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Article

Setup Time Reduction of an Automotive Parts Assembly Line Using Lean Tools and Quality Tools

Cátia Oliveira [1] and Tânia M. Lima [1,2,*]

[1] Department of Electromechanical Engineering, University of Beira Interior, Rua Marquês de D'Ávila e Bolama, 6201-001 Covilhã, Portugal; meneses.oliveira@ubi.pt
[2] C-MAST-Center for Mechanical and Aerospace Science and Technologies, Rua Marquês de D'Ávila e Bolama, 6201-001 Covilhã, Portugal
* Correspondence: tmlima@ubi.pt

Abstract: The business world is becoming more competitive. Therefore, it is crucial to increase the flexibility of production by decreasing the time used in the processes of preparing the production lines for new items' production, reducing changeover and setup times. This paper presents a case study where the main goal is to reduce the setup time of welding robots. Single Minute Exchange of Die (SMED) was implemented, using other tools such as the Spaghetti Diagram, ERCS Analysis (Eliminate, Rearrange, Combine, Simplify), Gemba Walk, Standardized Work, Flowcharts, and Pareto Diagram. The setup time decreased by 36% in the welding robots studied, decreasing the motions by 43% during the changeover process and reducing the time from the categories: "transportation", "main", "other", and "waiting". In addition to SMED implementation, this study offers an integrated study of several Lean tools and Quality tools to achieve the maximum reduction of changeover and setup times.

Keywords: Lean manufacturing; SMED; automotive industry; ERCS analysis; Spaghetti Diagram; Gemba Walk

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1. Introduction

Competitiveness in the industry is increasingly intense, especially in the automotive sector. Companies need to reduce costs, optimize production, and need to achieve products with higher quality to become more competitive [1,2]. To reach these goals, companies adopt the Lean manufacturing philosophy, which focuses on eliminating waste [3].

Nowadays, customers value products with higher quality, lower cost, and higher variety. Therefore, processes must become more flexible and efficient to meet the demand of product diversification and smaller batch production. It is mandatory to differentiate and thrive in an increasingly competitive and saturated market [4].

Production time and the diversity of items have become a new critical factor for the profitability of today's companies [5]. When the item to be fabricated changes, it is necessary to prepare the production line for the new fabrication. It is important to perform adjustments to equipment, change tools, and prepare raw materials. These are activities that do not add value to the final product. However, they are extremely important for ensuring their proper manufacturing [4]. The faster the changeover process is, the greater capacity there will be to respond to market needs, and the more flexible a company will be. This means that the number of changeovers can increase and it is possible to offer more variety of products and batch sizes [5].

The case study presented in this paper was made in a factory in the automotive sector. The factory has three similar production lines A, B, and C, where two of them spent about 40 min doing the changeover process and the other one was around 90 min. The production line chosen was the production line B; it was the one with a higher changeover time. The main goal of this paper is to reduce the welding robot's setup time of the production line chosen.

This paper starts with a literature review of the Lean Manufacturing Philosophy and Quality Tools. This provides background knowledge to define the problem presented and to find a solution to solve it. Then, the case study and the methodology used to solve the problem are presented just as the results and the discussion. Finally, a conclusion is made, where all the limitations of this study as future proposals can be read.

The study in this paper was not just an implementation of SMED. All the tools used served to underpin SMED and make the results even smaller. Tools such as the Spaghetti Diagram, Gemba Walk, Flowcharts, ERCS analysis, and Pareto diagrams led to improved efficiency and a swifter implementation of the SMED methodology.

Lean Manufacturing Philosophy aims to maximize the value from the customers' point of view by offering items with higher quality. To achieve this goal, it is necessary to eliminate waste as much as possible, contributing to the increase of the processes' flexibility and efficiency [6,7]. Therefore, this philosophy has the objective of reducing costs (maintaining the products' high quality), eliminating waste, and enhancing customers' satisfaction [8].

