation time.

Assembly line model creation and analysis

The Tecnomatix Plant Simulation program was selected to create a model of the fuse box assembly line [11, 12]. This program was chosen based on availability and features, i.e. it allows to simulate the entire manufacturing process and, based on the measured times, to reveal the bottlenecks of the assembly stations, i.e. the places where the assembled component (fuse box) is delayed the longest and other pieces accumulate before that station. The volume of outputs does not depend only on the number of inputs to the assembly line, but mainly on the number of components that pass through the bottleneck in a given time frame.

The simulations allow defining the time needed to produce the respective circuit boards, however this is not directly related to the assembly time. It´s also possible to set the non-conformity levels of power and logic circuit boards. This is however a matter of the previous production line (SMT) and is not critical for the assembly line itself.

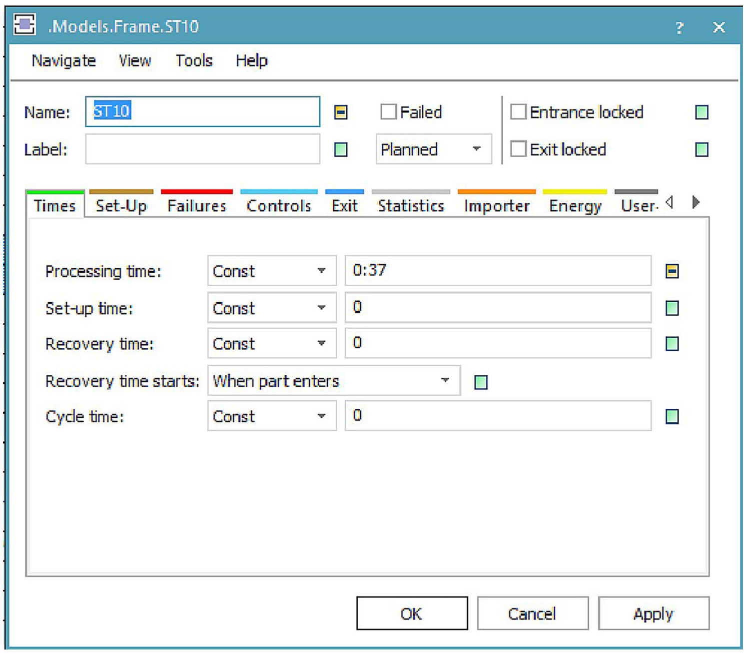


Figure 3. Defining process time on ST10

Individual workstations were inserted into the model as single process (the software uses "single proc" abbreviation). The first workstation ST10 is directly connected to the previous station using the "connector" function. In this case this is understood as a connection between individual stations, ensures the functionality of the simulation as well as the flow of material from one station to another. After inserting the station, it is necessary to define the process time, ie the time needed for performing operations at the workplace (Figure 3).

It´s necessary to enter the non-conformity level at the assembly station. This is defined in the "Failures" tab (Figure 4). During the simulation, the occurrence of real errors that affect workplace productivity is considered. Errors that usually occur on the ST10 are mainly the loading of the NIP code due to inappropriate placement of the boards in the fitting tool, or due to incorrect burning of the code during the circuit board production on the SMT lines. When defining errors, the time required to eliminate errors is determined,

