

Forrai, Sándor; Ludanyi, Balázs; Szabó, István Péter; Smagowicz, Justyna; Szwe, Cezary

Article

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RESEARCH METHOD FOR MANAGEMENT OF THERMOPLASTICS PRODUCTION IMPROVEMENT IN RUBBER INDUSTRY WITH THE USE OF 3D SIMULATION MODELING

Sándor FORRAI*, Balázs LUDANYI**, István Péter SZABÓ***,
 Justyna SMAGOWICZ****, Cezary SZWED*****

*, **, ***University of Szeged, Faculty of Engineering, Szeged, HUNGARY

*e-mail: forrais@mk.u-szeged.hu

**e-mail: ludanyi.balazs@gmail.com

***e-mail: pszi@mk.u-szeged.hu

****, *****Warsaw University of Technology, Faculty of Management, Warsaw, POLAND

****e-mail: justyna.smagowicz@pw.edu.pl

*****e-mail: cezary.szwed@pw.edu.pl

Abstract: The paper concerns research and improvement of production processes in one of the European companies in the rubber industry¹. The main goal is to improve the production process of the thermoplastics obtained from polymer materials on the company's production line. Improvement is defined as a reduction of the setup time of a key machine in the tested production process. The research method includes the analysis of the literature, observation of the studied process, and the accomplished computer simulation experiments. The proposed activities relate to the reinforcement of the key part of the machine, the change of the machine setup method, and the preliminary staff assignment to the specific tasks. The results of the simulation experiments confirm the implementation of the proposed improvements. The theoretical contribution to the research field development is the proposal of the simulation modeling methodology to improve production processes of continuous materials. Practical conclusions lead to recommendations for the implementation of improvements in the enterprise, with direct application of the proposed actions.

Keywords: production management, simulation modeling, improvement of production processes, SMED, rubber industry, calender.

JEL Classification: C6, D2, L6.

1 Introduction

Because of the globalization of the economy and the continuous increase in competitiveness, the effectiveness of enterprises is primarily determined by the rationality of decisions they make. This applies to the strategic and tactical level as well as the operational level. In production companies, the need to ensure the efficiency of production planning and control determine the method of organizing production processes. It also requires the rational use of available resources and the continuous improvement of the implemented production processes.

Accordingly to the complexity of production processes, production systems must demonstrate a high

degree of technological flexibility. This includes, among others, the possibility of their reconfiguration, extension, and changes in the work organization of the operating personnel. Reconfiguration may apply to the entire system as well as to the quick setup of individual machines and devices in order to implement changing production orders.

Aiming for continuous improvement of the implemented processes forces the use of methods and tools that will enable the verification of proposed improvements with the smallest possible interference in the execution of real processes.

At the same time, these methods must enable the quantification of improvements, including their

¹ The company did not allow the name or country to be given.

impact on process implementation costs, resource productivity, production order, execution time, etc.

The above-mentioned conditions also require information of the current state of knowledge in the subject field, the use of adequate methods of researching the problem, and assessing the possibility of implementing solutions.

The production process studied in the paper concerns the continuous forming of products from polymer materials. In the literature on the subject, this process is called calendering. It consists of softening the material in an earlier processing, then shaping it under the pressure exerted by groups of shaping rollers called calenders.

Calenders are also used in various branches of industry, for example, for the production of plasticizable or non-plasticizable PVC (PolyVinyl Chloride) films, for shining and smoothing paper, for producing plastic films and fabrics or embossing patterns on them, for the production of floor coverings, vinyl tiles, board rubbers, cord materials, for friction honing and doubling materials. The advantages of calendering include obtaining the special properties required for specific material applications, improving flexibility, improving the smoothness of the material, preventing crushing, and improving the appearance of the material.

A multi-roll calender for rubber or synthetic plastic-material comprises a pair of rolls mounted at their ends in a calender stand, in which each end of the pair, the rolls are rotatably mounted in a bearing block.

The pre-plasticized material in the rolling mill is once passed through several roll gaps, as a result of which a sufficiently wide web is obtained, which is collected on the cooling drums and coiled on the receiving shaft. As a consequence of this process, to which thermoplastics are subjected, a film is obtained (Choudhury, 2017). Calenders usually have 3–6 cylinders with mutually parallel axes arranged in one vertical row or they are suitably offset. The machine is operated by several operators. In the analyzed manufacturing company, a Comerio 2 calender is used.

Based on the information from the company, it was found that the production capacity of the products did not match the orders received by the company. The product forming process was indicated by the

company as the area of searching for potential improvements. On this basis, the research was prepared and carried out.

This paper proposes a method for improvement of the examined production process using the assumptions of the SMED and PDCA approaches described in the literature and computer simulation modeling. The obtained results concern mainly shortening of the setup time and reducing energy consumption in the process.

2 Literature review

The literature analysis covers issues related to the technological possibilities of improving the analyzed production process, the implementation of setups as part of the production process management, as well as issues related to the selection of the research method and tools aimed at solving the problem.

2.1 Technological process improvements

Calendering is a forming operation, in which the rubber compound is sheeted or spread evenly onto fabric. The calender is a heavy-duty machine equipped with three or more chrome-plated steel rolls that revolve in opposite directions. The rolls are heated with steam or circulated water, the gearing allows the rollers to operate at variable speeds, such as the mill rolls. Fabric or wire is passed through the calender rolls, and compound is applied above and below to fully cover the material (Mark, 2013).