The seven wastes of Lean are [7–9]:

- Overproduction: It occurs when the offer (quantity of products manufactured) is higher than the demand by customers. Overproduction leads to waste like production costs for goods that are not in demand, time, space used for storage, and transportation costs;
- Waiting: It is when an operation is stopped waiting for the conclusion of the previous ones. It also occurs when operators wait for a machine to finish its job, wait for orders, or wait for tools;
- Transportation: It happens when materials and tools are moved from one site to another, with no need. This type of activity does not add value to the final product and generates costs;
- Over-processing: This occurs when offering products comes with more characteristics than customers' requirements, and when there are more operations in a product fabrication than necessary;
- Motion: It occurs when some equipment or people are in motion without making operations. It includes motions, such as walking, looking for tools or information, and reaching and stacking parts or tools. There should be plans in action in every workplace to eliminate unnecessary movement;
- Inventory: It occurs when an excess of stock is not used for production, including raw materials or intermediate products. It can lead to longer delivery times, obsolescence of materials, transportation and storage costs, and damaged goods;
- Defects: It happens when products do not have the characteristics required by customers. These problems result in internal quality issues and cause wasted handling, time, and effort;

Below are presented all the Lean tools that seem to fit with the objective in the available time:

- SMED: It decreases the time used to prepare the production line and equipment to produce a new product, reducing setup and changeover times, and contributing to a quick and efficient change [6,10]. Setup time is the time of preparing machines or tools, and is also the time between the previous compliance item's part fabrication and the next compliance item part [11]. Changeover is all the activities of a production line preparation, and is the time between the previous compliance product and the next compliance product [6,11].

  The time spent performing the changeover is considered waste according to the Lean philosophy because changeover does not add value for the customer. Its elimination brings numerous advantages, such as stock reduction, increased production capacity, elimination of setup errors, improved quality, reduced production time, reduced production costs, and simplified use of tools [11].

- Gemba Walk: It occurs when someone goes to the shop floor to watch what is going on. It is essential to go to the local site where everything is made, watch and take notes about the process, and talk with people. By visiting the shop floor, you can find crucial information for eliminating problems such as cycle times, waiting times, stocks, and rework. It enables management to understand their employees' daily challenges, allowing leaders to have two different points of view: the management view and the operational view [12–14].
- Eliminate, Rearrange, Combine, and Simplify (ERCS) Analysis: It is used to analyze the processes and consists of eliminating all the non-value-added activities, rearranging the operations made, combining operations that can be conducted together, and simplifying all the tasks as much as possible to simplify processes [15,16]. The ERCS acronym is explained below [15,16]:
  - E: It is the elimination of all non-value-added activities;
  - C: It is the combination of two or more operations;
  - R: It is the reorganization of the processes sequence;
  - S: It is the simplification of operations, becoming easier to perform.
- Standardized Work: It is a set of working instructions and sequences of all the operations that establish a uniformization of all activities performed [17,18]. This documentation defines the optimal way of carrying out tasks and leads to increased quality levels, reduced variability, reduced injuries and strain, standardized takt-time, and it can also be a starting point for continuous process improvement activities [18,19]. The main objectives of Standardized Work are individual responsibility, experiential learning, and discipline in execution [17].
- Spaghetti Diagram: The representation of all motions in a workplace, including people motion, materials, or tools transportation [20,21]. The representation in the layout allows the identification of the process inefficiency so that unnecessary motions can be identified and eliminated, reducing or eliminating motion waste. It is also a tool used in the proposal of representations for improvement related to movements, such as reorganizing the layout or eliminating motions [20,21].

Quality can be defined as the level of customer satisfaction, depending on their requirements [22]. Quality tools are applied to obtain improvements in productive processes and quality control. These tools can support the analysis of non-compliance and contribute to defining some actions to be implemented and eliminate the problem's routes [23,24]. According to Djekic and Tomasevic [25], Karou Ishikawa has presented seven quality tools:

- Flowchart: It is a visual representation of all steps from a work process, leading to an easier process understanding [22,24].
- Pareto Chart: It is a graphic that represents the occurrence of events and it is used to categorize and analyze operational performance, challenges, situations, and causes. The Pareto principle holds that 80% of defects are determined by 20% of causes [25,26].
- Check Sheet: It is a tool used to collect and record data so that they can be further analyzed. These sheets are presented in simple columns and rows to be easily interpreted by everyone [27,28].
- Histogram: It is a bar chart that translates the shape of the data distribution [28].
- Control Chart: It represents the position of a sample relative to the mean [27].
- Fishbone Diagram: It shows the causes of a given problem, defining corrective actions to undertake and resources to invest [29].
- Scatter Diagram: It shows a potential relationship between some values employing a graph containing all the values [27].

