COMBINING SIMULATION AND MTM TO IMPROVE GLASS EYES PRODUCTION

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Abstract
The article focuses on the use of computer process simulation and MTM-1 analysis to improve the production process of handmade black glass eyes. The eyes are produced for taxidermy or toys. The production process was analyzed, and based on observation and measurement, the simulation model was created to search for improvement in material flow, identify bottlenecks, and find the optimal batch size. The MTM-1 was used to analyze movements in production and change the order or optimize the micro-layout of the workplace to reduce production time and improve the ergonomics of the operation. By combining improvement opportunities from simulation and MTM-1, the proposed processing time has been shortened by more than 3%.

Key words: *process improvement; MTM; simulation; micro-layout; glass production.*

INTRODUCTION
Using different and new approaches can be beneficial in improving the production system or just one of the production processes. If only one approach (tool or method) is used, some aspects of the production process can be missed. Only specific parameters of the process would be improved. That is why the used tools should be changed or used in combination.
The benefits of the use of different methods in combination are discussed and described by many authors. For instance reducing the lead time in chemical manufacturing by combining TOC (Theory of Constraints) and Lean by (*Lopez-Osorio et al., 2022*). The combination of Lean with agile principles is described by (*Ding et al., 2021*), Lean and green principles for sustainable improvement are combined in (*Teixeira et al., 2022*). Authors in (*Gupta et al., 2022*) combine TOC, Lean, and Six sigma. Other examples such as the combination of SMED (Single Minute Exchange of Dies) with Production Scheduling (*Parwani & Hu, 2021*), or with FMEA (Failure Mode and Effects Analysis) (*Yazıcı et al., 2021*). A combination of FMEA with computer simulation is shown in (*Leeftink et al., 2021*). More examples of tools and methods combined can be found in *(Apornak et al., 2021; Lizarelli et al., 2021; Purushothaman & Ahmad, 2022; Rihar & Kušar, 2021*).
One of the new approaches to combining two tools for process improvement could be the use of computer simulation together with movement measurement tools. The idea is that simulation can provide a broader point of view on the system. Simulation can focus on improving material flow, identifying bottlenecks, searching for the optimal batch size, and others (*Al-zqebah et al., 2022; Kormin et al., 2021; Murugesan et al., 2021; Pekarcikova et al., 2021*). The movement measurement method such as MTM or MOST can provide a more focused point of view on the detail of each activity. These methods are based on the research and measurement of many movements in industrial processes. The movements are categorized into types, and by the lengths, the time needed to execute the movement is found. From tables of movement codes, opportunities for improvement can be found. The result of using these methods can be an improvement of ergonomics, reducing unnecessary movements, redefining the order of movements, and others (*Gorobets et al., 2021; Hernandez Moreno et al., 2022; Riedel et al., 2022*).
This paper aims at the description of the use of the computer process simulation together with the MTM-1 method for improvement of the manual process of black glass eyes production.

MATERIALS AND METHODS
The process of the manual production of black glass eyes can be divided into several main steps. Firstly the wired loop is attached to the glass tube. Then a body of the eye is formed in the flame using several actions such as melting the glass, rotating it, and forming it in the metal mold. The diameter is also checked. Then the eye must be slowly cooled down to avoid tension in glass that can lead to breaks. After the eye is cooled down, it is broken off from the glass tube. Residual glass from the tube is attached

to the loop, so the loop is then cleaned up by the use of pliers. Just one person makes all operations in the process. Changes of material between process steps are shown in the figure (Fig. 1) below.

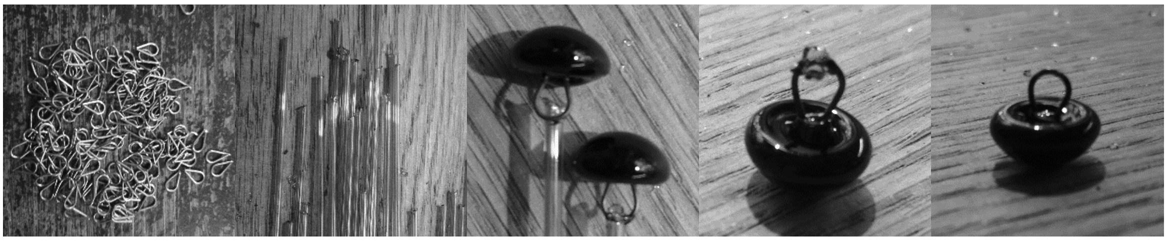

Fig. 1 Material change during the process

In a real production, activities were measured, and from the measured data, probability distribution was set using a goodness of fit testing in the software Statgraphic 18. The Kolmogorov-Smirnov test of the equality of probability distributions described by equation (1) below was used.

$$D_n = \sup_{-\infty < x < \infty} \left| F_n(x) - \Phi(x) \right| \tag{1}$$

Where F_n is the distribution function of the sample, and Φ is the reference distribution. The Probability distribution fitting for the whole production process is described in (*Sojka & Lepsik, 2021*). The figure (Fig. 2) shows plots of fitted probability distributions.

