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Benefits from a SMED Application in a Punching Machine

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***Abstract*—**This paper presents an application of the Single-Minute Exchange of Die (SMED) methodology to a turret punching machine in an elevators company, in Portugal. The work was developed during five months, in the ambit of a master thesis in Industrial Engineering and Management. The Lean Production tool SMED was applied to reduce setup times in order to improve the production flexibility of the machine. The main results obtained were a reduction of 64% in setup time (from 15.1 to 5.4min), 50% in work-in-process amount (from 12.8 to 6.4 days) and 99% in the distance traveled by the operator during the internal period (from 136.7 to 1.7m). These improvements correspond to gains of about €7,315.38 per year.

***Keywords*—**Lean production, setup process, SMED.

I. Introduction

GLOBALIZATION of the market brought the need for companies to present competitive advantages in relation to their concurrence. One of the most effective ways to achieve that purpose is to increase the production flexibility, by producing in smaller batches, to present a high variety of products. However, this type of production leads to a significant increase on the setup frequency. Thereby, according to McIntosh et al. [1], the ability to perform a quick setup process is fundamental to achieve small batch manufacturing and, consequently, good production flexibility. SMED is a Lean Production tool adequate to effectively reduce setup time [2].

This paper describes a SMED implementation in an elevators company, more specifically in a turret punching machine, developed in the context of a master thesis in Industrial Engineering and Management. The objectives defined for the project were: (i) implement a methodology to reduce setup times, (ii) increase the production flexibility, (iii) reduce the amounts of work-in-process (WIP), and (iv) standardize setup activities.

The paper is structured in five sections. After this introduction, Section II provides a brief literature review on Lean Production and SMED methodology. Section III presents the industrial application of SMED in the company. Section IV shows the main results obtained and their discussion. Lastly, in Section V some conclusions are outlined.

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II. Literature Review

Nowadays, companies have to produce according to the needs and requirements of their customers, presenting high quality products with low prices and short lead times. Lean Production appears as a possible alternative to increase the competitiveness of companies, regarding the production systems' performance. This organizational model aims at identifying and eliminating waste (in a systematic way), through continuous improvement, enabling increased flexibility of organizations [3]. Ohno [4] defines the concept of waste as any activity that does not add value to the product in the customer's perspective and considers seven types of waste: overproduction, inventory, waiting, defects, over-processing, motion and transports. To reduce those wastes, Lean Production offers a large set of tools and techniques that can be applied in companies (e.g. SMED, 5S, Standard Work, and Value Stream Mapping).

The SMED methodology encompasses a set of techniques aiming to achieve setup processes in less than ten minutes [2]. A setup represents the complete process necessary to change from the production of a product to the production of a different product, with adequate quality and production rate [5]-[7]. The implementation of SMED involves a detailed analysis of each setup operation [8]. Shingo [2] refer that the setup operations can be divided into two types: (i) internal operations, which can only be performed while the machine is stopped, and (ii) external operations, which can be performed while the machine is operating. To apply this methodology, four distinct stages have to be considered: (i) preliminary stage (identification of setup operations), (ii) stage 1 (separation of internal and external setup), (iii) stage 2 (conversion of internal into external setup), and (iv) stage 3 (rationalization of internal and external setup).

SMED can bring many benefits for a company, such as, reductions in terms of stock, WIP, batch size and movements, and, improvements on quality and production flexibility [2], [9]-[11].

Many examples of the application of SMED can be found in literature to prove that this methodology can be applied in various types of industries. A case of a pharmaceutical company is presented in Gilmore and Smith [12] where it was possible to reduce the setup time from 28.8 hours to 8.25 hours with the implementation of SMED. Trovinger and Bohn [13] report a case in an electronic printed circuit board (PCB) assembly line where savings of 1.7 million dollars per year were achieved, by reducing setup time on 85%. The effectiveness of applying SMED in a semi-automatic system was proved in the work of Tharisheneprem [14] where the setup time was reduced from 84 minutes to about 1 minute. Sousa et al. [8] also described the setup process improvement in a painting line of a wooden frames company, demonstrating that practically no monetary investments would be needed to reduce setup time by about 36 minutes. There are many other examples of SMED applications such as the ones presented in Patel et al. [15] in the aerospace industry, in Moxham and Greatbanks [16] in the textile industry, in Perinic et al. [17] in the automobile industry, in Singh and Khanduja [18] in the foundry industry, and in Fritsche [19] in the electrical components industry.

