ELSEVIER

CrossMark

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 51 (2020) 1416–1422

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021)
15-18 June 2021, Athens, Greece.

SMED methodology applied to the deep drawing process in the automotive industry

A. M. Vieira[a], F. J. G. Silva[a,*], R. D. S. G. Campilho[a], L. P. Ferreira[a], J. C. Sá[a,c], T. Pereira[a,b]

[a]*ISEP – School of Engineering, Polytecghnic of Porto, CIDEM, R. Dr. Antº Bernardino de Almeida, 431, 4200-072, Porto, Portugal*
[b]*CIDEM – Center for Research and Development in Mechanical Engineering, R. Dr. Antº Bernardino de Almeida, 431, 4200-072, Porto, Portugal*
[c]*IPVC – School of Business Sciences, Polytechnic Institute of Viana do Castelo, Av. Pinto da Mota, Valença 4930-600, Portugal*

* Corresponding author. Tel.: +351 228340500; fax: +351 228321159. *E-mail address:* fgs@isep.ipp.pt

Abstract

The automotive industry has evolved, becoming increasingly demanding. Thus, it becomes necessary to increase the availability of equipment, reacting efficiently to be able to respond to customer requests. Nowadays, the strong development of this industry is based on three main pillars: competitiveness, product quality and response time to requests. The focus of this work is to increase the availability of a deep drawing machine with extremely high setup time, with the main objective of reducing the average setup time by 20%. This reduction is even more important when it comes to the internal setup time, the time the machine is stopped. Thus, the Single-Minute Exchange of Die technique was applied and work standards were improved to reduce the equipment setup time, increasing the machine availability, leading to a production increased output. As a result of this work, it was possible to standardize setup, reducing 38% of total machine setup time, 53% of internal setup time and increasing 7.7% of OEE (Overall Equipment Effectiveness) availability.

Keywords: Automotive Industry; Deep Drawing; Productivity; SMED; Setup; Standard.

1. Introduction

The automotive industry began in the late XIX century and was evolving from artisanal production to the assembly line concept, becoming increasingly demanding. In Portugal, the automotive industry (including car and component production) represents 4% of total GDP (Gross Domestic Product), being a sector of high importance for the country's economy.

Nowadays, automotive companies are constantly evolving and are rapidly adapting to market demands [1], although they face some challenges with regard to the sustainability of their manufacturing processes and vehicle emissions [2,3]. The strong development of this industry is based on three main pillars: competitiveness, product quality and delivery time to requests [4].

This work was developed in a company dedicated to the production of components for the automotive industry, namely air conditioning systems for vehicles. Deep drawing machines are crucial to the productive process and their availability needs to be increased, because all the tubes need to be formed. Setup od these machines is critical. At the beginning of this work, these machines presented a setup time of 47 minutes and an availability of less than 95%. To reduce wasted time and increase machine productivity, continuous improvement techniques such as standard work and SMED (Single-Minute Exchange of Die) methodology have been implemented to reduce the setup time by changing internal tasks to external ones during the setup operation. Thus, the objective of this work was to reduce the setup time by 20%, contributing to the increase of machine availability. The novelty of this work is to

10.1016/j.promfg.2020.10.197

find real solutions to able to improve the setup of these deep-drawing machines.

This article is structured as follows: in the *Introduction* an brief contextualization of this work is made, *Literature Review* describes the theoretical foundations that underlie the development of the model, the *Materials and Methods* section describes the materials/tools used as well as the methodology applied, the *Results section* shows the results obtained and the *Discussion* analyzes them. Finally, in the *Conclusions* are highlighting the main achievements of this work.

