Applying Single Minute Exchange of Die – SMED methodology for the optimization of changeover times: A focused-on-practice research

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Abstract: Nowadays companies and manufacturers are increasingly looking for a high level of quality and flexibility in production, reducing at the same time production costs. The purpose of this work is to improve the set-up phase of a welding process through the application of Lean methods. Within the case study, the working conditions of a welding station have been analysed by using the spaghetti chart to detect those activities that may not add value to the process. Then, the Single Minute of Exchange of Die (SMED) technique was applied to reduce changeover time. One of the main results is a reduction of more than 45% over the total shift work time. The use of a stochastic simulator allowed to appraise the other reductions of process times and to detect other non-value-added activities, thus improving the efficiency of the process and increasing production capacity.

Keywords: Lean tools, Single Minute Exchange of Die, set-up time, Non-Value-Added activities

I. INTRODUCTION

Global competitiveness leads customers to ask for customized products, with exclusive details that meet specific and personalized needs [1]. To achieve this matter, it is necessary to increase the flexibility of production by producing in smaller batches [2]. [3] find the solution to this problem with the implementation of lean production tools. However, this type of production is closely related to an increase in the frequency of tooling [4]. Hence, companies are compelled to find a way to reduce setup times, eliminating at the same time all types of wastes, as well as limiting activities without real added value. [5] state that a fundamental methodology for the improvement of production processes and flexibility is the Single Minute Exchange of Die (SMED). This methodology is part of the lean production philosophy [6][7]. It aims to reduce wastes in the production system and to standardize setup times.
The present study was developed to improve a welding process by reducing its setup times.
The first objective of the study was to design the spaghetti chart of the area, then the SMED methodology was implemented, with the help of a simulator. The remaining of the paper is as follows. After introduction, Section 2 provides a brief review of the literature on Lean Production and the SMED methodology.
Section 3 describes the methodology used within the study, while Section 4 presents the problems identified, as well as the suggestions for improvement. In section 5 the results obtained are shown. Finally, in Section 6 the conclusions will be presented, describing how this study has strongly contributed to the reduction of changeover times.

II. LITERATURE REVIEW

One of the six big losses for production is setup time. [8] consider the setup time elapsed between the production of the last product of a series and the production of the first product of the new series to be a waste or an additional cost. They also classify the main reasons for the reduction of setup times into three main groups:

• Flexibility: Due to the large number of existing products and decreasing quantity, companies need to react quickly to customer needs. Therefore, if we need to produce in small batches, it is essential that these tools make the switch as fast as possible.

• Bottleneck Capacity: Especially in certain machine tools, every lost minute is a big waste. The changeover must be minimized to provide an increase in production capacity.

• Cost minimization: production costs are directly related to equipment performance.

Firms need to pursue product compliance along all the phases of product lifecycle, to reduce development time and development costs to achieve continuous improvement of processes and products [9]. This issue is also relative to production setup, in which a wrong setup may conduct to non-conformities that may also compromise product safety. As well known, since small batch production involves a significant increase in set-up frequency, a quick setup process is required. This may ensure an adequate answer to the flexibility requested by production demand diversification [10].

There are different methods and strategies that companies can use to reduce wastes. One of the most popular methods is the Single Minute Exchange of Die or SMED, which allows to evaluate the problem of reducing the setup time, exchange, setting up of the equipment [11]. The SMED methodology was developed by Shigeo Shingo as a way to respond to the emerging need of the Japanese automotive industry to reduce batch sizes [12]. This methodology, part of Lean production philosophy, supports organizations in the reduction of setup times and in the elimination of wastes identified in the changeover operations. A typical example of waste is changeover, as it is a value-added activity that may involve several hidden costs [8]. This time is defined as the time it takes to set up a certain production system to make a different product with all its requirements.

Furthermore, the implementation of SMED requires a preliminary analysis to clearly understand the format change process, in order to know in detail each configuration operation [13].