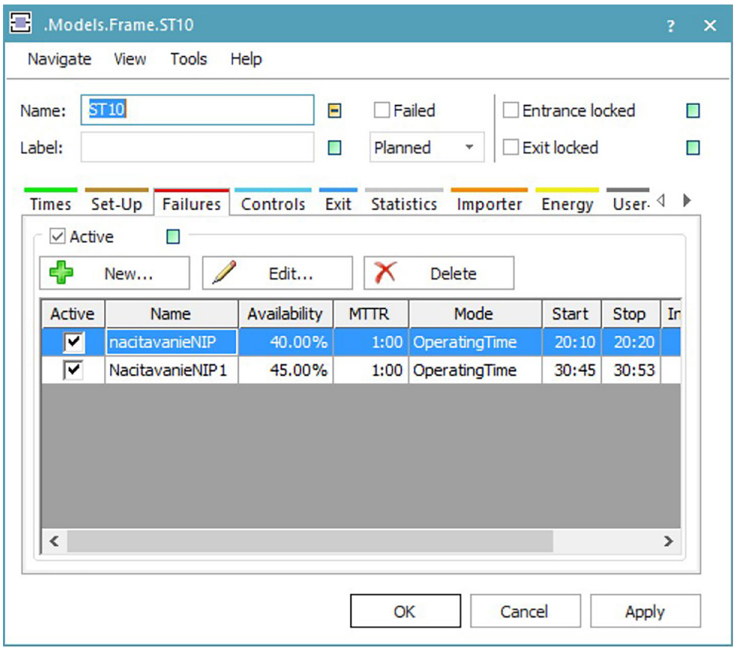


Figure 4. Defining errors on ST10

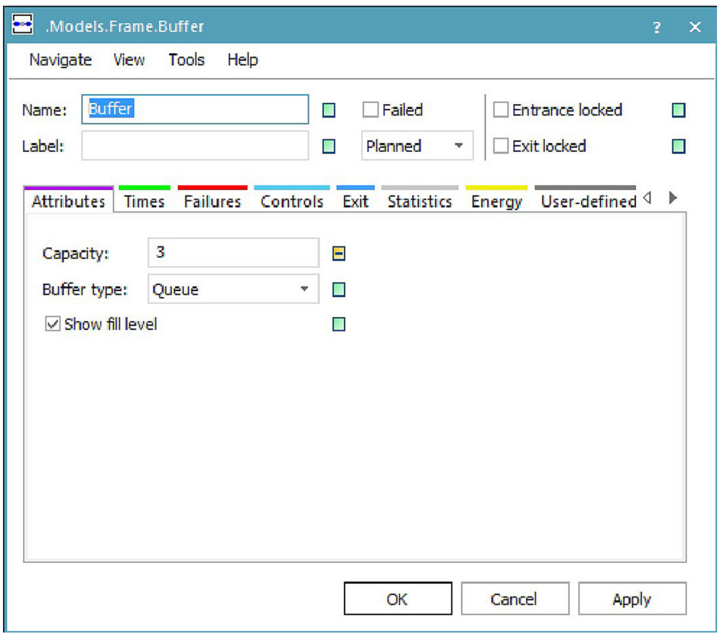


Figure 5. Defining the buffer

i.e. replacement of boards or, in case of incorrect position, the time needed to correct it.

There is a support working table between every two assembly stations. Each table is designed to the size needed to store 3 assembled components. This number is necessary for the smooth output of the completed components from the assembly line, i.e. to avoid waiting at the bottleneck station of the assembly line. In the simulation program, this is listed as a buffer. Buffer setting is shown in Figure 5.

The next stations of the assembly line are stations ST20, ST30 and the RUNIN station. These are inserted in the same way as ST10, i.e. as "single proc". ST20 is connected to stations ST10 and ST30 through the already mentioned buffers.

The process time at the RUNIN station is not directly related to the assembly process but focuses on testing. At a given workstation, the fuse box is tested by applying the maximum allowed electrical current to it.

At the next EOL station, the final tests are performed on the finished product. This station differs from the previous one in the type of tests performed on the final product. These tests are focused on the functionality of individual components and the uploaded software.

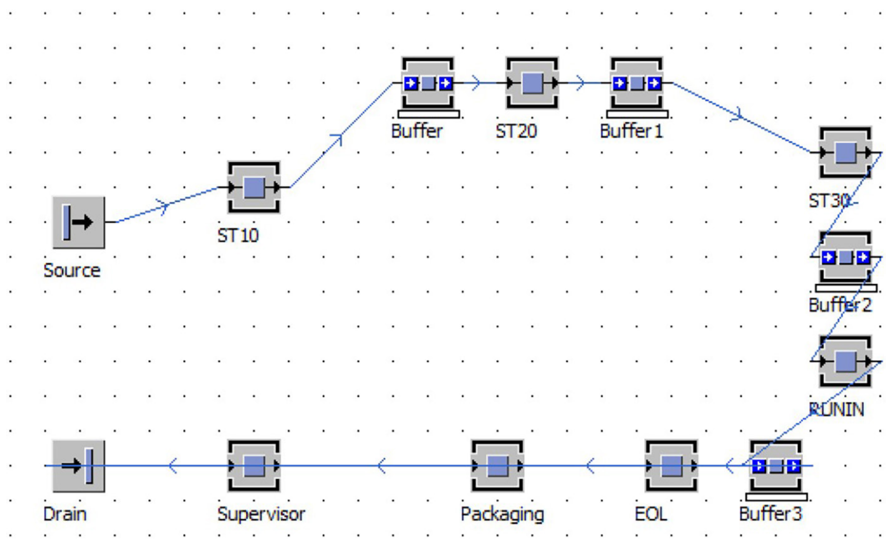


Figure 6. Current workplace in the simulation program Tecnomatix Plant Simulation in 2D and 3D version

