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PROPOSAL FOR STREAMLINING THE CNC MACHINE CHANGEOVER PROCESS THROUGH THE APPLICATION OF THE SMED METHOD

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Abstract:
In today's highly competitive business environment, enhancing the efficiency of manufacturing processes is of critical importance. This research focuses on the application of the SMED methodology to increase the efficiency of the changeover process of a CNC machining center. The core of the study is a detailed analysis of the current state of production and changeover procedures on a selected machine. The process was monitored using video analysis of work operations. Based on this analysis, internal and external changeover activities were identified, and by eliminating inefficient steps, a set of improvement measures was proposed. As a result, a standardized changeover procedure was developed to optimize the overall process duration and improving maintenance systems. The final part of the study presents the outcomes of the improvement, expressed through reduced changeover time, along with a proposed economic evaluation of the implemented optimization measures.

Key words: optimalization, SMED (Single-Minute Exchange of Die), OEE (Overall Equipment Effective-ness), maintenance

INTRODUCTION

In today's highly competitive environment, it is increasingly difficult to maintain a sustainable competitive advantage in almost every area of business. This is particularly true for smaller companies engaged in custom or low-volume production, where maximizing the efficiency of every single operation becomes essential. In such contexts, there is always a competitor capable of delivering faster, cheaper, and often with higher quality.

In manufacturing, competitiveness is frequently undermined by factors such as unskilled operators, inefficient labor utilization, quality issues, and inadequate production planning. These challenges compel organizations to adopt proactive strategies aimed at enhancing operational efficiency. Typical approaches include minimizing waste, reorganizing production flows and inventory systems, and, crucially, reducing setup and preparation times [1].

Lean manufacturing provides a comprehensive framework for addressing these challenges. Originally developed by Toyota, Lean focuses on maximizing customer value while systematically eliminating all forms of waste (Muda). Through its structured methodology and proven tools, Lean enables organizations to streamline processes, reduce costs, and improve product quality.

One of the key performance indicators used to monitor the impact of Lean implementation is Overall Equipment Effectiveness (OEE). Initially developed by Seiichi Nakajima [2], the founder of Total Productive Maintenance (TPM), OEE measures how effectively manufacturing equipment is utilized. It captures performance losses through six major categories: breakdowns, setup and adjustment, reduced speed, minor stoppages and idling, quality defects, and reduced yield.

In the pursuit of higher OEE, companies often turn to specific Lean tools. This article focuses on one such tool – SMED – developed by Shigeo Shingo in the 1950s, which aims to reduce changeover times by transforming internal setup tasks into external ones and eliminating unnecessary steps. By minimizing setup time, SMED increases machine availability and enhances overall production efficiency.

The main objective of the presented research was to apply the SMED methodology to simplify and improve the efficiency of the changeover process of a CNC machining center used for producing the most frequently manufactured product. Through detailed video analysis of the current operations, inefficiencies were identified and setup tasks were reclassified and optimized. As a result, a standardized changeover procedure was developed, achieving a 57% reduction in changeover time. These improvements also supported better maintenance practices and contributed to higher OEE [3]. An economic evaluation confirmed that the implemented changes enhanced competitiveness, especially in low-volume production environments.

LITERATURE REVIEW

Lean manufacturing, as defined by Liker (2004), is a philosophy, process, and system focused on the elimination of waste (Muda) across all stages of production, with the objective of maximizing efficiency and delivering value to the customer. Liker outlines 14 principles that underpin the Toyota Production System (TPS), which are considered essential for the successful implementation of lean manufacturing. Within this framework, even the waste of time and resources is categorized as a form of inefficiency that should be systematically eliminated [4].

Expanding on these principles, Frank (2025) examines the relationship between lean manufacturing and Industry 4.0, emphasizing the importance of strategically integrating enabling technologies. These technologies are not only designed to support lean principles and enhance operational performance but also to transform worker activities and improve workforce outcomes [5].