III. Industrial Application

As previously referred, this project was carried out in the metal-mechanic area of an elevators company and consisted in the setup process improvement of a turret punching machine (Fig. 1).

Fig. 1 Turret punching machine

Due to the large quantity of products involved, and consequently to the large amount of different setup processes, it was necessary to focus the study on a single product. The strategy adopted was to select the product that required the installation of the largest number of tools (matrices and punches) in the turret of the punching machine. The punching machine can accommodate eighteen different tools and the only product that needs the totality of them is the cabine panel of the elevator. Thus, the study was held for this specific product.

The main problems registered were: high setup times (15.1 min), long distances travelled by the operator (136.7m), lack of a standardized process, high quantity of WIP (12.8 days), disorganization of equipment and materials, lack of identification of matrices and punches, and flaws in the tools maintenance process. To carry out the SMED implementation was created a methodology with nine steps, presented in Table I.

Note that the first five steps can be considered integral parts of the Preliminary Stage of the SMED methodology. However, it was decided to make this separation to better illustrate the sequence of steps used in this project to implement SMED.

TABLE I

Nine Step Methodology to Implement SMED

Step	Description
Step 1: Initial observation	Identification of the tools used during the setup, locations where the operator moves around and all other aspects involved in the process
Step 2: Dialogue with the operator	Identification of potential problems in the setup
Step 3: Video recording	Registration of all the operations and movements during the setup
Step 4: Sequence diagram construction (current state)	Description of each setup operation, registration of its duration and distance travelled by the operator, and classification of the type of activity (operation, transportation, inspection, waiting or inventory)
Step 5: Spaghetti chart construction (current state)	Representation of the movements that the operator performs during the setup process and identification of the areas of greater affluence
Step 6: SMED stage 1 application	Separation of internal and external setup
Step 7: SMED stage 2 application	Conversion of internal into the external setup
Step 8: SMED stage 3 application	Rationalization of internal and external setup
Step 9: Analysis of results	Analysis of the results obtained and verification of the impact of the methodology implemented

A. Preliminary Stage – Identification of Setup Operations

In the preliminary stage of the SMED methodology is necessary to understand in detail the whole setup process. The punching machine operates with different types of matrices and punches (A, B, C) and different shapes (round, square, oval, rectangular and special). Of the eighteen positions of the punching machine's turret, eight are for type A tools, nine for type B, and only one for type C. Fig. 2 demonstrates the layout of the turret. Numbers 1 and 11 represent positions with "Auto Index" that allows to automatically change the angle of the tool. In the other positions of the turret, the angle alteration is executed manually.

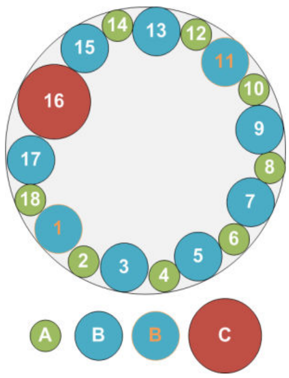

Fig. 2 Layout of the punching machine's turret

The setup process for cabin panels is the longest changeover, because, as previously mentioned, requires the exchange of the eighteen matrices and punches of the turret. Another important point to mention is the matrices' rectification. As they are used, the matrices become worn, and thus, when installing them during the setup process, the operator has to add some washers to regulate their height, to assure the attainment of the product's specifications.