Table 2. Portions of the states at the current workplace

Object	Working	Set-up	Waiting	Blocked	Powering up/down	failed	Stopped	Paused	Unplanned	Portion
Source	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ST10	34.94%	0.00%	0.00%	65.02%	0.00%	0.03%	0.00%	0.00%	0.00%	
ST20	36.11%	0.00%	0.13%	63.70%	0.00%	0.07%	0.00%	0.00%	0.00%	
ST30	28.60%	0.00%	0.39%	70.83%	0.00%	0.18%	0.00%	0.00%	0.00%	
RUNIN	99.09%	0.00%	0.37%	0.31%	0.00%	0.23%	0.00%	0.00%	0.00%	
EOL	98.89%	0.00%	0.76%	0.00%	0.00%	0.35%	0.00%	0.00%	0.00%	
Drain	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Packaging	12.57%	0.00%	87.43%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Supervisor	13.28%	0.00%	86.72%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer	0.00%	0.00%	1.93%	98.07%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer1	0.00%	0.00%	1.53%	98.47%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer2	0.00%	0.00%	0.78%	99.22%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer3	0.00%	0.00%	62.71%	37.29%	0.00%	0.00%	0.00%	0.00%	0.00%	

Table 3. Working time at the current workplace

Object	Portion	Count	Sum	Mean value	Standard deviation
Source	0.00%	0	0.0000	0.0000	0.0000
ST10	34.97%	272	2:47:44.0000	37.0000	0.0000
ST20	36.11%	268	2:53:18.4000	38.8000	0.0000
ST30	28.60%	264	2:17:16.8000	31.2000	0.0000
RUNIN	99.09%	260	7:55:37.2612	1:49.7587	3.8909
EOL	98.89%	256	7:54:39.7612	1:51.2491	4.0149
Drain	0.00%	255	0.0000	0.0000	0.0000
Packaging	12.57%	255	14.2000	14.2000	0.0000
Supervisor	13.28%	255	15.0000	15.0000	0.0000
Buffer	0.00%	0	0.0000	0.0000	0.0000
Buffer1	0.00%	0	0.0000	0.0000	0.0000
Buffer2	0.00%	0	0.0000	0.0000	0.0000
Buffer3	0.00%	0	0.0000	0.0000	0.0000

Table 4. Material flow properties at the current workplace

Object	Number of entries	Number of exits	Minimum contents	Maximum contents	Relative empty	Relative full	Relative occupation without interruption	Relative occupation with interruption
Source	273	272	0	1	0.00%	-	100.00%	100.00%
ST10	272	271	0	1	0.00%	-	100.00%	100.00%
ST20	268	267	0	1	0.13%	-	99.87%	99.87%
ST30	264	263	0	1	0.39%	-	99.61%	99.58%
RUNIN	260	259	0	1	0.37%	-	99.63%	99.63%
EOL	256	255	0	1	0.77%	-	99.23%	99.00%
Drain	255	255	0	1	100.00%	-	0.00%	0.00%
Packaging	255	255	0	1	87.43%	-	12.57%	12.57%
Supervisor	255	255	0	1	86.72%	-	13.28%	13.49%
Buffer	271	268	0	3	0.88%	98.07%	98.49%	98.49%
Buffer1	267	264	0	3	1.11%	98.47%	98.69%	98.69%
Buffer2	263	260	0	3	0.52%	99.22%	99.35%	99.35%
Buffer3	259	256	0	3	8.50%	37.29%	64.83%	64.63%

