Effective bottleneck analysis through simulation: a Lean case study

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***Abstract*— In this paper, the simulation is described as one of the best approaches for performing bottleneck analysis and process improvement. Further in the content, the bottleneck types are presented, the reasons for their occurrence as well as the methods for identifying the bottleneck in the process. The emphasis of this paper is the proposed methodology and the improvement and analysis of the bottlenecks using the simulation method. With the help of simulation software - Technomatix Plant Simulation, a production process for wooden chairs has been programmed for analysis. With the Bottleneck Analyzer tool, the process is analyzed and the bottlenecks are identified. The data obtained from each analysis were used to improve the model by experimenting with the basic model. From the experimentation process, few more improved models have been obtained, each with increased productivity than the previous one.**

Keywords—bottleneck analysis, simulation, Lean, production, improvement

I. INTRODUCTION

Business processes are of great importance to a company because well-designed processes increase their efficiency and effectiveness. With the help of the software and the tools it contains, detailed process analysis of the production of wooden chairs has been conducted. By creating the simulation model and analyzing it, bottlenecks that reduce productivity in production have been identified. Process analysis and bottlenecks identification is important, as there is almost no production process in which an operation is working with full capacity and still slows down the whole production. To present the way of dealing with such situations, this paper will present the ways of optimizing and reducing bottlenecks through the production processes, with a simulation model.

The aim in this paper is the improvement of processes through bottleneck analysis. There are several methods for identifying and analyzing bottlenecks. This paper presents the simulation method using the tools of simulation software Tecnomatix Plant Simulation, part of Siemens PLM software for modeling, simulation, analysis, visualization, and optimization of production systems and processes, the flow of materials, and logistics operations.

The paper is structured in the following way. Section 2 gives an overview of the methodology and methods used for the project. Section 3 describes the case and the used data to develop a simulation model. Section 4 explains the various experiments conducted, along with the results from them. Section 5 gives an overview and discussion of the results.

II. METHODOLOGY

For the foreseen project, ideas for improvement were brainstormed using the principles of Lean management, [1]. It is based on the House of Lean, where the High quality, Low cost, and Short lead times are the objectives to be achieved, [2]. Lean thinking is a philosophy of eliminating waste in the process and organization. Seven different types of waste are identified that need to be analyzed and tackled: waiting, overprocessing, overproduction, transport, motion, inventory, and defect correction.

The bottleneck analysis mostly tackles the first waste – waiting, but is crucial and affects all other wastes as well. The bottleneck is an activity that delays the operation of the system and reduces the overall efficiency of the process. The term "bottleneck" is used to describe the point of congestion in any system, from a production assembly line to a computer system or even a service process in a bank. In such a system, there is always a process, a task, a machine, etc. which is a limiting factor that prevents greater flow and thus determines the capacity of the entire system. For example, a production company that has different production lines, each of which is related to each other, i.e., work produced by one unit is the input to the other unit. If the outflow of the preceding process is somehow limited, it will affect the capacity of the succeeding process.

Fig. 1 represents the idea of what a bottleneck means in a process, where it is clearly shown that the input rate is

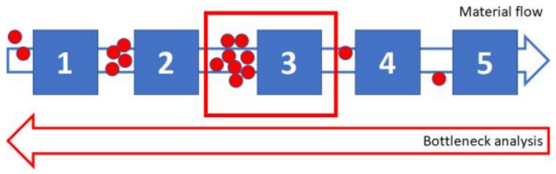

Fig. 1: Bottleneck analysis, adopted from **[3]**

higher than the output rate. In such a case, if a process is interrupted or stopped for some reason, it directly affects other production processes, causing a lower output level due to the bottleneck. One of the most important things when conducting the bottleneck analysis is that it is performed in the opposite direction of the material flow, i.e., from the end towards the beginning of the process. In this way, any improvement made at one station, defines the capacity of the whole process (the succeeding stations).

