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Application of the single-minute exchange of die system to the CNC sector of a shoe mold company

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Abstract: The aim of this work is to present a quantitative evaluation of the benefits of applying the Single-Minute Exchange of Die (SMED) implemented in a shoe mold company. Based on the application of this methodology, we noticed that real gains were obtained with very little financial investment. The improvements observed in the sector were the reduction of set-up time by 60%, with an average set-up time of approximately 7 min, and an increase in the productive capacity of the sector by around 3%. There was a reduction in the incidence of errors in the machined parts due to the standardization of the processes performed by the operators. Among the advantages presented with the new system are reduced material exchange time, reduced time spent fine-tuning, less chance of errors during exchanges, improved product quality, greater reliability with respect to reduction of dissociation stocks and the flexibilization of the production system.

Subjects: Manufacturing Engineering; Manufacturing Technology; Machine Science & Technology; Production Engineering; Manufacturing Engineering; Manufacturing Engineering Design

Keywords: Single-Minute Exchange of Die (SMED); set-up times; production planning; CNC machining; shoe mold company

ABOUT THE AUTHOR

SMED research projects are developed by Researchers of Production Engineering together with the researchers of manufacturing processes of Mechanical Engineering. The group of researchers acts collaboratively. Most of the researchers in this group work autonomously, participating in several projects in various institutions in Brazil. Dr. José de Souza has coordinated these projects that have resulted in several publications such as this one. The current text is also the result of a work by the engineer Rodrigo Borges Ribeiro in the course of Production Engineering.

PUBLIC INTEREST STATEMENT

One way to increase efficiency in industrial production is to reduce the time required to prepare machines and equipment. While this step is unfinished, the process remains stationary, rendering it inefficient. With the reduction of the preparation time, the size of the production batch is also reduced, thus increasing the productive efficiency. One of the methods of reducing the preparation time of machines is the application of the Single-Minute Exchange of Die (SMED). This method creates conditions that bring good results in a short time and with relatively low implementation costs. Reducing the tool changeover time makes the company more competitive due to more significant gains in agility, flexibility and rapid response to market changes, reaching specific previously unreachable market niches.

1. Introduction

According to Ferradás and Salonitis (2013), SMED is a system that aims at reducing the setup time focusing on continuous and cost-effective changes. The SMED system was spread throughout the world along with the evolution of the Toyota Production System (Tatàno et al., 2012). Assaf and Haddad (2014) defined the SMED system as a methodology used for analysis and reduction of the preparation times of machines and equipment. Mohamad and Ito (2012) pointed out that the main purpose of the SMED system is to convert all internal setup operations possible into external setup. This makes the machines stay in operation for more extended periods, allowing an increase in production capacity without the need to invest in new equipment or increase the production line (Mulla, Bhatwadekar, & Pandit, 2014) (Karam et al, 2018).

A detailed analysis of the setup operation is necessary for the implementation of the SMED system (Kumaravel, Sathya-Bharathi, & Kavinandini, 2018) (Karasu, Cakmakci, Cakiroglu, Ayva, & Demirel-Ortabas, 2014). The SMED system can bring numerous benefits to the company, among which are the reduction of decoupling stocks, the decline of the number of batches produced, reduction of unnecessary movements and improvements in the final quality of the product, as well as the flexibilization of the production systems (Costa, Bragança, Sousa, & Alves, 2013) (Mihok, Kádárová, Demečko, & Ružinský, 2015).

Ekincioğlu and Boran (2018) point out that the SMED system, initially, for environments of repetitive production of large amounts of batches, where, then, the production of smaller quantities was made possible. Before the development of the SMED methodology, the industry worked with the concept that large batches of production absorbed huge setup times, which, then, was diluted in the number of parts produced (Moreira & Pais, 2011) (Rosa et al., 2017).

Moreira and Pais (2011) point out the disadvantages of large-scale production: (i) the need for clients with higher production demand, (ii) more extended deadlines, (iii) higher inventory, pallet and forklift costs, (iv) quality problems, (v) money loss due to inventory depreciation, (vi) higher number of workers linked to transport and inventory activities and (vii) frequent returns due to the more significant amount of probable defective products.

The SMED system has two main advantages, the increase in productive capacity and the flexibilization of equipment. These advantages allow organizations to work with smaller amounts of production batches, creating a better material flow due to the elimination of waiting time (Chiarini, 2014).

Ferradás and Salonitis (2013) pointed out that one of the problems of the SMED system is that it analyzes the setup times performed by a single operator on a single equipment. This method does not generate uniformity when put into practice, considering the differences between the numerous operators, whether these differences be physical or technical.