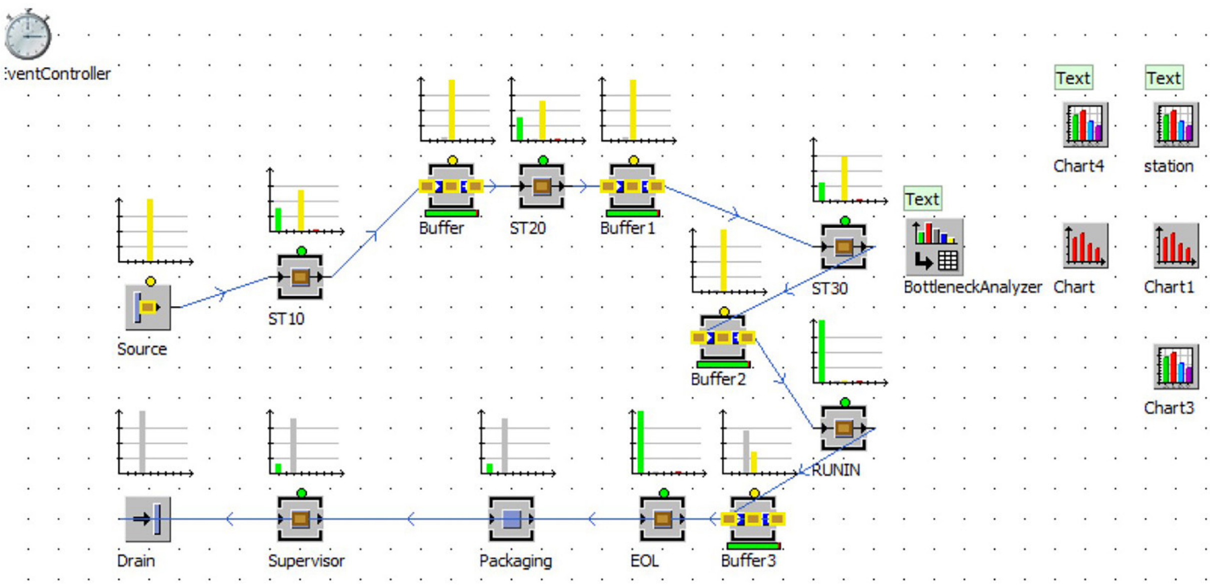


Figure 7. Representation of the model after the simulation showing the Bottleneck for each workplace

After successfully passing the tests, the fuse box continues to the next workplace, the packaging. After a visual inspection at this workplace, the components are packed into boxes in which they are then shipped to the customer.

Figure 6 shows the model created according to the current state of the assembly line. It includes all necessary assembly and test stations and auxiliary tables. Resource statistics at the current workplace are presented in Table 2, Table 3 and Table 4.

Simulations and analyses were performed once the workplace model was created. The duration of one work shift was simulated, i.e., 8 hours. Since the assembly line is operated by two operators whose break times alternate, we can count the entire 8-hour production time. There is no need to deduct a 30-minutes break. The result of the simulation with the representation of graphs for the bottleneck is shown in Figure 7.

In Figure 8 we can see the statistics of the resources of the current workplace after simulating one work shift. The graph shows the percentage utilisation of workplaces, including buffers. The green colour represents the activity when the assembly stations are performing an activity. The yellow colour indicates the cases when the station is blocked because the assembled pieces have accumulated in front of the bottleneck of the assembly line. The grey colour indicates the state when the stations are not performing any activity and waiting for the assembled part, and finally the red colour represents a time that is undesirable for us, since an assembly error occurred at that time. No assembly operation is performed on the auxiliary tables (buffers), therefore they have only two states, that they are blocked or waiting for a piece from the assembly station.

The occupation of assembly stations is shown by graphs depending on the amount of time and the number of assembled pieces visible in Figure 9. Column 1 expresses the number of assembled pieces at individual stations. Column 3 shows the occupancy of auxiliary tables (buffers). Columns 0 and 2 symbolise the time when the assembly stations are not occupied, and adding their values to group of columns (graphs 1 and 3 in Figure 9) results in 100 percent of the time analysed.

With the current line, 255 fuse boxes are assembled after 8 hours of operation. This means that the hourly production is 31,875 pcs. It is clear from the graphs that the longest process lasts at the RUNIN and EOL stations. As already mentioned, at the RUNIN station, the final product is tested with the maximum electric current load, and then at the EOL station, the functionality of the fuse box is checked to see if any component has not been damaged as a result of the previous station. Tests at both stations take about the same time.

ASSEMBLY LINE CHANGE PROPOSAL AND ANALYSIS OF PROPOSED CHANGES

Based on the production experience to date and following the test results, it was determined that the fuse box after the tests at the RUNIN station meets the necessary quality and therefore it is not necessary to test every single piece. Only