2. Literature review

The competitiveness and demands of the automotive industry increasingly require improvements and the elimination of waste. According to Lean thinking, these wastes are identified as all activities that do not adequately use the resources to value the product. Thus, this philosophy is based on identifying value, eliminating waste and generating a flow or value for the customer [5]. In this sector, continuous improvement may adopt different methodologies, through the investment of companies and the impact of the actions implemented. These may be technical, have small or large investments and cause large or small impacts on production. Thus, all Lean tools are widely used in the automotive industry, and the ones with the most results and the fastest, with the lowest investment, are Standard Work, 5 S, visual management and SMED [6] This work highlights the standard work and the SMED methodology. Standard Work is a process of standardization of all tasks. The purpose of the procedure is the standardization of tasks and processes for all employees. To achieve this standardization, documentation such as work instructions or product data sheets are used, reducing product variability [7,8]. The SMED methodology addresses the reduction of equipment preparation, tuning and replacement time. The main objective of the SMED is to decrease the time to efficiency loss caused by the reference change in production [9,10]. In order to reduce the waste inherent in tool changes in a cork industry line, *Sousa et al.* [9] implemented the SMED methodology in composed cork stoppers production, achieving a reduction of approximately 43% in setup time. In the study performed by *Martins et al*. [10], the SMED methodology was applied to electron beam machines in the production of cables for the automotive industry, reducing the setup time by 50% and eliminating setup scrap. On the other hand, the study carried out by *Rosa et al*. [11] presents the approach developed on an assembly line, assigned as a pilot project in the implementation of the SMED methodology, complemented by other lean tools, aiming to reduce the waste inherent to tool changes in the production of Bowden cables for vehicles. The solutions developed enabled to achieve a weekly reduction of approximately 58 % in the time due to setups, contributing to an increase in assembly line availability as well as to a productive capacity increase.

Antoniolli et al. [8] developed a study on the application of the standard work tool to an automotive industry production line, standardizing operations, eliminating waste and non-value-added activities. This study increased production from 1200 parts/day to 1800 parts/day, increasing OEE (Overall Equipment Effectiveness) by 16%. In the textile industry, *Neves et al.* [12] managed to reduce four hours per operator per week, representing a gain of 10% of their available weekly time. This gain was due to the application of lean methodologies. *Fisel et al.* [13] having as main problem the workload fluctuations in production lines, developed an algorithm capable of combining different balancing techniques. This algorithm allows distributing times and tasks along the line, giving the manager the ability to make faster line balancing decisions and save resources by avoiding the arrival of unnecessary materials. On the other hand, in the metallurgical industry, *Monteiro et al.* [14] implemented Lean tools to reduce 59% of the time required to move tools weighing around 1000 kg and reduce 2.04% for external nonconformities and 3.99% for internal nonconformities. *Pombal et al.* [15] undertook a makeover of kanban in a food business reducing at least 50% of the time required to replenish material. Also, this study resulted in a 70% reduction in the time required to locate consumable materials. *Rocha et al.* [16] applied Lean methodologies to improve the production control process and production support MES (Manufacturing Execution System) software. From this work, the company was able to achieve greater productive organization, standardize procedures, provide workers with good practices and generate useful reports to assist decision making. *Dias et al*. [7] carried out a study having as main goal the increasing of the production capacity of an automobile air conditioning system production line. The main tool used was line balancing, levelling loads and reducing line cycle time. As a result, it was possible to establish standard work with three, four or five operators, increasing production capacity to 1800 parts/day and line efficiency by 21%. Moreover, the work developed by *Dias et al.* [7] also had as main objective the application of Lean methodologies to increase the OEE of a car air-conditioning systems production line, reducing the setup time of the end forming process.

The next chapter presents the methodology applied to achieve the main goals of this work.

3. Materials and Methods

3.1. Product and processes definition

This study was carried out in an automotive components' manufacturing company that produces air conditioning pipes for different OEMs (Original Equipment Manufacturers). This piping is made from aluminium tube and undergoes processes such as cutting, end forming, drilling, welding or washing. An example of these tubes can be seen in Fig. 1 and the steps for the tube manufacturing process are described in detail in Table 1.

Fig. 1. Air conditioning tube example.

Table 1 - Steps of the manufacturing process of air-conditioning tubes.

Stage	Description
Cut	The aluminium is cut to the desired length.
End forming	Plastic shaping process of the material, so that the end of the tube gains the desired shape.
Washing	After the end forming, the parts are washed to remove the oil used in the process.
Drill and valve assembly	The tube is drilled, and valve body and a washer are placed.
Brazing	The valve support is brazed to the pipe.
Screw in valve interior	At this stage, a mechanism is screwed into the valve body.
Bending	The parts are curved to acquire the geometry indicated in the technical sheet of the tube to be produced.
Hydrogen tightness test	A flow of hydrogen is passed through one end of the tube to check for leakage.
Packing	Plugs are placed in the product and tubes are placed in the packaging.

