THE USE OF SIMULATION PROGRAM IN THE PRODUCTION OF PARQUET AND WOODEN FLOOR - CASE STUDY

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Received: July 14, 2021
Received revised: September 2, 2021
Accepted for publishing: September 6, 2021

Abstract

Motion and time study is part of the process planning which defines operation sequencing before the physical manufacturing of a product. It is a tool for the standardization, in this case the time needed for a single product manufacturing. Manufacturing time can be described as and divided into preparatory-finishing time, auxiliary time and machining time. Machining time depends on technical possibilities of available machine tools, while other two depend on human and work organization within the company. Accurately defined time standards and norms enable accurate production planning as well as the monitoring of workers' productivity and possibilities of their personal upgrade for the achievements. In this paper the use of simulation software in motion and time study will be described, rather than traditional manual methods. Its benefits will be proven on the case study, by simulation of line for making grooves in parquet and wooden floor. The bottlenecks will be identified and improvements of the production process will be suggested.

Key words: technological process planning, motion and time study, simulation, parquet and wooden floor production

1. INTRODUCTION

Production planning is an activity and phase in the product life cycle which describes the methods for production of a single product - beginning with the definition of the raw material up to the finished product. It consists of several disciplines such as: manufacturing process planning, technological process planning, motion study, scheduling and monitoring, quality control and material handling (Kiran, 2019).

Motion and time study is an essential part of technological process planning. It defines the norms, more specifically, the time needed for a single product manufacturing. Overall manufacturing time consists of preparatory-finishing time, auxiliary and machining time (Żywicki & Osiński, 2019). Machining time depends on machine characteristics, while others depend on human and work organization within the system. Work standardization and definition of optimal time norms minimize the manufacturing costs and therefore increases the competitiveness level on the dynamic market (Mor et al, 2019). It also enables accurate manufacturing planning as well as monitoring of efficiency and productivity of a single worker.

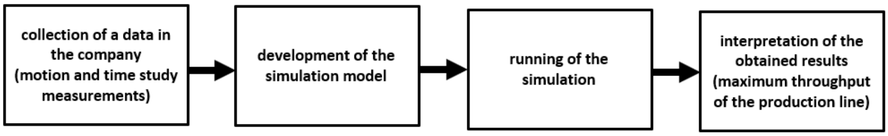
Every technological process must fulfill certain economic and technical requirements. As the starting point, technical requirements of the product are provided by product design. The product design and related technological process design, must fulfill certain economic requirements, which are minimization of costs, but at the same time the maximization of manufacturing and final product quality level (Uzair Khaleeq et al, 2017). Motion and time study define optimal time needed for certain tasks and actions by workers' training level, knowledge, normal commitment and possible fatigue level (Azemi et al, 2019). Most important parts of motion and time study are: calculation of machining time, analysis of overall manufacturing time and losses within the work operations, calculation of complete manufacturing time and definition of norms and definition of data needed for work standardization (Bortolini et al, 2020).

Work standardization enables the improvement and simplification of manufacturing tasks and actions for the worker, without unnecessary and inappropriate acceleration of human work, but rather with the adjustment to their abilities and needs. This is done by: workplace analysis, technological and manufacturing process analysis, definition of work improvements which result in easier and more productive work and implementation of improvements in the real work environment.

The optimal workplace environment in terms of motion and time study is provided by advanced scientific methods for time analysis and calculation and the definition of norms as the quantitative measure of the organization efficiency (Doiphode & Phatak, 2017).

In this paper authors present the possibility of using a discrete event simulation software for numerical modeling of the production line. The main objective of the simulation is to found out the maximal throughput (m^2 of the parquet) of the production line. There are two basic assumptions in the simulation. One is that all operation times are deterministic. For this purpose, the motion and time study measurements will be carried out and average time for operations will be used in the simulation. The second assumption is that all activity regarding the walking of the workers is taken in consideration in operation time. This is done to simplify the simulation model. Research methodology can be easy describe as a collection of the data in the company using motion and time study measurements, development of the simulation model, running of the simulation and interpretation of the obtained results as a maximum throughput of the production line. Research methodology is shown on Figure 1.