For this project, a simple methodology for managing the bottlenecks has been defined, Fig. 2. This methodology is a general one, and not limited to simulation models only. It can be initiated with a kind of a model of a system. It is a four-step methodology that will be explained in more detail within the practical case.

There have been efforts in defining how bottlenecks

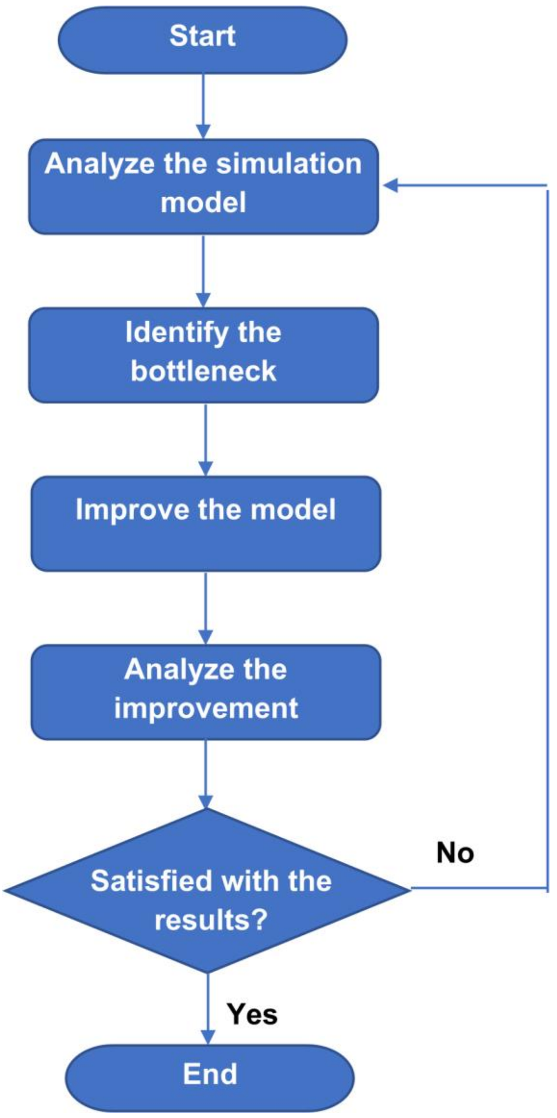

Fig. 2. Methodology for bottleneck analysis

could be measured and managed afterward, Table 1. For the particular project, the last four mentioned have been utilized to analyze the system and make improvements to the production. Especially, the last one, computer simulation, was seen as the best option to experiment with the production process and make the decisions more quickly and accurately. That is why the methodology for developing simulation models from [4] has been utilized. It is a thirteen-step methodology worldwide known and used.

Table 1. Bottleneck detection methods, [**5**]

Method	Characteristic	Measurement
Queue Size before the machine	The bottleneck is the machine that has the longest queue before the machine, waiting to be processed.	Quantity of products
Utilization Factor	The percentage of time that the machine is working concerning the system's overall time is measured. The machine with the highest utilization is the bottleneck.	Percentage
Waiting Time before the machine	It is measured on how long a product will wait in a queue to be processed.	Time
Shifting Bottleneck Method	Sum of the duration of the active state without interruption in a time for a production station. Even though instantly some machines can be the bottleneck, the one with the highest value is the bottleneck.	Time
Computer simulation	A virtual process model is created by setting realistic parameters and working conditions. Computer analysis of processes is performed, and more statistics are obtained. In this way, the bottleneck in the production process is visually easy to see.	Various statistics: (time of work, waiting time, pause)

The simulation is a virtual display or imitation of the functioning of a real process or system. The simulation process first requires the development of a model that represents the key features, behaviors, and functions of the selected physical or abstract system or process. The model represents the system itself, while the simulation represents the work of the system over time. Hence, the simulation can be used in many contexts, such as simulation for performance optimization of the technology, in the design phase of a project, testing, training, and education. Often, computer experiments are used to study simulation models and are one of the most important features of the simulation process.