[14] use this technique as an element of Total Productivity Maintenance (TPM) and of the “continuous improvement process”. The application of SMED methodologies is an effective way to analyze, improve and reduce existing processes used to change production equipment. With this work he demonstrated that it is possible to reduce the amount of time needed to run a step, as well as the amount of direct labor required to run a step through process improvement.

The one-minute mold swap is an important lean tool to reduce waste and improve flexibility in manufacturing processes, enabling batch size reduction and production flow improvement. Furthermore, through the SMED technique there is a reduction in non-productive times by rationalizing and standardizing the operations for the exchange instruments by means of simple techniques and easy applications. These authors also state that the SMED methodology can be combined with other classical methods, providing positive results for companies. Methods such as graph and statistical analysis allowed the identification and separation of different analytical groups, as well as to sport out the added value of the traditional SMED methodology.

III. METHODOLOGY

The research methodology developed for this focused on practice work, is divided into different phases according to figure 1.

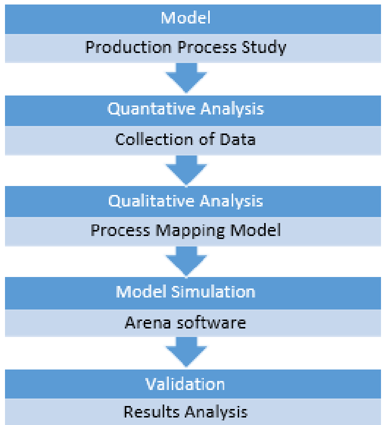

Fig. 1. Proposed model

A brief overview of the principle used in this research work is provided, followed by background information on the company where this study has been conducted.

The research conducted on field has been implemented on a workstation dedicated to the assembly of Eurocargo pipes (Fig. 1). This workstation is composed of a robot, a leak testing area and a cooling area. The products assembled are different, and each of them requires specific components and calibration equipment.

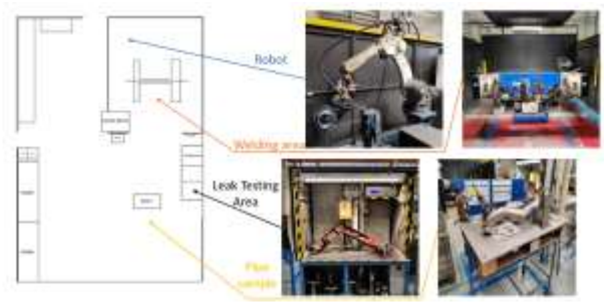

Fig. 2. Layout

The changeover data are referred to a one-month of production. These data depict the as-is situation have been grouped by working weeks (Fig. 3):

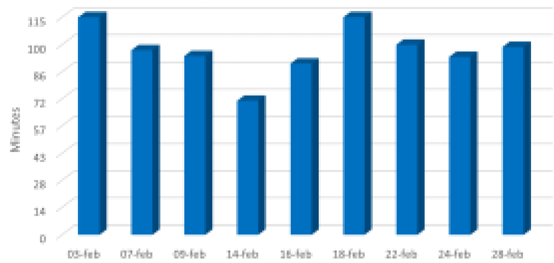

Fig. 3. Changeover time for one month.

Each activity carried out by the operator has been analyzed by video, as shown in fig. 4 to appraise and report its duration.

Fig. 4. Leak test area

Activities resulting from errors or production issues have been eliminated by the improvements presented in the next section. These data are shown in red. In contrast, the activities shown in yellow are necessary in the setup operations, but for these activities we may focus for improvement actions within the SMED principles.