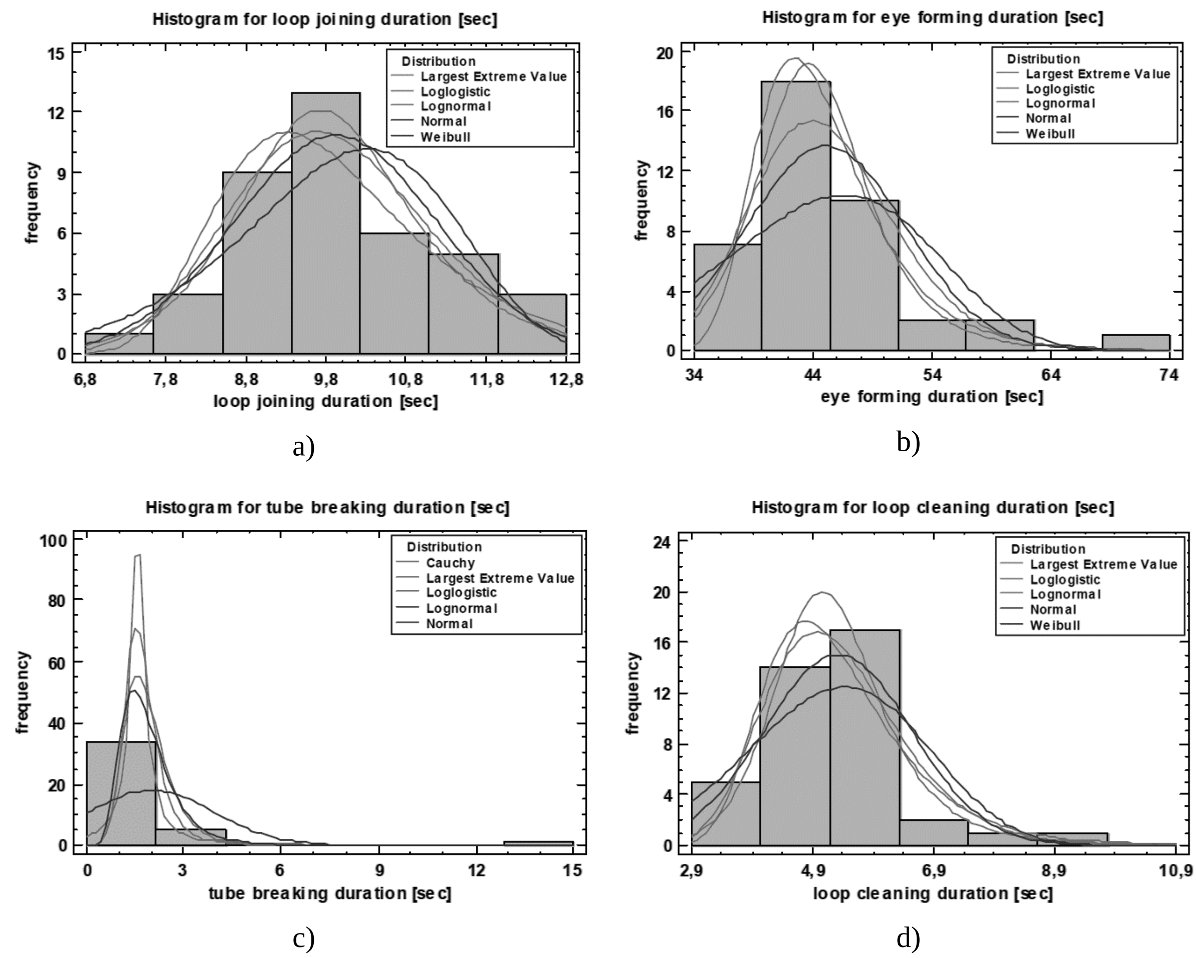

Fig. 2 Distribution fit from Statgraphic 18: a) loop joining; b) eye forming; c) tube breaking; d) loop cleaning

Using simulation software Siemens Tecnomatix Plant Simulation 14, the production process model was created. The probability distribution chosen from Statgraphic software was used for the times in the model steps. The process model can be seen in the figure (Fig. 3) below.