A widely adopted metric for evaluating the efficiency of production systems is Overall Equipment Effectiveness (OEE), which measures the effectiveness of capacity utilization in manufacturing settings [6]. OEE is a composite indicator that incorporates three fundamental dimensions: availability, performance, and quality [7]. Due to its comprehensive nature, OEE is frequently used as a key performance indicator (KPI) and tracked over time to support continuous improvement initiatives [8].

OEE is particularly useful in identifying the sources of production losses and revealing latent potential within existing systems. It is broadly implemented across industries, especially where the financial impact of lost capacity is significant [9]. A value of OEE below 100% signifies suboptimal performance and indicates areas where improvements can be made [10].

According to Bhade (2020), six major categories of losses contribute to diminished OEE: setup and adjustment, equipment breakdowns, reduced operating speed, lower yield, idling and minor stoppages, and process defects. These losses can be effectively addressed through the application SMED analysis [11].

Setup time is defined as the duration required to prepare a machine for a new production process, including tool changes, calibrations, and preparatory activities [12, 13]. In the context of lean manufacturing, this time is considered a form of waste. The implementation of SMED methodology enables significant reductions in setup time, thereby enhancing overall production efficiency [13].

SMED is a systematic approach aimed at minimizing equipment downtime – specifically the setup time between the processing of two different product types or production batches. This methodology falls under the broader domain of flow synchronization and lean equipment management. Common applications of SMED include reducing the time required to change molds in presses, reconfiguring production lines, or resetting machining centers. The implementation typically involves cross-functional teams and is carried out through a series of structured workshops. The use of SMED is well-documented in the automotive industry, where it has led to considerable reductions in setup times and associated costs [13, 14, 15]. For example Ferradas and Salonitis (2013) developed and validated a modified SMED methodology, which resulted in a 33% reduction in welding cell changeover time through organizational measures alone, and up to 35% with the implementation of technical improvements. A key factor contributing to the success was the effective distribution of team roles and the involvement of multiple departments through a structured four-phase project approach [16].

Furthermore, Antosz (2018) reports the successful application of SMED across multiple industrial sectors, demonstrating its versatility and efficacy. His research highlights the positive outcomes achieved by companies that adopted SMED practices at various workstations [17].

An essential enabler of lean methodologies such as SMED is standardization. Standardized work ensures consistency and repeatability in operational procedures and is critical for sustaining improvements. Within organizations, it is imperative to implement standard operating procedures and responsibilities for all employees, supported by documentation such as work instructions and product data sheets. Standardization not only enhances process stability but also contributes to reducing product variability and improving overall quality [14].

Building upon this foundation, recent developments have sought to align SMED with the principles of Industry 4.0. For instance, Khakpour and Ebrahimi (2023) propose the "SMED 4.0" method, which integrates Industry 4.0 technologies such as the Internet of Things (IoT) and machine learning to enable real-time process monitoring, predictive defect prevention, and dynamic online parameter adjustments. Their case study demonstrates the practical applicability of this enhanced approach in a real-world manufacturing setting, reporting a 93% reduction in defect occurrence. This advancement not only illustrates the evolution of SMED into a more intelligent, responsive tool but also underlines its role in supporting sustainability through environmental, social, and economic performance improvements [18].

MATERIAL AND METHODS

To evaluate the impact of SMED on manufacturing efficiency, a case study was conducted in a Slovak engineering enterprise engaged in metal cutting, grinding, pressing, welding, and assembly. The company primarily focuses on small – and medium-batch production, as well as custom-made components. The research aimed to investigate the effectiveness of machine changeover

processes and propose methods to minimize associated inefficiencies [19].
The subject of the analysis was a vertical machining center, the HERMLE B 300 U – an advanced 5-axis CNC machine operated via the Heidenhain iTNC 530 control system. The center is capable of spindle speeds up to 15,000 RPM and includes a tool magazine with a capacity of five tools. Additionally, it features a rotary-swiveling table with a diameter of Ø 280 mm, and a travel range of X = 800 mm, Y = 600 mm, and Z = 500 mm.
The study began with a detailed characterization of the machine and its role in the production line. A complete process mapping of the machine changeover was then performed, distinguishing between internal and external activities. Through direct observation and time analysis, inefficiencies in both activity types were identified. Based on the SMED methodology, targeted measures were proposed to reduce non-value-adding time, thereby improving overall equipment efficiency.