Before initiating the study it was important to perform

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several observations and informal interviews with the machine operator. Additionally, the setup process was video-recorded to allow a thorough analysis. Afterwards, a sequence diagram was created to help describe each setup operation. This diagram is an analysis tool that indicates the stages of completion of a product or process by its order in the supply chain, with the registration of the activities and the respective times and using appropriate symbols. Table II presents a summary of the information retrieved from this diagram.

TABLE II
INFORMATION GATHERED IN THE PRELIMINARY STAGE

Activity	Number of occurrences
Operation	67
Transport	17
Control/inspection	3
Waiting	0
Storage	0
Total Number of Activities	87
Total Time (min)	15.1
Distance (m)	136.7

After the operations' description, the setup activities were divided into six categories: (i) materials and tools organization operations, (ii) tools removal, (iii) tools gathering, (iv) washers adding, (v) tools placement, and (vi) other types of operations. Fig. 3 represents the percentage of time spent in each category of activities.

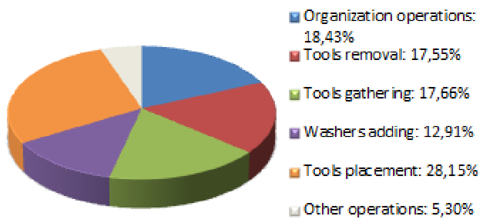

Fig. 3 Percentage of time spent in each category (initial situation)

From Fig. 3 it is possible to verify that the tools placement operation occupies a large percentage of the total setup time. This happens because the operator has to place all the eighteen matrices and punches in the machine's turret. After describing the setup process, the movements made by the operator were scrutinized and represented in a spaghetti chart (Fig. 4).

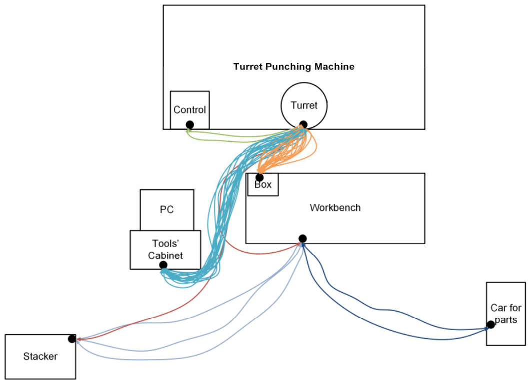

Fig. 4 Spaghetti chart (initial situation)

As can be seen, the paths most frequently performed by the operator are between the turret and the tools' cabinet and between the turret and the washers' box.

B. Stage 1 – Separation of Internal and External Setup

Part of the operating cycle of the punching machine is automatic, so the operator only needs to place the product on the table and validate the operations in the control panel. During the automatic operation, the operator only has to perform some control tasks over the product being processed. The remaining time could be used to carry out other activities, namely some tasks necessary for the next setup. However, from the analysis carried out in the preliminary stage, it was observed that the operator performs all the setup operations while the machine is stopped. As such, all those operations are considered as internal setup, although some of them could be directly transferred to external setup. That is the purpose of the first stage of the SMED methodology and Table III shows the significant improvements obtained.

TABLE III
SMED - RESULTS OBTAINED IN STAGE 1

SMED Stage	Total of Internal Activities (units)	Setup Time (min)	Distance Travelled (m)
Preliminary	87	15.1	136.7
Stage 1	69	9.7	64.4

The operations which have become external correspond to: (i) motions performed by the operator to pick up and store the turret's tools, and (ii) materials organization operations. At this stage of SMED, only one technique was used: improvements in transportation. The transportation of tools (matrices and punches), as well as materials (car with pallets of finished products), was transferred to the external period.

C. Stage 2 – Conversion of Internal into External Setup

In SMED stage 2, a new analysis was conducted and it was realized that the operation of adding washers to regulate the height of the matrices was done in the internal period. In this regard, it was suggested that the operator should execute this operation in the external period, placing the ready washers beside each matrix. Table IV demonstrates the results obtained in stage 2 of SMED.