The SMED system enables the reduction of equipment preparation times, allowing a more economical production as well as smaller batches. The system also provides for the reduction of lead times, making the company more competitive in the labor market. Another critical factor in the SMED system is its capacity for economic production of small batches without the need for high investment in the productive process, which, in turn, does not add value to the final product (Oliveira, Sá, & Fernandes, 2017) (Pautsch, 2018).

According to Ani and Shafei (2013), the production of large batches has the objective of achieving the shortest time possible, in percentage, of machine idle intervals per unit produced. By reducing the unit cost of preparation through the SMED system, the equipment's operation time increases and, therefore, the incidence of errors when adjusting the equipment is decreased (Harmon & Peterson, 1991) (Dias & Santini, 2018).

Matarrese, Fontana, Sorlini, Diviani and Maggi (2017) stress that to achieve a more productive and useful system, the flow of materials throughout the operations has to be agiler. Lead time reduction grants lower operation costs, adding benefits to the consumer. As a result, the complexity of setups and manufacturing costs are reduced, which can be considered an investment in consumer satisfaction (Simões & Tenera, 2010) (Tekin, Arslandere, Etlioğlu, Koyuncuoğlu, & Tekin, 2018). The time required to prepare the operators and the equipment for the manufacture of another product belonging to the global production mix is called setup (Kutschenreiter-Praszkiewicz, 2018).

The SMED system is essential to the competitive strategy of the company about its clients, whether the clients be internal or external (León-Cabezas, Martínez-García, & Varela-Gandía, 2017). To achieve a Just in Time production, lead time must be decreased progressively, and, to that end, there must be a reduction in decoupling stocks, production must be synchronized, and the company must have the capacity to manufacture small batches of product. To achieve this reduction in batch size without much loss with idleness, the setup must be reduced, which, in turn, depends directly on the implementation of a SMED system (Cheung et al., 2017) (Reddy., Panitapu, 2017).

There are two types of standard operations within the SMED system: internal setup an external setup. The internal setup is characterized by processes that can be performed while the machine is idle; the external setup is characterized by actions that can be performed while the machine is running (Chiarini, 2014) (Suganyadevi., Malmurugan, 2014).

A possibility for improving the setup time of machinery is to convert the internal setup into the external setup. According to Díaz-Reza et al. (2017) any machinery setup can be performed in less than 10 min, which characterizes the SMED system.

Setup time consists of four functions: (i) preparation of the raw material, assembly devices, accessories, etc.—30%; (ii) allocation and removal of matrices and tools—5%; (iii) centering and determining the tools dimensions—15% and (iv) initial processing and adjustments—50% (Díaz-Reza et al., 2017).

The advantages of implementing the SMED system are: fast and easy setup operations and product exchanges, cost reduction, increase in productive capacity, increase in the utilization rate of machines and equipment, decrease of idle time, easy production of a varied mix of products in a short span of time, flexibility in product alteration, reduction of production batches, reduction of response time, decrease of decoupling stocks, reduction of lead times, increase in quality gain, cost reduction due to the elimination of rework and waste of material, among others (Neumann e Ribeiro, 2004, Shingo, 2000).

Ferradás and Salonitis (2013) consider that the methodology applied by the SMED system created by Shingo focuses mainly on the improvement of processes, worrying about changing the concepts of how people work and often forgetting about the developments in equipment designs and intermediate devices.

2. Material and methods

This case study was carried out in the CNC milling sector of the company Matrizaria, which works with precision machining of molds and components for molds. The setup operations analyzed were the ones of CNC machines that run in three daily shifts from Monday to Friday, reaching approximately 22 working days per month. Considering this information, was noticed that approximately one service day per month is lost in one machine alone, according to the historical data collected by the production scheduling area. The CNC machines sector has the biggest production bottleneck in the company's production system.

2.1. Definition of the process to be addressed

In the company analyzed, the setup process is divided into three types: (i) probe setup, (ii) part setup and (iii) tool setup.

The CNC programmer and operators so named probe setup due to being the type of setup that requires a probe clock for the part to be placed in the CNC machine. That means that this part has already undergone a machining process before this step and needs to be in accordance with what was planned. Without this auxiliary equipment, the part would not have its final quality guaranteed. Probe clocks have the technical function of aligning elements and checking measurements based on the absolute values of the CNC machine.

Part setup, so named by the CNC programmer and operators, constitutes the setup process in which the part is placed in the CNC machine, whose absolute zero is its center. It is not necessary to use a probe clock to align this part since it has no previous machining process.

