Improvement of a Plastic Injection Process in an Automotive Industry Supplier Case Study

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Abstract

Nowadays, the increasing competition in the global market, in this case in particular the automotive market, make companies feel the need to improve their service level, not overlooking the efficiency of their industrial processes in order to maintain competitive advantage in the industry. In another hand, the costumer is also ever more demanding in regards to design and technological gimmicks inside the car, that puts suppliers of components like radios, clusters, air condition, etc. For this reason, suppliers should invest heavily in the technological innovation of their products, and improvement of their respective production processes, only in this way can a company strive to maintain competitive advantage in face of competition. In this context, the multinational company Visteon, based in Portugal dedicates itself to the production of electronical components to vehicles. This company has been, throughout its existence, investing in the innovation of their production processes, enabling them in this way to satisfy the demand of many renown automotive companies around the world, in an effective and efficient way. Visteon has acquired recently a plastic injection industrial unit, that manufactures components necessary for their main products. This industrial unit presents some problems that need special attention, and it is then necessary to introduce some methodologies that enable the improvement of this unit's production processes and in this way, improve the unit's efficiency in general. It is in this context of the need of improvement of the efficiency of production processes of the aforementioned industrial unit that this project takes place where after the analysis of the production process, it was identified an opportunity to improve the swapping of the injection mold, in the production line. To do this, the implementation of the Lean methodologies, with focus on the SMED (Single Minute Exchange of Die), enabled the reduction of the duration of the process activities in 26% compared to their initial duration. Following the improvement implemented, it was also identified the opportunity to improve the OEE (Overall Equipment Efficiency) a key performance indicator, where it was possible to achieve a 4% improvement in the production process of plastic injection concerning the product in question.

Keywords: Automotive Components Industry; Plastic Injection; *Lean Production*; SMED; OEE.

1. Introduction

Efficiency and competitiveness are nowadays challenges that take over the global market, leading many companies to plan new strategies for the management of their facilities (Zahraee *et al*., 2014). In this context, the greatest challenge of manufacturers nowadays is how to deliver their goods or raw materials in the shortest amount of time possible at competitive cost and with good quality (Holweg, 2007). According to Marques *et al*. (2013), The production of big quantities of products with high level of customization, is currently the greatest tendency in companies.

Over the years a big portion of the automotive multinational companies have been concerning themselves with improving their products in regards to technology, design, comfort, security, diversification of color choices and overall car quality. However, the greatest challenge still remains as on how to reduce production costs in such a way as to position the company in an advantage position in a highly competitive market. To achieve this the automotive industry seeks to use tools in the context of continuous improvement of their production processes (Geraldo *et al.*, 2015).

Various methods exist to implement continuous improvement such as computer simulation, statistical analysis, and optimization tools able to improve the efficiency and productivity by defining the best combination of resources and production lines, construction processes, energy, services and supply chains(Mohd & Mojib, 2015).

One of the approaches to efficiently implement and manage process improvements with high success rate and very frequently adopted in the industry is the *Lean Production* (Glass *et al*., 2016; Choomlucksana *et al*. 2015; Ar & Al-Ashraf, 2012), it is a system that has been affirming itself in many facilities around the globe, in various shapes and designations. *Lean Production* was first invented in the Japanese company *Toyota*

Motor Company, in the end of World War II with the implementation of the *Toyota Production System* (TPS) (Monden, 1983). The Main objective of TPS consisted in improving productivity and reduce costs by removing the so called “waste” or activities that did not introduce and value in the processes. (Womack & Jones, 2003).

In this context the present project is introduced, developed in an American multinational company, headquarters based in Portugal, where their main service is manufacture of electronical components for vehicles, integrating themselves in a series of manufacturing processes that also involve plastic injection, which is one of the crucial steps in the manufacture of their final product, and in which this paper gives its main focus. This automotive component supplier has greatly presented the need to increase their production capacity, in search to fulfil the demand of the automotive manufacturers that require products with high eves of customization, quality and short lead times from production. In response to this necessity, the company has been adapting themselves to the demands of the market, and has been, overall, successful in this aspect. However, the automotive industry is characterized for its high competition, and due to this, the company seeks to constantly develop, in conjunction with their workers, the continuous improvement of their production processes, in order to maintain themselves competitive in the market context.

2. Case Study

The automobile industry in Portugal began in the first decades of the twentieth century, but it was through the production of components in the 1980s that the country managed to reach a considerable level of efficiency in the automotive sector (Féria, 1999). According to Aicep Portugal (2016), the international success of components produced in Portugal is a reflection of the foreign country’s frequent investment in the country through the implementation of innovative projects and products that have contributed to the growth of exports, employment and innovation. The investments have been focused mainly on the sophistication of technological processes, which has allowed the Portuguese automotive industry to differentiate itself more in the world for its excellent quality. This distinction allows the automotive component manufacturing sector in Portugal to offer a range of competitive advantages, such as flexible production capacity, qualified human resources, integration of R & D, cooperation with other companies, certifications in production areas, as well as one of the more competitive costs in Western Europe. (Aicep Portugal, 2016)

Currently the automotive components industry in Portugal has a huge impact on the Portuguese economy, being the most exporting sectors and that contributes most to the country's GDP (Cordeiro, 2009). According to data collected by AFIA (2017), 2016 was an extremely positive year for the sector, with economic growth of 7% compared to 2015. Also marking, in the same year, a new record in absolute terms with regards to global sales, the largest share of this value, belonging to the export. The automotive components sector is therefore one of the main contributors to the country's exports Aicep Portugal (2016).