To achieve the best solution to the main objective of the case study presented in this paper, other case studies performed in the automotive industry were reviewed. In the literature, SMED is usually used to minimize the time to prepare the production lines. Some cases also use the Pareto Chart to verify the most critical operation during changeover time.

Analyzing the case studies, it could be observed that conventional SMED is performed in five steps [11,30–32]:

1. Data collection (video recording for analysis if possible);
2. Classification of internal and external activities;
3. Conversion of internal activities into external ones;
4. Simplification of setup tasks;
5. Analysis of results.

The cases that only used task reorganization achieved improvements by 30%, so if this value was accomplished in this study, it would be a success [11,30]. It was also noticed that Quality and Lean Tools could boost the decrease in setup time. In the same case study, the use of conventional SMED reached a 50% improvement, and using other lean tools reached 62% [33].

This study is further than a SMED implementation to reduce setup time. It was developed involving several Lean and Quality tools to decrease the setup time as much as possible. This is a relevant study because companies must minimize their production line preparation time to become more competitive and survive in the market.

2. Materials and Methods

This study was developed in a factory that produces automobile parts formed by several welding robots and its focus is to reduce the setup time of two of them. When a new product is ordered, all production lines need to do their preparation as fast as possible. The factory has three similar production lines: A, B, and C. A and C spent around 40 min doing their changeover, while B wasted around 90 min. The production line presented in this paper is line B. It was chosen because it was the one with the highest changeover time.

The changeover process in the welding robots consists of exchanging the welding tool used to fabricate the previous product for a tool that will be used to produce the next product. To exchange from one tool to another, it is necessary to unscrew the screws that fix the tool used to fabricate; clean the tool; transport the previous tool to a specific spot; transport the next tool to the welding robot; and screw the screws.

All the steps performed to achieve the main goal of this case study are described as follows:

1. Go to the shop floor to watch all the processes: Communicate with people, and do a flowchart about the process. As Gemba Walk indicates, it is important to be where everything is made. This step will help to understand the production line requirements and what needs to be changed when a new product has to be fabricated;
2. Data collection by video recording: Watch the video and list all the activities and their times and draw the Spaghetti Diagram;
3. Split the tasks mentioned into four categories: The categories are transportation, waiting, main, and other. Transportation and waiting are two of the seven wastes considered by Lean, as explained before. The main tasks are the ones where it is crucial to change the tool when it is necessary to fabricate other different products (it is screw and unscrew the screws). "Other" is a category to include all activities that do not fit with any of the categories mentioned before, such as cleaning activities or tool adjustments needed before screwing the screws. This is also applied to the four categories presented in Figures 6 and 7;
4. Classify every task as internal or external: Internal activities are the ones made while the setup process is counting and external activities are the ones made before or after the setup/changeover process [5,32];
5. Convert internal tasks into external and do Analysis ERCS: Convert internal tasks as much as possible to reduce the time spent in the changeover. At the same time, it is important to classify every activity into eliminate, rearrange, combine, and simplify, taking into account the explanation made before;

6. Do a Pareto Chart: To observe the most critical operation;
7. Define an action plan: Where every step presented before has to be considered as well as all the perceptions felt while the setup was being performed. In this case, it was noticed that the worker did not know where the materials used to change the tool were and there were a lot of motions and transports to pick up all the materials. The responsibilities of each worker were not defined and there was no transportation tools flow (racks used during the manufacturing process are in the production line, and there was no space to move the tools). Therefore, the action plan must include: a list of tasks for the worker, a changeover trolley/rack with all the necessary materials to perform the setup, and a reorganization of the production line before setup starts.
8. Repeat the setup and collect new data: Repeat steps 2, 3, 4.
9. Analysis of the results. In this step, a dashboard was made to have a better and easier understanding of all the improvements made. This dashboard is shown in Appendix A.

3. Results

In this chapter, all the results obtained in this study are presented. The Spaghetti Diagram, Internal and External Activities, Process Category, and Setup Time will be shown.

3.1. Spaghetti Diagram

Figure 1 shows all the motions without materials/tools (red) and transports of materials/tools (blue) performed in the first setup. To compare all the movements completed in the second setup in Figure 2, by observing the two figures, it can be proved that all the motions and transports have been reduced from 54 motions to 31 and organized. It was verified a 43% decrease in all motions. In Figures 1 and 2, black boxes represent the place where the changeover material is. It is shown that the material used in the changeover was placed all together, and due to this change, it is possible to pick up the changeover material before the setup process starts. Therefore, this has contributed to the motion reduction.