Figure 1. Research methodology



2. MOTION AND TIME STUDY - TRADITIONAL VS MODERN METHODS

Traditional motion and time study is characterised by manual measuring. This includes a high contribution of human subjectivity which can impact on the accuracy of the results (Genaidy et al, 1989). Direct observation of another person in the workplace in real time might cause stress for the worker, so the performance might not be at the standard level needed for the wanted work standardization and other improvements. Workers might act over productive or underproductive because of the pressure and awareness of the measurement in progress (Susilawati et al., 2015). The measuring must be repetitive and it demands the constant presence of the motion and time study specialist, which prolongs the data analysis and workplace improvements. Because of the various working environments, the measuring might be more or less complex, which can also interfere with the results. Every suggested improvement must be tested in the real work environment which stops the currently running processes and causes additional losses (Roca et al, 2019). Another traditional method can be self-reporting, which is also subject to subjectivity, in this case of the worker himself, therefore it has many disadvantages. It also can cause a resistance and unwillingness for workers to participate in this kind of measurement, because it is not his primary task and in general fear of change, which is proven to be one of the biggest barriers in any kind of improvement implementation in the working environment (Eggemeier & Wilson, 1991).

Modern methods can partially eliminate the disadvantages of the traditional methods, while the benefits of new, digital tools reduce costs in long-term. The digital transformation is currently an imperative, while the manufacturers include it into their strategic plan very often, highly aware of its benefits in the field of manufacturing, process planning and time and motion study (Trstenjak et al, 2020). They include use of computer software for data storing and analysis, but most advanced and state-of-art methods include special simulation software or advanced mathematical modelling (Ložar et al, 2021), finite state method or genetic evolution algorithm (Hadžić et al, 2021) which enables the accurate data analysis and simple implementation of what-if analysis with various scenarios so that the optimal solution can be found (Kumar et al, 2018).

The most frequently used commercial software for the time and motion study on the market are Siemens Jack, SimData, OTRS10, UmtPlus etc. In this paper, the principles of improvements by motion and time study will be provided by simulation software Enterprise Dynamics, which provides the virtual modelling and analysis of any problem, but most frequently used in the manufacturing industry. The advantage of discrete event simulation software is manifested in [Incontrol, Simulation Software - Enterprise Dynamics]:

- testing future production systems at an early design stage,
- creation of digital twin production facilities,
- testing and improving the proposed modifications without affecting the operating environment,
- modeling and analyzing various scenarios,
- assessment of the impact of uncertainties and variations (failures),
- system analysis and visualization in 2D, 3D and VR animation.

2.1. Use of simulation software in production improvement – literature review

The use of simulation software is very beneficial in production improvements (Abideen et al, 2020). The direct efect on organization's operation performance and efficiency has been proven on numerous practical case-studies and its use today has evolved to digital-twin concept in which the entire system is virtualized and provides data in real-time (Schmitt et al, 2020). Its specific use in the wood machining and processing activities over the years has improved the many processes in the organizational level, in order to reduce cost and time, while increasing the productivity and quality of performance and final product. The most interesting and relevant works from this field, for the purposes of this paper, have been found in Web of Science database and will be described in more detail next.

Lee (2021) sees the importance of the simulation equipped with virtual reality technology to overcome the limitations of the furniture and woodworking industry and notices that there is a need for education of workers in this field. With special training, proven on the several case studies, their familiarity with the dynamic production system and handling within the production lines was enhanced.

Petschnigg et al (2018) applied the simulation in improving the time necessary for program adjustment of robots, that were beforehand static and could not adapt to more complex manufacturing tasks and changes easily. Therefore, there are many benefits of simulation in production improvement in handling the digital and automated systems.

Straka et al (2017) have shown that the use of computer simulation, in this case EXTENDSIM simulation software, can streamline production logistics within the production company. They put emphasis on the high importance of efficient use of the simulation software and the need for the specific software for the specific industry or a single company.