Modern high-performance calenders are equipped with a large variety of devices that influence the quality of the calendered products decisively: calender rolls, calender frame, roll gap-adjusting devices, roll cross-axis devices, roll-preloading devices, roll-bending devices, splicing devices, roll bearings, roll heating/cooling devices, edge trimming device, calender drives, calender upstream and downstream equipment, feeding of calenders, mills, extruders, letoff and rewinder units, accumulators, thickness gauges, cooling devices.

The actual calendering process is carried out by the calender rolls. It is, therefore, essential that the rolls are manufactured to the highest standards. The major requirements they have to meet are: highest concentricity and accuracy of shape at process temperature,

high-quality surface finish and surface hardness, resistance to deflection and deformation caused by the rubber compounds to be processed, and impermeability to heating/cooling agents. To ensure that these requirements are fulfilled, the rolls of precision calenders are often ground at operating temperature. This allows concentricity tolerances to be reduced to a minimum of 0.005 mm. After the rolls have been ground and possibly polished, the roughness height is generally between 0.0008 and 0.001 mm (Anil, 1994). The conclusions from the analysis show that researchers so far have focused solely on the technical aspects of calenders. There are no direct references to the optimization of the parameters of using these devices in production processes. In this context, the implementation of the goals, in terms of solving the problem, will constitute the opening of research in this field.

2.2 Process management – machine setup

Improvement of machine setup is a widely discussed topic of streamlining production processes in the enterprise. Owing to efficient setups, high flexibility of the processes is obtained. In this way, it is possible to quickly adapt to the real needs of the market and respond to the real needs of customers. Furthermore, it builds the company's competitive advantage (it is able to produce and deliver the product faster than other contractors), and moreover, it reduces the costs incurred by the company and shortens the duration of these activities or the scope of resources used.

The paper discusses the problem of streamlining setup operations by reducing the duration of these activities and reducing the occurrence of non-productive operations. One of the best known methods to improve setup operations is the SMED (Single Minute Exchange of Die) method.

The SMED method includes a set of techniques, which make it possible to reduce the time of performing setup operations (Shingo, 1985). As one of the lean manufacturing tools, the SMED method provides waste reduction in the performed operations and increases flexibility in processes. Reducing the duration of setup operations allows for products being manufactured in smaller batches (Desai, 2012). Initially, the method was developed in the automotive industry (Desai, 2012, Cakmaci, 2009). However, over

time, it has been extensively implemented in various industries, such as electrical power control (Ribeiro, et al., 2011) or electronics assembly (Trovinger and Bohn, 2005). In the literature, the research focused on the effective application of the method but also concerns the improvement of safety and healthy of workers in the workplace during the setup activities (Deros, et al., 2011) or reduces the risk of setup operations (Stadnicka, 2015).

The method consists of several stages. In the first stage, all activities performed as part of the setup operations should be identified. During the research, it can be used for continuous observation of the process (video-recording) and interviews with employees. In the SMED method, it is crucial to divide setup operations into internal and external activities. Internal activities can be carried out only when the machine is in downtime mode (e.g., mounting and removing tools, setting of machine, trial runs, etc). External activities can be performed while the machine is running because they are independent (e.g., material delivery, review of the documentation). In the second stage, interval activities are converted to external activities.

These changes require the application of a new work organization (Shingo, 1985). In the last step, all aspects of setup operations are streamlined, specially internal activities (e.g., increasing the number of operators working in parallel) or more efficient execution of these operations using additional equipment or newer technologies (Karasu, 2013).

Within the application of the SMED method, it is also significant to focus on the improvement efforts of the machine, which is the bottleneck of the process. Therefore, it may not be cost-effective to shorten the setup time of the machine with the longest time, because only the individual operating time of the machine, not the entire process, will be shortened.

The SMED method, which is dedicated to study setup operations, provides the identification of potential areas for streamlining, the possible effects of their implementation, and the utilization assessment of the improvement. The computer modeling allows for a model of a given process being developed and the execution of experiments by representing various solutions that can be introduced in the enterprise.

The results obtained during the simulation indicate a decision regarding the implementation of a given solution. The presented scope of activities is adapted to the concept of continuous improvement, where the process is improved by successive execution of planning stages, conducting experiments, evaluation of the obtained results and establishing implementation conditions.

The PDCA cycle is a concept of continuous improvement of the process activities. The tool was proposed by W.A. Shewart and then developed by W.E. Deming. The main goal of the Deming cycle is the continuous improvement of management system processes (Deming, 2000). The model consists of four stages, such as: Plan–Do–Check–Act (PDCA). At the stage of „Plan” the goal of the improvement actions taken as well as the methods and techniques, by which the goal will be achieved, are determined.

The planning phase includes an analysis of the problem, which identifies the main causes and potential ways of solving them. The main activity is to collect quantitative data and visualize them with statistical or quality management tools. The better the data is received for the PDCA analysis, the higher the probability of finding the right solution (Junior and Broday, 2019).

Previously developed solutions should be implemented within the „Do” stage. The introduction of solutions can be carried out in the form of direct implementation on the production line or in laboratory conditions, for example, in the form of computer modeling (Imai, 2012). In the „Check” stage, the obtained results are verified and compared with the assumed goal specified at the planning stage. In the case of an unsatisfactory result, the planning stage should be returned to identify the causes. It is crucial to gather a large amount of information in order to effectively verify and carry out the last stage, which is the implementation.

The last stage „Act” is to consolidate the implemented solutions by establishing a new way of performing activities and the required training of employees. Standardization of the new way of performing activities is necessary to restart the implementation of the Deming cycle (Junior and Broday, 2019).