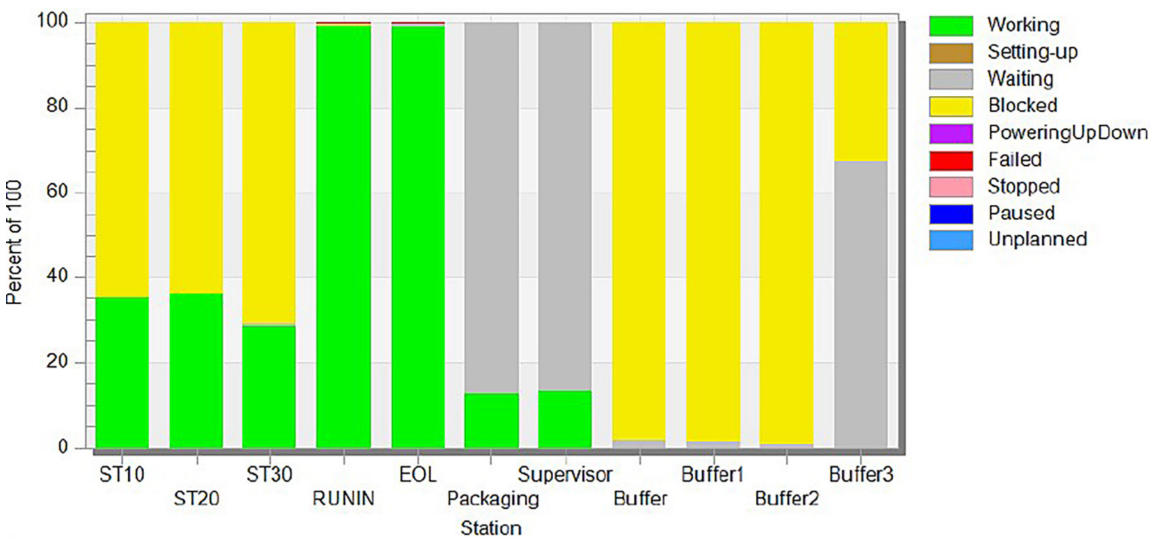


Figure 8. Statistics of the resources of the current assembly line after 8 hours of operation

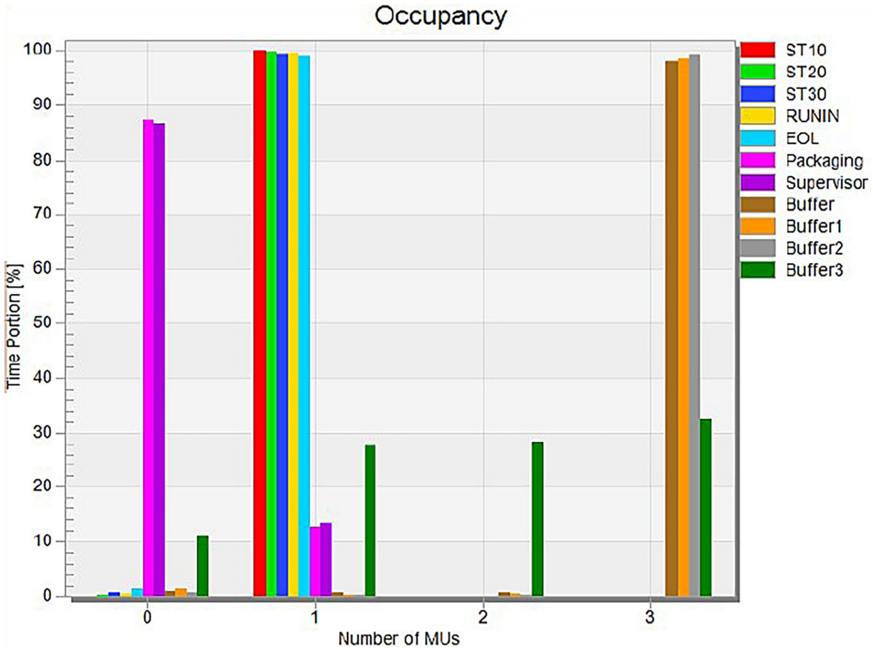


Figure 9. Usability of machines and tables at the current workplace after 8 hours of operation [1]

every second piece from the cycle will be tested. After the introduction of testing every other piece at the RUNIN station, the bottleneck on the assembly line becomes the EOL station. To multiply the potential output from the assembly line, a simple solution is to double the EOL stations. The second EOL station is located right next to the first EOL station to maintain the sequence of assembled pieces on the assembly line. After setting the same conditions and errors at the new workplace as there were at the old one, the new workplace was also simulated for 8 hours. The results of the analyses were compared. The simulation model of the adjusted line is shown in Figure 10.

Resource statistics at the proposed workplace are presented in Table 5, Table 6 and Table 7. In Figure 11 shows the model after running the simulation with graphs for the bottleneck.