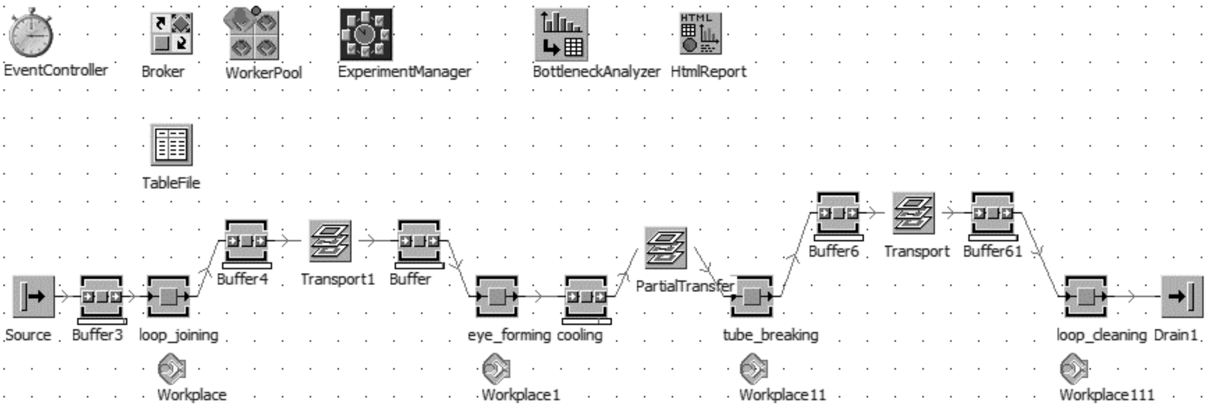

Fig. 3 Process model in Siemens Tecnomatix Plant Simulation

Several ideas and improvement opportunities were found from the simulation model and experiments that were run on it.
The workplace was measured, and a digital micro-layout was created. Based on observations and captured video records of processing, the MTM-1 analysis for each process step was made. The lengths of movements were measured from a digital model of the micro-layout of the work table. See figure (Fig. 4).

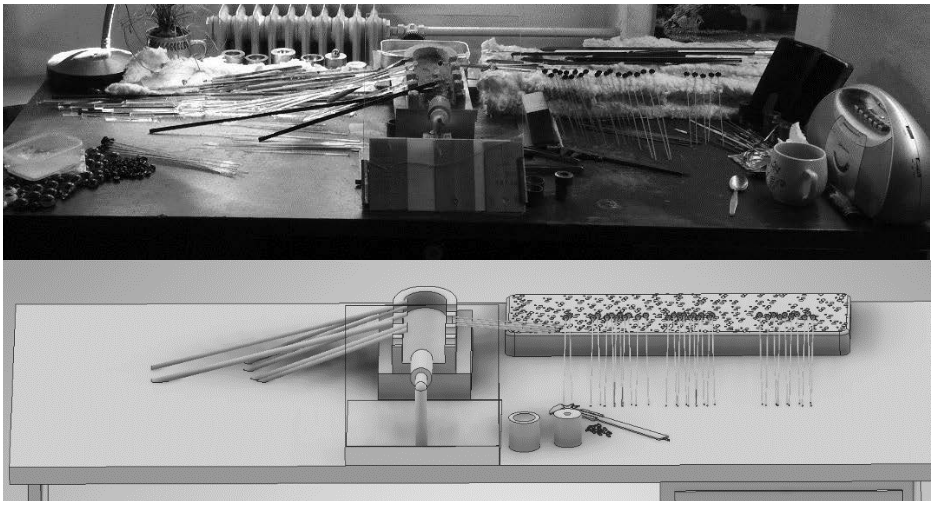

Fig. 4 Real work table and model of the micro-layout for measurement

From the MTM-1 analysis, several more improvement ideas and opportunities were found. Also, VA (Value added) analysis of the process activities was done to see what process activities should be focused on improving efforts.
Based on the findings from the simulation and MTM-1 analysis, improving changes to the process were proposed.
Another MTM-1 analysis was applied to the newly proposed process state. From these times, relatively to the analysis of MTM-1 of original state and real determined probability distributions of the process times. A shift of distribution means was determined. These shifted distributions were used in de new simulation model for overall comparison.

RESULTS AND DISCUSSION

As the main result, a new process proposal was developed. Findings in the MTM-1 analysis lead to the re-design of the micro-layout of the work table. Positions of materials were slightly changed to shorten the length of movements. The steps of breaking off the tube and cleaning the loop were integrated together. Using a special tool in a proposed method worker can break the tube with one hand, and directly after the break, the loop can be cleaned by pliers in a second hand. A comparison of micro-layouts is shown in the figure (Fig. 5).