The Deming cycle is a cycle of continuous improvement, so once the implementation of a given solution to a problem is complete, it should be started from the beginning for another phenomenon.

The Deming cycle is widely used not only in manufacturing companies (Liker, 2004) but also in many areas of management – for instance, quality management (ISO 9001) and risk management (ISO 31000).

2.3 Computer simulation methods and tools

As mentioned above, computer modeling allows for a model of a given process being developed and execution of experiments to verify various improvements that can be implemented in the enterprise.

The computer simulation method consists of examining the mathematical model of a given process, phenomenon, system, or device and identifying the parameters of this model. After developing the model, determining its parameters, variables, and constraints, the computer simulation program is determined. Then, experiments are carried out looking for the values of decision variables that meet the problem constraints.

This method is used in cases where the actual process tests are too expensive or need quite a long time to get the results. First of all, when proposing a research method for a class of problems, such as the one discussed in the article, it should be emphasized that the performance of computer simulations enables the solutions to be checked without disturbing the functioning of the real system. This is the main requirement for developing a research method.

Moreover, it can be used for hypothetical processes, when the research object does not exist in reality (it is in the development phase) or it is unknown, and the forecast is necessary in a timely manner.

Universal computer programs or dedicated programs, prepared especially for this purpose are used to implement the simulations. As part of the simulation, it is possible to change the parameters and limitations of the problem and to repeat the experiments multiple times.

There are many simulation modeling programs available, such as Tecnomatix Plant Simulation, FlexSim, Arena, Any Logic, Witness. These programs differ in functionality, the way of representing real objects, the scope of modeling the parameters of these objects, additional tools to improve simulation, and tools for presenting simulation results (Bangsow, 2016; Kelton, 2007; Murray, 2018). Among these programs, a useful tool for mapping the logic of the production process is implemented in FlexSim. The Process Flow tool enables programming in the model by using predefined internal commands (similar to the commands of the C programming language and the SQL query language), sequences of subsequent operations as well as entering and processing variables and parameters of these operations (Beaverstock, 2018).

3 Proposed research method

The possibilities of performing tests aimed at shortening the setup time in real conditions were significantly limited. The machine is used in the production process, and it was not possible to withdraw it from operation for research purposes. Therefore, as part of the search for process improvement options, computer simulation modeling was used. It allows for the analysis of the production process without the need to interfere with the actual activity of the enterprise.

The execution of the process and the possibilities of its improvement were examined. For this purpose, experiments were proposed, which allowed for finding a solution that would improve the defined criteria and determine the benefits of its implementation for the enterprise. The main goal of the research was to shorten the machine setup time.

The saved time could be used to perform productive operations leading to the production of a finished product. The effect of the actions taken should also reduce the downtime of the machine between successive starts. Additionally, it has been found desirable to reduce the energy consumption to produce the same amount of product. An important assumption of the proposed simulation model was also the possibility of its later use for further studies of the analyzed process.

The research method consist of four stages:

- 1) Building a simulation model;
- 2) Process analysis and selection of improvements;
- 3) Verification and evaluation of improvements;
- 4) Identification of the conditions for the implementation of the improvements.

In the first stage, various computer programs for simulation modeling were compared and a program enabling the examination of the process according to the adopted assumptions was selected. A model reflecting the current execution of the process was developed and experiments were performed on model validation. In the second stage, an analysis of the production process was carried out.

On the basis of the performed analysis, improvements of the process for further research were proposed. In the third stage, an experimental verification of improvements was carried out. On the basis of the obtained results, their evaluation was made. In the fourth stage, conditions were proposed that should be met for the improvements to be implemented in the enterprise.

The research method implements both the assumptions of SMED and PDCA as well as the use of the computer simulation method. The research method corresponds to the assumptions of the PDCA concept for a single cycle of improvement of the process under study. The assumptions of the SMED method were reflected primarily in the second stage of the proposed method. The elements of the computer simulation method were mainly used for the first and third stages of the research method. The core of the proposed approach is to use simulation modeling to prototype and verify the effectiveness of proposed production process improvements.

4 Research implementation

The next stages of the research are described in the following sections.

4.1 Model building

Taking into account the functionality, utility features, and the possibility of obtaining software for research, it was decided to use the FlexSim program. As stated

before, the FlexSim program, apart from the possibility of building a model reflecting the topology of the production process, also enables the implementation of the process control variable logic in the Process Flow module. An additional advantage is also an extensive layer regarding the visualization of results.

The first step in model building was importing the topological layout of the production area to the FlexSim program. The next step was to prepare a 3D model of the set of analyzed machines in Solid Edge. Both of these data were provided by the company. The next step was to import and place these 3D files according to reality in FlexSim (Fig. 1).

