INTRODUCTION

The development of technology allows the managers of companies to decide about the usage of simulation programs, which are a trend of today’s competitive environment. Simulation programs are tools that test the effects of different decisions on the model and then evaluate production capacities, duration of operations and other production parameters [1]. They also eliminate the possibility of introducing a change into the process that would not be advantageous for the process. In the paper, we will create a simulation of the concrete production process.

Simulation is a support tool that allows you to test the effects of different decisions on a simulation model. It is the modern tool for the analysis of individual business processes [2]. To reduce risk, we can verify in advance by „replaying“ the process and its behavior after making the changes that we require, verify the future behavior of the system, which can be removed in advance, avoid it, as well as solve any problems [3]. This allows us to better clarify and understand the production processes during real production process [4]. Computer simulation has the ability to evaluate the capacities of the production layout, the operation of the transport and storage system, information flow and management system [5, 6].

Simulation and simulation programs are now increasingly used in industrial enterprises. Competition pressure and customer requirements are still increasing, so businesses need to simulate production processes [7, 8]. The simulation program Plant Simulation is now one of the top simulation programs and therefore we selected it [9]. Plant Simulation (previously eM-Plant, Simple ++) is standard software for simulation of very complex production systems and managerial strategies. Object orientation, graphical and integrated modeling, simulation and animation of systems and business processes characterize the tool named Plant Simulation [10].

The aim of this paper is the creation of a simulation model of the saw blade production process in Plant Simulation.
and consequently to propose the possibility of improvements of this production process.

**Characteristics of Plant Simulation**

Businesses are increasingly trying to improve on-going production processes to become optimal. Plant Simulation is the ideal solution to improve the current state of production processes [11]. The biggest advantage of this software is that we introduce the changes to the process after data analysis from the simulation, i.e. if the optimization has been achieved [12, 13]. The working environment in Plant Simulation is in Figure 1.

Siemens Plant Simulation is a tool for creating digital models and on the basis of these models we can create simulations. The power of simulation experimentation is that it can create scenarios of the future state at the time of planning [14]. The possibility to use extensive analytical tools such as statistics, charts and diagrams is the reason why output is always measurable and well-founded results. Thus obtained results provide us information that are important for quick and correct decisions even in the early planning phases and also shorten the production start. Plant Simulation can create simulations of planned but also of real processes [15, 16]. The generated simulations acquire real values, with which the user can experiment without any intervention into production [17]. Plant Simulation also delivers cost reduction in the enterprise.

Plant Simulation currently utilizes every successful enterprise in various industrial areas, without exception of their size. Every day they rely on the power of simulation that gives them competitive advantages on the market [18]. Using Plant Simulation, we can model, simulate production systems and their processes. We can also:

- Optimize material flow.
- More efficient utilize the resources.
- Improve logistics processes.

**The procedure of saw blades production**

Saw blades are mainly used for quick and simple sawing of wood. Their production will be described in the following steps:

1. The first step in producing a saw blade is the movement of the steel sheets of the desired thickness to a laser device which cuts out from the steel sheet a toothed disk in the basic shape of the saw blade (Figure 2).
2. The next step is the manual selection of individual discs from steel sheet (Figure 3).
3. Then follow the manual insertion of the cut-out discs into the slotting machine and the grooving on both sides of the disc. This grooving prevents
vibrations during cutting, which is extremely important for straight cutting with saw blades.

4. The manual measurement of disc grooves unevenness is shown in Figure 4.

5. Later is performed rolling of the saw blades to compensate the unevenness of the disc.

6. Polishing of saw blades for removal of all impurities from previous production is shown in Figure 5.

7. Then follows burning of the saw blades in the furnace, which achieves a high hardness of the discs, takes about 24 hours.

8. Carbide tips on the teeth of the discs are in the meantime controlled by the laser whether they are correctly set for the next step, as shown in Figure 6.