Rafiei et al (2016) applied optimization and simulation framework and identified the impacts of uncontrollable supply in the wood remanufacturing company. Production improvements and performance was measured with set of key performance indicators (KPIs) and the simulation held the problem of different supply scenarios by which the optimal framework of future strategic plan was defined.

Altaf et al (2015) applied the simulation during the execution phase, as previously it was mostly used as a planning tool. The integration of a radio frequency identification (RFID) system and discrete-event simulation (DES) model enabled the real-time simulation of production processes and monitoring. The simulation model was developed in Simphony.

Lindner et al (2014) noticed that the the algorithms and procedures used in simulations, implemented in different softwares, can also have an effect on the final result. They determined the optimal machine settings for two interrelated operations with SIMSAW software which used the Population Based Incremental Learning algorithm and was proven to be more efficient than the previously used Sawmill Production Planning System simulation software package.

Horvath (2014) used Deterministic and stochastic Petri nets (DSPNs) in the wood industry as a substitute for high-level performance evaluation methods for decision-making in the company. With the model, the process of bottleneck determination was simplified as well as their elimination.

Varga et al (2010) used a special process-simulation software SIMUL8 in (furniture) manufacturing strategy development to maximize the production efficiency and to recognize the bottlenecks without additional investment or workcentres rearrangement.

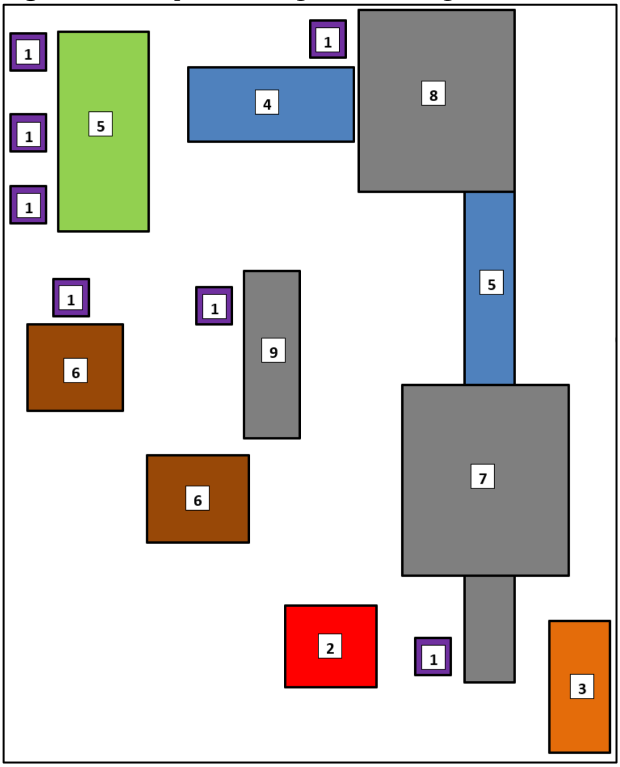
Therefore, there are many benefits and proven concepts of simulation software use in the production planning, organization, improvements and time and motion study that has now become a standard for the healthy organizational performance.

3. CASE STUDY

The case study on benefits of using simulation software in motion and time study will be provided on the example of the production line in one of the leading parquet manufacturers in Croatia. Their yearly production is estimated to be 750 000 m^2 parquet and floors for which 40 000 m^3 logs as raw material are being processed. This is a medium enterprise with over 50 years of experience and market presence. They are oriented to the local wood distribution as the main resource for their products.

The parquet board groove making line is shown on Figure 2 and consists of:
workplace (1), pallet with production boards (2), board record table (3), conveyors (4), putty table (5), product storage pallets (6), machine for production of longitudinal grooves (7), machine for production of transversal grooves (8) and machine for cutting of the boards (9).