According to AFIA (2017), regarding the turnover of the automotive components sector, the activities of metallurgy and metal-mechanics, electrical and electronic, and plastics are the ones that contribute the most. Therefore, it is important to emphasize that the company involved in the present study carries out activities in these same areas, and therefore, it is relevant to point out that this work focuses on two of the areas of activity that most contribute to the business volume of the components sector in Portugal.

3. Literature Review

3.1 Origins and Pillars of the Toyota Production System

TPS was deveoped by the founder of *Toyota Motor Company*, Eiji Toyoda and the engineer Taichi Ohno due to the need to fight a great economic crisis that settled in Japan in the 1950’s, induced by the end of Word War II (Liker & Meier, 2006). TPS can be understood as a structure and philosophy capable of organizing manufacturing facilities and processes at Toyota, as well as its interaction with suppliers and customers, to provide the best quality, lowest cost and lowest lead time by eliminating “waste” with the collaboration of all employees (Liker, 2004). TPS main structure is supported by two pillars, *Just-in-Time* and *Jidoka* (Ohno , 1988; Liker, 2004), among other elements that are described below:

1) ***Just-in-Time* (JIT)** - ensures the production and delivery of the right product, in the right quantity and at the right time, based on customer requirements (Liker, 2004).
2) ***Jidoka*** - the word means "Autonomation", consists of the automatic inspection of the machine for each product produced, in case an anomaly is detected, production is interrupted and the operator is notified (Santos *et al.*, 2006).

In addition to the pillars the TPS house comprises other elements, which allow the stability of the system, namely:

1) ***Standard Work*** - is defined as a set of working procedures that establish the best methods and sequences for each process and each worker (Productivity Press Development Team, 2002).
3) ***Heijunka*** - is a Japanese concept that means "leveling", in which its practice allows the leveling of production in terms of volume and mix of products, in this case, the production is programmed based on the

demand in the medium or long term, which tends to be more stable (Liker, 2004).

4) ***Kaizen*** - is a Japanese word where "Kai" means "change" and "zen" means "for the better", making the composed meaning "continuous improvement", of a series of activities, constantly creating more value for the customer by eliminating waste (Cudney *et al.*, 2014). Kaizen applied to standardized work motivates managers and workers to further improve their jobs in order to maximize productivity (Black, 2008).

3.2 Lean Production

Sugimori *et al.* (1977) was one of the first authors to introduce TPS in an academic paper, while John Krafcik, a researcher at the Massachusetts Institute of Technology (MIT), in 1988 published an article in which he described TPS as Lean Production. The study demonstrated the success of the Japanese automotive industries by emphasizing their superiority over other traditional production systems, in the form of organizing the operations, in the development of new products, as well as in the relationship with suppliers, obtaining the same results with half the resources (human, production area, equipment investment) (Krafcik, 1988). In the book "The Machine that Changed the World," published in 1990 by MIT researchers, the Lean Production concept was popularized as a benchmark in automotive production worldwide (J. P. Womack *et al.*, 1990).

According to J. P. Womack *et al.* (1990), Lean Production can be defined as an innovative production system that incorporates the advantages of the artisanal production system and those of the mass production system, avoiding the high cost of the first and the inflexibility of the second, thus allowing less human effort, less manufacturing space, less investment in tools, fewer hours of development of a new model, fewer stocks, thus reducing the associated costs. Today, thousands of companies have embraced the Lean Production concept because of their promising positive impact on corporate performance (Mackelprang & Nair, 2010). Pinto (2014), refers to *Lean Production* with the designation of *Lean Thinking* as does Womack & Jones (2003), where they define it as a management philosophy focused on the elimination of waste, in which techniques and tools are used to simplify and optimize productive processes and eliminate activities and resources that add no value to the process, this process requires the involvement of all employees in search of continuous improvement. Although Lean originally started from a set of production techniques, today Lean has evolved into a holistic business system, giving room to the appearance of new terms such as Lean Thinking (Womack & Jones, 2003), *Lean Enterprise* (J. Womack *et al*., 1990), and *Lean Philosophy* (Womack & Jones, 1994).

Womack & Jones (2003) describe a framework with five Lean principles, to help organizations combine Lean techniques into a coherent system:

1) **Value** - Defines the value of products from the customer perspective.
2) **Value Chain** - Identify the different activities for the manufacture of a product or service, and these can be divided into three categories: Activities that add value; Activities that do not add value and activities that do not have any associated value (unnecessary), those that are considered waste, and for that reason should be eliminated.
3) **Flow -** Establish continuous flow (be it of people, materials, information or capital) along the supply chain, without any bottlenecks.
4) ***Pull System*** - Produce only when the customer requests, according to the characteristics required.
5) **Perfection –** The pursuit of perfection is the ultimate principle of Lean philosophy. Womack and Jones (2003) advocate the complete elimination of waste so that all activities along the flow effectively add value, encouraging a culture of continuous improvement (Kaizen) within the organization.