9. Then, one of these carbide tips is grasped by the robot and transferred to the nozzles that eject the flux on it. Another robot places a metal solder on the flux and thus the carbide tip is delivered to the saw blade. Hard soldering melts resistive wires and flux. This process joins the carbide tip to the saw blade (Figure 7).

10. The next step in the production is to place the saw blade on the shaft. The disc is there slowly rotated while sanding through the spray nozzle (Figure 8). With this process, the saw blade is devoid of all impurities and has a specific structure.

11. In this step, each saw blade is tapered by grinding. The individual teeth are moved by
a mechanical finger. With the further grinding wheel is grinded the outside edge of the teeth (Figure 8). Next starts the grinding of the front of each tooth to achieve a sharp edge.

12. Then starts manual knocking out of the unevenness of the saw blade and when the disc has been knocked out, the worker has to check the wheel (Figure 9).

13. The last step in the production is to check the teeth of the disc with a computer. The camera scans each tooth step by step and the records are sent to the computer. The computer examines whether the cutting angle and shape of the wheel's teeth meet the required quality (Figure 10).

Proposal of simulation solution for selected production process in Plant Simulation

Inputs will represent the following 5 specific items:
- Steel plate.
- Carbide tips.
- Trucks.
- Flux input.
- Solder input.

It will be also necessary to create individual workplaces for activities that occur within the production process:
- Laser cutting.
- Grooving the disc.
- Measurement.
- Rolling.
- Polishing.
- Burning.
- Laser check.
- Application of flux (or assembly).
- Location of solder (or assembly).
- Sanding.
- Teeth grinding.
- Knocking out.
- Computer teeth control.
- Packaging.

In the simulation we will use conveyors and trucks to move between workplaces, so we will create a conveyor and truck object. The track is necessary to move the truck. In the Mobile Units folder, you’ll find the following items:
- Saw blade.
- Carbide tips.
- Truck.
- Flux.
- Solder.

According to layout of the production hall, we place individual objects in the Plant Simulation workspace (inputs, objects representing processes, output). Future simulation functionality will be ensured using the object Connections. Between the workplaces according to the hall design, we deploy conveyors or the road for the truck movement. The next step is to set each object and then start of the simulation.

After these settings, we’ll look at the timing of individual objects located in the workspace. The input of the Steel store will be the beginning of the simulation run, so all times will be 0. For the input of the truck we will mark Creation time 0:01, which is 1 second.
We change the lengths of the production process in the object Time – Processing time. They are summarized in Table 1.

The simulation model in 2D is in Figure 11. From the 2D model, it is possible to create the 3D simulation model, which is in Figure 12.

Plant Simulation output itself is not only 2D and 3D simulation models, but also various statistics that can be viewed after the simulation time is over (Table 2). The output is a saw blade, and 79 blades are produced in 8 hours. The times are divided into production, transport and storage and are reported in %. Production time of the production process is 95.7%, the material transport time in the production hall is 3.88% and the storage time is only 0.46% of the total time.

If we want to look at more detailed statistics, once we have completed the simulation, we mark all objects in the model and press F6, then

| Table 1. Times of operations duration of the selected production process |
|---------------------------------------------------------------|
| **Operation** | **Operation duration (seconds)** |
| Laser cutting | 40 |
| Grooving the disc | 30 |
| Measurement | 25 |
| Rolling | 20 |
| Polishing | 60 |
| Burning | 45 |
| Laser check | 5 |
| Application of flux (or assembly) | 2 |
| Location of solder (or assembly) | 2 |
| Sanding | 0 |
| Teeth grinding | 120 |
| Knocking out | 240 |
| Computer teeth control | 60 |
| Packaging | 150 |
| Laser cutting | 60 |
| **Total** | **859** |

Fig. 11. 2D model of saw blade production in Plant Simulation

Fig. 12. 3D model of saw blade production in Plant Simulation
program opens the new window and we can see statistics about:

- The working time of individual machines.
- The material flow passing through the individual simulation objects.
- The robot rotation time.
- The setting times.
- The waiting times.
- The unused time.
- The output (pending and working time, number of outputs, number of outputs per hour).