Figure 2. Floor plan of the groove making line



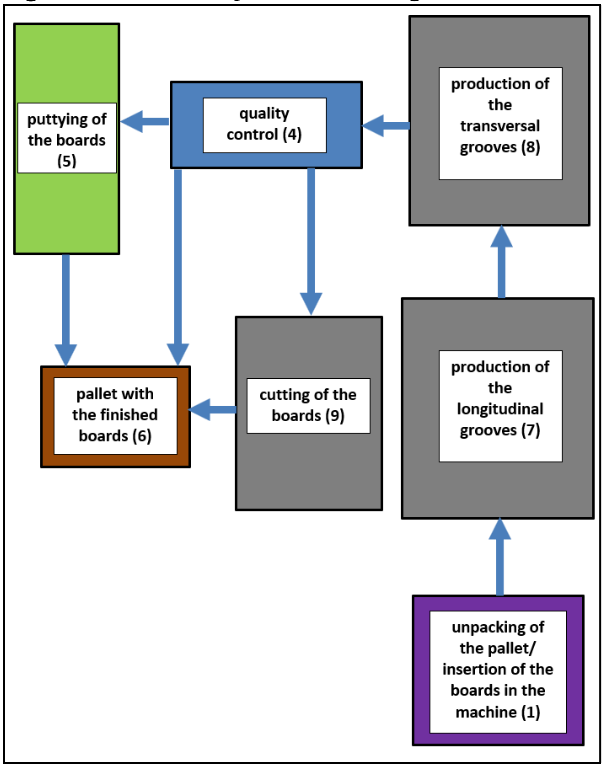
3.1. Manufacturing process

Before the beginning of the manufacturing process, the entire line should be prepared. After the preparation, the manufacturing process can start. Line begins with the first worker which must unpack the pallet with the boards (position 2). After unpacking of the pallet, at position 3 it is needed to check the following data: board type, board dimensions, board quality. After the quality control, the worker goes back to his workplace and begins to insert boards in the machine for production of longitudinal grooves. After the boards are inserted into the first machine, the pallet is taken away from position 2 and replaced by a new pallet. This process is repetitive. Boards inserted into the machine for longitudinal groove are disposed through the conveyor into the machine for production of transverse grooves. Then, boards are disposed through another conveyor where two workers are providing the quality control. It consists of following tasks: control of longitudinal grooves, control of transversal grooves and surface control.

After the quality control, boards are sorted by quality level. If the board doesn't satisfy the control of both grooves it is marked and sorted for the future cutting. If it fulfils the required quality level, it is sorted for the packing. After sorting, there are three paths available for the material (board) flow. In the first flow, the board goes to a cutting operation where a single worker is in charge of: taking the boards, cutting the boards, releasing the boards on the palette. In the second path the board goes to puttying, where one of the four workers can be present and their tasks are: take the boards for puttying and puttying of the boards. A single worker then is responsible for the finished boards disposal and also does the packing. Third path is for releasing and packing of the boards who have satisfied the quality standards and for this work the single worker is in charge. Production process as a flow diagram is shown on Figure 3. The numbers in brackets, according to Figure 2 represent the machine or work place where the operation is performed.

Since the quality of boards for the parquet varies from log to log, it is very difficult to plan how many m^2 of parquet will be done in a one shift. Because of that, it is very difficult to plan production. With development of simulation model, it is easier to calculate the amount of m^2 of parquet that can be done in one shift. Also, using the simulation model will allow company to easily change the parameters within the simulation which allows the creation of different scenarios.

Figure 3. Production process flow diagram



3.2. Time measurement

To analyse the current situation and calculate the work norm of this production line, times for the certain activities were measured with a basic stopwatch. Firstly, the time needed for line preparation was calculated. Afterwards, the line was separated into several parts for easier measuring. First part was measuring the first worker. Activities that were measured were: unpacking the pallet with boards, recording information, inserting the boards into the machine and disposing of an empty pallet. To assure the accuracy of the data, activities were measured several times in each case. Second part is measuring the machining time for the production of longitudinal and transversal grooves. On the machine for the production of longitudinal grooves those were: preparatory-finishing time, machining time, auxiliary time and additional time.