3.3 Muda

The waste or *Muda* (japanese terminology), regards all activities that are executed and do not add value, as they consume time and resources, making the products or services available in the market more expensive (Liker, 2004; Nicholas & Soni, 2006). According to Ohno (1988) and Shingo (1989) there are seven wastes, namely: Overproduction, Waiting, Transport, Inventory, Over processing, Movements and Defects.

3.4 3.4 Methodologies and Lean Tools

There is usually a wide variety of tools and techniques used to create an effective production system in a company (Azian *et al*., 2013). Lean Production enables the integration of various tools into the production system and supply chain, focusing on eliminating waste to reduce costs, improve quality and decrease waiting times, inventory, and equipment downtime (Chen *et al*., 2013).

3.4.1 VSM (*Value Stream Mapping*)

According to Rother & Shook (2003) Value Stream Mapping (VSM) is a Lean tool that provides an overview of all activities, whether they add value or not, that integrate the manufacturing process from the customer's request to the delivery of the product. The main objective of VSM is to identify all types of waste and reduce them (Rother & Shook, 2003). Rother & Shook (2003) propose five steps in the implementation of VSM: 1) Product family selection; 2) Current State Map; 3) Future State

Map; 4) Definition of the Work Plan; 5) Execution of the Work Plan.

3.4.2 SMED (*Single Minute Exchange of Die*)

Over the last few decades, the advancement of technology and global competitiveness have given customers the possibility to choose customized products with special specifications, which shape themselves by their usage (Ang *et al.*, 2009). Therefore, with the increase of individual expectations and needs, a new trend in the industry was created: to produce reduced lots in short lead times, in order to respond as quickly as possible to the customers' needs (Sullivan *et al*., 2002). One way to achieve this goal is to establish a quick tool change by reducing the setup / changeover time consisting of the time elapsed between the production of the last good part of the first lot and the first good part of the next lot (Chen, 2009). According to McIntosh *et al.* (1996), the changeover time consists of the sum of the setup time and the run-up time. In the existing literature, there is no standardized terminology and concept, which defines the procedures of changeover, however, it is over the aspects of setup that are applied the procedures of improvement in the time of changeover, that is why many authors use the term reduction of setup (Mileham *et al.,* 1999).

When it is intended to maximize production capacity, it is very important to consider the bottleneck machines' setup time reduction because they limit the performance and capacity of the entire production line (Van Goubergen & Van Landeghem, 2002). However, a reduction in setup / changeover time sets out other significant positive impacts, such as: quality improvement, reduction of waste and rework, low inventory, as well as increased system flexibility and responsiveness to costumer (Allahverdi & Soroush, 2008). According to authors Goss *et al.* (2010) and Mackelprang & Nair (2010), the biggest advantage of reducing set-up time is that it allows for the reduction of production batches. The reduction of setup time in production lines with a wide variety of products, has been playing an increasingly important role (Kumar & Abuthakeer, 2012). According to Conceição *et al.* (2009), the SMED (*Single Minute Exchange of Die*), is a widely used tool when it comes to developing methodology for the execution of changeover activities.

SMED was developed by the Japanese industrial engineer Shingeo Shingo, who suggested an approach that allowed the execution of changeover operations in less than 10 minutes. The purpose of this tool is to reduce wasted time, as much as possible, in the various changeover procedures, by performing the activities that are possible to execute while the equipment is in operation, as well as to simplify and quicken the remaining activities, making the production more efficient (Shingo, 1985).

Also according to Shingo (1989), in the SMED method, the activities implied in the changeover operations can be divided into two categories: 1) Internal activities: these are activities that can only be performed while the machine is stationary, so they should be minimized as much as possible, since they slow production; 2) External activities: are those that can be performed while the machine is running.

The conventional SMED procedure proposed by Shingo (1985), is composed by four distinct phases:

- **Preliminary Phase:** the internal and external setup conditions are not distinguished; the purpose of this phase is to have an overview of all the setup activities included in the changeover process
- **First Phase:** classification of the setup activities as external or internal, separating them
- **Second Phase:** conversion of internal activities to external ones, wherever possible.
- **Third Phase:** improve all internal and external setup activities. In the case of internal activities, the improvements pass by avoiding the use of manual fasteners or fixations, allowing a significant reduction of setup time, and in the case of external activities, the improvements should include activities that help the operator to perform the setup tasks in the best possible way.

The two main benefits of applying the SMED methodology are: increasing production capacity and improving equipment flexibility (Coimbra, 2009).

4. Analysis of improvement opportunities for plastic injection area

4.1 Caracterization of present state: *Value Stream Mapping* (VSM)

To characterize the current state of the system, the value chain mapping (VSM) of the product under study was elaborated. The selection of the product to be analyzed lacks statistical analysis to determine which was the most appropriate. The selection of the product to be studied was carried out jointly with the managers of the plant, where it was determined that the study should be carried out focusing on the product with the highest sales volume of the company, cluster AA0. In order to design the VSM, in the case of production processes in the plastics area, the data collection was carried out with the managers and factory workers, however most of the information related to the production processes of the other areas were supplied by the company. Due to the size and complexity of the value chain under study, some metrics and micro flows (particularly logistical) were not considered, which should generally be included in the construction of the VSM, however, since the study only focuses on the productive processes in the area of plastics, it has been ensured that the information regarding this area is as complete as possible.