The resource statistics of the newly designed line after simulating 8 hours of operation is shown in Figure 12. In Figure 13 green colour represents the percentage evaluation when the assembly stations are performing activities. Yellow colour indicates the cases when the station is blocked because the assembled pieces have accumulated in front of the bottleneck of the assembly line. The grey colour indicates the state when the stations do not perform any activity and are waiting for

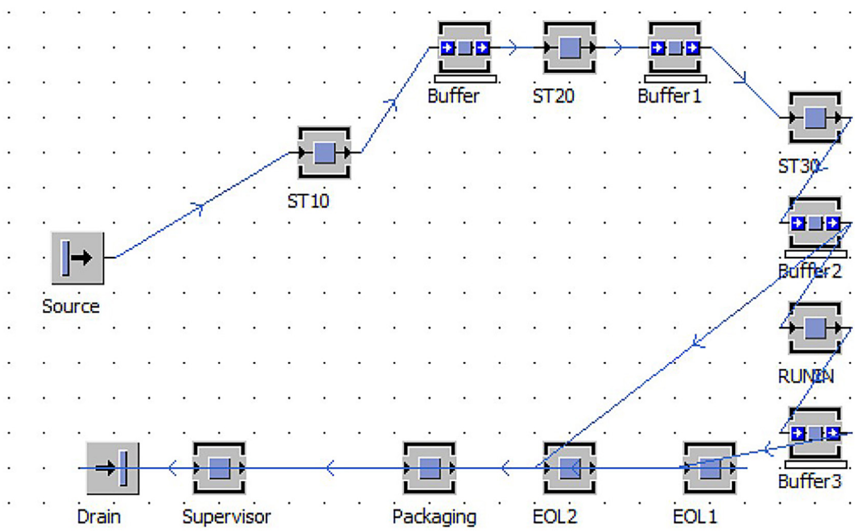


Figure 10. Model of modified workplace in 2D and 3D version

Table 5. Portions of the states at the proposed workplace

Object	Working	Set-up	Waiting	Blocked	Powering up/down	failed	Stopped	Paused	Unplan-ned	Portion
Source	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
ST10	67.72%	0.00%	0.00%	32.25%	0.00%	0.03%	0.00%	0.00%	0.00%	
ST20	70.47%	0.00%	0.13%	29.33%	0.00%	0.07%	0.00%	0.00%	0.00%	
ST30	56.24%	0.00%	0.52%	43.14%	0.00%	0.10%	0.00%	0.00%	0.00%	
RUNIN	98.94%	0.00%	0.37%	0.46%	0.00%	0.23%	0.00%	0.00%	0.00%	
EOL1	98.74%	0.00%	0.76%	0.00%	0.00%	0.50%	0.00%	0.00%	0.00%	
EOL2	99.07%	0.00%	0.52%	0.07%	0.00%	0.33%	0.00%	0.00%	0.00%	
Packaging	25.11%	0.00%	74.20%	0.69%	0.00%	0.00%	0.00%	0.00%	0.00%	
Supervisor	26.51%	0.00%	73.49%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Drain	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer	0.00%	0.00%	3.33%	96.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer1	0.00%	0.00%	7.78%	92.22%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer2	0.00%	0.00%	11.51%	88.49%	0.00%	0.00%	0.00%	0.00%	0.00%	
Buffer3	0.00%	0.00%	51.56%	48.44%	0.00%	0.00%	0.00%	0.00%	0.00%	

Table 6. Working time at the proposed workplace

Object	Portion	Count	Sum	Mean value	Standard deviation
Source	0.00%	0	0.0000	0.0000	0.0000
ST10	67.72%	528	5:25:02.5000	36.9366	1.4579
ST20	70.47%	524	5:38:15.9000	38.7326	1.5421
ST30	56.24%	520	4:29:56.3000	31.1467	1.2147
RUNIN	98.94%	260	7:54:53.5000	1:49.5904	6.6048
EOL1	98.74%	256	7:53:33.3000	1:51.0781	6.7500
EOL2	99.07%	256	7:55:33.3000	1:51.4582	0.6687
Packaging	25.11%	510	2:00:31.3000	14.1790	0.4738
Supervisor	26.51%	409	2:07:15.000	14.2000	0.0000
Drain	0.00%	509	0.0000	15.0000	0.0000
Buffer	0.00%	0	0.0000	0.0000	0.0000
Buffer1	0.00%	0	0.0000	0.0000	0.0000
Buffer2	0.00%	0	0.0000	0.0000	0.0000
Buffer3	0.00%	0	0.0000	0.0000	0.0000