Preparatory-finishing time is already included in the preparation of the production line. Technological time is obtained by calculation using the operating mode machine and does not need to be measured. Auxiliary time was measured repeatedly to keep the data accurate and it consists of the time required to control the machine during the process making. There was no additional time with the machine for making the longitudinal groove. Same measuring is provided for a machine for making transverse grooves. As with the first machine, preparatory-finishing time of the machine for making the transverse grooves has already been measured in the preparation of the line itself. Machining time is also obtained by calculation using the operating mode of the machine (cutting speed). Auxiliary time consists of time to control the machine during the process. There was no additional machining time to make the transverse groove.

Final part consists of a series of jobs and the measuring was done in the order of the activities. First was time measurement for product control. The times that were measured contained the following tasks of workers: quality control and product sorting.

After product quality control, measurements were provided for the worker who was in charge of disposal and packaging of products that have satisfied the quality standards. After that measurement, the time of a worker in charge for boards that haven't satisfied the quality standards was measured. His task is: removal of boards, cutting boards and disposal of the cut boards on a pallet.

Finally, the time of workers in charge of products puttying that did not meet quality control of the surface and the worker in charge of disposing and packing these products. The task of the worker who is in charge of puttying products that have not met the surface quality control is taking (removal) of putty boards and puttying of the boards.

The measurement was performed on boards with dimension 600 mm x 120 mm x 14.5 mm. Measurements of these tasks were performed several times and average time for activities is presented in Table 1.

Table 1. Description of operations and average measured times

Machine/work station	Operation	Average time [s]	Remark
Machine for production of longitudinal grooves	preparatory-finishing time of the line for making the grooves	1200.00	-
	unpacking the pallet with boards	41.52	-
	recording information	68.83	-
	inserting the boards into the machine	1.12	-
	disposing of an empty pallet	16.05	-
	machining time	2.00	-
	auxiliary time	34.51	-
Machine/work station	Operation	Average time [s]	Remark
Machine for production of transversal grooves	machining time	0.40	-
	auxiliary time	40.72	-
Quality control and sorting of the boards	quality control	5.34	5 boards at once
	sorting of the boards	5.55	5 boards at once
Machine for cutting of the boards	removal of boards	4.38	-
	cutting of the boards	7.87	-
	disposal of the cut boards on a pallet	6.56	-
Puttying of the boards	removal of the boards for puttying	8.36	10-15 boards at once
	puttying of the boards	13.72	-
	disposal of putted boards	55.98	15-20 boards at once
	disposal of correct boards	22.12	5-10 boards at once

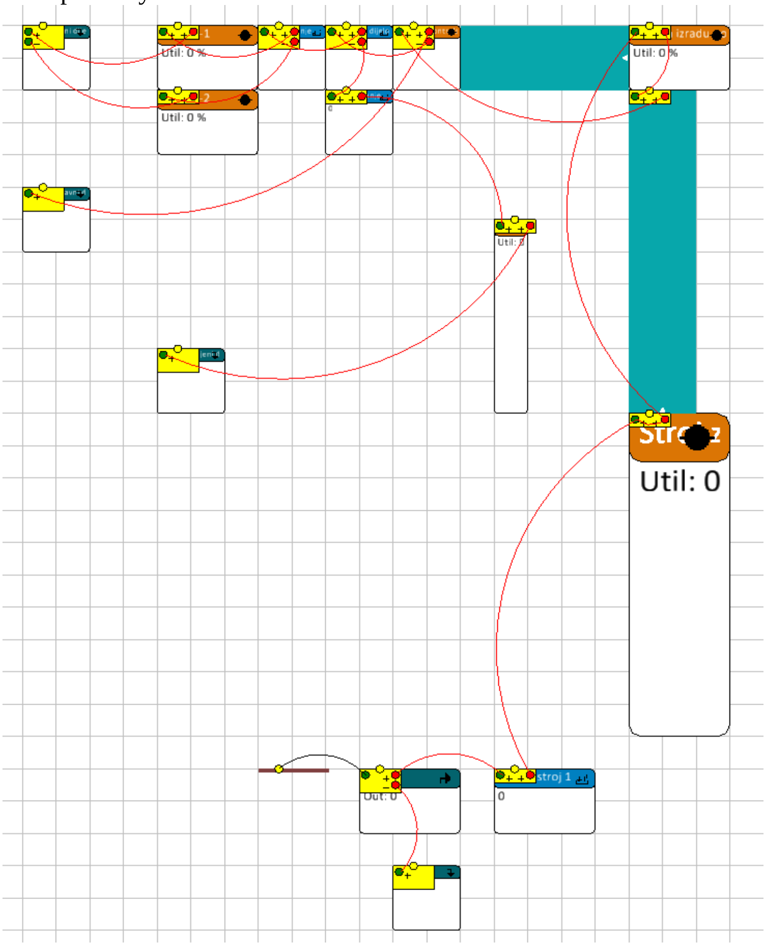
3.3. Numerical modelling - simulation model