III. The Case and the Simulation Model

The process that is analyzed is a production of chairs. The times for each of the operations are given in minutes and are deliberately altered than the real process.

The metal bars that are purchased are 2 meters in size. They should be cut to a size of 180 cm [2:30], then grinded [3:00] and twisted [4:00]. The bars are released for cutting every 15 minutes. In painting, 10 bars are going at once and this lasts 10 minutes. 12% of the painted bars are not of the proper quality and are again hand-painted, which requires 1 minute for each bar.

The seats and the back are made of wood. The first operation for the two pieces is cutting 2 [12:30], then pressing [30:00].

• At the first assembly place, two metal-shaped bars, a seat, and 4 bolts are connected in 13:00 minutes.

• The second assembly station merges the previous sub-assembly with the backrest and 2 screws, during a normal distribution of 3 minutes and μ = 1: 00.

• At the third assembly station, 4 rubber feet are put on the metal legs in 2 minutes.

• The stool goes to the control [00:15], and is later packed [6:00] in boxes of 5 pieces in one. They are stored in the warehouse.

People are needed at all assembly stations, control, and packaging. The availability of all stations is 90%, with MTTR = 2 minutes.

The emphasis in this paper is put on the bottleneck analysis and because of that, the whole process of creating the simulation model is omitted. The next chapter starts with a complete simulation model, a basis that will be further analyzed in detail.

IV. EXPERIMENTS AND RESULTS

The steps for the bottlenecks analysis of consist of the four phases, already mentioned before:

- Analyze the model;
- Identify the bottleneck;
- Improve the model;
- Analyze the improvement.

In the first phase, an analysis of the simulated model is carried out. The analysis in the software is done using the Bottleneck Analyzer tool. All the elements in the model are analyzed and a report is provided containing data on the way each machine works. This Statistic Report gives a detailed analysis for each object in the simulation model on the following criteria, but not limited to: Working, Set-up, Waiting, Blocked, Powering up/down, Failed, Stopped, Paused, and Unplanned, all in percentages of the simulation time.

In the second phase, based on the simulation model and the data obtained from the simulation, the bottleneck is being detected. The first and the second phase are closely connected, that is, according to the data obtained from the analysis of the simulation model, detection of the bottleneck processes is performed. The schematic view of the analysis is given in Fig. 3. and it enables easier and more accurate detection of the bottlenecks.

From the data obtained from the statistical report, there are more bottlenecks in the considered process:

• The machine for pressing the backrest

• The machine for pressing the seat

• Assembly station 1

Pressure stations represent bottlenecks because they operate at full capacity while the cutting stations that precede them are blocked by them. The assembly station 1 is a bottleneck because it blocks the stations that precede it while it waits for the material from the station for pressing the seat.

After determining the bottlenecks in the simulation model, we approach the third phase of the methodology - to define and implement improvements to the basic model.

The third and fourth stages are in fact the most important stages in resolving the problem and eliminating the bottleneck in the process. The number of improvements created depends on how the client is satisfied with the improved model and the data it generates. If the improved model meets the expectations, the next step is implementing the improvement. After the improvement is implemented, the newly generated model (i) is re-analyzed, comparing the data from the new model with the initial (previous) model, and if the client is satisfied with the achieved result, the process is completed, and the improvements need to be implemented. If the results are not satisfactory, the steps are repeated again. That is, new improvements are implemented until the desired results are achieved. For this case, four continuous improvements have been made.