METHODOLOGY

The SMED method was applied in the research to improve the changeover process of a specific production machine. The entire procedure of the method is based on a thorough analysis of changeover, which is mostly carried out by observation directly at the workplace. Radical shortening of changeover times from a few hours to a few minutes is achieved by gradually eliminating waste from the changeover process, changing the organization of changeover, standardizing the changeover procedure, team training, special aids and technical modifications of the machine. The method is used at workplaces that are bottleneck places, where changeover is done frequently and the times for changeover represent significant losses from machine or line capacity. The SMED method is often also part of the TPM program [20, 21].
The SMED method is based on 4 basic steps, as illustrated in Fig. 1. These include:

1. Separation internal and external changeover activities.
2. Reduction of internal changeover time.
3. Reduction of external changeover time.
4. Minimalization of the total changeover time [20].

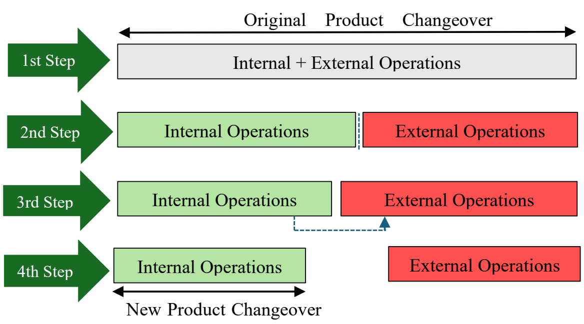


Fig. 1 Sequence of steps performed during SMED analysis
Source: [20].

The means to achieve a better state can generally be classified into two basic groups [22]:

1. Organizational changes that can reduce the total changeover time by 20 to 30% without high costs. These are primarily changes in the changeover organization (e.g. preparation of tools, fixtures, maintenance of machines in external time, visualization of the changeover process).
2. Technological changes affecting the design of machines, which often require initial investments (e.g. the principle of the least common multiple, performing parallel operations simultaneously, magnetic clamping of molds or clamping with one turn).

A successfully implemented project for applying the SMED method can bring the following benefits to the organization [23]:

- Lower production costs: faster changeovers mean less equipment downtime.
- Smaller batch sizes: faster changeovers allow for more frequent product changes.
- Improved responsiveness to customer demands: smaller batch sizes allow for more flexible planning.
- Lower inventory levels: smaller batch sizes lead to lower inventory levels.
- Smoother starts: standardized changeover processes improve consistency and quality.

There are general recommendations for eliminating various types of waste and achieving rapid changeover, including:

- Standardization of changeover operationes,
- Standardization of machines,
- Visualization of the changeover process,
- Parallel execution of operations,
- Use of quick clamps,
- Use of automatic tools,
- Automate the changeover process,
- Creation of changeover teams [20].

Analysis of the current state of changeover processes

The analyzed 5-axis CNC HERMLE B 300 U is a machining center focused primarily on milling very precise and complicated products. This machine is used in the company mainly for small to medium series-oriented production.
To analyze the process of changeover the device, the procedure of recording the entire changeover process on a video camera was chosen. The first point after taking the video recording was to re-watch and then analyze the activities that were performed during the changeover process. For each activity in the process, the time period that the machine setter needed to perform the given task was determined from the recording. We wrote down the values measured in this way in a summary table, which was divided into tab. X1 and tab. X2 in the next steps. After analyzing the video recording, it was found that the resulting machine changeover time was 3 hours 26 minutes and 32 seconds. The categories of main activities that the entire changeover process consisted of were determined from the list:

1. Removing the fixture from the previous production process.
2. Study of the clamping sheet and drawing documentation.
3. Cleaning the machine.
4. Clamping the fixture into the machine.

5. Positioning the zero point of the machine.
6. Measuring the tools.
7. Clamping the tools into the machine magazine.
8. The production process of the 1st piece of the product.
9. Inspection.