In Figure 1 is represented the VSM that reflects the characterization of the current state of the productive system under study.

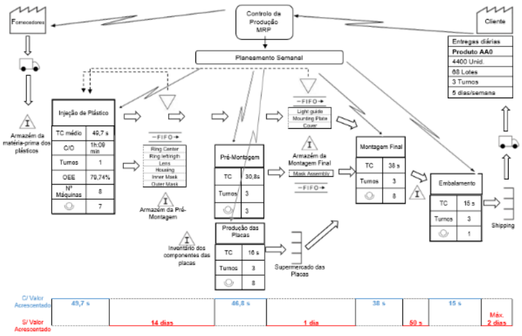

Figure 1 - Current state VSM

4.2 Improvement opportunities

Improvement in the changeover process

The mold changeover process needs to be improved, so that the mold change process must be analysed in order to list all the changeover procedures, separating the external activities from the internal ones and thus standardizing the execution of the tasks, namely in the changing the mold 108 to the 105 in the machine 300-10, so as to decrease the down time of the machine and consequently increase the production of the components within the time of production. In addition, it is also important to develop solutions to improve some procedures and consequently the mold setup times. In order to fill this opportunity for improvement, SMED presents itself as the most appropriate tool to solve this problem, and it will be based on this approach that the problem will be solved later and the improvement achieved.

Improvement in OEE

Some injection machines have very low OEE values, so that during the improvement in the changeover process, solutions must be developed that essentially allow to reduce the number of wasted components in the initial phase of operation of the plastic injection machine and to improve the performance rate availability of machines.

5. Implementation and analysis of improvement results

5.1 Improvements in *changeover*

The changeover process, namely in the exchange of molds for plastic injection machines, was one of the most inefficient processes in the plastics area. This inefficiency was essentially caused by the high setup time of the molds, which sometimes caused delays in the production of the plastic components. The main objective of this improvement is to reduce the time of mold exchange in the machine 300-10. Since the present study is focused on the cluster AA0 product, this improvement proposal is aimed at changing the molds 108 and 105, respectively, of the Inner Mask and Housing components, the process being carried out by two technicians.

In order to make the changeover process more efficient, the SMED methodology was applied, which is divided into four distinct phases: Preliminary Phase, First Phase, Second Phase, Third Phase, which are discussed in later subchapters.

Preliminary phase

At this phase all pre-implementation setup activities inherent in the changeover process are listed, from the production of the last good mold component 108, the Inner Mask, to the production of the first good mold component 105, Housing. This way it is possible to obtain an overview of all the activities of the changeover pro it is possible to check all the activities, in order, that the changeover process comprises, as well as the duration of each activity and its accumulated time.

Table 1 - Changeover process activities

Nº	Activity	Duration	Accumulated
1	Programming the machine in semi-automatic mode	00:00:30	-
2	Wait for the cycle to finish - Obtain the last good part of the mold 108	00:00:39	00:00:00
3	Close mold and recoil cylinder	00:00:50	00:00:50
4	Turn off the heating of the mold and switch off engine	00:00:15	00:01:05
5	Tool preparation	00:00:50	00:01:55
6	Move gantry to the injection machine	00:03:00	00:04:55
7	Put safety bar in the mold	00:00:25	00:05:20
8	Lower gantry hook to mold eye and fasten hook	00:00:25	00:05:45
9	Disconnecting electrical plugs from the probe and resistor	00:00:20	00:06:05
10	Attach the retention lock	00:00:25	00:06:30
11	In the machine software put the extraction at point 0	00:02:30	00:09:00
12	Remove screws and washers from the mold	00:03:00	00:12:00
13	Disconnect the extraction plug from the mold and the machine	00:00:30	00:12:30
14	Disconnect cooling circuit hoses	00:01:20	00:13:50
15	Reset and start the machine motor	00:01:00	00:14:50
16	Set the machine to the setting mode for maximum aperture	00:01:40	00:16:30
17	Remove mold by lifting the gantry and storing the mold in the respective storage area	00:03:40	00:20:10
18	Programming the machine for the next mold	00:02:30	00:22:40

19	Switch off the engine	00:00:30	00:23:10
20	Move gantry to mold 105 and engage hook in eye	00:00:50	00:24:00
21	Move mold 105 to machine	00:03:15	00:27:15
22	With the help of the gantry, lower mold until it engages the fixed plate of the machine	00:02:30	00:29:45
23	Reset machine and start engine	00:01:00	00:30:45
24	Press the movable plate of the machine to the mold	00:00:50	00:31:35
25	Switch off engine	00:00:30	00:32:05
26	Insert the screws and washers into the mold 105	00:03:30	00:35:35
27	Connecting the probe electrical and resistance plugs	00:00:30	00:36:05
28	Turn on mold heating	00:00:10	00:36:15
29	Connecting the Injection cooling and extraction hoses	00:02:30	00:38:45
30	Connect the extraction plug to the mold and the machine	00:01:30	00:40:15
31	Remove the hook from the mold and lift gantry	00:00:50	00:41:05
32	Remove the safety bar and reposition it to the rest position	00:00:50	00:41:55
33	Change the robot hand to the mold part 105	00:03:00	00:44:55
34	Switch on the machine engine and open the mold in adjustment mode	00:02:00	00:46:55
35	Remove the securing bracket from the support	00:00:40	00:47:35
36	Switch on the machine in semi-automatic mode (Mold to heat up)	00:00:30	00:48:05
37	Analyze and adjust quality until obtaining the first good part of the molde 105 - Switch on automatic mode	00:20:45	01:08:50