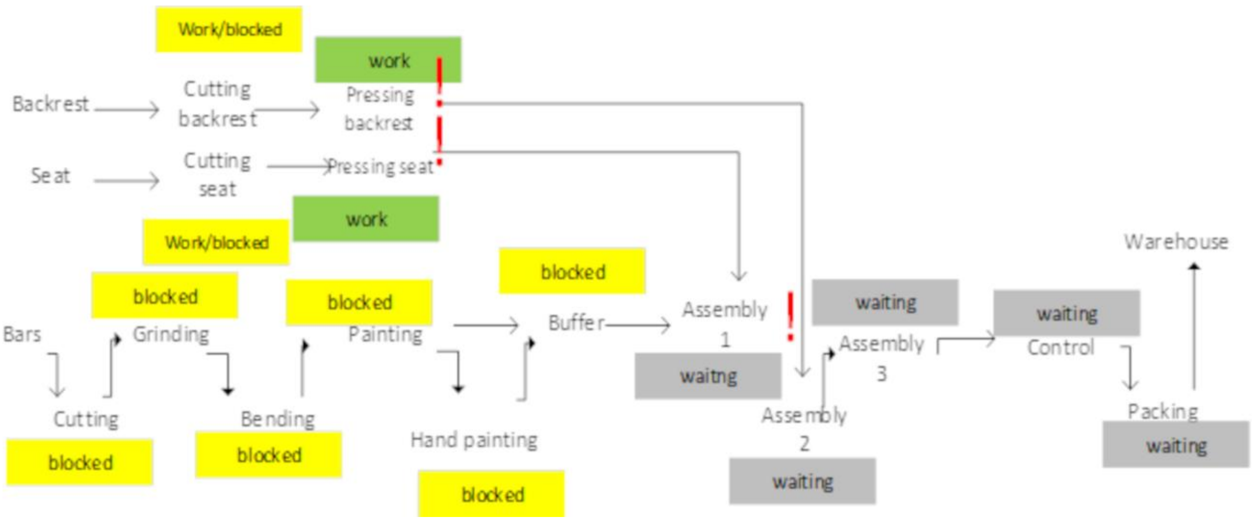

Fig. 3. Schematic view of the simulation model

Table 2. Comparison data for the basic and the first improvement

	Working		Waiting		Blocked	
Station	basic	model 1	basic	model 1	basic	model 1
Bending	6.61%	7.80%	1.14%	1.28%	14.94%	13.61%
Cutting	4.14%	4.89%	0.71%	0.73%	17.69%	16.92%
Grinding	4.96%	5.86%	0.95%	1.05%	16.75%	15.76%
Bars	0.00%	0.00%	1.01%	1.04%	98.99%	98.96%
Painting	1.63%	1.92%	1.53%	6.19%	19.50%	82.02%
Hand painting	0.67%	0.73%	3.74%	2.62%	85.75%	19.24%
Preparation for painting	0.16%	0.19%	30.19%	35.96%	69.64%	63.85%
Dismantle Station	0.16%	0.19%	4.02%	7.14%	95.82%	92.67%
Backrest	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
Seat	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
Cutting backrest	9.28%	13.32%	0.00%	0.00%	13.39%	9.35%
Pressing backrest	22.20%	1.06%	0.13%	5.45%	0.44%	18.64%
Assembly station 1	9.64%	5.42%	11.21%	17.03%	1.60%	0.00%
Bolts	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%
Assembly station 2	2.22%	2.50%	20.37%	20.07%	0.10%	0.12%
Packaging	0.88%	0.99%	21.65%	21.54%	0.00%	0.00%
Control	0.18%	0.21%	22.30%	22.22%	0.09%	0.15%
Assembly station 3	1.48%	1.66%	21.17%	20.99%	0.08%	0.08%
Cutting seat	9.33%	10.45%	0.00%	0.14%	13.37%	12.25%
Pressing seat	22.29%	25.02%	0.11%	0.14%	0.33%	0.00%
Buffer2	0.00%	0.00%	4.11%	7.13%	95.89%	92.87%
Assembly station 11	/	5.39%	/	17.19%	/	0.00%

A. Improvement 1: Adding another assembly station 1

The first improvement will be achieved by eliminating one of the bottlenecks, Assembly station 1. The improvement is done by placing additional station in the simulation model, which would be expected to reduce the blockage at the stations that preceded them. Numerous data and graphical analyses have been performed like the machine capacity utilization, worker utilization, as well as working, waiting, and blocking percentage graphs. Due to the limitations of the paper, only one comparison table will be shown, for the improvement 1, as presented in Table 2. It shows the data for each dynamic object and the change of the improvement from the base model, i.e. the previous stage of the process. The green color represents an improvement of the object from the previous condition, yellow means that the value is the same as before and red represents a worsened condition as before. These kinds of analyses are performed after each improvement and based on the data, the next improvement is foreseen.