After the measurement is done, the next step is the numerical modelling of the production system. For the purpose of numerical modelling of the production system discrete event simulation software Enterprise Dynamic 10.3. is used.

In the case the simulation is used for testing how much products (m^2) can be done in production line in one shift. This is very useful because you can make analysis whiteout interfere in production plan.

The model is developed using the standard atoms (elements): source, server, conveyer, queue and sink. A detailed floor plan of the groove making line with connections in software Enterprise Dynamic is shown in Figure 4.

Figure 4. Detailed floor plan of the groove making line with connections in software Enterprise Dynamic



The simulation of the groove making line will be carried out for different board lengths such as: 600 mm, 1500 mm and 2100 mm. The width of the board for simulation will not change because the differences in the width of the boards are very small and have no effect on the change of production. The width of the board which is used in the simulation is 120 mm. In addition to different board lengths, the simulation will be conducted for different board qualities such as: Gal quality and Fly quality.

The quality of Gal is the best quality of the board where the percentage of correct pieces is 75 % while the quality of Fly is the worst quality of the board where the percentage of correct pieces is only 5 %. Also, the quality where the percentage of correct pieces is 40 % will be also taken in consideration, because that it the quality which is between Gal and Fly quality. When the board is correct that means there is no need for puttying of the board and it can go directly to the pallet for finessed product.

Table 2. Time for operation used in the simulation

Dimension of the board [mm]	Machine for production of longitudinal grooves [s]	Machine for production of transversal grooves [s]	Quality control and sorting of the boards [s]	Puttying of the boards [s]	Machine for cutting of the boards [s]
600	2	-	2	15	12
1500	5	-	4	40	12
2100	7	-	5	55	12
120	-	0.4	-	-	-

Table 2 shows the time for operation used in the simulation. There are some differences between time used in the simulation compared to the recorded times in the company. The reasons for that is that measured time are for batch of the boards (remarks in Table 1) while simulation models use the time need to do operation for one board.

3.4. Results of the simulation

In the previous chapter it was shown that the simulations will be carried out for different dimensions of the board length and different board qualities.

Table 3 shows the results of the simulation where the groove making line gives the maximum number of correct grooved boards (m^2) that the line can make without any delays in one shift for different lengths. Running time of the simulation is set to 7 h. Production time of a line for grooves is 8 h, but you need to take down half an hour for a lunch break and half an hour for starting the production.

Table 3. Maximum production capacity of the production line for grooves

Length of the board [mm]	Surface of the board [m^2]	Number of the boards produced in one shift [piece]	Surface of the boards produced in one shift [m^2]
600	0.072	12591	906.552
1500	0.180	5036	906.480
2100	0.252	3597	906.444

From Table 3 we can see that the line for making grooves for the board length of 600 mm can make without any delays a maximum of 12591 pieces of boards with a groove. For the board length of 1500 mm without any delays 5036 pieces of boards with a groove can be made, while for the board length of 2100 mm, 3597 pieces of boards with a groove can be made. This is a display of the ideal number of pieces of boards that the line can make with predefined machine modes, where all the pieces are correct, without any downtime and waiting. Also, we can see that in all scenarios (board length) the line can make approximately 906,50 m^2 of parquet.

So, we can conclude that dimension of the board doesn't have any influence on the capacity of the line. Next step is to see how does the quality of the boards influence on the production capacity.