TABLE I
LIST OF OPERATIONS

Activity	Duration
Moving pallets and crates	00:00:38
Removing cable ties	00:00:29
Cleaning welding bench with blowgun	00:00:46
Picking up gloves and hex keys	00:00:16
Bolts removal	00:04:18
Retrieving tools	00:00:05
Pins removal	00:00:31
Picking up cleaning equipment	00:00:08
Cleaning welding bench	00:03:33
Unplugging and loading pallet on shelf	00:01:36
Cleaning pipe sample	00:02:25
Loading/Unloading pipe sample	00:01:53
Moving pipe sample on trolley	00:01:53
Loading/Unloading pallet	00:02:44
Placing table in workstation	00:02:00
Positioning bench	00:01:21
Picking up wrenches	00:00:17
Bolts tightening	00:08:52
Loading/Unloading pallet	00:01:51
Positioning bench and tightening bolts	00:06:25
Retrieving cable ties	00:00:24
Wrapping cables	00:02:02
Retrieving tools	00:00:19
Setting up robot - change of side	00:01:37
Retrieving tools, unplugging	00:01:04
Cleaning welding bench with blowgun	00:00:43
Locating forklift	00:01:18
Bolts removal (right side)	00:02:20
Cleaning welding bench (right side)	00:01:57
Loading/unloading pallet (right side)	00:01:14
Bolts tightening (right side)	00:03:14
Wrapping cables (right side)	00:01:36
Bolts removal (left side)	00:02:25
Loading/unloading pallet (left side)	00:01:06
Retrieving wrench (outside the workplace)	00:00:18
Pins removal (left side)	00:00:50
Cleaning welding bench (left side)	00:02:14
Loading/unloading pallet (left side)	00:01:47
Bolts tightening (left side)	00:01:44
Connecting cables	00:01:15
Returning wrench (outside the workplace)	00:00:30
Returning tools	00:00:29
Disassemblying leak test area	00:03:17
Cleaning leak test area	00:00:21
Assemblying leak test area	00:12:14
Loading misplaced sample in warehouse	00:01:34
Closing activities	00:00:50
Overall time	**01:30:43**

As shown in table 1, about 60% of the setup time is relative to changeover time. The graphic method used to depict the as-is situation is the Spaghetti chart.
Spaghetti chart is a method to draw the path and distance travelled of a facility or operator throughout a process. The main reason to create a spaghetti chart is to document the as-is movement of work and people. It gives an idea of the distances traveled and the number and places that the operator must reach. Figure 5 is a spaghetti chart showing transport wastes, giving a bird's eye view of our operations which we rarely encounter on a day-to-day basis.
The Operator flow during each operation was detected; different colors were assigned to separate each operation flow.

Fig. 5. Spaghetti Chart of as-is scenario.

From these diagrams it is possible to see the need to optimize and rationalize the movements of the operator. In particular, the most time consumed on a single activity refers to the preparation of the pipe sample, with a duration of 6 minutes and 11 seconds.

IV. SMED IMPLEMENTATION

The SMED implementation in this work is based on the original procedure established [15] following three steps: Separate, Convert and Streamline. In the initial stages of the project the relevant data were collected. first, the most complex types of changeovers were recorded.
Furthermore, many additional recordings of individual operations, such as pipe sample displacement, forklift recovery, etc. were made. To implement the first phase, it is useful to analyze the setup process more thoroughly. The workstation setup can be divided into three macro-activities, the task of a single operator:

- The replacement of equipment in the welding area;
- The preparation of the pipe sample of the new product;
- The development of the components of the leak testing area.

Considering these activities, the only macro-activity necessary for the start-up and execution of the new production is the preparation of the welding area. A pipe sample is used at the start of the new production shift, to compare the pieces with the standard. The leak testing area is used to test products. In addition, workstation operators tend to place an approximate number of five pieces in the cooling area before gradually starting to test on the bench. Another important information can be found by analyzing the welding process of finished products. Welding operations are carried out exclusively by the robot. The operator is tasked with introducing the components to be welded and verifying the result of the operation. Yet, during the process he may carry out other short operations outside the welding area, because the robot can take up to two minutes to assemble each piece.
After the analysis of the data collected, they have been grouped as regards the various activities, according to Shingo's methodology. As a result of this portion of the research, we sorted out that the preparation of the pipe sample and the leak testing may be considered external activities, thus they can be carried out outside the changeover process. As for the pipe sample, an easy solution is to replace it at the end of the previous production shift, when the test the pieces produced is no longer needed. In contrast. the leak testing area may be set after a new production already started, thus getting advantage of the operator downtime. In this case it may be necessary to delay the start of the leaking tests compared to the as is situation.
At this step of the research a quantitative analysis is needed to assess the overall impact of manufacturing activities, as well as the possible benefits of potential improvements. Analysis can be applied at different resolution levels to derive opportunities incrementally [16]. For this step a stochastic simulator has been used to appraise the new setup times, eliminating or reducing critical activities, according to the improvements reported in table 2.