Through the listing of the activities inherent to the changeover process, presented in Table 1 it was possible to verify that the changeover process performed on the machine 300-10 lasts for 1 hour, 8 minutes and 50 seconds. The high changeover time reflects a lack of planning of this operation, since all activities are carried out while the machine is stationary.

First phase

After listing all the activities inherent to the changeover process in the preliminary phase, in this phase the classification of all the setup activities as internal is performed, i.e. all activities that are not possible to be performed while the machine is in operation, and as external, that is, the activities that are possible to be carried out while the machine is in operation. Data concerning the operations that are carried out while the machine is stopped, and the first step of the SMED methodology, the separation of the activities by type was performed, classifying them in external or internal activities. After classification of activities, it was possible to identify the following activities as external, presented in Table 2.

Table 2 - External activities

Nº	External activity	Duration
5	Tool preparation	00:00:50
6	Move gantry to the injection machine	00:03:00
20	Move gantry to mold 105 and engage hook in eye	00:00:50
21	Move mold 105 to machine	00:03:15
Total duration of external activities		00:07:55

Being that in total the external activities have a duration of 7 minutes and 55 seconds. It was possible to verify that external activities correspond, therefore, to 12% of the total duration of the changeover process, as can be seen in the graph of Figure 2.

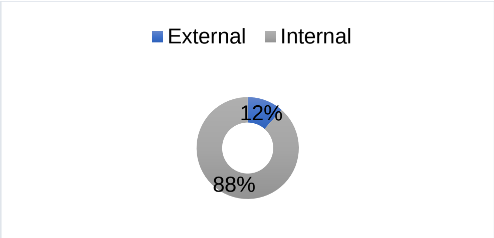

Figure 2 - External vs internal activities

It is concluded that with the separation of the external activities of the internal ones, it was possible to achieve a reduction of 12% in the duration of the changeover process.

Second Phase

At this stage the analysis of all internal activities that can be converted to external, wherever possible. However, after a thorough analysis of the process no internal activities that could be converted to external were detected.

Third Phase

Finally, in this phase, the goal is to quicken all the external and internal setup activities, in order to reduce setup times. To achieve this, some solutions were found that make it possible to quicken both internal and external activities, that being the implementation of a metal platform on plastic injection machines and the implementation of preheaters in the molds that will allow a significant reduction of the total duration of the changeover process.

5.1.1 SMED Impact Analysis

After the application of the SMED tool, the impact of this changeover process was analyzed, from the first phase, where the internal activities were separated from the external ones until the third phase where the improvements were implemented, which made it possible to quicken both internal activities as external.

5.1.1.1 Separation of external and internal activities (First phase)

After applying the first phase of the SMED tool, namely the separation of internal activities from the external ones, it was possible to verify a significant improvement in the changeover time of the molds 108 to 105 in the machine 300-10. Being that the process of changeover changed to be concluded in 1 hour and 55 minutes, that was possible to obtain thanks to the reduction of 12% previously verified.

5.1.1.2 Implementation of the metal platform (Third phase)

With the implementation of the metal platform on the injection machines it was possible to achieve improvements in the changeover time, namely in the machine 300-10, in which the changeover process was analyzed. This implementation allowed for improvements, both in internal activities and in external activities.

After the implementation of the platform on the injection machines, it was possible to achieve a significant improvement in the times of external and internal activities. With regard to external activities, it was possible to achieve a reduction in the duration of activities 20 and 21. With this improvement, it was possible to observe a total reduction in the duration of external activities of almost 3 minutes, and they were carried out in 5 minutes instead of 7 minutes and 55 seconds.

As for the internal activities, it was possible to reduce its duration in 3 minutes, starting to be performed in 3 minutes and 10 seconds, through the improvement of activities 17 and 22.

It can then be concluded that with the implementation of the metal storage platform of the molds on the injection machines it was possible to reduce the duration of internal activities more external in the total of 5 minutes and 55 seconds. Being that in internal activities a reduction of 3 minutes and 10 seconds was possible, which value had a very significant impact on the total duration of the changeover process.

5.1.1.3 Implementation of mold pre-heaters (Third phase)

After the implementation of the metal platform on the plastic injection machines came the opportunity to implement another improvement, namely the implementation of preheater molds. These devices were implemented in the base of the metal platform and allow the preheating of the molds to be assembled during the changeover process in the respective machine, in this case the assembly of the mold 105 of the Housing component in the machine 300-10. With this improvement it was possible to obtain significant gains in the changeover time of the machine 300-10 as well as an increase in the number of units of Housing components produced since it was possible to achieve the production of less defective components.