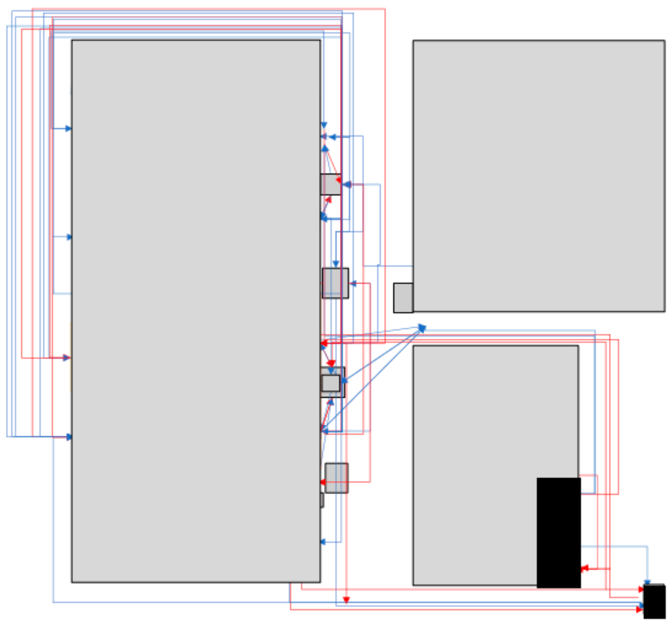

Figure 1. Spaghetti Diagram in the first setup.

3.2. Internal vs. External Activities

Figure 3 presents the number of internal and external activities comparing the first setup with the second setup. Internal tasks are those executed during the changeover period and external tasks are executed outside the changeover period [5,32]. The internal tasks converted into external ones are all related to the preparation of every material used in the setup process before the process starts; this is the preparation of cleaning material and the keys used to screw and unscrew. Unscrewing or screwing the screws, and transporting and cleaning the tools, are internal tasks that are impossible to convert into external tasks because it is impossible to perform these activities while the robots are running. Figures 4 and 5 show the percentage of internal and external tasks in the first setup and the second setup, respectively. The number of external activities has increased from 1 to 3 tasks, increasing their importance from 1% to 6%. The number of internal activities has decreased from 93 to 44, decreasing their significance from 99% to 94%.

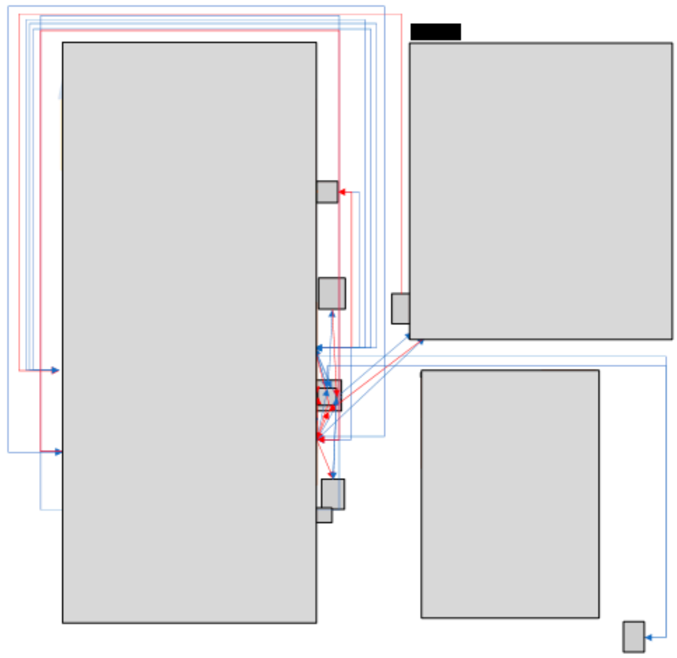

Figure 2. Spaghetti Diagram in the second setup.