The manufacturing process under study is the aluminium tube end forming, second process of Table 1. This process is intended to plastically transform the tip of an aluminium tube with high dimensional demands, as can be seen in Fig. 2. Beyond the high accuracy needed, the operation is very demanding in terms of requirements regarding the materials' properties.

Embedding is carried out at an early stage in the manufacturing process of air conditioning tubes, followed by the cutting of the aluminium tubes.

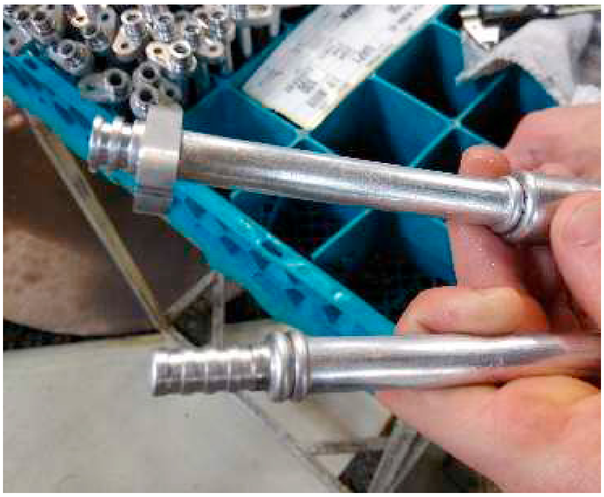

Fig. 2. Tubes after end forming.

The end forming machine (Fig. 3) produces the shape using between three and five steps. A step is an embossing step, and the tools for each are in different positions of the equipment. The tools define the final geometry of the tube and vary according to the desired plastic deformation.

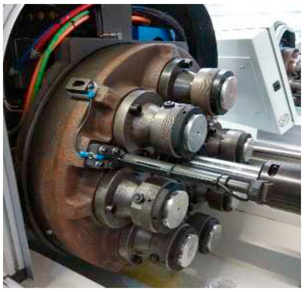

Fig. 3. Interior of an end forming machine.

The main difficulty of this process can be related to the material or method. The problems in material (Table 2) includes oil quality and tube cutting tools, while the method includes poorly assembled tools, tool changes or programming errors (Table 3).

Table 2. Problems related to the materials used in tube end forming process

Material	
Oil quality	The oil is subject to reuse, being filtered. It can become damaged over time and with aluminium powder, damaging the visual quality of the tube.
Tube cut	The quality of the tube cut defines the quality of the plastically transformed part. A quality cut avoids the appearance of chips.
Tool	If the tool is damaged, does not have the required surface quality and is not cleaned or polished regularly, causing a not OK part.

The tool, as a component that works directly on the tube, always needs to be very clean and polished, avoiding to cause damage, such as dents or marks. Moreover, this care increases its useful life.

Table 3. Problems related to the methods used in tube end forming process

Method	
Poorly assembled	The tool is assembled by the preparer and correctly, ensuring that assembly is not responsible for its break. However, the tool can be incorrectly assembled: → Off-centre tool - if the tool is not centred, there is a shock between the tool and the part, causing the machine to break and stop. → Loose screws - When the screws are not tightened, there are gaps in the tool that will cause interference. These interferences will have consequences similar to those of the previous point, the breaking of the tool. → Tool in the wrong position - the plate supporting the tools must have a balanced weight so that there is no interference between the work units.
Tool change	If the preparer does not install the correct tool when setting up the machine, the part will not work as intended and will have to re-execute the tool change and machine programming procedure. This problem will create a waste of time and, consequently, machine downtime.
Programming errors	When end forming tests are carried out, the correct dimension should be used to process the tube. However, the tool must be replaced, so there is risk of collisions and consequent breaks due to programming.

Problems with the method occur due to failures of the preparer. These are the programming errors that occur most often, and it is extremely important that before starting the machine to produce, the tool position coordinates are guaranteed through programming. A clash between tools can be quite expensive and can lead to serious damage to the machine. The most common part quality problems are parts with out-of-specification dimensions or lack of material. All the parts are subjected to a *poka-yoke* test and, besides, there is a register of dimensional control of the parts. When the parts are out of specification, the machine must stop and the preparer will solve the problem. In Fig. 4 and Fig. 5, it is possible to observe an example with a good part and a part with a lack of material.

