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Improving the Machining Process of the Metalworking Industry Using the Lean Tool SMED

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Abstract

The project here presented was developed in a metalworking company, where several areas requiring improvement were identified. The study addresses the elimination of waste and increase of productivity in the machining sector of the company. To this purpose key processes were identified and mapped using flowcharts and VSM (Value Stream Mapping). Achieved improvements involved decreasing setup times by resorting to the lean tool SMED (Single Minute Exchange of Die). Setup times were reduced in 40% on the vertical milling machine of the company, and in 57% on the horizontal milling machine.

Keywords: Lean Thinking; Continuous Improvement; Machining; SMED.

1. Introduction

Due to strong competition in the metalworking sector, continuous improvement has become critical to sustain competitiveness. Therefore, continuous improvement is of utmost importance for the companies of this industrial sector, particularly in finding ways to eliminate waste. According to Caffyn [1], continuous improvement consists of an extensive process involving the entire organization, focused on incremental innovation. Simões [2] refers to continuous improvement as of great relevance in the industrial context. Industrial companies of the metalworking sector are complex, where most of the workers simply follow instructions without questioning the work method or the procedures used. Even so, if one is to proceed with improvements, one must first identify the need for the change, question the reasons for specific procedures, abandon one's comfort zone and transform the status quo; namely, Kaizen must be implemented by means of Lean. The work described in this article was developed at a metalworking company with the main objective of improving the production process in the machining sector. The purpose was to increase productivity and reduce waste. The framework of this article is structured as follows: section 2 presents a review of the literature; section 3 describes the methodology used to undertake the work in question; section 4 presents all the practical work developed at

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the company, and suggests proposals for the improvement of the process studied; section 5 deals with all of the results achieved through the development of this work; and section 6 consists of the conclusions reached by the study.

2. Review of literature

All stakeholders are conscious of the need for change. However, the issues on how to begin and how to make change happens have always been important. In order for this to occur, and so that increasingly better results can be reached, some of the basic principles, methodologies and tools must be embraced. In a study developed in the area of logistics and the supply chain, the authors analyzed methods and times, with the aim of reducing delivery times and improving efficiency. It was demonstrated that, on a normal day of production of 220 vehicles, daily time-saving would be 114,4 minutes and 57 hours per month [3]. In another study in the area of industrial production, the authors claim that continuous improvement promotes the development of processes based on existing patterns, and that the coach is a key element in this network. To this end, the authors analyzed 77 factors of success established by 14 authors and research groups. They also devised a tool to measure success, leadership and the best coaching practices. This measurement is undertaken by means of an assessment of managers and key users. When one compares the competencies related to coaching before and after activities of continuous improvement, the coach's success can thus be measured [4]. Another study developed at a company in the metalworking sector presents a case study from a process-based perspective. The main conclusion reached is that, after implementing SMED (Single Minute Exchange of Die) techniques, the company was able to eliminate waste, as well as all those activities that add no value, and which represent approximately 2% of the company's sales volume [5]. In an additional study in the same area, it was demonstrated that the implementation of SMED in the furniture industry contributed to a decrease of 83% in the setup time required for the operation studied, which then led to a reduction in the size of the lot manufactured for the product under analysis [6]. Another study evaluated the implementation of Lean principles in construction, which used computer simulation. In all of the cases presented in this study, the simulated principles improved the performance of the project. This performance improved drastically when all of the principles were simultaneously implemented. The elimination of waste, for example, allowed for a time-cycle improvement of 9,79% and an enhancement in productivity of approximately 9,17% [7]. Finally, in another study pertaining to the manufacturing area, the authors refer to the existence of a link between the stock required for a process and the productivity of the latter. This connection has been described in many case studies but has never been tested statistically. This article uses the historical data from 52 Japanese companies in the automotive sector to evaluate the stock-productivity relationship. It was discovered that companies increased their productivity levels during periods of substantial stock reduction. Tests of greater detail suggest that these reductions stimulated the following gains in productivity: on average, each 10% reduction in stock led to a 1% gain in work productivity, within a one-year time period. These discoveries indicate that a reduction in stock acted as an important guideline for process improvement in many companies in the Japanese automotive sector, although some of the companies emphasized other methods [8]. A study was undertaken at a company which produces pressure vessels, used in the manufacture of air compressors, aimed to improve productivity by addressing various problems detected in the production system. The improvement actions implemented led to reductions in: the operational time cycle, ongoing work, transport, and delays in delivery. It was also able to create better organized working procedures [9]. Another study carried out in the service and production industries lists and compares the Lean tools used by these sectors through the data collected from articles published between 2002 and 2012. It was thus possible to point out the trends in the implementation of several Lean tools by both industries. It was observed that TQM (Total Quality Management) and JIT (Just-In-Time) constituted the most common tools which are frequently used by both groups of industries [10]. A study carried out at a company dedicated to the production of mechanic materials was able to observe that various types of waste can be detected and supported by Value Stream Mapping (VSM). The article also suggests that TPM (Total Productive Maintenance) can be used, and other improvements achieved [11]. Another study analyzes the implementation of a 5S methodology to optimize safety in laboratory work at an engineering university. Through the implementation of 5S methodology, the laboratories at the university became industrial laboratories, similar to those found in the metallurgical industry. It was demonstrated that training, control and maintenance of resources are carried out in less time and with a considerable reduction in costs. One also saw an increase in the space available for the location of resources [12]. Finally, another study demonstrated the implications of using the 5S tool. The results proved to be an incentive, since they were able to imitate those achieved in real-life occurrences. While the simulation results encouraged the implementation of other improvements, the model itself is generic and common to most production systems. Positive impacts were observed in various indicators, and even aspects related to JIT and TPM were improved [13].