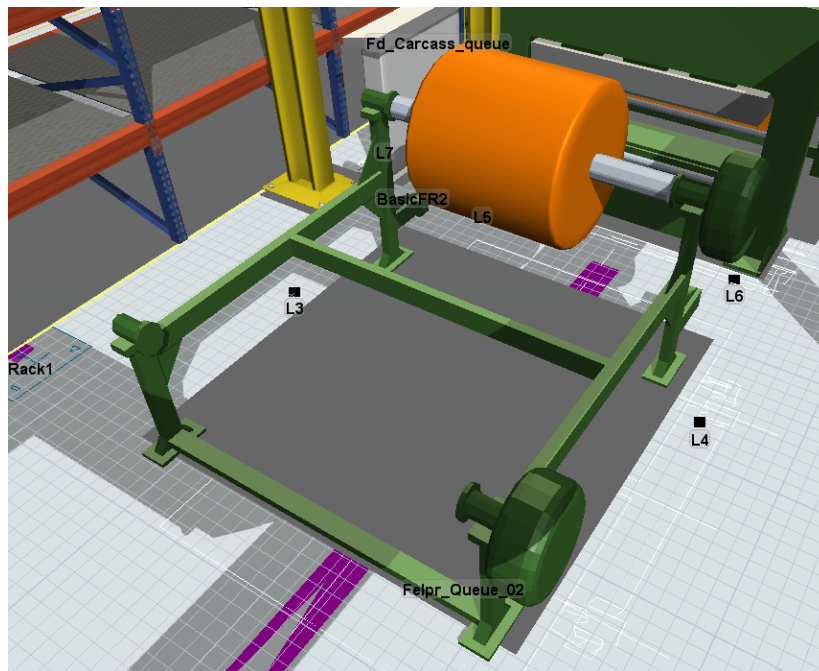


Figure 1. Part of the placed machine units in FlexSim (*Source: Own study*)

Subsequently, the material flow was mapped in the program, consistent with the actual implementation of the process. FlexSim does not support continuous material flow modeling. In order to model this element of the process, a dedicated advanced programming procedure was prepared using the commands of the internal programming language in FlexSim.

As part of the procedure, standard program objects (BasicFR) were placed side by side in the model space and their colors, parameters and visibility were dynamically changed using the program code. In terms of simulation modeling techniques, this type of way of preparing a model of complex process elements is completely innovative and can be used to elaborate on a variety of problems with continuous flow elements.

The control of the material flow within the analyzed production process was implemented in the Process Flow environment. The main part of the modeled process for which simulations were conducted was calendaring. The characteristic objects of the Process Flow environment – tokens come from a process distributor logic, and two tokens were created.

One goes to a subflow, which runs as many cycles as many shapes are in the material flow and which visualizes a moving material flow.

The other token has to go to a delay, which calculates the time of producing a product by normative time (Fig. 2). Tokens correspond to particular objects (called in FlexSim “flowitems”) in the 3D visualization model.

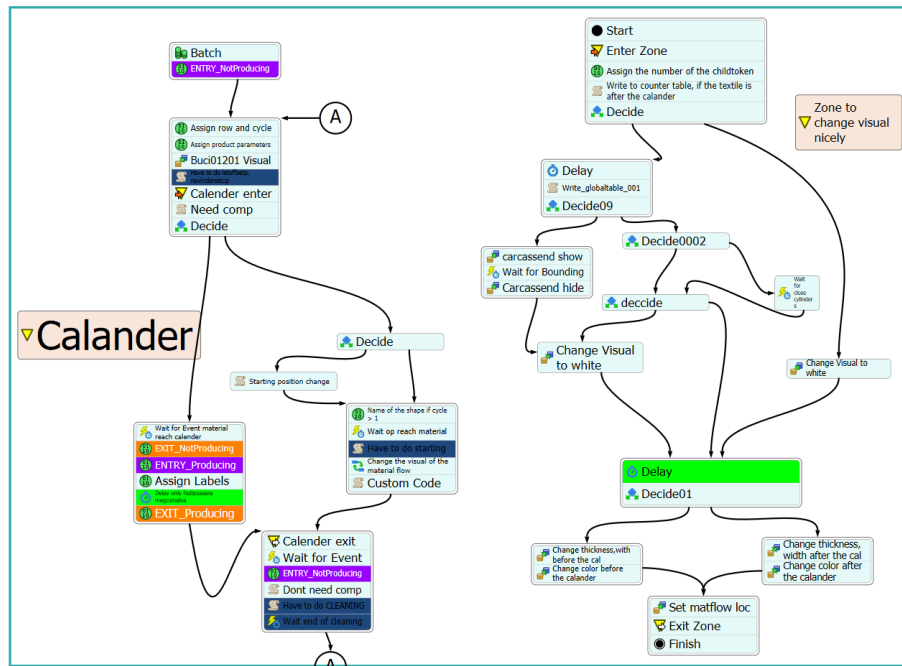


Figure 2. Part of Process Flow of the material flow (Source: Own study)

When the subflow runs, it changes the color, thickness, and width according to the parameters of the simulating products. This made it possible to visualize

the flow of continuous material during the simulation (Fig. 3).

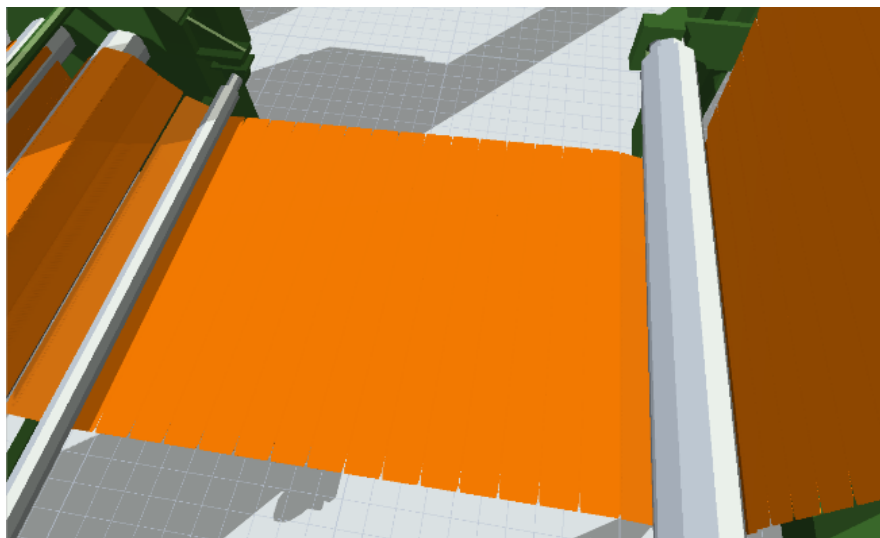


Figure 3. Continuous material flow (Source: Own study)

The next step was to model the movement and work of the operators controlling the machine. Complete data on the operations performed (duration of the operation, the ability to perform the operation by a given employee, mapping of employees' competences) were

collected in a table in a MS Excel program. Furthermore, they were imported into FlexSim using the GlobalTable tool.