Tool setup, so named by the CNC programmer and operators, consists of the setup in which the addition of a tool, at any point of the machining process, to the CNC machine is necessary to produce the part according to the specifications determined in the initial design.

In the study of the types of setup addressed by the analyzed sector, the following data were observed in Table 1.

Based on an analysis of the data in Table 1, was decided to work with probe setups. During the months of study, the minimum time found for this operation was 18 min.

2.2. Application of the SMED system

The application of the SMED system was based on the methodology proposed by Meirelles (2004), who sought to follow the conceptual stages proposed by Shingo (2000).

The application started on the strategic stage. In this stage, we had to persuade the senior managers. The data collected in Table 1 served as proof for the managers to allocate human and financial resources to implement the system.

When organizing the work teams, it was decided that half the operators of each shift would be relocated to work on the application of the SMED system. We arranged a meeting with the operators for them to get involved with the project and, later, a training of the SMED methodology

Table 1. Historical data of setups in the CNC sector.

Month/year	Nov/2014			Dec/2014		
Type of setup	Time (min)	Number of Setups	Average time (min)	Time (min)	Number of setups	Average time (min)
Probe	782	42	19	642	31	21
Part	188	11	17	60	7	9
Tool	556	59	9	225	17	13
Month	jan/15			fev/15		
Type of setup	Time (min)	Number of setups	Average time (min)	Time (min)	Number of setups	Average time (min)
Probe	1013	56	18	881	48	18
Part	468	33	14	216	20	11
Tool	139	13	11	106	21	5

was carried out in loco. According to Mohamad and Ito (2012), the instruction on the SMED system will only be practical if performed in real situations of manufacturing processes.

With the analysis of the process, products, production cycle, setup times and numbers, it was decided that the setup time should conform to the Single Minute Exchange of Die (or SMED) concept (tool exchange in less than 10 min). Thereby, we would reach a reduction of approximately 45% in setup time. With the historical data and the goal to be reached in hands, we started the preparatory stage. In this first moment, we analyzed the setup processes that were taking place in the CNC sector. We filmed a setup that frequently occurs in this sector—the probe setup. The total time of this setup was 21 min and 25 s.

The video recording of the setup process analyzed has an essential educational and motivational role, and with it, one can make detailed analyses of the process under study. A recording should be made before and after the implementation of the SMED system (Karam et al., 2018) (Chen, Fan, Xiong, & Zhang, 2017). Chart 1 shows the results collected during the first filming.

Based on this information, we can notice the difference between what Shingo proposed and the situation of the setup time in the machine analyzed.

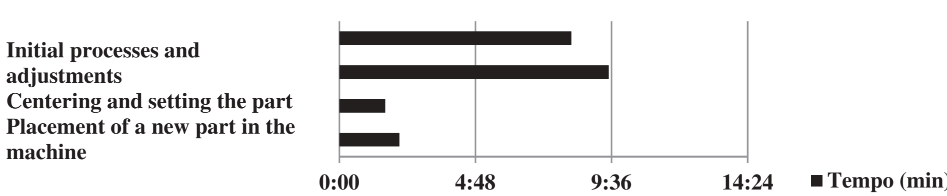
One of the results that most generated concern was the discrepancy between the setup time found in the video and the setup times found in the notes of the months from November 2014 to February 2015. In these notes, the operators indicated an average time, for this type of setup, of approximately 18 min, meaning a difference of 3 min concerning the time found in the film. Some of the details observed were the incorrect handling of tools, unnecessary movements during the setup process, excessive time spent on centering the part and on final adjustments.

When analyzing the milling process, it was found that the operators erroneously perform several setup processes in a single setup. The machine remains idle while the operators adjust the tools so that the part continues in the milling stage. In one of the processes, in single milling, the machine was interrupted 10 times, each interruption lasted 2 min for the adjustments to be made. If we add the time of these interruptions to the initial setup time, we can say that the setup time is close to 30 min.

With the first footage and the subsequent critical analysis of the activities under observation, we showed the operators the improvements that could be employed immediately in their actions. We separated internal and external setup operations and converted all internal setup operations possible into external. The tools must be placed close to the CNC machines, the next material to be milled must be affixed to the milling device and be close to the CNC machine, and the material that is removed from the machine must only be taken to its next step after the milling of a new part starts.

Through this analysis, the operators themselves suggested the assembly of a car to transport the tools—this car has the function of assisting the operators, leaving them with the tools they need as close as possible to the CNC machines. Changes in equipment designs and the addition of

Chart 1. Analysis of the first footage of the setup process.



intermediate devices combined with methodological improvements can generate acceptable results with moderate investment (Ferradás e Salonitis, 2013). The car costs R$ 1.725,23.