3. Methodology

This study adopted the research methodology designated as Action-Research (A-R), which is used to solve immediate problems through gradual solutions and is led by subjects whose work in association with others, or are part of a group. A-R implies planning, acting, observing and reflecting more carefully on what is done during everyday activities. This methodology promotes an increase in workers' knowledge regarding the activities they perform daily, inducing the desired improvements [14]. Five phases must be considered in the broad definition of Action Research [15]: Diagnosis: Identify and define the problem; Planning of actions: Consider different types of actions to address the problem; Implementation of actions: Select types of action; Evaluation: Analyze the consequences of actions; Specification of learning: Identify general discoveries. To this end, one first carried out an analysis, selection and mapping of the processes to be studied by means of Pareto diagrams, flowcharts and VSM (Value Stream Mapping).

A review of the bibliography was undertaken at the same time; this focused on Lean philosophy and its relationship with Industrial Production. Several sources were consulted: some were primary, such as dissertations; others were secondary, for instance, books and articles; and those of a tertiary order consisted of online research tools. A definition of the improvement proposals was then performed; these were set out as a plan of actions, which were subsequently implemented.

4. Analysis and improvement of the machining process

Since this study focuses mainly on the area of Production, from the entry of RM (Raw Material) to the exit of the FP (Finished Product) in the company's Machining sector, it is important to first proceed with a presentation and explanation of the processes. Subsequently, one will deal with the selection of the products subjected to analysis, propose improvements and, finally, discuss the implementations involved.