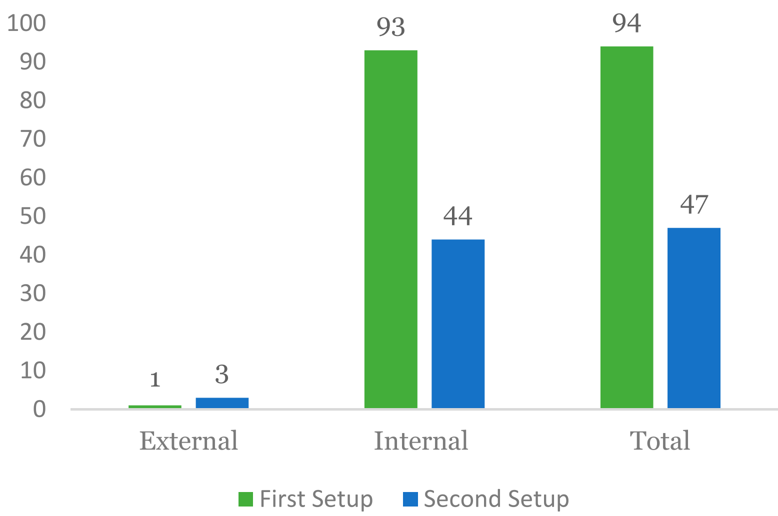

Figure 3. Number of internal and external activities in the two setup processes.

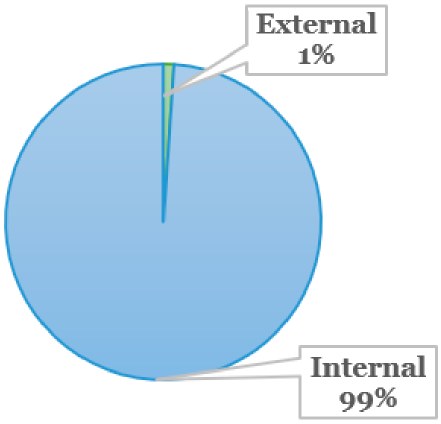

Figure 4. Percentage of internal and external activities in the first setup.

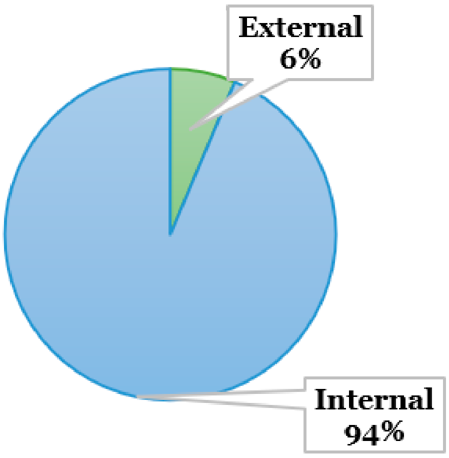

Figure 5. Percentage of internal and external activities in the second setup.

3.3. Process Category and Setup Time

Figure 6 presents the time difference, in seconds, spent in setup by the four categories selected: transportation, main, other, and waiting. Figure 7 shows the difference in percentage in each correspondent category.

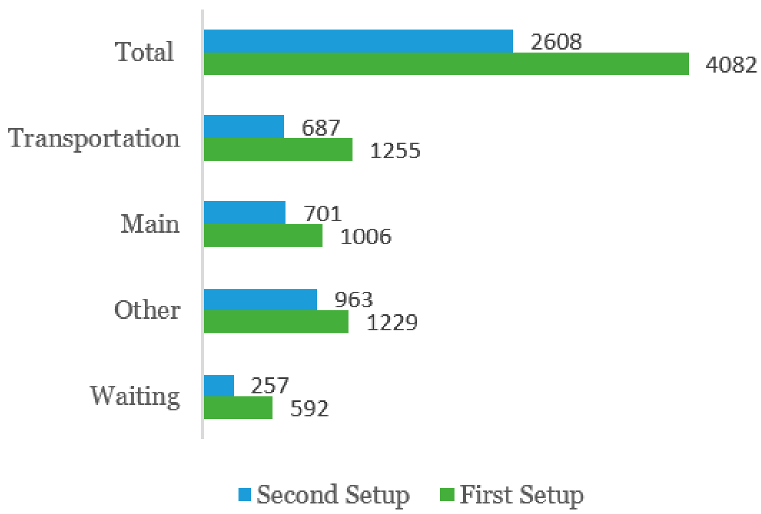

Figure 6. Spent time by each category in seconds.