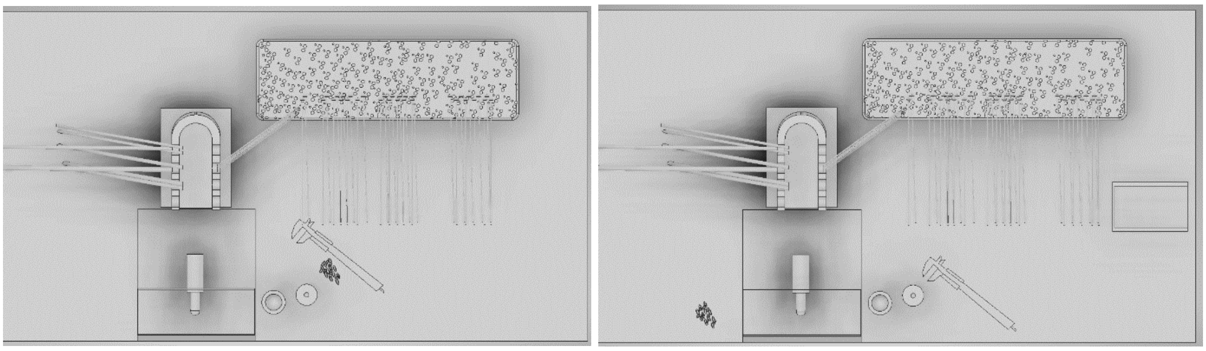

Fig. 5 Comparison of micro-layouts original state (left), and proposed state (right)

From the simulation, findings about the process were learned. The bottleneck of the process is cooling. Unfortunately, there is impossible to speed up the cooling process because more defects would occur by speeding up the cooling time. Due to this cooling procedure, the bigger the batch size, the faster the production. Because when a new batch starts, no eyes are cooled, and overall time is longer. Based on that, there is a recommended to make all the requested eyes as one batch, to reduce stops in the cooling. A comparison of the original state and the proposed one is summarized in the table (Tab. 1) below.

Tab. 1 Comparison of production time by simulation and MTM-1, comparison of VA-index

Process state	Simulation	MTM-1		VA-index
	50 pcs.	min/pcs.	min/50 pcs.	-
Original process	1:19:31.2310	1.04130	52.065	0.10558
Improved process	1:16:52.6474	0.98082	49.041	0.10810

From the table (Tab. 1), there can be seen that the time of manual processing was improved. Measured by computer simulation, the production time reduction is 3.33%. Time reduction by MTM-1 analysis is by 5.81%. VA-index of the process was increased by 2.39%. The real improvement rate should be measured after the realization of the improvement proposal. These values are just approximations.

The benefits of using the simulation and MTM together are clear; if only simulation would be used, a bottleneck of the process would be found, and the information about the relation between batch size and production time. See simulation case studies (*Kutin et al., 2018; Rosova et al., 2022*). On the other hand, if only MTM would be used, there would be found and improved lengths of movements and handling, but there would be no information about the batch size or bottleneck step. See case studies using MTM or MOST (*Bedny et al., 2019; Bures & Pivodova, 2013*).

These particular improvements also positively affect other production processes since all types of eyes are made at one workstation. Improved micro-layout reduces time and improves handling in other similar eye production processes. The findings of the beneficial use of MTM-1 with computer simulation can be used in any production process with manual operations. By using both methods, we focus on the process details and worker comfort, but we also see a broader point of view on the production system and material flow. There are studies where the MTM or MOST principles are used together with simulation software. However, the software is focused on the ergonomic aspects of the production (*Kim et al., 2021; Santos et al., 2007*).

CONCLUSIONS

The production process of the glass eyes was described, and improvement opportunities were identified based on experimenting with computer process simulation and the use of MTM-1 analysis, improvement opportunities were identified. Based on that findings new process state was proposed and again analyzed by computer simulation and MTM-1 analysis. The main change in the process is re-layout of the micro-layout to change the order of some activities and improve movement lengths. Also, two process steps were integrated to eliminate several handling activities. Overall improvement rate of production time was bigger than 3%, but it should be verified on the final improved process after implementation of changes. The improvement in the VA-index is by 2.39%.

The use of simulation with MTM can be beneficial because, by this combination, the improvement focus is both on the overall process and on process details. Results of the use can bring improvements in material flow, bottleneck step improvement, batch size optimization, re-layout of the workshop, movement improvement, better ergonomics, movement elimination or integration, and others.

ACKNOWLEDGMENT

This work was supported by the Student Grant Competition of the Technical University of Liberec under the project No. SGS-2020-5027 - Research of new approaches to process improvement.

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