Table 7. Material flow properties at the proposed workplace

Object	Number of entries	Number of exits	Minimum contents	Maximum contents	Relative empty	Relative full	Relative occupation without interruption	Relative occupation with interruption
Source	529	528	0	1	0.00%	-	100.00%	100.00%
ST10	528	527	0	1	0.00%	-	100.00%	100.00%
ST20	524	523	0	1	0.13%	-	99.87%	99.87%
ST30	520	519	0	1	0.52%	-	99.48%	99.45%
RUNIN	260	259	0	1	0.37%	-	99.63%	99.63%
EOL1	256	255	0	1	0.77%	-	99.23%	99.00%
EOL2	256	255	0	1	0.53%	-	99.47%	99.48%
Packaging	510	509	0	1	74.20%	-	25.80%	25.80%
Supervisor	509	509	0	1	73.49%	-	26.51%	26.51%
Drain	509	509	0	1	100.00%	-	00.00%	00.00%
Buffer	527	524	0	3	0.89%	96.67%	97.67%	97.67%
Buffer1	523	520	0	3	1.77%	99222%	96.07%	96.07%
Buffer2	519	516	0	3	0.64%	88:49%	95.64%	95.64%
Buffer3	259	256	0	3	4.70%	48.44%	73.52%	73.52%