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TABLE IV
SMED - RESULTS OBTAINED IN STAGE 2

SMED Stage	Total of Internal Activities (units)	Setup Time (min)	Distance Travelled (m)
Preliminary	87	15.1	136.7
Stage 1	69	9.7	64.4
Stage 2	59	7.8	34.7

The solution implemented in this stage matches the SMED technique outlined in the methodology for the anticipated preparation of operations.

D. Stage 3 – Rationalization of Internal and External Setup

In SMED stage 3, improvements in internal and external operations were distinguished. The external improvements do not act directly on the setup time reduction but can assist the operator in improving his tasks.

1. Improvements in the Internal Operations

One of the punching machine's major problems is the absence of a standard method to perform the setup process. In this study it was found that the operator places the tools in the turret without following a logical sequence, i.e. not considering the order of the turret position numbers. In some cases the operator jumps positions and wastes time, at the end of setup, to verify all positions. Another problem with this situation is the absent/deficient identification of the turret's positions (as they were marked with a pen and disappeared over time). To improve the process of placing tools in the turret it was created a board to use during the setup process (Fig. 5).

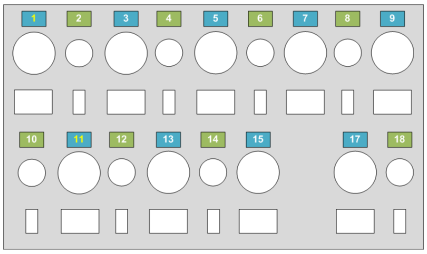


Fig. 5 Board for the setup process

This board has a space reserved for each position of the turret. Thus, there are seventeen spaces for the punches and seventeen spaces for the corresponding matrices, with different dimensions (depending on tools' type - A or B). The sixteenth position of this board was not included, since it is a position for type C tools that are rarely exchanged. It was also necessary to perform the identification of each position of the turret, by assigning colors to each tool type (A and B), in order to facilitate the visual management process. These positions were also identified in the turret (Fig. 6) keeping the consistency of colors used in the board and thereby making the setup process faster.

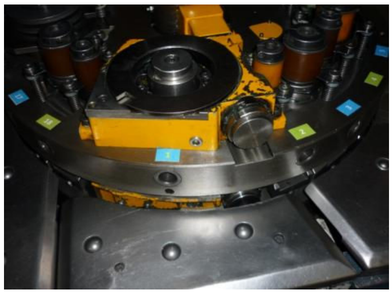
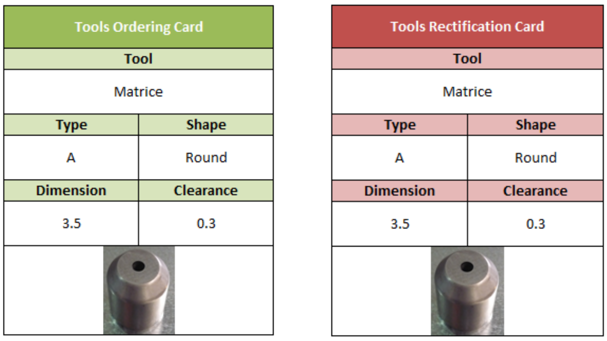


Fig. 6 Identification of positions in the turret

With these improvements, during the external period the operator has only to check which tools are needed for the next product and place them in the respective board positions. In this board he also prepares and places the washers for the matrices. Finally, with the tools properly organized, and already during the internal period, the operator removes the old tools and installs the new ones following the positions' order (1 to 18). In the end, and again in the external period, the operator stores the old tools in the closet and prepares, on the board, the tools for the next product.