With the implementation of mold preheaters, it was possible to achieve a very significant improvement in the duration of the internal activity 37. This activity corresponds to the last activity performed in the changeover process, in which after the machine starts the production of the Housing component, it is necessary to analyze the first components produced, as well as some quality adjustments in the parameters of the machine, until obtaining a component without defects. With the preheating of the mold 105, it is already mounted in the machine at an almost ideal temperature, contrary to what occurred prior to the implementation of this improvement in that the mold 105 was mounted to the machine at room temperature and heating was performed only by the system of the injection machine. Thus, it was possible to reduce the heating time of the mold 105 by the machine 300-10 until it reaches the ideal temperature, i.e. the temperature which allows obtaining components without defects. Therefore, with the implementation of the preheaters of the molds it was possible to obtain a reduction of the internal activity 37 of almost 7 minutes, happening to be realized in 14 minutes.

5.1.2 Global analysis and conclusion of the changeover process after application of SMED

With the application of all phases of the SMED tool it was possible to obtain a total final changeover time of 51 minutes and 10 seconds.

In the graphic of Figure 3 it is possible to verify the variation of the changeover time after the application of the different phases that the SMED tool understands in comparison with the changeover time of the initial state.

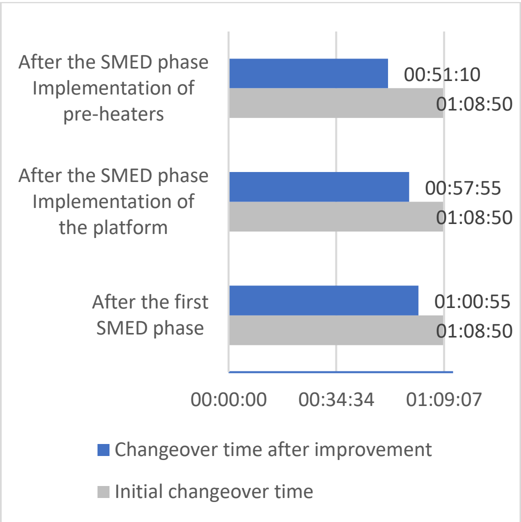

Figure 3 - Changeover time after application SMED phases

Through the graphic of Figure 3 it is possible to verify that after the application of the SMED tool there was a very significant reduction of the changeover time along the various phases, happening in 51 minutes and 10 seconds, being in the initial state the process of changeover had a duration of 1 hour, 8 minutes and 50 seconds. The final changeover time verified corresponds to a reduction of 26% from the initial state.

5.2 Improvements in the OEE

In order to improve the key performance indicator, the OEE. (Overall Equipment Effectiveness) was identified during the analysis of the changeover process and after the application of the SMED tool the opportunity to reduce the OEE.

Following the reduction of the changeover time with the application of the SMED tool, it was possible to obtain a significant reduction of the stop time in the machine 300-10. This reduction had a very positive impact on the production of the Inner mask and Housing components, so it was possible to observe a considerable increase in the number of components produced within the production time. Table 3 presents the improvements that were possible to achieve in the production variables and efficiency indicators of the machine 300-10 in the production of the Inner mask and Housing components, after the application of the tool SMED

Table 3 - Production of injection machine 300-10 before and after SMED

	Inner Mask Mold 108		Housing Mold 105	
	Before SMED	**After SMED**	**Before SMED**	**After SMED**
Operational time (hours)	3,75		3,75	
Planned stops (seconds)	3415	2885	3415	*2885*
Changeover time (segundos)	2065	1535	2065	*1535*
Unplanned stops (seconds)	210	210	210	*210*
Total stops (seconds)	3625	3095	3625	*3095*
Available time (hours)	2,80	2,95	2,80	*2,95*
Production time (hours)	2,74	2,89	2,74	*2,89*
Theoretical production (units)	514	542	652	*687*
Good parts (units)	450	474	546	*630*
Defective parts (units)	39	41	73	*51*
Injection machine 300-10	**Before SMED**		**After SMED**	
Performance(%)	95,00		97,04	
Availability (%)	97,92		98,02	
FTT (%)	90,07		92,29	

According to Table 3 it is verified that before the implementation of SMED, the changeover time of 4130 seconds (1h, 8 minutes and 50 seconds) was distributed by the two components, i.e. 2065 seconds was the stop time due to changeover for each of the components in the machine 300-10. After applying the SMED, and consequently reducing the changeover time, it was possible to verify a reduction of the total time of stops, from 3625 seconds to 3095 seconds. By reducing the machine downtime 300-10 it was possible to increase the time available and the production time to 2.95 and 2.89 hours, respectively, for each component.

At the level of impact on the indicators, with the improvement of the available time and the time of production it was possible to verify an increase of the Availability indicator (%). It was also possible to verify a significant increase in the Performance indicator (%), and the Inner mask component did not contribute to its increase, unlike the Housing component, this is justified by the fact that in the first component the number of units of components with a defect produced in relation to the theoretical production was maintained, in the second with a decrease in the duration of the activity 37 in obtaining the first good component, it was possible to verify a significant decrease in the number of units of the defective Housing component, which becomes an improvement of the 300-10 machine performance. With the implementation of the preheaters, and consequent decrease of the activity 37, it was also possible to verify for the Housing component a significant decrease of the time that elapses until obtaining the first good component. With this improvement there was a significant decrease in the number of defective components, which therefore had an impact on the FTT indicator

The improvements in the above-mentioned indicators have therefore had a positive impact on the OE of the machine 300-10 in the production of the Inner mask and Housing components. The final values of the percentage of OEE for the plastic injection process of the product AA0 are shown in Table 4.