From the comparison we can observe that the stations in the improved model 1 have a higher percentage of working and a smaller percentage of blockage compared to the basic model and that the waiting at some stations is reduced. It can also be seen that the number of output boxes is increased compared to the basic model. Regarding the operation and blockage of the assembly station 1, we can notice that there are no improvements, but the work has been split between the two assembly stations in the improved model 1.

The reason for this is the bottleneck that is located at the station pressing the seat. Therefore, the next step is to make a new improvement.

To have a better overview of the whole process of analysis and improvements, a special table presenting only the comparison data for the Blockage percentage is presented in Fig. 4. The same kind of table has been created for the waiting and working percentages.

B. Improvement 2: Add another station for pressing the seat.

With the second improvement of the already improved model 1, another station for pressing the seat was added. This improvement was expected to reduce blockage at stations, increase work and reduce the waiting at the assembly stations.

From the comparison it can be noted that the working percentage at assembly station 1 and assembly station 11 is increased. The blocking percentage at the stations is also reduced, which contributes to the reduction of blockages and to the processes that precede them. As it can be seen from Fig. 4, an improvement in the throughput has been achieved (from 72 to 141 packages).

C. Improvement 3: Add another station for pressing the backrest

Since the desired results are not obtained, a new improvement was initiated. This means the elimination of the last bottleneck detected at the beginning was located at the station for pressing the backrest. From the comparison, it can be seen that the percentage of operation of the stations has increased significantly and that the percentage of blocking at the stations has dropped significantly.

New bottleneck analysis has been performed, and although the bottlenecks that were identified at the beginning were eliminated from the new analysis, it was noticed that the assembling stations are waiting, i.e., they do not receive the material in time, and therefore there is a delay in the production and blocking of the stations that precede them.

As the capacity of the stations for pressing the seat and backrest has already been increased, it was concluded that the stations for cutting the seat and backrest do not meet their needs i.e., they represent the new bottleneck.

Station	basic	model 1	model 2	model 3	model 4	dynamics between the models	relative improvement	absolute improvement
Bending	14,94%	13,61%	11,43%	5,09%	4,32%		246%	10,62%
Cutting	17,69%	16,92%	15,54%	11,87%	7,61%		132%	10,08%
Grinding	16,75%	15,76%	14,04%	9,31%	3,97%		322%	12,78%
Bars	98,99%	98,96%	98,64%	98,64%	98,25%		1%	0,74%
Painting	19,50%	82,02%	67,88%	63,59%	0,00%		#DIV/0!	19,50%
Hand painting	85,75%	19,24%	16,94%	15,24%	0,00%		#DIV/0!	85,75%
Preparation for painting	69,64%	63,85%	59,38%	17,61%	4,59%		1417%	65,05%
Dismantle Station	95,82%	92,67%	79,08%	75,60%	0,00%		#DIV/0!	95,82%
Cutting backrest (+1 in M4)	13,39%	9,35%	12,22%	2,27%	2,59%		417%	10,80%
Assembly station 1 (+1 in M1)	1,60%	0,00%	12,25%	0,00%	0,00%		#DIV/0!	1,60%
Assembly station 2	0,10%	0,12%	0,18%	0,29%	0,00%		#DIV/0!	0,10%
Packaging	0,00%	0,00%	0,00%	0,00%	0,00%		#DIV/0!	0,00%
Control	0,09%	0,15%	0,12%	0,29%	0,42%		-79%	-0,33%
Assembly station 3	0,08%	0,08%	0,11%	0,27%	0,39%		-79%	-0,31%
Cutting seat (+1 in M4)	13,37%	12,25%	6,40%	0,00%	2,96%		352%	10,41%
Buffer2	95,89%	92,87%	79,31%	75,94%	0,00%		#DIV/0!	95,89%
Buffer3	/	/	43,53%	0,00%	0,00%		#DIV/0!	43,53%
Buffer4	/	/	0,00%	0,00%	97,98%		-100%	-97,98%
Assembly station 11	/	0,00%	11,66%	0,00%	0,00%		#DIV/0!	0,00%
Buffer6	/	/	72,72%	0,00%	0,00%		#DIV/0!	72,72%
Pressing backrest (+1 in M3) (+2 in M4)	0,44%	18,64%	0,36%	0,00%	0,90%		-51%	-0,46%
Pressing seat (+1 in M2) (+2 in M4)	0,33%	0,00%	0,00%	0,00%	0,89%		-63%	-0,56%
Throughput (packets)	63	72	141	156	218		246%	
Cycle Time (h)	22:58:08	20:07:31	10:18:02	09:19:00	06:40:10		244%	16:17:58