From these different statistics, we first introduce material flow statistics (Table 3) in objects where you can see the amount of material inputs into individual program objects (devices). Table 3 doesn’t contain data about all objects that are in the model. Through this table we demonstrate that Plant Simulation (when it is properly used) can provide users a lot of necessary statistical and mathematical data that they would otherwise have to calculate using different methods.

We also introduce Table 4, which shows the individual working times of the objects.

**Proposals for improvement of saw blade production**

The production of saw blades is partly automated, but there are still places in production that could be improved. The possibilities for improving the process are clearly seen in the following places:

- Transport of material in the production hall between workplaces through the truck.
- Manual measurement of the unevenness of saw blade grooves.
- Manual feeding of saw blades into the machine at some workplaces.

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Table 2. Basic statistical output from Plant Simulation

| Object                  | Name                          | Mean life time | Throughput | TPH | Production | Transport | Storage | Value added | Portion |
|-------------------------|-------------------------------|----------------|------------|-----|------------|-----------|---------|-------------|---------|
| Saw blade               | Disc after soldering          | 14:24:1654     | 81         | 10  | 95.66%     | 3.88%     | 0.46%   | 72.90%      |         |

Table 3. Statistical material flow data

| Object          | Number of entries | Number of exits | Minimum contents | Maximum contents | Relative empty | Relative full |
|-----------------|-------------------|-----------------|------------------|------------------|----------------|--------------|
| Steel store     | 84                | 84              | 0                | 1                | 97.81%         | -            |
| Road 1          | 1938              | 1937            | 0                | 1                | 50.00%         | -            |
| Road 2          | 2255              | 2254            | 0                | 1                | 50.11%         | -            |
| Road 3          | 2254              | 2254            | 0                | 1                | 50.13%         | -            |
| Transfer station| 84                | 84              | 0                | 1                | 97.08%         | -            |
| Buffer 1        | 84                | 84              | 0                | 1                | 98.25%         | 1.75%        |
| Truck 1         | 1                 | 1               | 0                | 1                | 100.00%        | -            |
| Road 4          | 2700              | 2700            | 0                | 1                | 50.21%         | -            |
| Road 5          | 2700              | 2699            | 0                | 1                | 50.24%         | -            |
| Truck 2         | 1                 | 1               | 0                | 1                | 100.00%        | -            |
| Transfer station| 84                | 84              | 0                | 1                | 97.08%         | -            |
| Transfer station| 84                | 83              | 0                | 1                | 97.09%         | -            |
| Unevenness measuring | 83        | 83              | 0                | 1                | 92.80%         | -            |
| Rolling         | 83                | 83              | 0                | 1                | 93.05%         | -            |
| Polishing       | 83                | 83              | 0                | 1                | 82.71%         | -            |
| Road 6          | 3372              | 3371            | 0                | 1                | 50.28%         | -            |
Table 4. Statistical data about working time