4.1. Mapping of the process and selection of products

In order to inform the reader of the operation of the process analyzed, it is relevant to proceed with a brief explanation and illustration of the activities involved. Once the contract of work is agreed upon, the following stages are followed: Placement of the order by the commercial department; Followed by the printing of the Internal Execution Order for the cutting of the workpiece; Planning of production relating to the cutting of the workpiece. Printing of the Manufacturing Order for Machining; After this phase, and depending on the workload, the workpieces to be executed in subcontracts are analyzed and selected. This selection is undertaken manually. Once a decision is made as to whether the workpiece will be executed internally, the planning of production for Machining is carried out manually; Subsequently, execution in the Machining area itself takes place, which constitutes the most important phase. Having presented the general process, it is important to explain the execution sub-process "Execution of Machining", according to Figure 1, which is the sector that this study will focus on. The sub-process in question is also the most susceptible to improvements, with the potential to generate greater gains in the short term. After the raw material enters the sector, the following activities are carried out: Milling of the two faces on vertical milling machines; Milling of the four sides on vertical milling machines; Chamfering of all the extremities so that the workpiece has no sharp edges; Depending on the client's requirements, tapped holes are drilled so that eyebolts can be placed to facilitate handling. In order to dispel any doubts, these tapped holes are also designated internally as "eyebolts"; The workpiece is ground, if the client so wishes; Finally, the finished product is cleared and transported to its respective shipping zone. In order to identify the areas which are of greater impact to this sector, one had to proceed with a record of materials produced in larger quantities. Namely, one had to identify all the relations through which improvements might produce better results. A correct recording procedure must consider the main characteristics of the material in question, its length, width and thickness. On analysis, the most frequently produced material is F10 STEEL, with a length ranging from 1200 mm to 2000 mm, a width of between 800 mm and 1200 mm and a thickness varying from 50 mm to 100 mm.

4.2. Identification of problems

In order to ensure a better perception of the process, a mapping of the VSM flows and the current state are presented. This will allow one to visualize how the flow of information and materials occur in the production system. This constitutes an analysis of greater focus, paying more attention to the details of the process being dealt with. Since VSM pertains to the mapping of the value flow, Figure 1 demonstrates that the delivery of RM by the suppliers is variable. After cutting takes place, the material proceeds to milling (faces + sides), and then to chamfering, drilling and grinding. The final phase consists of its internal trajectory in the shipping section. One can thus conclude that the longest operation consists of milling; consequently, it is on this activity that improvements must focus. To this end, the improvement of the milling operation must obviously be subjected to a reduction of setup times, a task which will be supported by the SMED Lean tool. SMED is a tool used in Lean Methodology, which was created in Japan (Toyota) by Shigeo Shingo [16]. It essentially focuses on the reduction of the times required for changeover and tuning, namely, setup. This can be defined as the space of time between the last unit of a production lot and the first good unit of the next lot, including the time needed to re-establish the parameters for the next task. It also includes the time used to carry out all of the machine tuning required until the next unit is produced with the correct specifications. Subsequently, the selection of all the products to be analyzed was undertaken by means of ABC methodology. The processes and operation range subjected to study were then mapped. Once these activities were executed, one was able to identify the operation which was responsible for the greatest expenditure of time: Milling. This process consists of two sub-operations - the Milling of Faces and Sides. One then identified the machines on which the selected products are executed: Milling of Faces: Droop Rein Mill (vertical); Milling of Sides: Scharmann Mill (horizontal). Once this verification has occurred, the execution of the setups was filmed on video (5 per machine), and corresponding analysis was undertaken (Fig. 1).

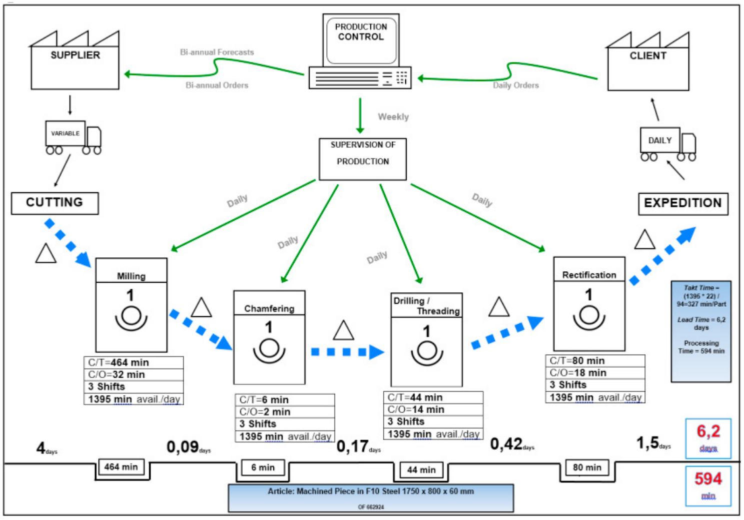

Fig. 1. VSM of the sub-process Execution of Machining.