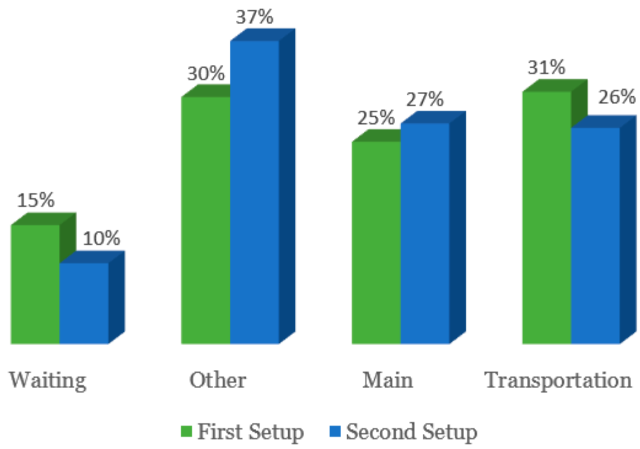

Figure 7. Process category in percentage.

The total time of SMED in pre-implementation was 4082 s and in post-implementation was 2608 s. It can be observed that every time spent in each category has reduced. The bigger reduction was in transportation and it can be due to the reduction of motions and transportation shown in Spaghetti Diagrams above. Transportation and waiting have decreased their weight in the total setup time, at the same time the main and other categories have increased.

3.4. Standardized Work with Takt-Time

Takt-time is the frequency with which the product or part of the product is required by the customer, relating the time available to the customer demand. It is the ratio of available time to consumer demand [3].

Standardized work was implemented by applying a list of tasks, such as: taking the wrench to loosen the screws; loosening all the screws counterclockwise; adjusting the new tool to the robot; and tightening all the screws.

The fact that the setup time has been reduced means that the time available for manufacturing has increased, allowing more products to be manufactured while maintaining the same takt-time. The 24-min reduction in setup time means that 24 more parts can be manufactured without altering the takt-time. In other words, it is possible to satisfy an increase in customer demand.

4. Discussion

The first setup lasted 4082 s and the second setup 2608 s, reducing 1474 s from one setup to another. In other words, the first setup was completed in 1 h 8 min and two seconds, and the second one spent 43 min and 28 s. There was a reduction from 24 min and 34 s. The reduction of setup time by 36% was due to all the steps being performed and explained above. These results were achieved only with task and space reorganization, without any monetary investment.

There were recorded 94 tasks performed by the operator before the SMED implementation. After implementation, a total of 47 tasks were recorded, and there was a reduction of tasks performed by 50%. In pre-implementation, there was only one internal task and 93 external tasks and in post-implementation, there were three external tasks and 44 internal tasks. In terms of percentage, it can be seen that there was an increase in the weight of external tasks from 1% to 6%. Although the increase in external tasks was not very strong in quantity, it represented 5% more of the total tasks than before.

The importance of the main activities was demonstrated, and the “other” category increased its weight, in the total setup time. As can be seen in Figure 7, the main activities increased their importance in the total setup time from 25% to 27% and the “other” activities from 30% to 37%.

The main activities are all the tasks that allow the preparation of a machine for the production of the new reference, so the weight increase of this activity in the total setup time is quite positive. It means that this activity started to have more representativeness in the total setup time. The activities classified as "other" are also important because they assist the main activities and, by assuming greater importance in the total time, indicate that there was an improvement associated with the implementation of SMED. The increases in the importance of these categories in the total setup time represent a positive balance, as it is highlighted that the indispensable activities are increasing their importance in the setup. However, it would be even more beneficial for a higher setup time reduction if the activities of the "other" category reduced their weight in the setup time, and the activities of the main category increased their importance even more.

5. Conclusions

This SMED implementation was a success. The reduction reached had a good value, taking into account that the measures implemented were only about the reorganization of tasks and the workplace. In the analysis of the case studies, it was verified that the application of SMED using only task reorganization measures returns results of around 30%. Therefore, it can be concluded that the reduction of 36% of the robots was successful, having reached the expected values. The conversion of internal tasks to external tasks was not significant to achieving these improvement values, although it also contributed.

The main activities and "others" have increased their relevance in the setup time, while the others reduced it. This represents an improvement in the process since they are essential activities in the preparation of the machines for a new reference and are the ones that occupy more of the setup time. However, it is important that the activities of the category "others" are reduced so that the main activities occupy even more time of the total time.