| Object           | Portion | Count | Sum     | Mean Value | Standard Deviation |
|------------------|---------|-------|---------|------------|--------------------|
| Steel store      | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Road             | 47.08%  | 2022  | 3:46:00.0000| 6.7062    | 1.3520             |
| Road 1           | 47.08%  | 2021  | 3:45:59.0000| 6.7091    | 1.3463             |
| Truck            | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Transfer station | 2.92%   | 84    | 14:00.0000| 10.0000   | 0.0000             |
| Transfer station 1 | 2.92%  | 84    | 14:00.0000| 10.0000   | 0.0000             |
| Buffer           | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Road 2           | 46.97%  | 2339  | 3:45:27.0000| 5.7832    | 1.0704             |
| Road 3           | 46.96%  | 2338  | 3:45:24.0000| 5.7844    | 1.0696             |
| Transfer station 2 | 2.92% | 84    | 14:00.0000| 10.0000   | 0.0000             |
| Transfer station 3 | 2.92% | 84    | 14:00.0000| 10.0000   | 0.0000             |
| Truck 1          | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Grooving         | 8.75%   | 84    | 42:00.0000| 30.0000    | 0.0000             |
| Buffer 1         | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Road 4           | 46.88%  | 2784  | 3:45:00.7500| 4.8494    | 0.8111             |
| Road 5           | 46.86%  | 2783  | 3:44:55.2500| 4.8492    | 0.8126             |
| Truck 2          | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Transfer station 4 | 2.92% | 84    | 14:00.0000| 10.0000   | 0.0000             |
| Transfer station 5 | 2.91% | 84    | 13:57.0000| 9.9543    | 0.3273             |
| Unevenness measuring | 7.20% | 83    | 34:35.0000| 25.0000   | 0.0000             |
| Rolling          | 5.76%   | 83    | 27:40.0000| 20.0000   | 0.0000             |
| Polishing        | 17.29%  | 83    | 1:00.0000| 1          | 0.0000             |
| Road 6           | 46.63%  | 3455  | 3:44:46.0000| 3.9039    | 0.5745             |
| Road 7           | 46.82%  | 3454  | 3:44:44.0000| 3.7844    | 0.5745             |
| Truck 3          | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Transfer station 6 | 2.88% | 83    | 13:50.0000| 10.0000   | 0.0000             |
| Transfer station 7 | 2.88% | 83    | 13:50.0000| 10.0000   | 0.0000             |
| Buffer 2         | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Burning          | 12.97%  | 83    | 1:02:15.0000| 45.0000   | 0.0000             |
| Hard soldering   | 0.00%   | 83    | 0.0000  | 0.0000     | 0.0000             |
| Sanding          | 34.58%  | 83    | 2:46:0.0000| 2:00.0000 | 0.0000             |
| Teeth grinding   | 69.03%  | 83    | 3:51:19.2168| 3:59.5086 | 4.4765             |
| Knocking out     | 17.08%  | 82    | 1:22:00.0000| 1:00.0000 | 0.0000             |
| Control of saw blade | 42.71% | 82    | 3:25:00.0000| 2:30.0000 | 0.0000             |
| Packaging        | 17.08%  | 82    | 1:22:00.0000| 1:00.0000 | 0.0000             |
| Saw blade        | 0.00%   | 81    | 0.0000  | 0.0000     | 0.0000             |
| Line             | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Conveyor        | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Conveyor 1       | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Road 8           | 47.38%  | 2811  | 3:47:24.0000| 4.8538    | 0.6001             |
| Road 9           | 47.36%  | 2810  | 3:47:20.0000| 4.8541    | 0.7995             |
| Transfer station 8 | 1.42% | 82    | 6:50.0000| 5:0000     | 0.0000             |
| Buffer 3         | 0.00%   | 0     | 0.0000  | 0.0000     | 0.0000             |
| Laser cutting    | 11.67%  | 84    | 56:00.0000| 40.0000    | 0.0000             |
| Conveyor 2       | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Laser control    | 61.29%  | 2531  | 4:54:11.0000| 4.9989    | 0.0673             |
| Conveyor 3       | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Line 1           | 100.00% | 1     | 8:00:00.0000| 8:00:00.0000| 0.0000             |
| Flux application  | 24.50%  | 3528  | 1:57:36.0000| 2.0000     | 0.0000             |
We suggest conveyor belt (Figure 13) for transport between workplaces, which would save time for workers, remove inter-operational warehouses and thereby make production more transparent.

The cost of the conveyor depends on its length and width. The width of the conveyors would be equal (700 mm). This improvement would increase the flow of production. Conveyors would be placed instead of trucks between the following objects:

- Steel store and laser cutting (6 meters).
- Laser cutting and grooving (6 meters).
- Grooving and unevenness measuring (6 meters).
- Rolling of discs and polishing (5 meters).
- Teeth grinding and knocking out (5 meters).