Application of the SMED method

From the analysis of the current state of the CNC machining center changeover, it was found that the process duration is too long and there are certain activities that do not bring any value. Throughout the entire time, most operations were performed while the machine was not producing. According to our assessment, it would be possible for some activities to be moved to external time, while the machine was producing. All these activities performed in internal time extend the re-typing time and thus reduce production productivity.

After dividing the activities from the summary table into internal (Table 1) and external activities (Table 2), it was decided that only those operations in the process that play a more significant role would be addressed, that is, we focused on activities exceeding the duration of five minutes.

Table 1
Internal activities

Duration	Operation description	Int./Ext.
0:06:10	Removing and storing the previous fixture from the machine	Internal time
0:01:00	Cleaning the machine	Internal time
0:08:36	Preparing and clamping fixtures into the machine	Internal time
0:01:32	Cleaning the machine conveyor	Internal time
0:10:19	Preparing and clamping the workpiece into the machine	Internal time
0:05:57	Defining the workpiece zero point with a probe	Internal time
0:02:40	Arranging and clamping tools into the magazine	Internal time
0:15:57	Starting and manufacturing the first test product	Internal time
0:01:56	Cleaning and removing the part from the machine	Internal time
0:58:26	Waiting for the first product to be inspected	Internal time

In Table 1 and Table 2, we marked them in yellow and then searched for the optimal solution for reducing the times of the marked activities. Based on the analysis of the distribution of internal activities (Table 1), we found that the total duration of internal activities is: 1 hour, 52 minutes and 33 seconds.

We also found that the total duration of external activities is: 1 hour, 33 minutes and 59 seconds. We again focused only on activities with a duration of more than five minutes (marked in yellow), since the analysis showed that activities under five minutes were either carried out relatively efficiently or were solved by a standard that would result from the entire analysis.

Subsequently, in addition to activities over five minutes, we also marked in Table 2 activities that were related to production on another machine. We then combined these recurring activities into one time period and looked for an overall solution to the problem.

Table 2
External activities – marked are assessed

Duration	Operation description	Int./Ext.
0:00:31	Logging in to the work task in the system	External time
0:41:02	Searching for the clamping and program sheet	External time
0:00:27	Going to the tool and fixture dispensing room	External time
0:05:20	Searching for the fixture in the dispensing room	External time
0:00:31	Writing the fixture	External time
0:00:29	Walking to the machine with the fixture	External time
0:00:30	Walking from the dispensing room to the machine	External time
0:01:24	Studying the fixture sheet and drawing documentation	External time
0:01:55	Preparing semi-finished products for the machine	External time
0:01:00	Cleaning the machine surroundings	External time
0:01:07	Checking the production of parts on another machine	External time
0:05:00	Searching for tools in the dispensing room, at the machine	External time
0:00:30	Writing in the dispensing room	External time
0:00:20	Walking from the dispensing room to the machine	External time
0:01:22	Searching for suitable fixtures on the machine	External time
0:01:07	Checking the production of parts on another machine	External time
0:02:38	Measurement of tools	External time
0:02:23	Checking the production of parts on another machine	External time
0:06:05	Checking the production of parts on another machine	External time
0:08:56	Searching for the program in the PC and uploading it to the machine	External time
0:10:46	Editing and checking the program	External time
0:00:36	Bringing the finished part for inspection	External time

Proposal of measures for optimizing machine changeover using the SMED method

After the basic division of activities into internal and external, we further focused on specific possibilities for corrective measures in this part of the work. First, we focused in detail on the reduction of internal and external times in such a way that we sought solutions on how this time in a manufacturing company can be optimized based on organizational or technical solutions.

A. Reduction of internal changeover time

1. The proposed solution is the use of a zero-point clamping system – ZeroClamp, which is a modern system for clamping various types of fixtures, clamping vices,

2. as well as the products themselves. In essence, it is a palletization of the part, which means that the part with the fixtures themselves is prepared in advance, clamped in the ZeroClamp clamping system and is ready on a pallet at the machine for quick exchange between different types of products. Likewise, the previous product that was produced on the machine would have the same clamping system and dismantling of the previous production would be very fast. ZeroClamp is an ideal choice also because it is a very fast identification of the zero point. The manufacturer states that the time will be reduced by at least 90%. In our case, this would mean reducing all three activities to a maximum of 3 minutes. The savings in this case are at the level of twenty-two minutes.
3. Change in the organization of inspection activities – creation of a registration system where the first manufactured piece will be prioritized for inspection, without which the adjuster cannot start a series of products. The average time for checking the first product in this case will be reduced to a maximum of ten minutes, of course taking into account the complexity of the product.