Fig. 4. OK part

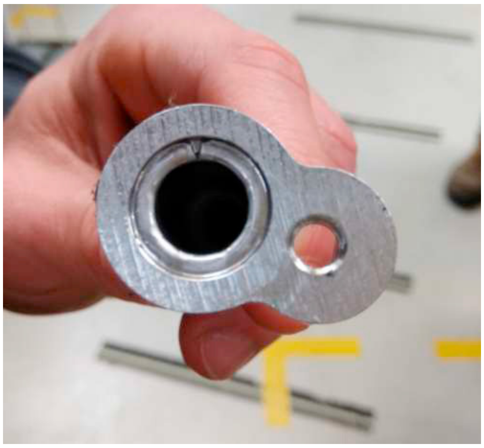

Fig. 5. Part with lack of material

3.2. Setup

The setup of the embedding machines is done by technicians designated by preparers. These are responsible for setting up the machines, doing both external and internal operations within the setup, and cleaning and polishing tools. To setup a machine, the preparers have a preparation instruction for each reference to be produced, and a procedure that they must follow. A standard end forming preparation instruction is a document that, as the name implies, allows the process of preparing a filling machine to follow a standard. It is through this document that the preparer knows the tool to use, in which position of the plate the tool must be located, whether lubrication is used and which dimensional parameters of the part are necessary to guarantee. For these reasons, whenever there is a reference change, the preparer must follow the respective standard. Following the standard, the preparer has almost all the information necessary to properly prepare the machine and obtain a good part. However, the programming values needed will depend a lot on preparer's knowledge and experience. In this way, following the standard, part of the end forming is obtained, and the remainder depends on quota adjustments in the program. The main parameters are the internal diameter, the length of the tube and the lack of material. These parameters are crucial because they can cause broken parts, customer specifications not being met or tool have been damaged.

3.3. SMED methodology

The SMED technique was applied to reduce the setup time of end forming equipment and contribute to the development of production, increasing the availability of the machine.

4. Results

To implement this methodology, the procedure represented in Fig. 6 was used. Following the procedure adopted, the setup was analyzed and timed, and a table was prepared with the tasks performed, identifying them as internal or external (Table 4 and Fig. 7). Internal actions are activities performed when the equipment is stopped, and external actions are activities that can be performed while the equipment is running [10]. Since machines have an identical process between them, the times of a randomly chosen machine were timed.

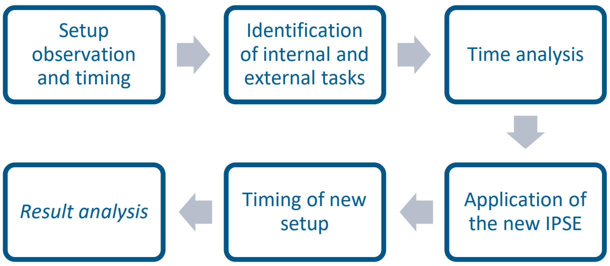

Fig. 6. SMED technique implementation procedure.

Table 4. Setup tasks in the initial scenario.

Task description	Time (min)	Accumulated time (min)	Task type
Searching for the tool	2	2	External
Tool change in the machine	8	10	Internal
Machine programming	25	35	Internal
Produce first part	0,5	35,5	Internal
Check first part	0,5	36	Internal
Fill in the documentation regarding the first part produced	1	37	External
Disassemble, wash and reassemble the tool	10	47	External

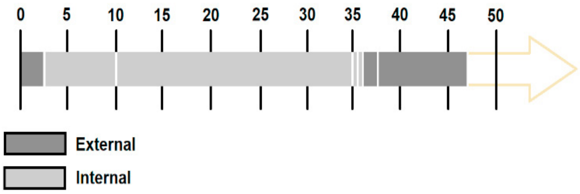

Fig. 7. Duration of setup tasks before implementation improvements (in minutes).