Table 4 - OEE Improvement

Injection machine 300-10	Before SMED	After SMED
Performance(%)	95,00	97,04 (+2,04%)
Availability (%)	97,92	98,02 (+0,1%)
FTT (%)	90,07	92,29 (+2,22%)
OEE (%)	83,78	87,79 (+4%)

As can be seen in Table 4, with the increase in the indicators inherent to the calculation of the overall efficiency, it was possible to increase the OEE. In the graph of Figure 4. it is possible to visualize the evolution of the OEE in the machine

300-10 in parallel with the improvements verified in the indicators, FTT, Availability and Performance, after the application of the SMED tool.

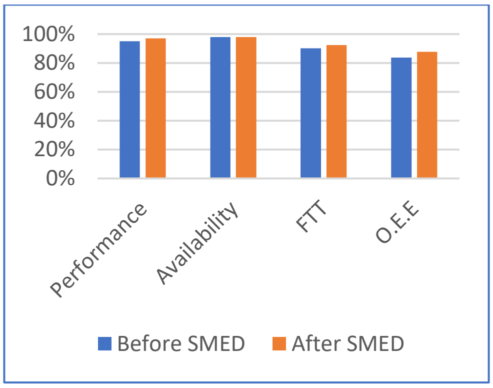

Figure 4 - OEE Evolution

6. Conclusions

Throughout the analysis of the production process of the plastic injection unit it was possible to identify the various problems that generated waste and consequent inefficiencies in the process, through the analysis of the production process of the plastic injection unit on the factory floor and the construction of the VSM. Therefore, the opportunities for improvement were identified and the proposals were presented, with the help of plastics managers, it was possible to develop solutions that helped to achieve the objectives of the proposals. Through the Lean tool, SMED and in parallel with the solutions found, it was possible to achieve quite satisfactory results and expose to the company the repercussion of the implementations in the plastic injection production process. With the SMED tool it was possible to obtain significant improvements in the process of changeover of the molds of the components Inner Mask and Housing, in the machine 300-10, from the separation of the activities to the quickening of internal and external activities, which allowed to reduce the changeover time and provided the necessary premises to move forward with the second improvement proposal, namely the improvement of the key performance indicator OEE. Finally, it is important to point out that during this project Kaizen events were held, bringing together all the managers and officers of the factory, in order to discuss and monitor all the improvements implemented, thus adopting continuous improvement behavior throughout the company.

7. References

AFIA, 2017. Indústria de Componentes Automóveis - AFIA. Available at: http://www.afia.pt/index.php?option=com_content&task=view&id=4717&Itemid=61&lang=pt_PT [Accessed February 5, 2017].

Aicep Portugal, 2016. Portugal Global. *Indústria automóvel e componentes*, p.66. Available at: http://www.portugalglobal.pt/PT/PortugalNews/Documents/Revistas_PDFs/Portugalglobal_n87.pdf.

Allahverdi, A. & Soroush, H.M., 2008. The significance of reducing setup times/setup costs. *European Journal of Operational Research*, 187, pp.978–984.

Ang, A.T.H., Sivakumar, A., I. & Qi, C., 2009. Criteria selection and analysis for single machine dynamic on-line scheduling with multiple objectives and sequence-dependent setups. *Computers & Industrial Engineering*, 56, pp.1223–1231.

Ar, R. & Al-Ashraf, M., 2012. Production Flow Analysis through Value Stream Mapping : A Lean Manufacturing Process Case Study. *Procedia Engineering*, 41(Iris), pp.1727–1734.

Azian, N. et al., 2013. Lean Manufacturing Case Study with Kanban System Implementation. *Procedia Economics and Finance*, 7, pp.174–180.

Black, J.R., 2008. *Lean production : implementing a world-class system* 1st ed., New York: Industrial Press, Inc.

Chen, J.C., Cheng, C. & Huang, P.B., 2013. Expert Systems with Applications Supply chain management with lean production and RFID application : A case study. *Expert Systems With Applications*, 40(9), pp.3389–3397. Available at: http://dx.doi.org/10.1016/j.eswa.2012.12.047.

Chen, W.J., 2009. Scheduling with dependent setups and maintenance in a textile company. *Computers & Industrial Engineering*, 57, pp.867–873.

Choomlucksana, J., Ongsaranakorn, M. & F, P.S., 2015. Improving the productivity of sheet metal stamping subassembly area using the application of lean manufacturing principles. *Procedia Manufacturing*, 2(February), pp.102–107.

Coimbra, E.A., 2009. *Total Flow Management: Achieving Excellence with Kaizen and Lean Supply Chains* 1st ed., Kaizen Institute.

Conceição, S.V. et al., 2009. Desenvolvimento e implementação de uma metodologia para troca rápida de ferramentas em ambientes de manufatura contratada. *Gestão & Produção*, 16, pp.357–369.