Therefore, the implementation of SMED led to numerous benefits through the reduction of changeover time, such as cost reduction and increased process efficiency. It can then be proven that SMED was successfully implemented. These results demonstrate the importance of implementing Lean tools and methodologies in companies to increase their competitiveness in the market.

The limitations of this study are related to data collection. Data were only collected once after implementation, and to obtain results more reliably, it would be better to repeat the setup process and do this analysis again. The available time to perform this study was also seen as a limiting factor since it was not possible to make a monetary investment to boost the time decrease.

In the future, it would be interesting if this methodology was implemented in other factories of other sectors to optimize and increase their efficiency. To improve the analysis conducted in this case, it would be valuable to do a financial analysis.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

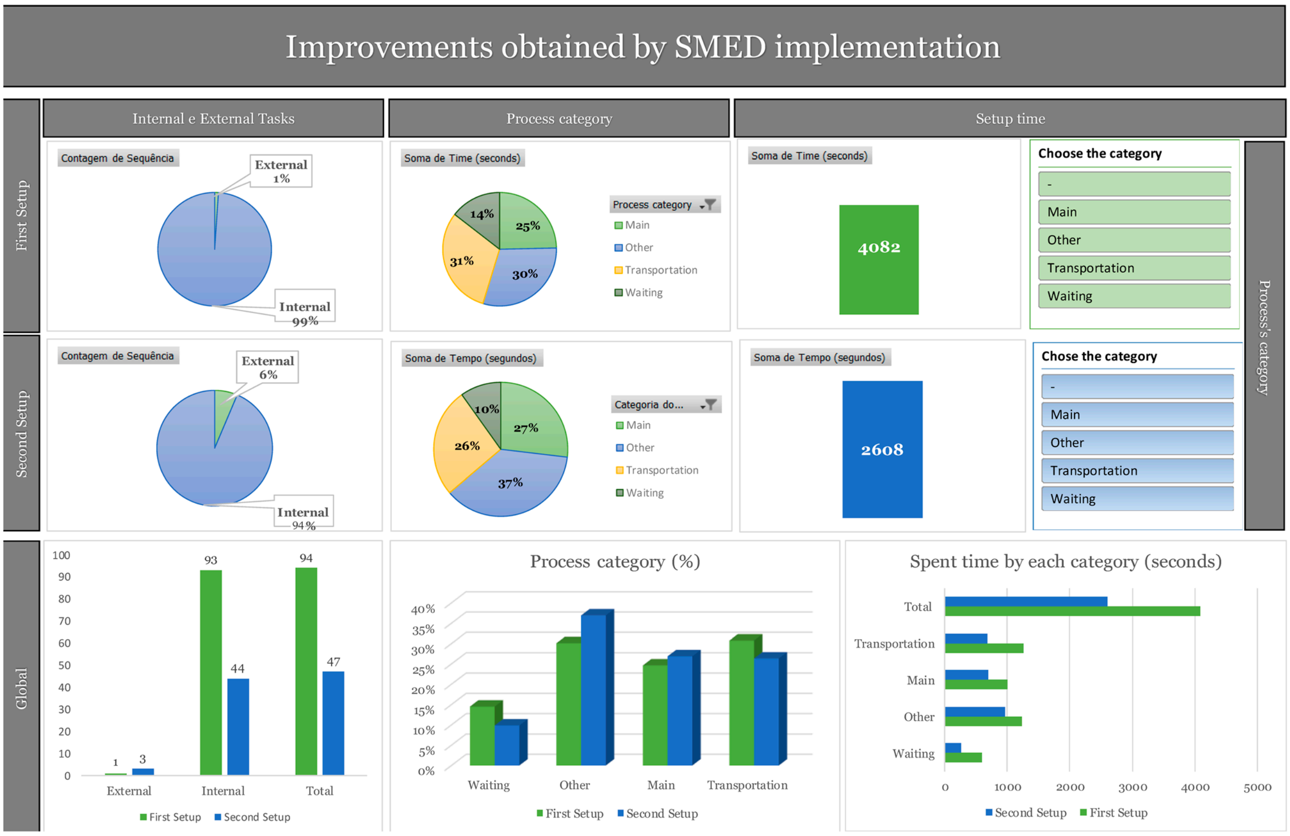

Figure A1. Results Dashboard.

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