4.2.1. *Vertical milling machine (Before)*

Table 1 allows one to visualize a typical setup on the vertical milling machine analyzed. Of the 5 setups recorded, Table 2 shows that the average time was determined as being 11 minutes and 12 seconds, with a standard deviation time of 2 minutes and 46 seconds. The general analysis undertaken (see table 3) points out that improvements should focus primarily on inappropriate operations and transport.

Table 1. Typical setup: Vertical Milling Machine

Task Description	Time for Task	Classification per Operation	Classification per Phase
1. Roller Bridge Unavailable	0 h 11 m 4 s	1. Inappropriate Operation	1. Remove machined Workpiece
2. Demagnetization of the Workpiece FP (Magn.Platen)	0 h 0 m 16 s	2. Fitting and tightening	2. Fastening
3. Movement to Compressed Air	0 h 0 m 8 s	3. Movement of operator	3. Remove machined Workpiece
4. Cleaning of FP with Compressed Air	0 h 0 m 6 s	4. Cleaning	4. Remove machined Workpiece
5. Movement to Roller Bridge	0 h 0 m 10 s	5. Movement of operator	5. Remove machined Workpiece
6. Movement of Roller Bridge FP (Out)	0 h 0 m 22 s	6. Transport	6. Remove machined Workpiece
7. Magnetization + Demagnetization of Workpiece FP + RM (Electromagnet)	0 h 1 m 34 s	7. Transport	7. Remove machined Workpiece
8. Movement of Roller Bridge (In) (on Empty)	0 h 0 m 10 s	8. Transport	8. Place new Workpiece
9. Movement of Roller Bridge RM (In)	0 h 0 m 50 s	9. Transport	9. Place new Workpiece
10. Movement to Sweeper	0 h 0 m 4 s	10. Cleaning	10. Prep. Machine and tools
11. Cleaning of RM with Compressed Air	0 h 0 m 31 s	11. Cleaning	11. Prep. Machine and tools
12. Movement to Sweeper	0 h 0 m 23 s	12. Cleaning	12. Place new Workpiece
13. Cleaning of RM with Sweeper	0 h 0 m 10 s	13. Cleaning	13. Place new Workpiece
14. Centering of Workpiece	0 h 0 m 56 s	14. Fitting and tightening	14. Fastening
15. Movement of Roller Bridge (Out) (on Empty)	0 h 0 m 17 s	15. Transport	15. Place new Workpiece
16. Change of Mill	0 h 0 m 34 s	16. Tool change	16. Prep. Machine and tools
17. Setting of Parameters	0 h 2 m 29 s	17. Programming	17. Setting of parameters

Table 2. Setup Times for the Vertical Milling Machine (Before).

Setup Times (hh:mm:ss)			
Average Time	Maximum Time	Minimum Time	Standard Deviation
00:11:12	00:15:42	00:08:52	00:02:46

Table 3. Operation Ratios for the Vertical Milling Machine (Before) (hh:mm:ss).

Operation Ratios:	Maximum	Minimum	Average	Standard Deviation
Inappropriate	00:11:04	00:00:00	00:02:13	00:04:40
Cleaning+Movement of Operator+Transport	00:12:12	00:04:26	00:07:13	00:02:58
Fitting+Positioning	00:01:33	00:01:10	00:01:22	00:00:10
Tool Change+Mechanical Preparation of Machine	00:00:50	00:00:26	00:00:34	00:00:09
Programming+Tuning	00:02:45	00:01:08	00:02:04	00:00:39

4.2.2 Horizontal milling machine (Before)

Table 4 presents an overview of a typical setup for the horizontal milling machine under analysis.