TABLE II
CRITICAL ACTIVITIES

Issue	Solution	Duration	Expected duration
Duration of unloading/loading operations in the warehouse	Avoid placement of crates near the shelves, apply 5S rules to reorganize the warehouse	180 seconds	60 seconds
Wasted time on picking up wrench	Duplicate the tool, providing one to each workbench in the plant	45 seconds	Removed
Wasted time on picking up degreaser	Duplicate the tool, providing one to each workbench in the plant	45 seconds	Removed
Duration of leak test area cleaning	Apply 5S rules on the counter, build internal shelves to store the objects now placed on the plate to be cleaned	124 seconds	13 seconds
Time to locate items on the workbench	Apply 5S rules to clean the drawer and dispose of unnecessary tools	60 seconds	30 seconds
Time to disassemble and reassemble the sample trolley	Equip each sample with its clamps	480 seconds	Removed
Time to locate items placed in the trolley	Check compliance of the 5S rules already introduced on the trolley, introduce new containers for frequently used objects	48 seconds	8 seconds
Errors during leak test assembling	Check compliance of the 5S rules already introduced on the lower shelf	260 seconds	90 seconds
Difficulty loading the pipe sample on its trolley	Place oversized pipe samples in more accessible areas of the shelf or introduce a larger trolley	100 seconds	30 seconds
Wasted time on cleaning the pipe sample	Introducing a new compressed air blowgun in the trolley area	144 seconds	67 seconds
Movements to retrieve tools	Introducing tool checklists and retrieving them before changeover starts	150 seconds	20 seconds

After simulation, the second and the third phase of the SMED technique has been implemented. For these phases, it is necessary to act on the internal activities. Various interventions would be possible for the area

object of this simulation. For example, all cleaning activities and the warehouse loading of the replaced equipment could be classified as external and therefore excluded from the changeover process.
These operations could be shifted to the next production raster or be carried out by a second operator.

The to-be process is mapped in Fig. 6, that reports a screenshot of the simulator, implemented with the Arena software. The Delay and Process modules were mainly used to model the activities carried out by the operator and their times, using a sequential approach: these activities are mainly static, and the relative times were similar in the various changeover shifts. Their cycle time was simply calculated from their average value. The transport sequences (Distance and Transporter data modules, Transport, Allocate, Free and Station modules) were adopted to simulate the new movements of the operator. In particular, it was necessary to adapt the real distances and routes within the Arena environment, using the animation entities and estimating an average speed of the operator. Stochastic parameters were introduced in these sequences, in order to model the randomness of the worker's movements: the speed of the operator could be influenced by several factors (fatigue, obstructions, errors…), impacting noticeably the overall time of these activities.

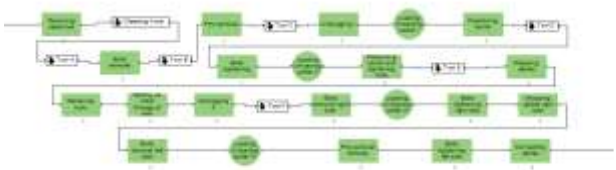

Fig. 6. SMED simulation model in Arena

V. DISCUSSION

After running the simulation of the SMED model with Arena, the results of Table 3 were obtained.