The first element in this process was the creation of the logic of selecting the central operator. In order to do this, it had to be determined which tasks could be performed in a specific workflow. In the developed solution, it is possible to freely change employees participating in the performance of a given task. Hence, this element can be used to improve the implementation of the production process by selecting people with appropriate competences and automatically assigning them to specific works. In FlexSim, any number of operators can be set dynamically. At the moment of starting the simulation, the program creates the appropriate number of operators. At the same

time, it enables their identification at every stage of the production process by giving them a name and assigning a unique color code.

In FlexSim, the routes of individual operators are generated automatically. For this reason, it needs to be sure that employees perform the assigned tasks in designated work areas. Therefore, the internal tool of the FlexSim program – Navigator A* was used to define the area to which the operator has no access, and at the same time, to define the scope of the production room, in which the employee's movement is allowed/possible.

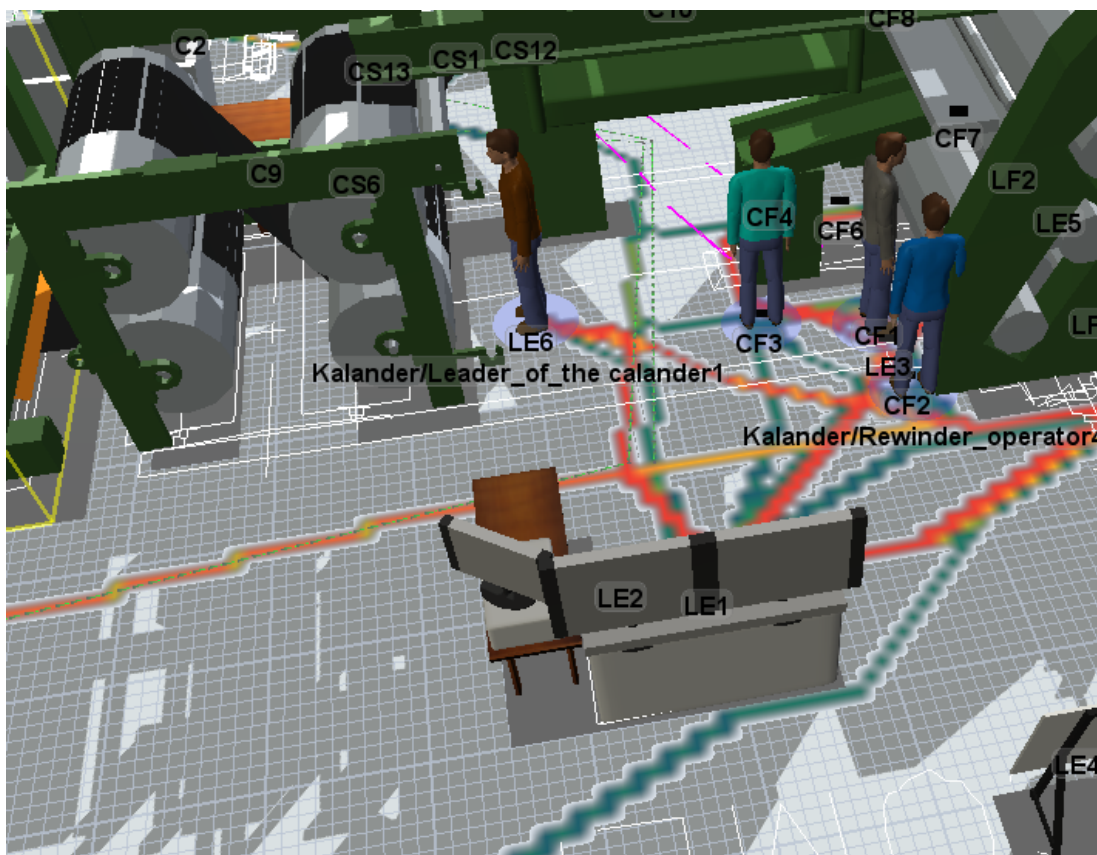


Figure 4. Example of path drawing (*Source: Own study*)

Moreover, Navigator A* is equipped with the function of monitoring routes taken by operators. On this basis, a temperature map is developed that identifies and marks the routes traveled by employees with cold–warm gradients. The more frequently a given route is traveled by an employee, the warmer color is marked (Fig. 4).

The model built in this way was validated. The results concerning the implementation time of individual activities within the real process were compared, taking into account the sequence of subsequent activities of the calendar, with the results obtained from the model. The results were consistent. This way, it was certain that the simulation model that was built reflects the actual execution of the production process in the enterprise.

4.2 Process analysis

The analysis was carried out in the field of process research in the enterprise. The study consisted the observation of process implementation (continuous observation, working-day picture), interviewing employees (process engineer, machine operators) and analyzing historical data on the course of the process.