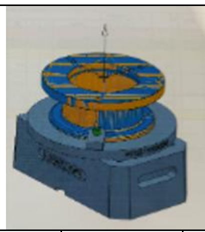
B. Reduction of external changeover time
1. Creation of an archiving system and systematic issuance of all recurring program and fixture sheets from various customers. If the necessary sheets are immediately available, the setter does not have to search for them during external changeover time. We can reduce the original time of forty-one minutes and two seconds to even less than one minute
2. Reduction of the time for searching for a fixture in the dispensing room and searching for tools in the dispensing room and at the machine will be a task for the warehouseman and not for the machine operator.
3. Reduction of the time for searching for a program on an external computer in the production hall, where he then downloaded it to a USB drive and had to re-insert it into the machine. The solution is to connect the machine to the Internet, where the programmer can very easily insert the setter's program directly into the machine after completing the program.

Creating a standard for the HERMLE B 300 U CNC machining center

Upon completion of all stages within the SMED analysis framework, the development of a standardized machine changeover procedure was essential [19]. This standard represents a conclusive measure aimed at enhancing changeover efficiency and ensuring process consistency. As illustrated in Table 3, the standard systematically arranges individual activities in the exact sequence to be followed by the operator.

The document presents a detailed account of each operational task, specifying the corresponding standard time allocated for its completion, thereby supporting the sustained efficiency of the entire process.

Table 3
Standardized Setup Procedure for the HERMLE CNC Machining Center for a Specific Product

Machine Changeover Standard		Position No. 1		
Part Number:	00-1			
Name:	Product 1			
Machine:	3022			
Customer:	X			
Program Run (min):	0:10:00			
Operation:	E/I operation	Time standard (min)	Responsible person	Notes
Logging in to a work order and signing up for an inspection	External	0:02:00	Foreman	
Finding the clamping, program and tool sheet	External	0:01:00	Sorter	
Studying the drawing documentation and the program	External	0:05:00	Sorter	
Checking/editing the program	External	0:08:00	Sorter	
Picking up tools	External	0:05:00	Warehouse worker	
Measuring tools	External	0:03:00	Sorter	
Tool clamping	External	0:03:00	Sorter	
Fixing the fixture/ clamp to the ZeroClamp	External	0:10:00	Sorter	
Removing the ZeroClamp from the machine	Internal	0:02:00	Sorter	
Cleaning the machine	Internal	0:02:00	Sorter	
Mounting the ZeroClamp into the machine	Internal	0:02:00	Sorter	
Clamping the zero point of the workpiece	Internal	0:06:00	Sorter	
Launch and production of the 1st piece	Internal	0:15:00	Sorter	
Inspection of the 1st piece	Internal	0:10:00	Controller	
Correction	Internal	0:05:00	Sorter	
Cleaning and placing the ZeroClamp in the dispenser	External	0:10:00	Sorter	
Explanations: E-external activity, performed while the machine is running I-internal activity, performed when the machine is stationary				

Evaluation of the results of the application of the SMED method for process improvement

After identifying the current state of the changeover process and subsequently completing the SMED analysis, we arrived at the final values for time savings related to inefficient activities, as shown in the graph in Fig. 2. The graph illustrates the total time recorded after the video analysis of the original state and the comparison with the final time after implementing corrective measures, accounting for the estimated time savings and the creation of a standardized procedure.