TABLE III
ARENA REPORT, SOURCE: ARENA

Time	Minute
Waiting (min)	1,62
Transfer Time (min)	7,17
Value Added Time (min)	39,2
Overall time (min)	48,54

In addition, the appraised that changeover time after the changes is equal to 48 minutes, which is within the time limit. All the parameters have been entered according to the distributions which have been adjusted with input analyzer tool of Arena, indicating that there is a high level of confidence in the proposed data. Therefore, the proposed methodology is considered operationally feasible and the considerations of the model in question have been taken into account along with the software, the restrictions of the company and work schedule.

The project budget included the purchase of clamps, to simplify the pipe sample preparation, and new tools to shorten waiting times. Furthermore, a new procedure is needed regarding tool recovery. Within this portion of the study we proposed the following steps:

1. The operator picks up all necessary tools beforehand (following a checklist), placing them in the tool trolley (see figure 7, showing an applied solution to one of the critical activities cited earlier);
2. Cleaning activities are conducted on shorter paths;
3. Unnecessary movements to retrieve tools must be eliminated;
4. Alongside the pipe sample and leaking test area preparation, some of the cleaning and warehouse activities were flagged as external, as well as moving pallets and crates and closing activities to streamline internal activities as much as possible.

Before SMED After SMED

Fig. 7. Improvement implemented in the organization of the parts

This process was modeled using sub models in Arena according [17]. It has a deep impact on movement wastes and thus on worker's fatigue and changeover time.
In the simulation, after structuring the conditions and changes of the machine preparation process for the production change in the software, the overall changeover time was reduced from 98 minutes (on average) to 48 minutes, with an overall improvement equal to 46% (figure 8).

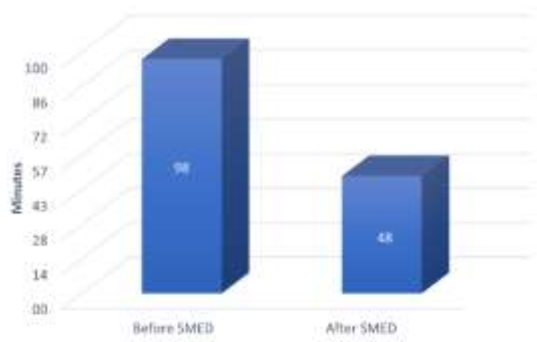

Fig. 8. Comparison before and after SMED

The implemented improvements can also be seen on the Spaghetti chart as shown in figure 9.

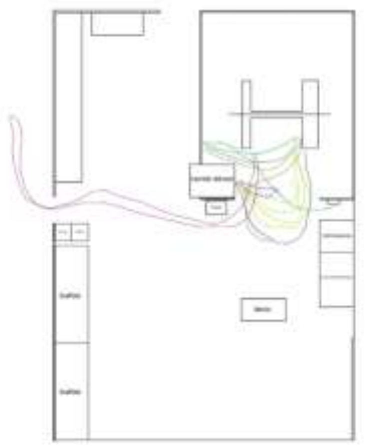

Fig. 9. Spaghetti chart of after SMED scenario

The results are consistent with the data collected, in which the sequences of the process activities were considered. This means that the proposal is technically viable. In addition, the time estimated by the simulator during the running of the model is within the range indicated by the technical specifications of the machine, meaning that there are no problems in the production related to the changeover times after making the improvements.

VI. CONCLUSION

This study described an effective industrial application of the SMED methodology which led to reduction of 46% in the changeover time. SMED methodology was applied to prepare an optimal standard procedure for changeover operations on welding area. The improvements implemented had a positive impact on the process and the main goals were almost achieved. A series of time study data was collected during the setup activities.

All the improvements implemented are only a small step if we consider that there are still many hypotheses to be explored.

However, further changes could be implemented to the process according to the principle of continuous improvement as there are various activities considered internal, which in a future development could still be optimized or even transformed into external activities. For example, the duration of the pallet loading/unloading activities could be reduced or entrusted to an operator other than the one in charge of preparing the welding area.

In terms of future developments, creation of one or more SMED teams might be a future evolution of this work.

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