Table 4. Typical Setup: Horizontal Milling Machine.

Task Description	Time for Task	Classification per Operation	Classification per Phase
1. Cleaning of FP with Compressed Air	0 h 0 m 14 s	1. Cleaning	1. Remove machined Workpiece
2. Demagnetization of the Workpiece FP (Magn.Platen)	0 h 0 m 27 s	2. Fitting and tightening	2. Fastening
3. Movement to Roller Bridge	0 h 0 m 18 s	3. Movement of operator	3. Remove machined Workpiece
4. Movement of Roller Bridge (In) (on Empty)	0 h 0 m 41 s	4. Transport	4. Remove machined Workpiece
5. Magnetization + Demagnetization of Workpiece FP (Electromagnet)	0 h 0 m 15 s	5. Transport	5. Remove machined Workpiece
6. Movement of Roller Bridge FP (Out)	0 h 1 m 1 s	6. Transport	6. Remove machined Workpiece
7. Movement of Roller Bridge (Out) (on Empty)	0 h 0 m 23 s	7. Transport	7. Place new Workpiece
8. Magnetization + Demagnetization of Workpiece RM (Electromagnet)	0 h 0 m 31 s	8. Transport	8. Place new Workpiece
9. Movement of Roller Bridge RM (In)	0 h 0 m 32 s	9. Transport	9. Place new Workpiece
10. Cleaning of Table + Workpiece	0 h 0 m 20 s	10. Cleaning	10. Fastening
11. Magnetization + Demagnetization of Workpiece RM (Electromagnet)	0 h 0 m 51 s	11. Transport	11. Place new Workpiece
12. Movement of Roller Bridge (Out) (on Empty)	0 h 0 m 8 s	12. Transport	12. Place new Workpiece
13. Cleaning + Magnetization of Workpiece (Magn.Platen)	0 h 0 m 25 s	13. Positioning	13. Place new Workpiece
14. Setting of Parameters	0 h 2 m 24 s	14. Programming	14. Setting of Parameters
15. Return of FP to Initial Position (Turning) + Cleaning of Edges	0 h 0 m 43 s	15. Fitting and tightening	15. Fastening
16. Demagnetization + Rotation of Table	0 h 0 m 23 s	16. Fitting and tightening	16. Fastening
17. Cleaning of Table + Workpiece	0 h 0 m 20 s	17. Cleaning	17. Fastening
18. Rotation of Workpiece using Bridge	0 h 1 m 0 s	18. Fitting and tightening	18. Fastening
19. Setting of Parameters	0 h 6 m 51 s	19. Programming	19. Setting of Parameters

Table 5 shows that, for the 5 setups recorded, the average time was determined as being 19 minutes and 4 seconds, with a standard deviation of 2 minutes and 59 seconds. The general analysis undertaken (see table 6) indicates that improvements should focus primarily on programming operations.

Table 5. Setup Times for the Horizontal Milling Machine (Before) (hh:mm:ss).

Setup Times			
Average Time	Maximum Time	Minimum Time	Standard Deviation
00:19:04	00:22:26	00:15:26	00:02:59

Table 6. Operation Ratios for the Horizontal Milling Machine (Before) (hh:mm:ss).

Operation Ratios:	Maximum	Minimum	Average	Standard Deviation
Inappropriate	00:02:18	00:00:00	00:00:41	00:01:07
Cleaning+Movement of Operator+Transport	00:05:34	00:04:15	00:05:01	00:00:33
Fitting+Positioning	00:07:35	00:02:58	00:05:26	00:01:35
Tool Change+Mechanical Preparation of Machine	00:00:00	00:00:00	00:00:00	00:00:00
Programming+Tuning	00:10:04	00:06:01	00:08:36	00:01:48

4.3 Proposals for improvement

After an in-depth analysis of the previously setups, several proposals for the implementation of changes/improvements were put forward, namely: Alteration of the setup procedures; Assignment of two operators for some of the setup tasks; Alteration of the workbenches (5 s); Alteration in the positioning of key elements required for the setup, thus minimizing operator movement; Creation of pools for the material in use, thus minimizing movement times and facilitating the organization of work. Following the implementation of the above changes/improvements, 5 setups were measured on each machine once again, the results of which are shown below.