Something that called our attention during the analysis of the first video was that there was no standard checklist for the operators to follow. Some tools were arranged on the panel of CNC machines, others were in the car used to transport parts, and others were stored in tool cabinets. Thus, we created a checklist in the form of cards that were affixed to the panel of CNC machines. We tried to synthesize in these cards the steps of the SMED system, as well as the items to be observed during the setup process. The elements that compose the checklist cards can be seen in Table 2.

On top of the practices adopted to make the setup process faster, we also analyzed the organization of the sector. Through this analysis, we observed that, because some identifications in the places destined for tool storage were lacking, the operators took more time than should be necessary to find what they were looking for.

After the implementation of these improvements—the standard processes for the employment of the Single-Minute Exchange of Die system, the pre-established methods and processes and the conversion of internal setup into external setup—we made second footage of the setup process, similar to the one recorded initially. The total setup time found this time was of 6 min and 46 s. Chart 2 presents the results found in the second video.

Based on this analysis, we can see the real gain obtained in the sector with the techniques proposed to implement the Single-Minute Exchange of Die system. In the operational stage of the application of the SMED system, we analyzed the results obtained in comparison to the goals and indicators previously established. Table 3 shows the comparison of the first and second footages.

The initial goal was to lower probe setup time from 18 min (average time found in historical data) to less than 10 min (SMED standard time), as established by Shingo (2000). Already in the second footage, the setup time fell to less than 7 min, that is, approximately 40% of the average time found initially.

Table 2. Checklist cards affixed to CNC machines.

Operation to be done while the machine is running					
Set apart the next part (material) to be milled by placing it in the trolley close to the CNC machine	Check with the CNC programmer how many and which tools are going to be used in the milling process of the part in question, set apart these tools by placing them in the container trolley	Set apart the dial indicator and leave it in the same container trolley	Set apart the key needed to loosen/secure the part in the machine table	Set apart the screws required to secure the part to the machine	Set apart the clamping wedges required for the milling process
Check the operating conditions of the items listed					
⇩					
Improvement in the transport of matrices and components					
Check the operating conditions of the items listed					
All items used in the setup process must be returned to their storage location only once the machine is running (external setup)					

Chart 2. Analysis of the second footage of the setup process.

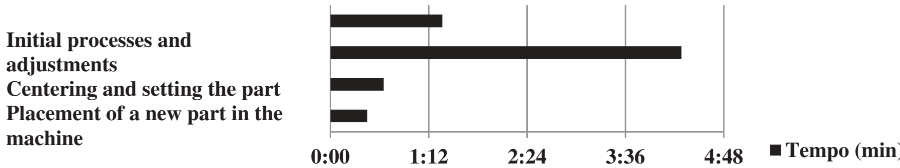


Table 3. Comparison between the first and second footages of the setup process

	First footage		Second footage		Difference	
Operation	**Time (s)**	**%**	**Time (s)**	**%**	**Time (s)**	**%**
Time spent on the removal of the previous part	127	9.88%	28	6.90%	99	77.95%
Time spent on placing a new part in the machine	97	7.55%	39	9.61%	58	59.79%
Time spent on centering and setting the part	570	44.36%	257	63.30%	313	54.91%
Time spent on initial processing and adjustments	491	38.21%	82	20.20%	409	83.30%
Total	1285	100.00%	406	100.00%	879	68.40%

In the testing stage, the practices were standardized, consolidating the changes into operational standards, and new rules were disseminated, training the rest of the company's functional team. After the probe setup analysis, we also worked on the part and tool setups.

Moreira and Pais (2011) asserted that, for the application of the SMED system to be successful, the company must perform continuous analysis of the actual process. The adoption of strict procedures has the objective of reducing mistakes during the implementation of the SMED system.

3. Results

3.1. Setup times

The implementation of the SMED system generated benefits to the CNC sector, such as the reduction in setup time and the standardization of processes. Meirelles (2004) argues that traditional production systems become more active with the implementation of setup time reduction techniques. The distance traveled by the employees in the setup stage was reduced, given that, after the training and dissemination of the practices adopted, all necessary materials were placed very close to the CNC machine.

The dissemination of the practices adopted to implement the SMED system reduced the time of the three types of the setup used in the CNC machines of this sector: (i) probe setup; (ii) part setup and (iii) tool setup.