Only three external tasks were identified, which can be done before or after setup, namely "Search tool", "Fill in first OK part" and "Disassemble, wash and reassemble the removed tool". The total setup time was 47 minutes, most of which is due to internal tasks and the "Machine programming" task (adjustments) is the most representative one. Counting only the operations performed with the machine stopped, an internal setup time of 34 min is obtained, about 72% of the total time. As referred before, the preparer plays a key role in the preparation and it is his experience that allows the machine to be adjusted/tuned programmatically. The problem arises when the preparers do not yet have the necessary experience and therefore take longer to set up the machine and consequently use a larger quantity of raw material/tubes for preparation resulting in a higher amount of scrap. As in the standard end forming preparation instructions there is no information about machine programming (distances, rotation, and so on), lubrication time or minor adjustments, a rigorous update has been made for each part number. Thus, the following information was added to each production documentation, obtaining a more complete document to be used by the preparers:

- Tools that are used in each updated step;
- Program reference values such as:
  - Rotation speed (in scroll operation);
  - Fast forward and slow forward quota;
  - Fast and slow-motion speed;
  - Waiting time for the end of advance;
  - Fast backwards and slow backward quota;
  - Intermediate waiting time;
  - Lubrication time and lubricant to be used;
- General remarks, so that the preparer pays attention to certain details;
- Pictures and diagrams helping to understand the data.

4.1. OEE

The OEE is the first measure to verify the efficiency of the production. This parameter can be applied to a single or to a set of equipment, and its main function is to indicate machine's behavior towards the management of the process and the respective planning [17]. This is calculated by multiplying performance by availability and by quality, as can be seen in the following equation.

$$OEE\ (\%) = Performance\ (\%) \text{x} Availability\ (\%) \text{xQuality}(\%) \quad (1)$$

The availability of the equipment relates the total time available for the operation, with the effective time that the equipment has been producing. This time includes stops due to malfunctions, adjustments, setups, among others. The performance of the equipment relates the quantity produced to the quantity that was expected to have been produced. The last indicator is quality, which compares the number of units produced with the number of defective units. During this work, the data of six months of a pilot zone were analyzed to observe the evolution of availability and, consequently, of the OEE after the implementation of the new setup standards. The objective was to reach a minimum of 95% availability, the factor that influences the most the machines being analysed.

After the update of the standard end forming preparation instructions, the operation was timed to quantify the reduction of time compared to the initial situation. The average times obtained were recorded in Table 5 and Fig. 6, as well as the improvements achieved.

Table 5. Setup tasks performed after updating the standard setup document.

Task description	Time (min)	Accumulated time (min)	Task type
Search tool	2	2	External
Machine tool change	8	10	Internal
Program machine	7	17	Internal
Produce first piece ok	0,5	17,5	Internal
Check first piece ok	0,5	18	Internal
Fill in first piece ok documentation	1	19	External
Disassemble, wash and reassemble the removed tool	10	29	External

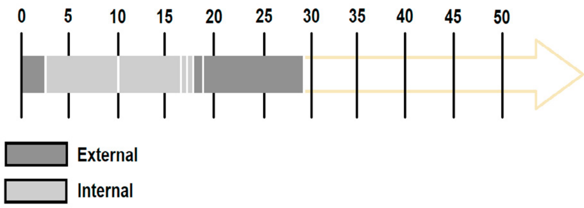

Fig. 8. Duration of setup tasks after implementation improvements in minutes.

The upgrade of the document allowed to reduce to 7 min the "Machine Programming" task, which was the most significant for the total setup time, and with the greatest impact for the machine downtime. This reduction is shown in Table 6 and in green color in the Fig. 9. Counting only the operations performed with the machine stopped, an internal setup time of 16 min is obtained, 55% of the total time.

Table 6. Comparison between initial and final setup.

	Total Setup Time	Internal Setup Time
Initial	47 min	34 min
Final	29 min	16 min
Improvement	38 %	53 %

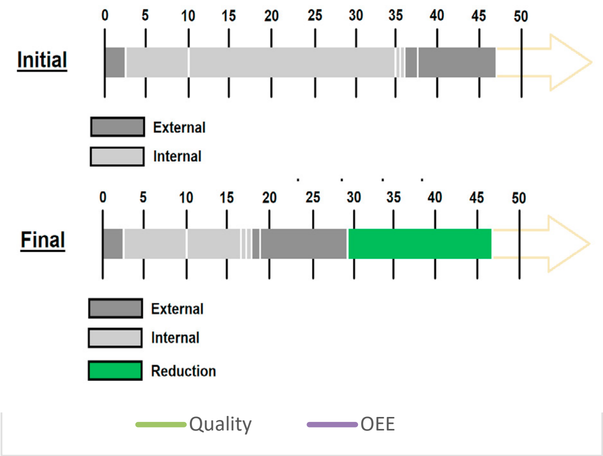

Fig. 9. Evolution of machine setup time in minutes.