Cordeiro, J., 2009. Componentes da gestão estratégica nas empresas do sector automóvel. *Revista de Gestão dos Países de Língua Portuguesa*, pp.55–65.

Cudney, E.A., Furterer, andra L. & Dietrich, D.M., 2014. *Lean Systems - Applications and Case Studies in Manufacturing, Service, and Healthcare*, New York: Taylor & Francis Group.

Féria, L.P., 1999. *A História do Sector Automóvel em Portugal (1895- 1995)*, Lisboa.

Geraldo, Z., Vieira, L. & Balbinotti, G., 2015. Lean Manufacturing and ergonomic working conditions in the automotive industry. *Procedia Manufacturing*, 3(Ahfe), pp.5947–5954.

Glass, R., Seifermann, S. & Metternich, J., 2016. The Spread of Lean Production in the Assembly , Process and Machining Industry. *Procedia CIRP*, 55, pp.278–283.

Goss, R. et al., 2010. Leveraging new SEMI standard to reduce waste and improve flow for semicondutor manufacturing. *Robotics and Computer Integrated Manufacturing*, 26, pp.658–664.

Van Goubergen, D. & Van Landeghem, D., 2002. Rules for integrating fast changeover capabilities into new equipment design. *Robotics and Computer Integrated Manufacturing*, 18, pp.205–214.

Holweg, M., 2007. The genealogy of lean production. *Journal of Operations Management*, 25, pp.420–437.

Krafcik, J., 1988. Triumph of the Lean Production System. *MIT Sloan Management Review*, 30, pp.41–52.

Kumar, B.S. & Abuthakeer, S.S., 2012. Implementation of lean tools and techinques in an automotive industry. *Journal of Applied Sciences*, 12, pp.1032–1037.

Liker, J. & Meier, D., 2006. *The Toyota Way Fieldbook*, New York: McGraw-Hill.

Liker, J.K., 2004. *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill.

Mackelprang, A.W. & Nair, A., 2010. Relationship between just-in-time manufacturing practices and performance: A meta-analytic investigation. *Journal of Operations Management*, 28(4), pp.283–302.

Marques, A.F., Alves, A.C. & Sousa, J.P., 2013. An approach for integrated design of flexible production systems. *Procedia CIRP*, 7, pp.586–591.

McIntosh, R. et al., 1996. An assessment of the role of design in the improvement of changeover performance. *International Journal of Operations & Production Management*, 16(9), pp.5–22.

Mileham, A.R. et al., 1999. Rapid changeover – a pre-requisite for responsive manufacture. *International Journal of Operations & Production Management*, 19(8), pp.785–796.

Mohd, J. & Mojib, S., 2015. Production line analysis via value stream mapping : a lean manufacturing process of color industry. *Procedia Manufacturing*, 2(February), pp.6–10.

Monden, Y., 1983. *Toyota production system: Practical approach to production management*, Industrial Engineering and Management Press - Institute of Industrial Engineers.

Nicholas, J. & Soni, A.V.I., 2006. *The Portal to Lean Production: Principles and Practices for Doing More with Less*, New York: Auerbach Publications - Taylor & Francis Group.

Ohno, T., 1988. *Toyota Production System - Beyond Large-Scale Production*, Portland, Oregon: Productivity Press.

Pinto, J.P., 2014. *Pensamento Lean - A filosofia das organizações vencedoras* 6th ed., Lisboa: LIDEL - Edições Técnicas, Lda.

Productivity Press Development Team, 2002. *Standard work for the shopfloor*, New York: Productivity Press.

Rother, M. & Shook, J., 2003. *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda*, Brookline: Lean Enterprise Institute.

Santos, J., Wysk, R.A. & Torres, J.M., 2006. *Improving Production with Lean Thinking*, New Jersey: John Wiley & Sons, Inc.

Shingo, S., 1985. *A Revolution in Manufacturing: The SMED System*, Cambridge: MA: Productivity Press.

Shingo, S., 1989. *Study of the Toyota Production System from an Industrial Engineering Viewpoint* Revised., Cambridge: Productivity Press.

Sugimori, Y. et al., 1977. Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system. *International Journal of Production Research*, 15(6), pp.553–564.

Sullivan, W.G., MacDonald, T.N. & Van Aken, E.M., 2002. Equipment replacement decisions and lean manufacturing. *Robotics and Computer Integrated Manufacturing*, 18, pp.225–265.

Womack, J., Jones, D.T. & Roos, D., 1990. Focus on Books Changed the World. , May-June, pp.81–82.

Womack, J.P. & Jones, D.T., 1994. From lean production to the lean enterprise. *IEEE Engineering Management Review*, 24(4), pp.38–46.

Womack, J.P. & Jones, D.T., 2003. *Lean thinking: banish waste and create wealth in your corporation*, Simon & Schuster.

Womack, J.P., Jones, D.T. & Ross, D., 1990. *The Machine that Changed the World*, New York: Rawson Associates.

Zahraee, S.M. et al., 2014. Lean manufacturing implementation through value stream mapping: A case study. *Jurnal Teknologi (Sciences and Engineering)*, 68(3), pp.119–124.