2. Improvements in the External Operations

Regarding the external improvements, some aspects influencing the storage and transportation of materials and tools have been improved. In the first stage of the methodology, the motions to get the matrices and punches were converted into external operations. However, in order to make the process of getting tools faster, it was necessary to improve the storage cabinet (that was initially disorganized and without a visible identification of the tools). Although the tools were organized by type, there was not enough room for all of them. Thus, some tools were not visible and, consequently, the search process was quite time consuming. To solve this problem, it was created a new storage cabinet so that each matrix and each punch have their own clear and visible space. By using these visual management concepts, the process of tools' searching was clearly improved and a more visually pleasing space was created. Additionally, with the new cabinet it was also possible to improve the tools' maintenance process, which was one of the main problems identified. Previously, the tools' rectification was often performed by the operator while the machine was stopped, thus increasing the downtime. This happened due to the lack of a mechanism to identify the tools that need to be rectified or replaced. Thus, two types of cards were created for each tool: (i) tools ordering card (Fig. 7 (a)), and (ii) tools rectification card (Fig. 7 (b)).



(a) (b)

Fig. 7 Cards for (a) tools ordering (b) tools rectification

With these cards, the operator can easily know which tools require rectification and which ones need to be replaced. So, when the machine is running and when the operator has free time, he can rectify the labeled tools. When a new tool is necessary, the machine operator delivers the respective ordering card to the production chief, which carries out the order. Table V presents a summary of the results obtained in SMED stage 3.

TABLE V
SMED - RESULTS OBTAINED IN STAGE 3

SMED Stage	Total of Internal Activities (units)	Setup Time (min)	Distance Travelled (m)
Preliminary	87	15.1	136.7
Stage 1	69	9.7	64.4
Stage 2	59	7.8	34.7
Stage 3	53	5.4	1.7

To finalize this SMED project, the standardization of the setup process was conducted. To this end, a Standard Work Combination Sheet was created with details of each operation.

IV. Analysis and Discussion of Results

To implement the SMED methodology in the turret punching machine, the longest setup process was analyzed. This process corresponds to the exchange of the totality of the positions in the turret. Fig. 8 presents the setup durations recorded along each of the stages of the methodology.

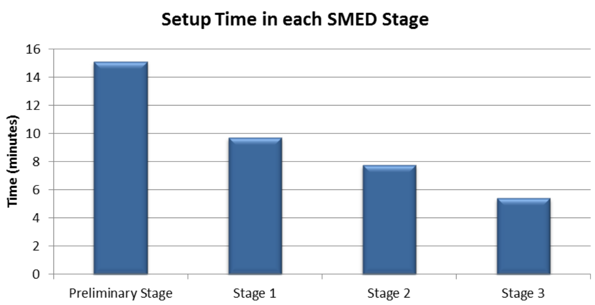


Fig. 8 Setup time at each SMED stage

By analyzing Fig. 8 it is possible to verify that the setup time has decreased in each SMED stage, achieving a total reduction of 64%. With these results the percentage of time spent in each setup process category was also changed. Fig. 9 represents the final situation obtained.

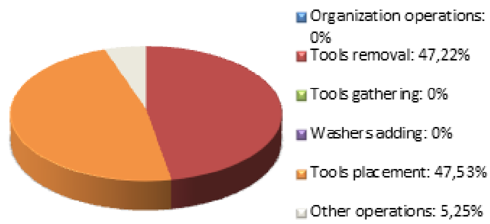


Fig. 9 Percentage of time spent in each category (final situation)

In the final situation several operations were removed from the internal period: (i) materials and tools organization operations, (ii) tools gathering, and (iii) washers adding. These operations are now performed in external period. Thus, in the setup process, the operator only carries out the operations strictly necessary, which cannot be executed in the external period.

Since the reduction in setup time allowed the decrease of downtime, production rates have increased. Table VI presents the gains attained by the company by reducing setups for the product under study.

TABLE VI
GAINS PER YEAR WITH SETUP TIME REDUCTION

Performance Indicators	Values
Number of setups per year (units)	54
Setup time per year in the initial situation (min)	815.4
Setup time per year in the final situation (min)	291.6
Production time gained per year (min)	523.8
Time per piece (min)	1.2
Gains per year (pieces)	437
Cost per piece (€)	16.74
Gains per year (€)	7,315.38

After SMED implementation in the turret punching machine, it was possible to produce more 437 panels per year, which corresponds to an annual gain of €7,315.38.