In the probe setup, there was a gain of approximately 60%. In the part setup, the average increase was off roughly 80%. In the tool setup, the average gain obtained was of approximately 60%. The basis for calculating the results was the following: we calculated the average times of setup between the months of November 2014 and February 2015 and compared it to the average times of setup of the last month in which we advised the application of the SMED methodology in the company—June 2015, when all techniques had already been disseminated throughout the company and its employees.

As the process of implementation of the SMED methodology advances, the idleness of machines and equipment decreases (Moreira e Pais, 2011). Table 4 shows the evolution of the setup times practiced in the CNC sector during the implementation and consolidation of the SMED system.

3.2. Productive capacity

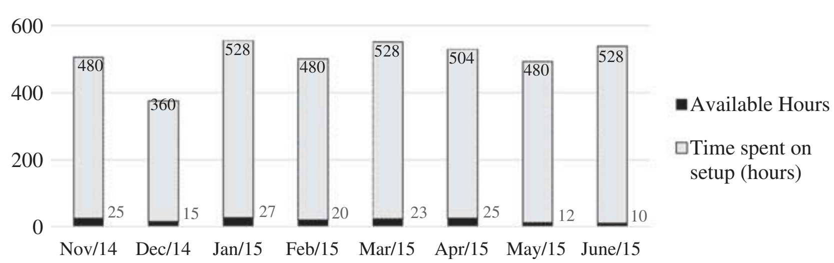
The application of the SMED system contributed to an increase of 3% in the productive capacity of the CNC sector. Since this sector produces an average of 300 parts per month, the percentage represents an increase in milling capacity of approximately nine parts per machine. Moreover, taking into account that the sector works with five CNC machines, the real increase in milling capacity reaches approximately 45 pieces.

Approximately 5% of the total capacity hour/machine available in the sector used to be spent on setup times. With the implementation of the SMED system, the setup time spent in the sector became equivalent to approximately 2% of the total time hours/machine available. Chart 3 shows the time spent with setup, hours/machine per month, during the implementation of the SMED system.

Table 4. Evolution of the setup times practiced in the CNC sector during the implementation and consolidation of the SMED system.

Month	Mar/2015			Apr/2015		
Setup time	**Time (min)**	**Number of setups**	**Average time (min)**	**Time (min)**	**Number of setups**	**Average time (min)**
Probe	843	47	18	978	73	13
Part	355	23	15	198	35	6
Tool	178	22	8	334	36	9
Month	**Mai/15**			**Jun/15**		
Setup time	**Time (min)**	**Number of setups**	**Average time (min)**	**Time (min)**	**Number of setups**	**Average time (min)**
Probe	530	78	7	480	60	8
Part	90	35	3	75	29	3
Tool	87	17	5	68	17	4

Chart 3. Time spent with setup, hours/machine per month.



Analyzing Chart 3, we can see a significant reduction in setup times. The time reduced is equivalent to approximately R$ 680,00 per month for each machine, which corresponds to an annual savings of about R$ 40.000,00. We reached these numbers considering an hour/machine cost of R$ 45,00.

4. Conclusions

The application of the SMED methodology brings benefits in a fast and organized manner and at a low implementation cost. With the implementation of the method, the sector reduced the time spent with setups in 60%, lowering the average setup time to 7 min. There was also an increase of approximately 3% in productive capacity. The investment applied to the sector was of R$ 1.725,23, for the construction of the tool transport car, added to the time spent on training the operators, a relatively low cost when compared to the gain obtained in the sector in the first month alone with the methodology in full operation. Considering only the first month of operation of the SMED methodology, the sector saved approximately R$ 680,00 per machine. There was also a gain in commitment in what regards the operators involved in the implementation process of said methodology.

We noticed that, with a more critical analysis of the productive environment, improvements could be made by just adjusting the way the processes are executed. Creating a standardized checklist has brought a rapid return on setup time reduction. Many of the activities performed by the operators would end up being repeated merely because there was no organization in the disposition of tools and materials. Based on the application of this methodology, we noticed that real gains were obtained with very little financial investment. What another detail saw in this analysis was how unaware the operators were of how long they would take to execute the setup: each operator believed they were performing the process within a specific time, which differed from the times of the other operators. The operators became more confident after the adoption of the SMED methodology, as it helped reduce the likelihood of errors during the setup process. Besides, there was the flexibilization of the productive system.

The SMED methodology opens the way for the application of other management tools, among them is the Lean Manufacturing system, which works with the continuous analysis of setup processes. Further studies can be developed, working primarily with the cultural issue of the productive environment as well as employing simultaneously the 5S system.

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