4.3.1. Vertical milling machine (after)

Table 7 presents a record of the 5 setups: average time was determined as being 5 minutes and 52 seconds, with a standard deviation of 46 seconds. A new general analysis (see table 8) indicates that the improvements result in time decreases of "Inappropriate operations" and "Cleaning + Movement of operator + Transport".

Table 7. Setup times for the Vertical Milling Machine (After) (hh:mm:ss).

Setup Times			
Average Time	Maximum Time	Minimum Time	Standard Deviation
00:05:52	00:06:56	00:04:40	00:00:46

Table 8. Operation ratios for the Vertical Milling Machine (After) (hh:mm:ss).

Operation Ratios:	Maximum	Minimum	Average	Standard Deviation
Inappropriate	00:00:20	00:00:00	00:00:04	00:00:08
Cleaning+Movement of Operator+Transport	00:04:38	00:02:33	00:03:48	00:00:49
Fitting+Positioning	00:01:13	00:00:02	00:00:34	00:00:24
Tool change+Mechanical Preparation of Machine	00:00:00	00:00:00	00:00:00	00:00:00
Programming+Tuning	00:02:05	00:01:00	00:01:30	00:00:26

4.3.2. Horizontal milling machine (after)

Table 9 shows that, of the 5 setups recorded, the average time was determined as being 8 minutes and 14 seconds, with a standard deviation of 1 minute and 44 seconds. A new general analysis (see table 10) indicates that the improvements result in time decreases of "Inappropriate operations" and "Programming and tuning".

Table 9. Setup times for the Horizontal Milling Machine (After) (hh:mm:ss).

Setup Times			
Average Time	Maximum Time	Minimum Time	Standard Deviation
00:08:14	00:10:07	00:06:10	00:01:44

Table 10. Operation ratios for the Horizontal Milling Machine (After) (hh:mm:ss).

Operation Ratios:	Maximum	Minimum	Average	Standard Deviation
Inappropriate	00:00:00	00:00:00	00:00:00	00:00:00
Cleaning+Movement of Operator+Transport	00:07:42	00:04:19	00:05:30	00:01:09
Fitting+Positioning	00:02:04	00:00:11	00:01:01	00:00:40
Tool Change+Mechanical Preparation of Machine	00:00:00	00:00:00	00:00:00	00:00:00
Programming+Tuning	00:02:50	00:00:13	00:01:43	00:00:55

5. Results and Discussion

The balance of the SMED carried out on the vertical milling machine is extremely positive. Once an initial analysis was undertaken, one was able to define and implement new procedures and improvements for the workstations. It was thus possible to reduce the average time required for setup by about 40%, as is illustrated in Table 11. The initial average of 9 minutes and 51 seconds decreased to the current average of 5 minutes and 52 seconds (see Fig. 2).

Table 11. SMED Improvements for the Vertical Milling Machine.

	Before (mm:ss)	After (mm:ss)	Difference
Average	09:51	05:52	-40,44%
Maximum	12:36	06:56	-44,97%
Minimum	08:01	04:40	-41,79%
Standard Deviation	01:44	00:46	-55,77%

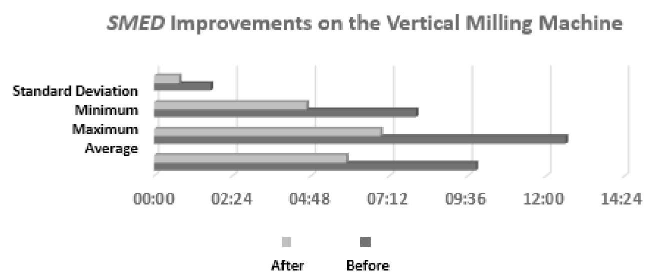

Fig. 2. SMED Improvements for the Vertical Milling Machine.