The product forming process is defined as a continuous process. While the machine is in a downtime mode, all necessary work is carried out to start the next cycle – preparing the machine for operation and components for production. The machine is then started up and the product is continuously produced. After the end of production, the cycle repeats itself.

Due to technological reasons, it was found that it is not possible to accelerate the machine's operation. The continuous observation of the process and interviews with employees drew attention to the problem of too long setups of the machine, which led to delays in the implementation of assigned production orders. In addition, shortening this time will allow the company to provide most of the flexibility of its production processes by adapting production to the current needs of customers.

The setup process is described below. The last products empty reel should be pulled out of the letoff, and

a new reel with material on should be put in. The product on the rewinder should be pulled out and a new empty reel should be put in. The parts and surroundings of the machine should be cleaned, the compound should be changed and softened. The parameters of the machine should be changed.

In the course of the observation, it became apparent that most of the setup time concerns operations on the calender letoff.

According to the SMED method, the activities performed as part of the machine setup were divided into internal and external activities, that is, activities performed with the machine in downtime and with the machine in working mode.

The classification of these tasks is crucial due to the determination of which preparatory activities can be performed for the execution of the next process during the preceding process. It was established that in the tested configuration of the machine, it is practically impossible to separate external activities. These were the following activities:

- the last products empty reel should be pulled out of the letoff,
- the new product should be spliced with the puller fabric,
- a new reel with material on should be put in.

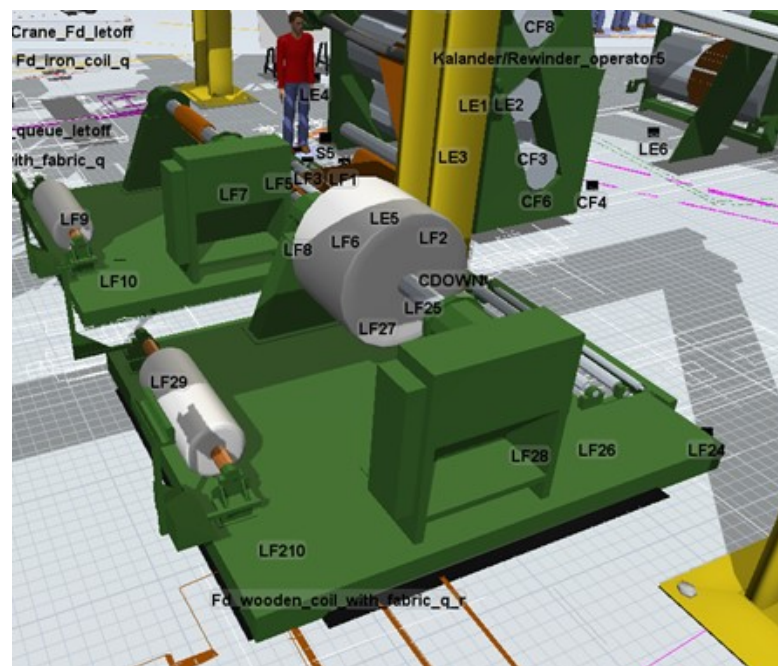


Figure 5. The two letoffs next to each other (*Source: Own study*)

The performed research allowed the identification of the two key elements of the process to be improved:

- 1) The division of tasks related to the setup of the machine (after reinforcement of the calender) into two groups of activities. The first part is performed while the machine is in downtime, the second part is performed while the machine produces the next product. This should reduce machine downtime.
- 2) Reinforcement of the calender outlet part with an additional letoff (Fig. 5).

4.3 The verification of the improvements

The aim of the experiments was to assess whether the proposed improvements were feasible and whether they contributed to the improvement of the results of the process. The implementation of the first indicated goals consists of:

- checking whether there is room for the reinforcement of the machine and whether the machine is able to perform the assumed functions after its reinforcement;
- verification of the scope of activities related to the setup that can be performed while the machine is in operation and that can be performed while the machine is in downtime mode.

The implementation of the second goal consists of:

- mapping in the original simulation model of the machine operation after reinforcement,
- verification of the effectiveness of the assignment of work to operators after the reinforcement of the device and a change in the method of setup,
- checking how the setup time changes in relation to the time in the primary process,
- checking how the machine downtime is necessary for setup changes in relation to the time in the primary process,
- checking how the setup time changes due to the addition of the second letoff compared to the time in the primary process.

During the experiments, the energy consumption was also checked and compared with the primary situation.

The new working method was designed, documented, and verified in an expert manner based on interviews with process engineers and machine operators. First, expert verification covered the possibility of performing the assumed functions after its reinforcement (including appropriate room) and the scope of activities related to setup and performed while the machine was in operation. The verification confirmed the possibility of introducing improvements.

The second step was to develop a simulation model with a reinforced machine. For this purpose, a model developed for the current process was used. The construction of the new model was carried out in the same way as for the original model. At the outset, data on individual operations after the expansion of the machine were prepared in the MS Excel program. They were then imported into FlexSim using GlobalTable.

Afterward, the logic for selecting the central operator was created, and it was defined which tasks could be performed in a particular workflow. Necessary operations were distributed in the program and were added to the workflow. Due to the fact that the model concerned a hypothetical process, its validation was limited to checking the correctness of operation and comparing the production time of the same number of products in relation to the actual process. The correct operation of the model was found, and it was consistent with the expected order of magnitude of production time for the same amount of products.