5. Discussion

Following the proposed methodology, it is possible to elaborate a detailed analysis about the setup, standardizing tasks and cutting waste of time in the production. In this work, SMED methodology was used adapting the documents used by the preparers, making it possible to obtain interesting results. From a setup time of 47 minutes, it was possible to move 29 minutes, being the biggest reduction in the internal setup time (with the machine stopped), which reduced from 34 minutes to 16 minutes.

In similar works, *Rosa et al.* [10] implemented the SMED methodology and achieved a 58.3% reduction in setup time, increasing the availability and production capacity of an assembly line. Also, *Martins et al.* [9] implemented the SMED methodology and reduced more than 50% of setup time on electron beam machines. Thus, it was possible to obtain results within the expected values and, consequently, quite positive in comparison with other studies.

Regarding the OEE, there are also quite interesting improvements. The six-month data from a pilot zone was analyzed and it was possible to observe that availability increased, on average, by 7.7% in May 2019, the month in which the new standard was implemented, reaching the required 95% minimum. This value may increase more with new updates to the setup standard and, therefore, there are new challenges in improving these standards more and more.

The performance also increased slightly, while quality maintained its value. However, these indicators were not analyzed in this work.

In the work of *Antoniolli et al.* [8] focused on the standardization of operations, the elimination of scrap and activities with no added value, allowed the OEE to be increased by 16%. In comparison with this work, it is possible to perceive that the increase in OEE achieved is already quite positive, however, there is a possibility of improving it even more. The results about the OEE indicator can be observed in Table 7, regarding the 6 months analyzed in this work. The evolution of the three components of the OEE indicator can be seen in the graph of Fig. 10.

Table 7. Monthly evolution of OEE.

	Performance (%)	Availability (%)	Quality (%)	OEE (%)
December 2018	92	96	99	87.4
January 2019	96	95	99	90.3
February 2019	97	96	99	92.2
March 2019	98	97	99	94.1
April 2019	97	98	99	94.1
May 2019	98	98	99	95.1

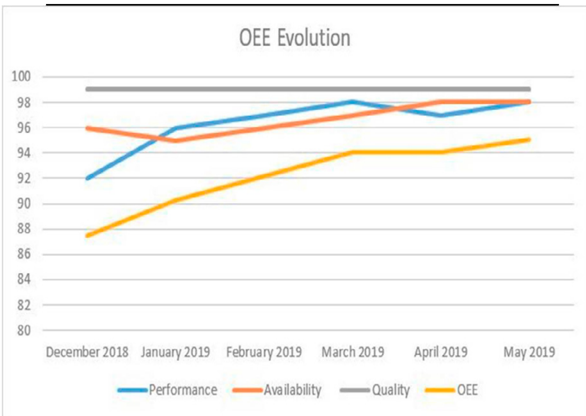

Fig. 10. Evolution of OEE indicator into the considered period.

Despite the extremely positive results, there is still room to reduce the setup time, increasing improvements in standards, to achieve a reduction of at least 50%. To this end, it is necessary to continue training people and continue to evaluate the process with multidisciplinary teams, to analyze the problems that the process presents and find solutions to solve them from their root cause.

6. Conclusions

The main goal of this work was to reduce the setup time by 20% of the end forming machines, to increase their production capacity and, consequently, their OEE. To achieve this goal, improvement methodologies were used, namely SMED methodology and Standard Work. These made it easier for the preparer to work by setting a working standard and speeding up the setup.

By making this change, the work preparation can be standardized, reducing its influence on value variation, and reducing 53% of the machine's internal setup time.

It was then possible to achieve a very satisfactory 38% reduction in the setup time, and there will always be a margin for progression to achieve increasingly reduced times. Besides, it has increased the production capacity of the machines and reduced scrap produced in unnecessary programming adjustments. These results also allowed the OEE to increase by 7.7%, meeting the internal goals for the machine (Table 8).

Table 8. Comparison between established target and obtained result.