For each dimension of the board length, three types of quality will be displayed. The quality is ranked in such a way that the higher the percentage of correct pieces, the better the quality of the board. Since defective pieces are sent for either puttying or cutting, their ratio is always the same, where 95 % of defective pieces go to puttying and the other 5 % to cutting. This is collected by measurement. Simulation was run 10 times and in Table 4 the average results are presented 4. Column "number of workers on puttying operation" represent the maximum number of a works on puttying operation. If we further increase the number of workers, their utilization of a workers will drop drastically, so hiring an additional worker is not profitable.

Table 4. Average results of the simulation

Length of the board [mm]	Surface of the board [m^2]	Percentage of correct board [%]	Number of the boards produced in one shift [piece]	Surface of the boards produced in one shift [m^2]	Number of workers on puttying operation	Utilization of a workers on puttying operation [%]
600	0.072	75	12587	906.264	2	89.24
600	0.072	40	10842	780.624	3	100.00
600	0.072	5	12299	885.528	6	100.00
1500	0.180	75	5026	904.680	2	94.00
1500	0.180	40	4037	775.260	3	100.00
1500	0.180	5	4679	842.220	6	100.00
2100	0.252	75	3592	905.184	2	91.80
2100	0.252	40	3463	872.676	4	100.00
2100	0.252	5	3533	890.316	7	100.00

Already at the first acquaintance with the work of the line for making grooves after getting acquainted with the process of the line for making grooves it was obviously that the operation of puttying is the bottleneck of the line. On that operation. depending of a quality of a boards 2-5 workers were constantly doing their job. The worse the quality of the board, the more and more workers are needed. So, idea of the simulation was found out how many workers are needed for puttying operation (depending on the quality of boards) to have production close to maximum capacity presented in Table 3.

From Table 4 we can se that for quality of 40 % and 5 % of correct boards, production cannot achieve maximum productivity. To do that some rearrange of organization is needed. Because if we put additional works to puttying operation the utilization of a workers will drop drastically and quality control operation become bottleneck of the line. A simple solution to this problem is to hire additional worker who will work on putting operation and quality control, depending on needs.

Also, a possible solution is to purchase a puttying machine where manual puttying would be replaced by machine puttying. The worker would be transferred to another job. Before each shift, the machine would be prepared for a certain quality of the board to be worked on, the puttying time would be reduced and production in one shift would increase.

4. CONCLUSION

Customer need, product quality, company competitiveness in the market and making a profit are the main goals of every company. The study of work and time as one of the parts of technological process planning has a very important impact on these goals of the company. Various programs and technologies make it easier for the company to monitor production, and based on the information gathered through quality analysis, it enables production optimization and better organization of production.

In addition to programs for monitoring production and collecting information, there are a number of programs that are used to simulate the production process in a simple and economical way without stopping production can reach the optimal method of production.

In this way, the line for making grooves on the parquet was shown and analysed, where a simulation model was made in the Enterprise Dynamics program. After several different simulations, it was noticed that the main problem of the line was the putty operation, which was performed manually. For this problem, a possible improvement was given in the form of buying a machine that would replace the manual way of puttying with a machine or hiring of the additional workers. Using these new technologies, it is necessary to continuously analyse and observe improvements in the production system in order to ensure the main goals of manufacturing companies which is profit and further growth by conquering new markets.

For further research, a statistical distribution of the production time needed for manual operations could be used in simulation model, as they depend a lot on the training of the workers. Also, by applying a Design Of Experiments (DOE), depending on the dimensions of the boards, the time of production and the quality of the boards, a response surface could be obtained, which could later be used to plan the production process. For this, more detailed measurements of the production line for making grooves in company need to be done.

Funding: The research was supported by the Croatian Science Foundation, project UIP-2019-04-6573 ANTYARD (Advanced Methodologies for Cost-Effective, Energy Efficient, and Environmentally Friendly Ship Production Process Design) and by the University of Zagreb, project Multicriterial Mathematical Models for Design and Construction of Ships.

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