In addition, using the Navigator A*, the effectiveness of work allocation to operators after the reinforcement of the machine was verified. Based on the analysis carried out with the use of this tool, it was established that employees perform the assigned tasks in separate work areas. Additionally to this, the value of setup time, machine downtime, activities related to setup during machine operation, and energy consumption by the machine were tested. The experiments were carried out with the same assumptions regarding the production volume for the original model as well as for the model with the machine reinforced by a second letoff. The overall results of the experiments are presented on Fig. 6². The setup time after applying the improvements was reduced by 12%.

² The company did not allow the presentation of detailed results.

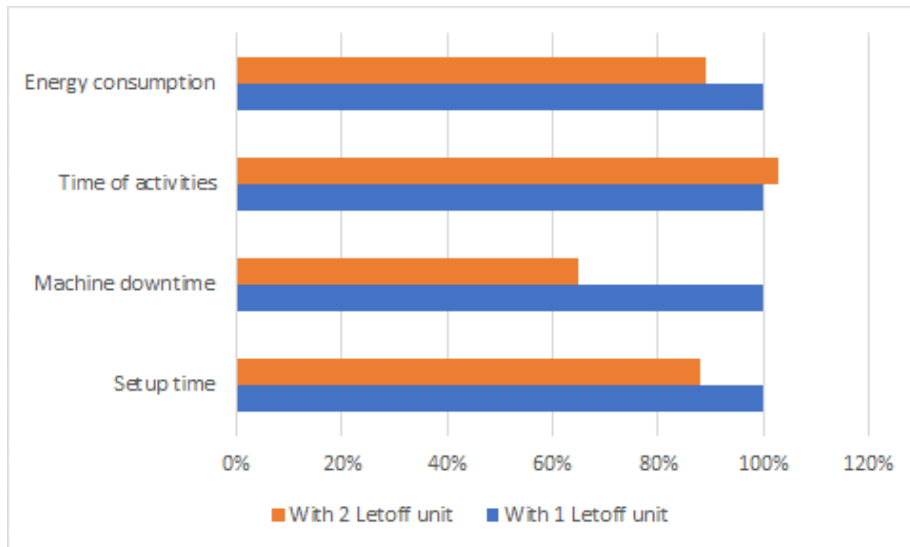


Figure 6. Results of the experiments (Source: Own study)

The machine downtime necessary for the implementation of setup was reduced by 35%. The time of activities related to setup due to the addition of the second letoff was increased by 3%.

As planned, the energy consumption on the production line, i.e. the consumption of steam and electricity, was also controlled. When installing the second letoff, about 11% less energy was used to produce the same amount of products (Fig. 7).

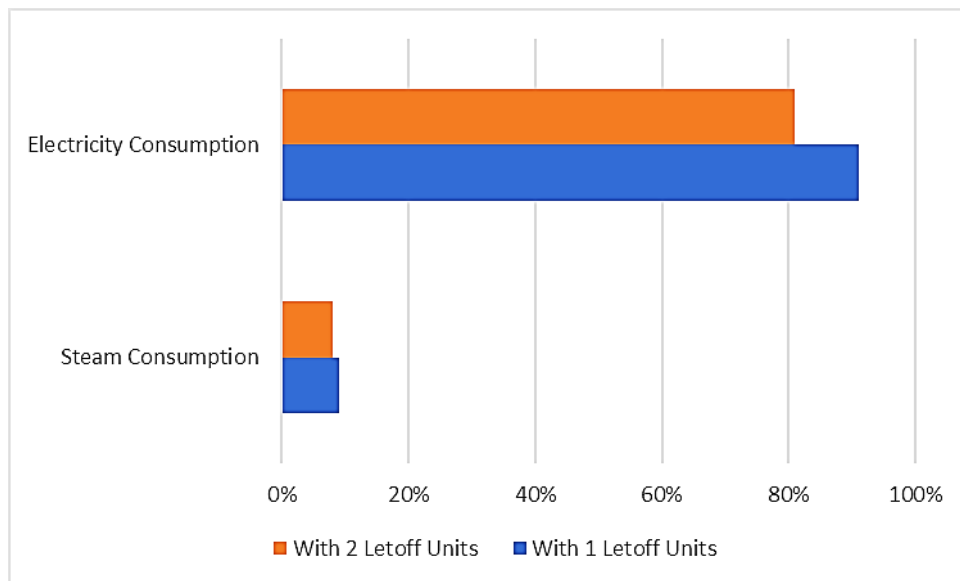


Figure 7. Electricity and steam savings (Source: Own study)

All assumed experiments were carried out. The goals of the experiments were achieved. The most important measurable effect of the works is the reduction of setup time (Fig. 8). This implies increased machine

productivity. In the scale of the company's operations, the cumulative financial effect will depend on the number of setups carried out in a given planning period.