Fig. 4: Comparison table of the blockage percentage and throughput data

Therefore, the next step is implementing a new improvement, that is, an increase in the number of stations for cutting back and seat, which entails and again increases the number of pressing stations.

D. Improvement 4: Adding stations for cutting and pressing the seat and backrest

Additional stations (for cutting and for pressing) were added in the improved model 4. From the comparison, it can be noted that the number of outputs on the final boxes has increased, the blocking of the stations has been drastically reduced, and as a result, the percentage of work at the stations has increased.

This improvement eliminated the bottlenecks that were detected. The results of the improved model 4 are satisfactory, which means that it completes the analysis and approaches the next step - implementing the new solution and configuration.

As discussed before, the process of bottleneck analysis stops when the desired results are obtained. As seen in Fig. 4, the throughput of the production process has been increased from the initial 63 packages to 218 packages, resulting in 246 % increase. The cycle time has been improved by more than 16 hours, i.e., from the initial 22:58 hours to the new 6:40 hours.

V. Conclusion

The problem of bottlenecks is a key issue in optimizing and increasing the efficiency of production processes. Discovery and analysis of bottlenecks is one of the fundamental constraints of modern manufacturing companies. That is why companies should not ignore this problem that significantly impacts the efficiency of the processes. One of the ways to solve the bottleneck problem is using the simulation method that was presented in detail in this paper.

Bottleneck analysis is a detailed process in which a company collects information about the production flow of a particular product or process. In particular, data are collected on the step or steps in the process where work is closely related. This type of analysis can be done specifically to identify the existence of the bottleneck causing problems or to anticipate processes where a bottleneck may occur in the future. Regardless of the reason for conducting this type of analysis, important information is provided on how things are done and how they can be improved. Effectively managing the bottlenecks in the process, directly influences the elimination or reduction of a few of the Lean waste types. As it was seen in this case, the throughput has been increased by 246%, and so are the takt and cycle time improved.

When performing bottleneck analysis, it is important not only to look at the specific step in which a bottleneck occurs, but rather the entire production process. This will provide essential information about processes leading to the very bottleneck itself, and what happens right after the bottleneck. This is important for various reasons, including the fact that if the bottleneck in the production process is eliminated, it may result in the formation of a new bottleneck in the future. Properly analyzed, this will not only help find solutions to the existing bottleneck, but also help prevent the formation of new ones.

Companies should find ways to continuously analyze and improve their operations. The use of the simulation method is proving to be an effective tool for finding ways to improve the productivity of the processes. The possibility of presenting various scenarios and their analysis, without the need for them to be tested in reality, leads to a reduction in time and costs for finding optimal solutions to the problems. The purpose of this paper was to develop a simulation model of the production process and to analyze the model and to find and eliminate the bottleneck in the production process. The study confirms the possibility of using the simulation software Tecnomatix Plant Simulation in the analysis of both simpler and more complex production processes. As it can be seen, with four iterations of changes in the process, a significant improvement in the process has been achieved. At the end, these improvements have added value to the whole process and made it more according to the Lean philosophy.

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