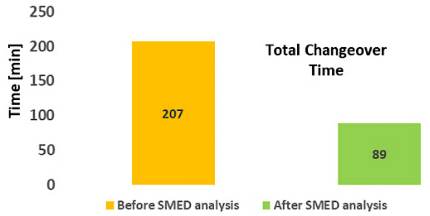


Fig. 2 Total Setup Time Before and After Implementation of Corrective Actions and Standardization

From the chart showing the total changeover time before and after the implementation of corrective measures, it is evident that changing over to a new product type originally took approximately 207 minutes. After the corrective measures were implemented and a standard was introduced, a clear improvement can be seen, reducing the time to 89 minutes, which represents a 57% time saving.

In the next step, we attempted to economically evaluate the proposed measures. The graph (Fig. 3) summarizes the utilization of the analyzed machine from 2018 to 2023. The graph shows that the OEE value, which is an indicator of the efficiency of the equipment, does not have a growing curve, but rather a stagnant one.

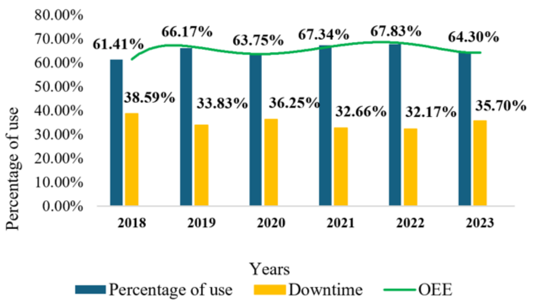


Fig. 3 Utilization of the HERMLE CNC Machining Center Over the Years

This suggests that there is significant room for improvement within the company, including through the use of the SMED method, which we focused on in our work.

The average operational cost of a 5-axis CNC machine, including the operator's wage, is approximately €30 per hour. Over the past six years, the average utilisation rate of the 3022 machine has been maintained at approximately 65%. The machine operates five days per week in two shifts, each consisting of 7.5 hours of net productive time.

Based on this arrangement, the average number of productive working hours over the last six years was calculated as 1,872.5 hours per shift annually. With a two-shift system currently implemented in the company, this corresponds to a total of 3,745 operating hours per calendar year. These variables are clearly summarised in Table 4.

Table 4
Comparison of Revenues at Different Utilization Levels of the HERMLE CNC Machining Center

Total Annual Production Capacity	**3,745 hours/year**
Sales Revenue Scenario	
100% Utilization	**112,350 EUR**
65% Utilization	**73,027.50 EUR**
Downtime (35%)	**39,322.50 EUR**

As shown in Table 4, under ideal conditions – defined as 100% machine utilization throughout the calendar year – the company could theoretically achieve a maximum revenue of 112,350 EUR. However, such a scenario is practically unattainable due to various operational constraints, including machine breakdowns, insufficient order volumes, changeover times associated with different production types, and other unforeseen interruptions.

At present, the machine is utilized at an average rate of 65%, which translates into an estimated annual revenue of approximately 73,027.50 EUR. This indicates a significant opportunity for improvement. The application of SMED analysis presents a promising approach for increasing the machine's utilization rate by reducing changeover time and enhancing production flexibility. As a result, the company could realize a substantial increase in revenue, with potential growth of up to 35 % in the event of achieving optimal utilization levels.

CONCLUSION

This article presents a case study on the application of the SMED methodology within a manufacturing company. The primary objective of the research was to reduce the changeover time of production equipment, thereby contributing to process optimization, enhancing overall production efficiency, and ultimately improving the company's competitiveness.

The study employed video analysis to monitor and examine the changeover activities associated with a HERMLE CNC machining center. Recorded operational times were analyzed to identify inefficiencies and potential areas for improvement. Activities were subsequently reclassified as either internal or external, their necessity critically evaluated, and a revised task allocation was proposed. The overarching aim was to simplify and streamline the changeover process for the most frequently manufactured product.

The research culminated in the implementation of a standardized machine changeover procedure, which resulted in a significant reduction in changeover duration. Specifically, the total time required for changeover decreased from 207 minutes to 89 minutes – corresponding to a reduction of approximately 57%.

Finally, the effectiveness of the implemented corrective measures was assessed through an economic evaluation, which quantified their impact on the overall utilization of the machine. The results demonstrate the substantial potential of SMED methodology to deliver measurable improvements in operational performance and resource efficiency.

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