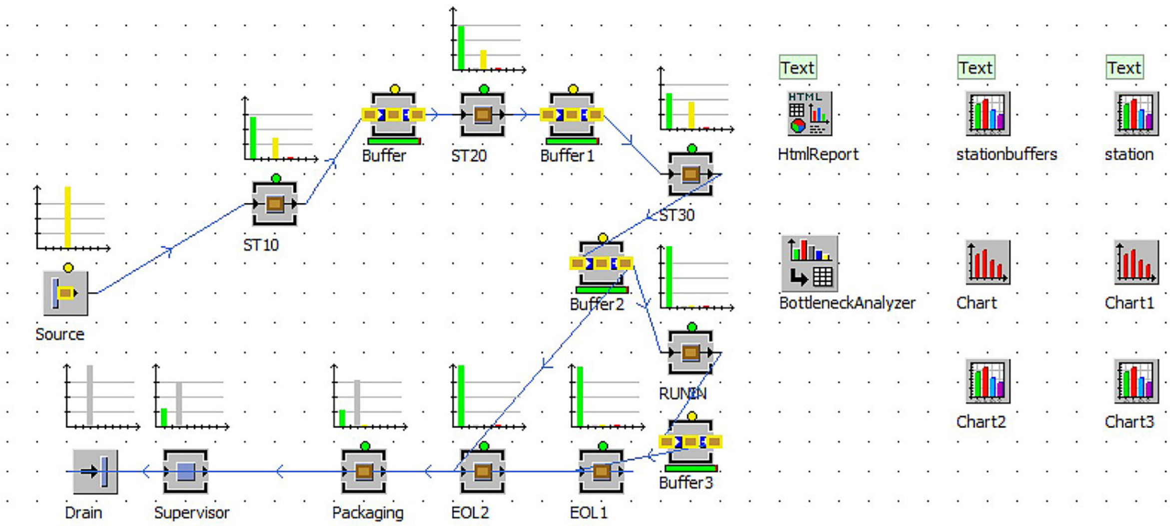


Figure 11. Model of modified workplace after simulation

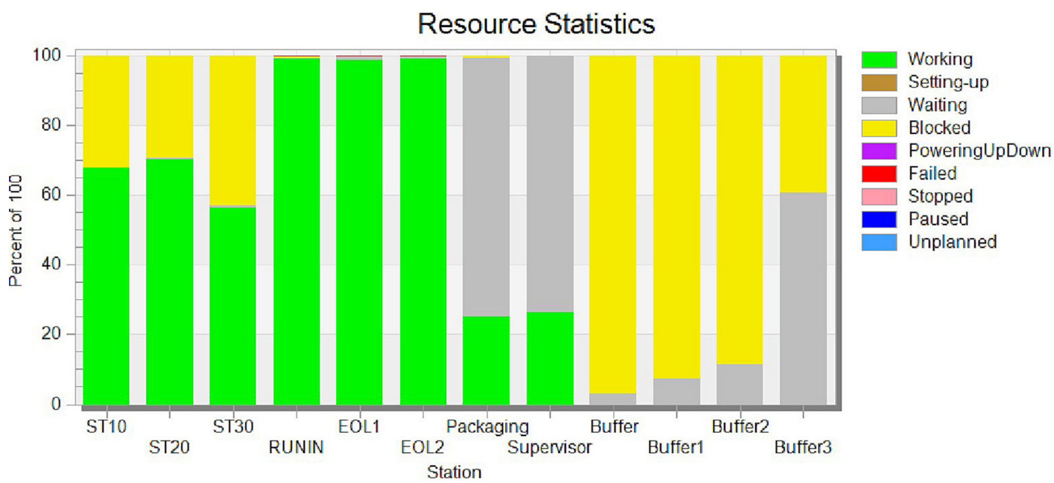


Figure 12. Source statistics of the changed assembly line after 8 hours of operation

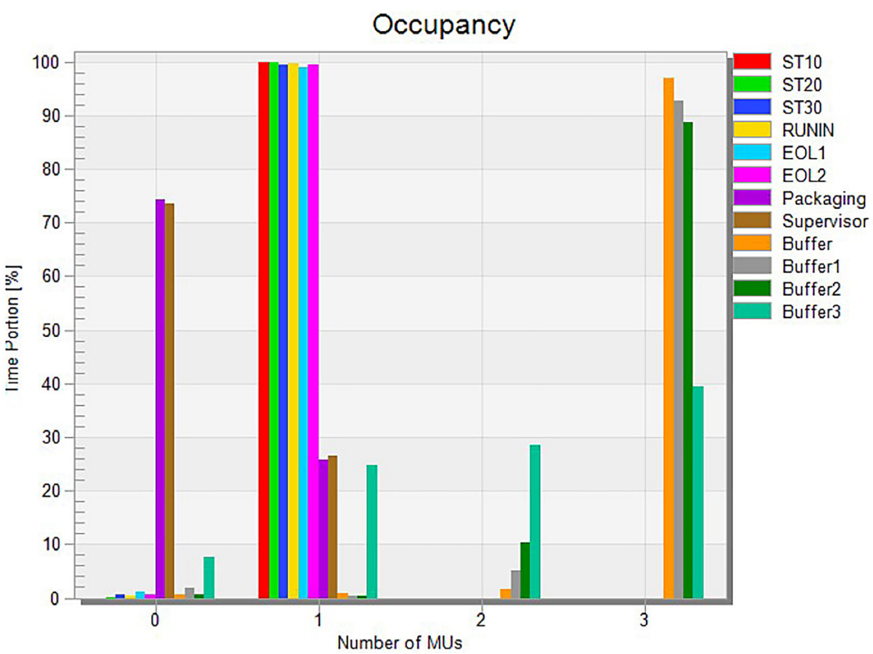


Figure 13. Usability of machines and tables at the new workplace after 8 hours of operation

the assembled part. Finally the red colour represents the time when a defective piece was assembled at the assembly station.

The graphs show that the most used workplaces are RUNIN, EOL1 and EOL2. In this modified model, production increased to 510 pieces in 8 hours work shift. This represents a twofold increase in production, i.e., increase of hourly production by 100% to 63.75 pcs per hour. The graphs also show that if it were possible to improve and optimize the activities at the RONIN, EOL 1 and EOL 2 workplaces, the production can be increased even more. This is due to the fact that there are still reserves at the other workplaces. This will be the subject of future research.

CONCLUSION

At the end of the 20th century, production companies entered a new era, which, on the one hand, offered tremendous technical and IT solutions, but, on the other, brought them into competition with other firms not only on a local and national, but also on a global level [15]. The goal of this paper was to reveal the bottlenecks of the selected assembly workplace and propose measures to achieve an increase in the production of fuse boxes. After creating a model of the current assembly line and simulating its operation, the bottlenecks were revealed. Actions were designed and based on them, the simulation model was modified, and further simulations were performed. Based on them, it was found that the proposed measures will increase production by 100% from 255 pieces per work shift to 510 pieces per work shift.

In addition to the emerging trend of Industry 4.0, the creation of digital twins of production structures, processes or operations is coming. Currently, some of the created models are aimed at solving actual problems, with which are they met (e.g., quality, productivity, maintenance, etc.). In order to achieve maximal effects from the application of digital twins, these virtual models need to be made at a scale of 1:1 with real existing structures, processes, or operations. The presented model was focused on solving a specific problem and not all detailed procedures are included in the presented model.

In the future, the intention is to refine the model so that it fully corresponds to the real state of the structure, process or operation.

This research can help the staff of the company in the practical purposes as well as the students of the universities in their practical training.

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