The balance of the SMED carried out on this machine is positive. Following a prior analysis, one was able to define and implement new procedures and improvements at the workstations. Thus, it was possible to reduce the average setup time by about 57%, as is illustrated in table 12. From the initial average of 19 minutes and 4 seconds, the current average is now 8 minutes and 14 seconds (see figure 3). The results obtained are in line with the ones achieved by Sousa et al. [17] regarding the SMED methodology application to equipment devoted to composed cork stoppers production, who obtained 55% of changeover time reduction through the analysis of the process and changing some internal activities to external ones, shortening the setup time and improving the flexibility of the process. Another work presented by Martins et al. [18] also achieve setup time reductions higher than 50% in the electron-beam welding process of battery cables for motor vehicles. In this case, the study of the surrounding devices was crucial to optimize the setup time and increase the process flexibility. Regarding also the automotive industry, Rosa et al. [19] were able to reduce the setup time by 58,3% in the manufacturing process of wire-ropes for motor vehicle door drive cables. Together with other Lean tools, in addition to saving time and increasing flexibility, it was possible to assign the setup operations to the employees of each of the production lines, without the need for specialized technicians to make the setups and tune the workstations. In an analysis carried out over five years, setup time related to the printing process in the graphics printing industry was also reduced by between 25 and 35%, as reported by Moreira et al. [20], through systematic analysis of the different product change activities in the manufacturing process, in which case it was necessary to act in a broader way, changing some consumables used. In fact, from the presentation of the SMED methodology [16] to the present, there are countless successes achieved through this tool [21], allowing to meet the flexibility that the market demands, meeting a growing demand for increasingly personalized products, and imply the production of smaller series, and shorter setup times [22, 23].

Table 12. SMED Improvements for the Horizontal Milling Machine.

	Before (mm:ss)	After (mm:ss)	Difference
Average	19:04	08:14	-56,82%
Maximum	22:26	10:07	-54,90%
Minimum	15:26	06:10	-60,04%
Standard Deviation	02:59	01:44	-41,90%

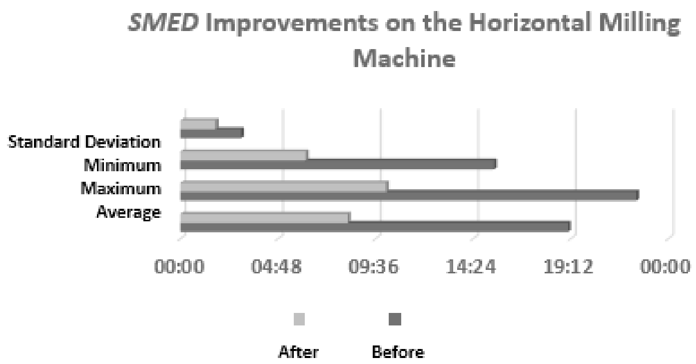

Fig. 3. SMED Improvements for the Horizontal Milling Machine.

6. Conclusions

Currently, the industry is undergoing considerable development and is increasingly tending towards digitalization and automation (designated as Industry 4.0). However, since the profitability of the sector analyzed in this study does not allow for great investments, simple changes had to be made to generate high gains. This study has demonstrated that with the involvement of all the staff concerned, even those who carry out manual tasks, and with little investment, significant gains can be achieved. It was also proved that the use of one single Lean tool is rather ineffective; instead, one ought to use several of these tools, while simultaneously complementing them with related concepts. Finally, the combination of all the tasks and work carried out allowed for a 40% reduction in setup time on the vertical milling machine, and 57% on the horizontal milling machine.

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