The setup time reduction allowed the decrease of the batch sizes for the analyzed product. This aspect was very significant to achieve an important objective for the company, which is the WIP reduction on the shop floor. Table VII presents the improvements achieved in terms of WIP.

TABLE VII
IMPROVEMENTS OBTAINED IN WORK-IN-PROCESS

Situation	Parts per box (units)	Daily Demand (units)	WIP (days)	Cost per piece (€)	Total Value (€)
Initial	66	30	12.80	16.74	1,104.84
Final	33	30	6.40	16.74	552.42

Another improvement attained was the reduction of the distances traveled by the operator during the setup process. Fig. 10 shows the improvements achieved in the travelled distances, in each stage of SMED.

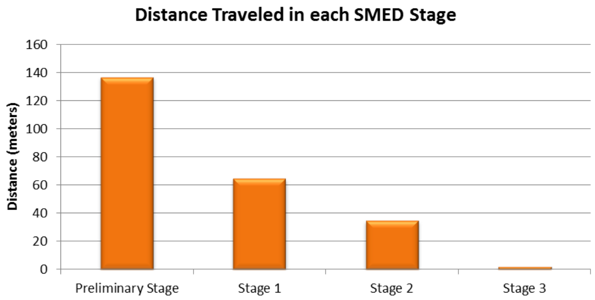


Fig. 10 Distance traveled at each SMED stage

Throughout each SMED stage, the total distance traveled by the operator decreased significantly from an initial distance of 136.7 meters to a final distance of only 1.7 meters. Fig. 11 presents a spaghetti chart to demonstrate the operator's movements after the improvements. Therefore, it is possible to verify that just a few movements are performed during the internal setup, allowing a reduction in the machine downtime. The only movement that the operator has to do (during the internal setup period) is to validate information on the control panel. During the remaining period, the operator does not need to perform movements, since the required materials are located close to him.

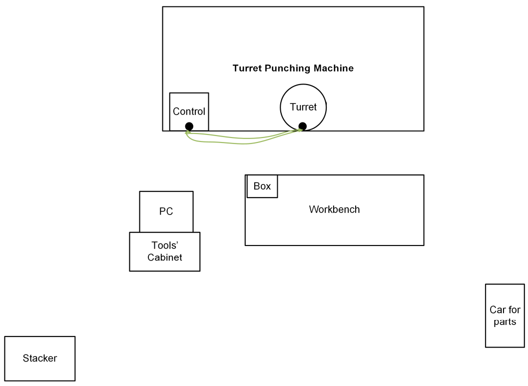


Fig. 11 Spaghetti chart (final situation)

The developed Standard Work Combination Sheet for the setup operations provides the operator with the adequate information to perform each setup in a homogeneous way, spending a similar time.

With the SMED methodology, the setup process is more obvious and more efficient for the operator. The workspace of the punching machine became also properly organized. The introduction of two types of cards (tools rectification card and tools ordering car) improved the maintenance process, allowing rectification tasks to be performed while the machine is running. This also allowed the prevention of delays in the tools ordering processes.

V. Conclusion

This study described an effective industrial application of the SMED methodology (setup of a turret punching machine), which led to significant improvements, namely reductions of 64% in the setup time, 50% in WIP and 99% in the travelled distance. The implementation was conducted according to a nine step methodology proposed by the authors and resorted to the typical SMED techniques. It was possible to verify that relatively simple solutions can bring great improvements at low cost. Additionally, the setup operations were normalized using a Standard Work Combination Sheet. To ensure the sustainability of the achieved results, the setup occurrences should be frequently monitored.

The tools' maintenance and acquisition processes became more effective due to the development and adoption of rectification and order cards.

In terms of future developments, and aligning with the continuous improvement approach, the authors propose the creation of one or more SMED teams. These teams would be responsible for the analysis and improvement of the company's setup processes.

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