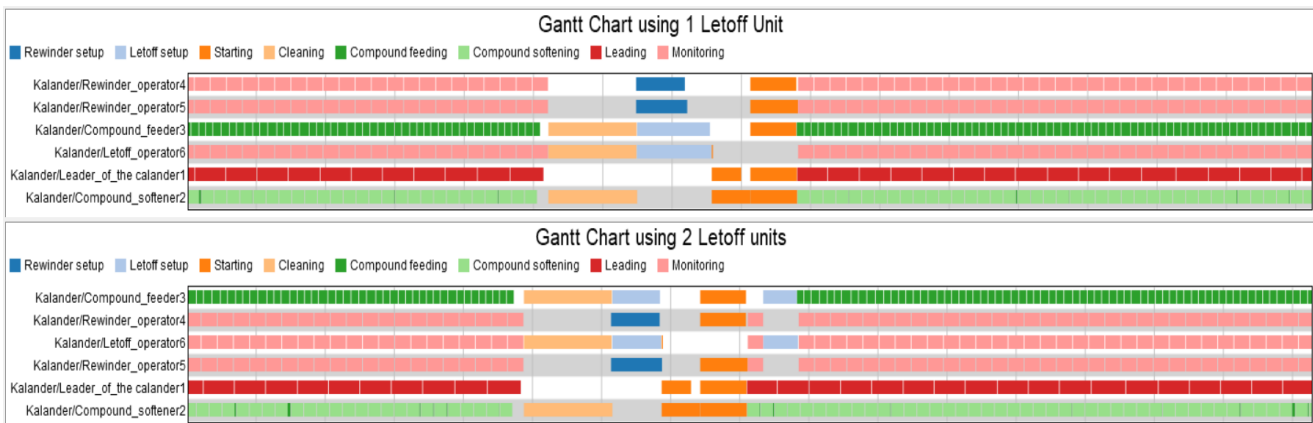


Figure 8. Gantt diagram of setup times – one and two letoff units used (*Source: Own study*)

A slight increase in the total time necessary to perform the activities related to the implementation of setup (while the machine is in operation), after adding a second letoff, implies an increase in the labor intensity of setups. As in the case of setup time reduction, the cumulative financial effect for the company will depend on the number of setups in a given planning period.

Reducing the downtime required for the machine setup (Fig. 9) means that the return on investment regarding the purchase of the machine should be achieved in a shorter time, assuming the same long-term machine load.

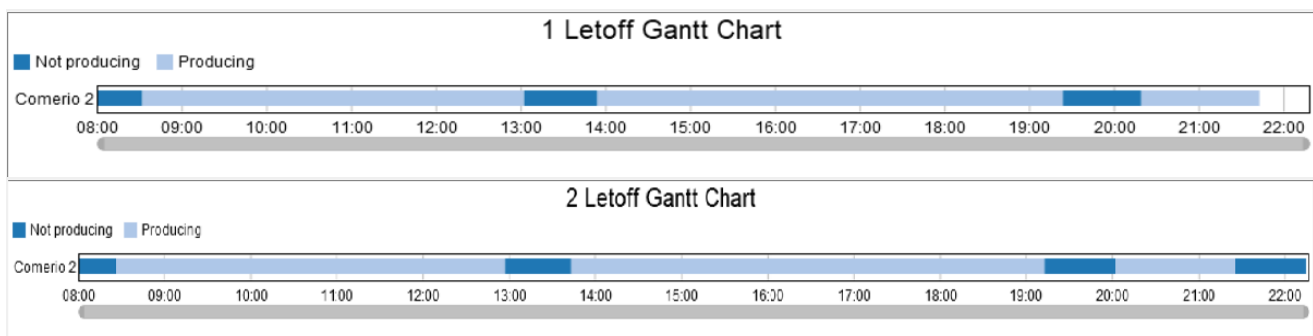


Figure 9. Gantt diagram of machine downtime and process time with one and two letoff units used (*Source: Own study*)

As in the previously discussed cases, the cumulative financial effect for the company resulting from the reduction of energy consumption will depend on the production volume in a given planning period.

It can be stated that the proposed improvements made it possible to achieve the goals of the experiments.

4.4 Conditions for improvement implementation

The conditions for improvement implementation in the enterprise depend on technical factors, organizational factors, and economic factors.

Technical factors include the possibility of purchasing and installing a second letoff. Assuming the availability of a letoff compatible with the one used so far, it is primarily required having the necessary room in the production area. This possibility was confirmed at the stage of improvement verification.

The organizational factors include, above all, the possibility of organizing work in such a way that the personnel can perform all the necessary activities to support the production process within the assumed time. This possibility was checked and confirmed as part of the improvement verification.

The assessment of economic factors includes checking whether the benefits resulting from the reduction of setup time, downtime, and energy consumption exceed the costs of increasing the labor intensity for the setup and the investments for the purchase of an additional letoff. Due to the need for confidentiality of information, the company decided to carry out this assessment on its own. As a rule, the cost of preparing and performing the research was not included.

Overall, the technical and organizational factors confirmed the feasibility of improvements. Economic factors require verification by the enterprise.

5 Conclusions

The paper proposes a research method aimed at improving the production process of thermoplastics obtained from polymer materials in a manufacturing company. The results of the application of the proposed method allowed the proposals of improvements in the examined process and the confirmation of the possibility of implementing these improvements. As part of the practical conclusions, the conditions that should be met for the result implementation expected by the company were indicated. The implementation of the decision lies with the company. The implementation of the proposed solution should lead to shortening the process execution time and reducing the costs as well as more efficient use of company resources. The effective use of simulation modeling in the enterprise can be an incentive for further improvement of the production process in other areas.

The theoretical contribution to the studied area is the combination of literature analysis, analysis of the considered process, and computer simulation modeling within the proposed method. The usage of computer simulation modeling has proven to be very effective primarily due to the possibility of preparing a complex model of the production process, mapping continuous flow elements in the model in 3D form and the implementation of advanced process control. The developed method is the general one. It can be used to verify various types of improvements in different production processes using machines with calendars. An important result of the work is also the development of a method of modeling continuous materials

in the simulation modeling program. The developed simulation model can also be expanded with other elements of the examined process and constitute the basis for the search for further improvements as the PDCA concept proposed. In further work, the PDCA concept can also be directly used in creating a production process model.

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