	Target	Results
Setup Time	20 % reduction	38 % reduction
OEE	-	7.7 % increase

End forming machines are presented in the company as the most important machines and with the greatest impact in the event of a stoppage. These machines work at the beginning of the tube transformation process and define the production rate. Therefore, the application of the SMED methodology of this work brought to the company a lot of contributions in the number of tubes produced, in the preparation of the preparers and in the reduction of scrap values. If there are gains in time and scrap, the company obtains significant monetary gains.

Acknowledgements

The authors want to thank Dra. Anabela Matos and Ing. Filipe Borges for their collaboration in providing opportunities to carry out internships at the company's facilities.

The Authors acknowledge the financial support of CIDEM, R&D unit funded by the FCT – Portuguese Foundation for the Development of Science and Technology, Ministry of Science, Technology and Higher Education, under the Project UID/EMS/0615/2019.

References

[1] Rosa C, Silva FJG, Ferreira LP. Improving the Quality and Productivity of Steel Wire-rope Assembly Lines for the Automotive Industry. *Procedia Manuf* 2017;11:1035–42.

[2] Giampieri A, Ling-Chin J, Taylor W, Smallbone A, Roskilly AP. Moving towards low-carbon manufacturing in the UK automotive industry. *Energy Procedia* 2019;158:3381–6.

[3] Silva FJG, Gouveia RM, Cleaner Production – Toward a better future. Springer Nature, Switzerland, 2020. ISBN: 978-3-030-23164-4.

[4] Tellini T., Silva FJG, Pereira T., Morgado L., Campilho RDSG, and Ferreira LP. Improving In-Plant Logistics Flow by Physical and Digital Pathways. *Procedia Manuf* 2019;38:965-74.

[5] Moreira A., Silva FJG, Correia AI, Pereira T., Ferreira LP, and Almeida F. Cost reduction and quality improvements in the printing industry. *Procedia Manuf* 2018;17:623–30.

[6] Melton T. The benefits of lean manufacturing: What lean thinking has to offer the process industries. *Chem. Eng. Res. Des.* 2005;83(6):662–73.

[7] Dias P, Silva FJG, Campilho RDSG, Ferreira LP, Santos T. Analysis and Improvement of an Assembly Line in the Automotive Industry. *Procedia Manuf* 2019;38:1444-52.

[8] Antoniolli I., Guariente P., Pereira T., Ferreira LP, and Silva FJG. Standardization and optimization of an automotive components production line. *Procedia Manuf* 2017;13:1120–7.

[9] Sousa E., Silva FJG, Ferreira LP, Pereira MT, Gouveia R, Silva RP. Applying SMED methodology in cork stoppers production. *Procedia Manuf* 2018;17:611–22.

[10] Martins M., Godina R., Pimentel C., Silva FJG, and Matias JCO. A Practical Study of the Application of SMED to Electron-beam Machining. In Automotive Industry. *Procedia Manuf* 2018;17:647–54.

[11] Rosa C., Silva FJG, Ferreira LP, Pereira T, and Gouveia R. Establishing Standard Methodologies to Improve the Production Rate of Assembly Lines Used for Low Added-Value Products. *Procedia Manuf* 2018;17:555–62.

[12] Neves P, Silva FJG, Ferreira LP, Pereira T, Gouveia A, and Pimentel C. Implementing Lean Tools in the Manufacturing Process of Trimmings Products. *Procedia Manuf 2018;*17:696–704.

[13] Fisel J, Exner Y, Stricker N, Lanze G. Variant flexibility in assembly line balancing under the premise of feasibility robustness. *Procedia CIRP* 2018;72:774-9.

[14] Monteiro C, Ferreira LP, Fernandes NO, Silva FJG, and Amaral I. Improving the Machining Process of the Metalwork Industry by Upgrading Operative Sequences, Standard Manufacturing Times and Production Procedure Changes. *Procedia Manuf* 2019;38:1713-22.

[15] Pombal T., Ferreira LP, Sá JC, Pereira MT, and Silva FJG. Implementation of Lean Methodologies in the Management of Consumable Materials in the Maintenance Workshops of an Industrial Company. *Procedia Manuf.* 2019;38:975-82.

[16] Rocha HT, Ferreira LP, and Silva FJG. Analysis and Improvement of Processes in the Jewelry Industry. *Procedia Manuf* 2018;17:640–6.

[17] Hedman R. Subramaniyan M and Almstrom P. Analysis of Critical Factors for Automatic Measurement of OEE. *Procedia CIRP* 2016;57:128-133.