Manual measurement of the unevenness of saw blade grooves is work-intensive and lengthy, so it would be profitable to buy a laser device for measuring unevenness (Figure 14). This would shorten production time, making work easier for workers, because it is a monotonous and hard-working job for eyes.

The laser distance sensor will be between the grooving and rolling operation. A belt conveyor is placed between these operations according to the new design. At the edge of the belt conveyor

| Table 4. Cont. Statistical data about working time |
|-----------------------------------------------|
| Line                                    | 24.48% | 3525 | 1:57:30.0000 | 2.0000 | 0.0000 |
| Conveyor 4                              | 100.00% | 1    | 8:00:00.0000 | 8:00:00.0000 | 0.0000 |
| Flux input                              | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |
| Robot                                   | 15.33%  | 7057 | 1:13:35.3244 | 0.6257   | 0.0000 |
| Solder input                            | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |
| Robot 1                                 | 15.32%  | 7051 | 1:13:31.5704 | 0.6257   | 0.0000 |
| Buffer 4                                | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |
| Saw blade input                         | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |
| Truck 4                                 | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |
| Transfer station 9                      | 1.42%   | 82   | 6:50:00.0000 | 5:0000   | 0.0000 |
| Buffer 4                                | 0.00%   | 0    | 0.0000       | 0.0000   | 0.0000 |

Fig. 13. Example of conveyor belt

Fig. 14. Example of laser device for measuring unevenness

Fig. 15. Measuring the saw blade diameter

In Plant Simulation, we will not add this laser sensor as an object, because the time of the groove distance measurement takes only a few seconds, which doesn’t have a significant effect on the simulated process. In Figure 16 there is a simulation section that relates to grooving...
measurements before the placing a belt conveyor and a laser device. Figure 17 shows a simulation in Plant Simulation after change.

By comparing these two figures (Figure 16 and Figure 17), it can be stated that the purchase of the conveyor and the laser device would have a positive effect on the production, such that it occurs:

- Higher production continuity.
- Greater production clarity through removing buffers.
- Shorten process time.
- Productivity increasing.

We suggest changing manual delivery to individual machines for automatic feed of material from machine to conveyor or vice versa. We suggest buying a multifunctional industrial robot (Figure 18).

Industrial robot would deliver the material before the operations below and at the same time after the operation on the conveyor:

- Grooving.
- Rolling.
- Polishing.
- Sanding.
- Grinding.

The purchase of the equipment that was described in the section “Proposal for improvement of saw blade production” is costly. The aim of the contribution is not to calculate the economic efficiency of this investment, so we only present a simulation model of the production process after introducing all proposed improvements. The entire production process would be more automated, arise fewer stoppages, productivity would increase, production capacity would increase, fluency in production would increase, etc. 2D simulation model after the proposed improvements is shown in Figure 19 and 3D simulation model after the proposed improvements is shown in Figure 20.

We can evaluate best the effectiveness of the proposals by comparing the output statistics after
After comparison, we found out that the number of outputs (saw blades):
- Increased by 2 pieces in 8 hours.
- The percentage of production time increased to 97.9%.
- Storage times were reduced to 0%.

CONCLUSION

This simulation model is a simplified version of saw blade production because it is not possible to look at all the settings, all the times, stoppages, etc. But Plant Simulation offers a wide range of simulation options, so detailed simulation is not a problem.

Businesses that need to find improvements in processes can this program undoubtedly help and can helping them to become market leaders if they will apply findings from simulations to practice. A disadvantage for some businesses may be the difficulty of program control or the lack of necessary objects in the object library for a 3D model, although these objects can be gradually added.

Our simulation model improve some crucial performance indicators in this production process of saw blade and the most important are that the output of production process increased by 2 pieces in 8 hours, also the percentage of production time increased to 97.9% and on the other hand storage times were reduced to 0%.

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